FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2012-08CMY-Jung

Impacts of Global Warming on Coastal and Marine Ecosystems in the Northwest Pacific

The following collaborators worked on this project:
Sukgeun Jung, Jeju National University, Korea, sukgeun.jung@gmail.com
Gennady V. Khen, TINRO-Centre, Russia, gennady1@tinro.ru
Hiroya Sugisaki, Fisheries Research Agency, Japan, sugisaki@affrc.go.jp
Xianshi Jin, Yellow Sea Fisheries Research Institute, China, jin@ysfri.ac.cn
Dohoon Kim, National Fisheries R&D Institute, Korea, delaware310@nfrdi.go.kr

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Non-technical summary

The highly-productive western North Pacific has experienced dramatic changes in oceanographic conditions and ecosystem structure, driven by climatic changes and anthropogenic interventions. We conducted comparative studies across NOWPAP countries (China, Japan, Korea and Russia) to evaluate regional differences in the responses of marine ecosystems to the changes in the NOWPAP sea area (33-52°N; 121-143°E) by a working group composed of natural and socioeconomic scientists. In 2011-2013, we analyzed spatial and temporal variability in oceanographic conditions and recruitments of major fish species in the NOWPAP sea area for the last 40 years. In 2013-2014, we tried to forecast changes in potential production of fisheries resources and evaluate risks and vulnerabilities, induced by climate change, in fisheries-dependent sectors across NOWPAP countries (China, Japan, Korea and Russia). We held 3 workshops. We hope this report provides scientific basis to decision makers in developing policy strategies that incorporate regional differences in 1) marine ecosystems supporting fish stocks, 2) vulnerability and adaptation of fisheries industries to climate change. This report is expected to contribute to comprehending the status and outlook of marine ecosystems supporting fisheries in the Northwest Pacific, and to extending regional policy makers' knowledge and understanding for adapting fisheries sectors to climate change.

Keywords

climate change; western North Pacific; fisheries; marine ecosystems; oceanography;

Objectives

The main objectives of the project were:

1. Analyze spatial and temporal variability in oceanographic conditions and recruitments of major fish species in the NOWPAP sea area for the last 40 years
2. Forecast changes in potential production of fisheries resources and evaluate risks and vulnerabilities, induced by climate change, in fisheries-dependent sectors across NOWPAP countries (China, Japan, Korea and Russia)

Amount received and number years supported

The Grant awarded to this project was:
US$ 47,000 for Year 1:
US$ 39,000 for Year 2:

Activity undertaken

We performed three main activities: 1) Gathering information available in each country and developing national reports; 2) Compiling four national reports into a regional report; 3) Holding three workshops at Jeju National University, Korea (March 22-24, 2012; July 9-14, 2012; and November 10-13, 2013). The first workshop was to introduce the research findings and discuss the future activities. The second workshop was held for better understanding by policy makers of possible implications of climate change impacts on fisheries production in the NW Pacific, and for raising their awareness about possible policy implications. During the third workshop, we 1) synthesized past studies and available data from each participating countries, 2) combined national reports to complete draft of the final report.

We forecast changes in fish production and habitat ranges based on climate-driven hydrographic changes simulated by a general circulation model under a climate change scenario.

Results

In 2011-2013, we conducted retrospective analyses on times-series of climate and oceanographic data that have been collected and compiled by each involved country during the past 40 years. We tried to seek and utilize more sources of oceanographic and fisheries time-series data from the NOWPAP region. We also developed a new statistical technique (change-point detection) that can detect and predict significant changes from spatially-extensive multivariate times-series data by collaborating with statisticians (Mantua, 2004). Because sharing data among participating national experts is the most critical and difficult component of this project, we first tried to collect data and published papers after dividing the study area into 4 regions. In 2013-2014, we forecast changes in potential production and habitat ranges of fisheries resources and tried to evaluate risks and vulnerabilities, induced by climate change, in fisheries-dependent sectors across NOWPAP countries.

Our empirical relationships predicted that the ranges of five of the fish species examined will shift poleward by 19–71 km from the 2000s to the 2030s. The strongest relationships between mean latitude and sea surface water temperatures were observed for the large pelagic species, Spanish mackerel and yellowtail. We conclude that large pelagic species will respond most sensitively to warming oceans in their distribution range. Despite their greater decadal variability in recruitment, small pelagic species seem to be more resilient than large pelagic species to climate change in their distribution range. Long-term plans need to be made, especially in regard to large pelagic species, to adapt fisheries to climate change and global warming (e.g., vessels equipped with freezers for preserving tuna for more profitable marketing).

Our project confirmed that a strong climatically induced ecosystem regime shift has occurred in the NOWAP region in the late 1980s. However, the results indicated that climate-driven oceanic changes and the subsequent ecological impacts can occur asynchronously, often with time lags of several years, between the upper and the deep layer, and between epi-pelagic and deep-water fish assemblages.

Climate change will impact on both artisanal and industrialized fisheries that exploit demersal and bentho-pelagic species in the NOWPAP area. We expect that artisanal and coastal fisheries, which have benefited from a capacity to quickly supply live or unfrozen fishes, will become less competitive than industrialized fisheries in adapting to possible climate-driven range shifts in their respective target species. Therefore, more attention should be paid to artisanal, small-scale fisheries in developing fisheries policies for adaptation to climate change in the region.

Relevance to the APN Goals, Science Agenda and to Policy Processes

This project directly pursues the APN Goals 1 and 2. As the proponent is a lead author of IPCC AR5 (WG II, Chapter 30, Open oceans) and a member of PICES fishery science committee (FIS), the outcomes and activities from this project are expected to contribute to IPCC, NOWPAP, PICES and IMBER (Theme 4). This project addresses the research areas 1 - 4 of APN Science Agenda and is in line with policy strategies APN has committed to: strengthening science-policy interactions and improving cooperation with other institutions and bodies, such as IPCC.

Self evaluation

Scientists of the four countries involved in this project have compiled an amazingly ample set of physical and biological data sets from the area of investigation. The project focuses on two oceanic regions: (i) the Yellow Sea and (ii) the waters between Korea, Japan and Russia. There is comparatively little information available from the Yellow Sea, whereas the other region is well covered. Three country reports deal with the waters between Korea, Japan and Russia, but cover mainly the areas adjacent to their coasts. A joint analysis of this data would lead to a much better understanding of the entire NOWAP region. The goal of the project is to evaluate the impact of global warming in the NOWAP region. To do so, first, the impact of natural climate variability has to be documented by retrospective analysis, as is attempted in this report. In contrast to many other regions in the world, the impact of climate drivers such as the Siberian High and the East Asian Winter Monsoon, are clearly visible, but have been only cursory treated. Climate impact would become much clearer when the results from the different sub-areas, for example sea temperature, would be presented in a single graph. Also, the country reports should be harmonized and presented in a more uniform way: for example, with respect to oceanographic data, the Korean report shows an extensive analysis, the Russian report gives a short description and the Japanese report shows only figures without any description. Similarly, the information on fish is presented in different ways making comparisons difficult.

It was unfortunate that we could not undertake economic analyses to evaluate quantitatively vulnerability of regional fisheries sectors to climate change, because of lack of relevant data and a sudden change of occupation of the fisheries economist of this project.

Potential for further work

International cooperative research among fisheries scientists from countries throughout the region, especially Japan and China, is required to more reliably and comprehensively assess and project the range shifts of fish species. This project suggested that volume transports by the Tsushima warm current and the Korea Strait Bottom Cold Water seemed to be a dominant factor in shaping fish community structures in the NOWPAP area with respect to climate change. Thus, the time-series of volume transport can be historically restored based on general ocean circulation models and the observed oceanographic data to understand the mechanisms of climate change on marine ecosystems and fisheries in the area.

Publications (please write the complete citation)

i. Hwang, K., Jung, S., 2012. Decadal changes in fish assemblages in waters near the Ieodo ocean research station (East China Sea) in relation to climate change from 1984 to 2010. Ocean Science Journal 47 (2), 83-94.

ii. Jung, S., Cha, H.K., 2013. Fishing vs. climate change: an example of filefish (*Thamnaconus modestus*) in the northern East China Sea. Journal of Marine Science and Technology 21 (Supplementary), 15-22. DOI: 10.6119/JMST-013-1219-3

iii. Jung, S., Pang, I.-C., Lee, J.-h., Choi, I., Cha, H.K., In Press. Latitudinal shifts in the distribution of exploited fishes in Korean waters during the last 30 years; a consequence of climate change. Reviews in Fish Biology and Fisheries. DOI: 10.1007/s11160-013-9310-1

iv. Kang, Y.S., Jung, S., Zuenko, Y., Choi, I., Dolganova, N., 2012. Regional differences in response of mesozooplankton to long-term oceanographic changes (regime shifts) in the northeastern Asian marginal seas. Progress in Oceanography 97-100C, 120-134.

References

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TECHNICAL REPORT

Preface

We conducted comparative studies across NOWPAP countries (China, Japan, Korea and Russia) to evaluate regional differences in the responses of marine ecosystems to the changes in the NOWPAP sea area (33-52°N; 121-143°E; Fig. 1) and their implications in developing adaptation policies for climate change by establishing a working group composed of natural and socioeconomic scientists. We performed three main activities: 1) Gathering information available in each country and developing national reports; 2) Compiling four national reports into a regional report; 3) Forecasting changes in potential production of fisheries resources and evaluate risks and vulnerabilities, induced by climate change, in fisheries-dependent sectors across NOWPAP. We hope this report will provide scientific basis to decision makers in developing policy strategies that incorporate regional differences 1) in marine ecosystems supporting fish stocks, and 2) in vulnerability and adaptation of fisheries industries to climate change.

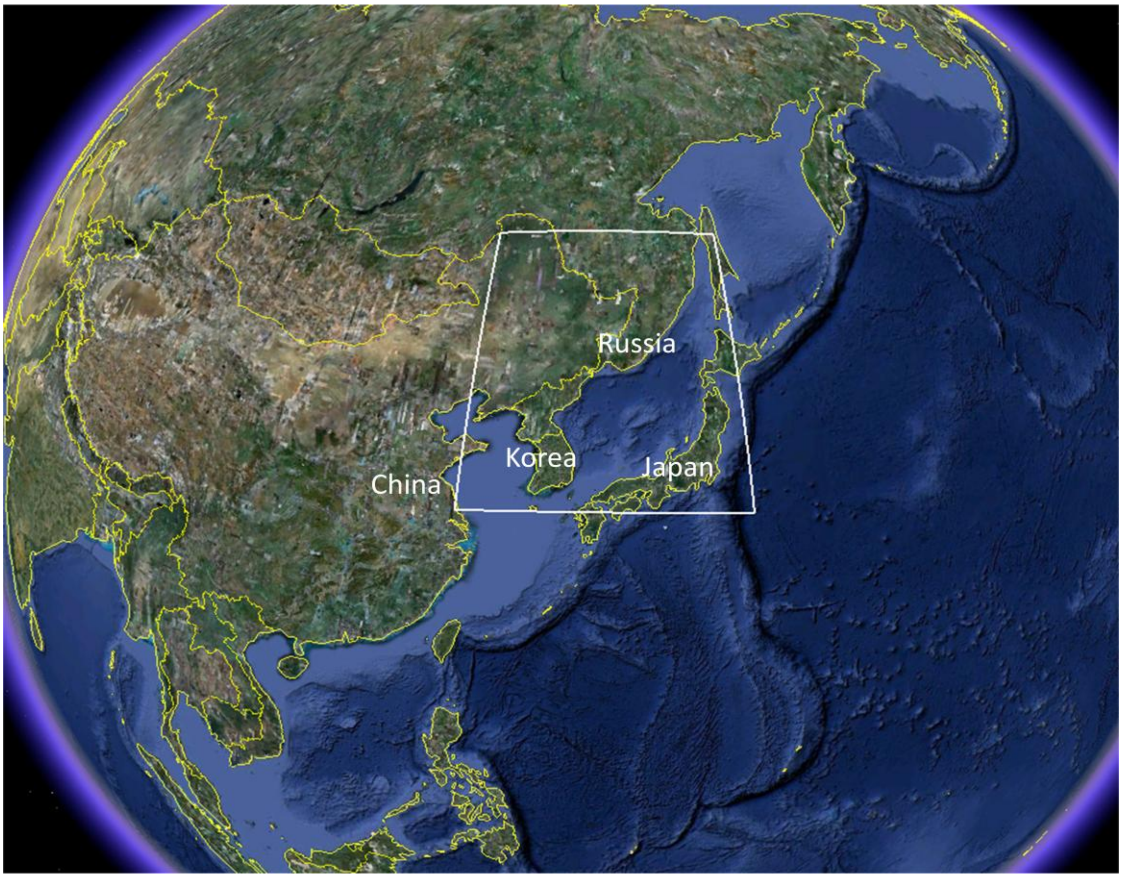

Fig. 1 Proposed study area, the NOWPAP sea area (33-52°N, 121-143°E) indicated by the solid box, and the four participating countries.

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Electronic supplementary materials

1.0 Introduction

The western North Pacific is highly productive, supporting the largest fisheries yields in the world and high consumption of fish products by residents of its bordering countries. Recently, however, the western North Pacific has experienced dramatic changes in coastal water quality, oceanographic conditions, and ecosystem structure, driven by global climatic changes and anthropogenic interventions, such as rapidly increasing human populations and industrial activity. Understanding climatic influences on marine ecosystems and fisheries in this region has been the focus of international and multidisciplinary studies since the North Pacific Marine Science Organization (PICES) was established in 1992. Increasing scientific evidence indicates that the responses of marine ecosystems to climatic change are not simple, but vary among regions and according to the scales of the processes. However, implications of these regional differences to vulnerability and possible policies for adapting fisheries industries to climate change have not yet been explicitly studied. Here we conducted comparative studies across NOWPAP countries (China, Japan, Korea and Russia) to evaluate regional differences in the responses of marine ecosystems to the changes in the NOWPAP sea area (33-52°N; 121-143°E; Fig. 1) and their implications in developing adaptation policies for climate change by establishing a working group composed of natural and socioeconomic scientists.

2.0 Methodology

2-1. Study area

We divided the study area into 4 regions (Fig. 2). A deep basin of the maximum depth = 4,049 m includes Region R and J. Region Y is a shallow, semi-enclosed shelf sea, and its mean depth is 44 m. Region Y is distinguished by shallow depths, strong tidal mixing, and high turbidity (Yoo and Park, 2007). Region K has intermediate geomorphology and ecology between Region Y and J.

Tidal ranges in Region Y are among the highest in the world, and strong tidal fronts form parallel to the western coast of Korea (Chung et al., 2002; Hong et al., 2002). During the winter, warm, saline water originating from the Tsushima Warm Current (TWC) in the East China Sea, one of the branches of Kuroshio Warm Current, enters Region Y episodically (Lie et al., 2001) and cooler, fresher waters from rivers empty into Region Y, flowing south along the coasts of eastern China and western Korea (Lee, 1998) (Fig. 3).

Region K is mostly shelf area, shallower than Region J, but deeper than Region Y (Hong and Cho, 1983). The TWC mainly influences the waters in Region K. In summer, low-salinity, high-turbidity waters from the Yangtze River reach Region K and gradually mix with the TWC waters (An, 1974; Hong et al., 2002). Tidal fronts are also frequently formed in Region K (Kang and Jeon, 1999; Kang and Kim, 2002). Cold waters from Region J can episodically intrude to the bottom layer of Region K (Min et al., 2006).

Region J is a large, deep (> 1,000 m) basin that is also influenced by the warm, saline TWC flowing northeastward through Region K into Region R. The North Korea Cold Current flows south along the eastern Korean coast (Fig. 3). The confluence of the two currents, together with the Primorye and the East Korean Warm current, forms the Polar Front that is generally located south of 40°N (Hong and Cho, 1983). Coastal upwelling and fronts are also important features (An, 1974; Lee and Na, 1985).

Region R lies in the cold subarctic sector. The Subarctic/Polar Front divides the subarctic and subtropical waters, usually between Region J and R. However, waters of Region R can invade Region J and vice versa because the North Korean Cold Current flows south and the East Korean Warm Current flows north, mainly driven by wind, eddies and large-scale horizontal waves. Areas of coastal upwelling are also important features in Region R (An, 1974; Lee and Na, 1985).

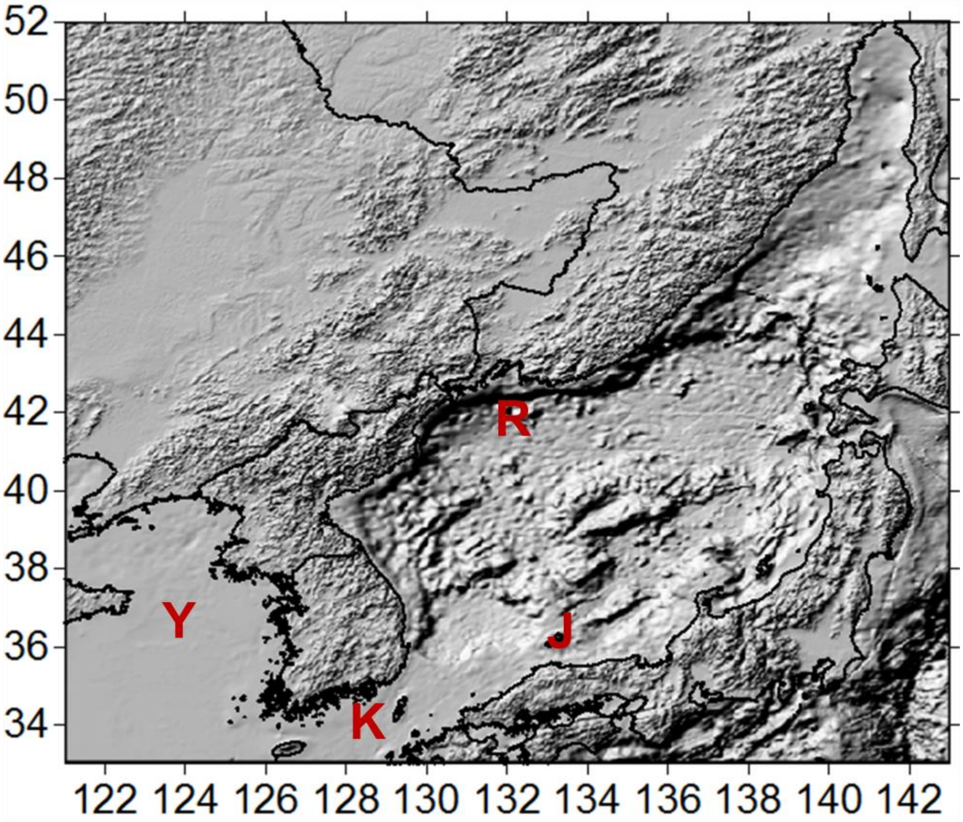

Fig. 2. The four designated regions in the NOWPAP sea area (33-52^{o}N, 121-143^{o}E).

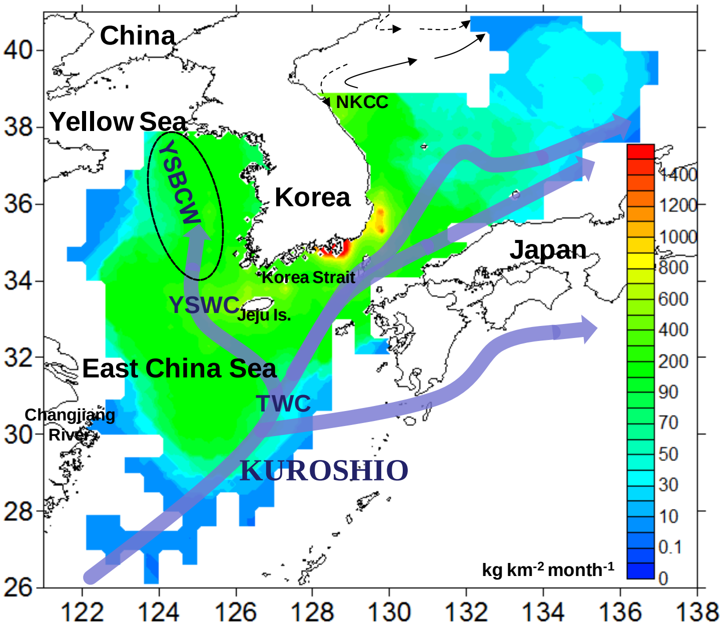

Fig. 3. Major currents (arrows) and mean biomass (color contour, kg km^{-2} month^{-1}) of all combined fishes captured and reported by Korean fishers from 1984 to 2010. TWC: Tsushima Warm Current, YSWC: Yellow Sea Warm Current, YSBCW: Yellow Sea Bottom Cold Water, NKCC: North Korea Cold Current

2-2. Data and materials

Because sharing data among participating national experts is the most critical and difficult component of this project, we first tried to collect data and published papers in the study area.

2-2-1. Region Y

Data on oceanographic conditions (water temperature, salinity, dissolved oxygen, nutrient, etc), phytoplankton, and zooplankton are available to the public, but benthos data are unavailable. Fishery data have been collected by bottom trawl by R/V “Beidou” in Region Y from the 1980s to the present (Fig. 4). Chinese fisheries statistics on catches of 26 taxa in Region Y were compiled for the period of 1950-2010. Socio-economic data are not available. There are published papers in relation to climate change and fisheries in Region Y, but most of them are written in Chinese with English abstract.

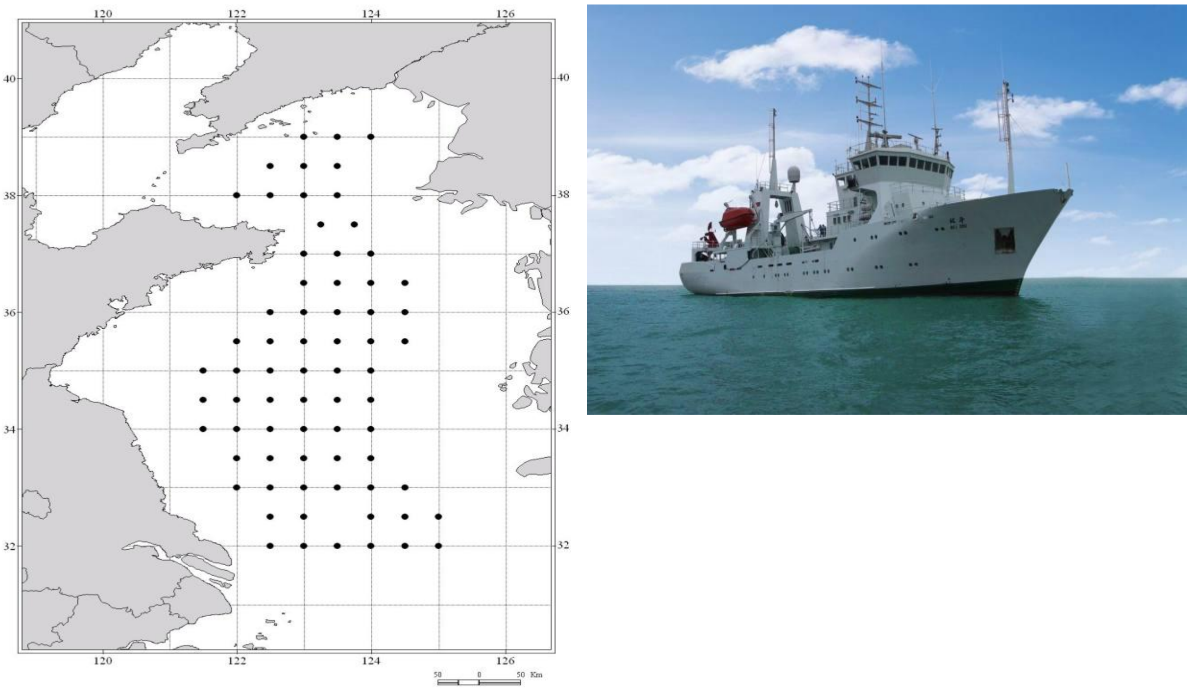

Fig. 4. Designated stations for bottom trawl by R/V "Beidou" in Region Y from the 1980s to the present.

2-3-2. Region K

The oceanographic data in Region K has been collected by the National Fisheries Research & Development Institute (NFRDI) through bimonthly measurements of depth-specific oceanographic variables (temperature, salinity, and dissolved oxygen) for the water columns at 31 fixed stations along 6 oceanographic lines in Region K (Figs. 2 and 5). The monitoring was started in 1991 along Line 204-207, 1997 along Line 203, and 1968 along Line 400 (Fig. 5). The data is available to the public at the web page of Korea Oceanographic Data Center (KODC: http://kodc.nfrdi.re.kr/page?id=eng_index). The measuring stations are located in areas deeper than 20-m depth, in which research vessels can enter. Most of data was collected at the seven standard water depths of 0, 10, 20, 30, 50, 75, and 100 m.

Phytoplankton data is not available from KODC. However, bimonthly samples of meso- and macro-zooplankton have been collected since 1967 along the same 6 oceanographic lines of NFRDI in the Korean waters, partially covering Region Y, K and J (Figs. 2 and 5). The sampling consists of vertical tows made from the near bottom to surface or from 100 m to the surface for depths greater than 100 m. A Norpac net (0.5-m diameter, 330-㎛ mesh) has been consistently deployed for collecting zooplankton. The zooplankton samples are then used to estimate biomass as wet weight and to identify and enumerate taxonomic groups. The total biomass of zooplankton per tow is calculated by measuring the wet weight of a zooplankton sample after removing individuals > 3 cm in length. Time-series data of meso- and macro-zooplankton biomass for the period 1967-2006 and the abundances of four zooplankton groups (copepods, euphausiids, amphipods and chaetognaths) for the period 1978–2006. Because the four zooplankton groups are dominant elements of the zooplankton community and generally have represented more than 90% in abundance and biomass, this grouping was expected to represent the status of the mesozooplankton community.

At present, benthos data is not available in Region K. However, there have been many short-term surveys in various sampling sites along coastal lines and estuaries.

Long-term fisheries-independent fish data is not available in Region K, but NFRDI conducted bottom trawl surveys in Region K in August 1967, and March-November 1980. In 2004, NFRDI started regular bottom trawl survey program to sample fishes in summer and winter, but the data is not yet available to the public.

Two types of fisheries-dependent data are available in Korean waters, partially covering Region Y, K and J. One is fishery catch statistics that have been compiled through the statistical year books by the Korean central government since 1926 (Office of Fisheries, 1960-1977; Central Fisheries Experiment Station, 1961; Ministry of Agriculture and Fisheries, 1971-1997; Ministry of Agriculture and Fisheries, 1978-1987; Korea National Statistical Office, 1998-2003; Ministry of Maritime Affairs and Fisheries, 2004-2007; Korea National Statistics Office, 2008). However, there is inconsistency and uncertainty in identification and taxonomic code for minor fisheries species.

Another data set has been compiled for the purpose of providing information on fishing ground and condition. Because of a computer accident, some old data were lost and the time coverage of this data set starts in 1986. While this data does not include all fishing operations in the area, it provided information on relative taxonomic catch compositions and fishing locations for selected vessels. The data variables included 1) catch amount in biomass (kg), 2) species or common fish names, 3) fishery type, 4) date, and 5) location (latitude and longitude at an interval of 30 min. degree).

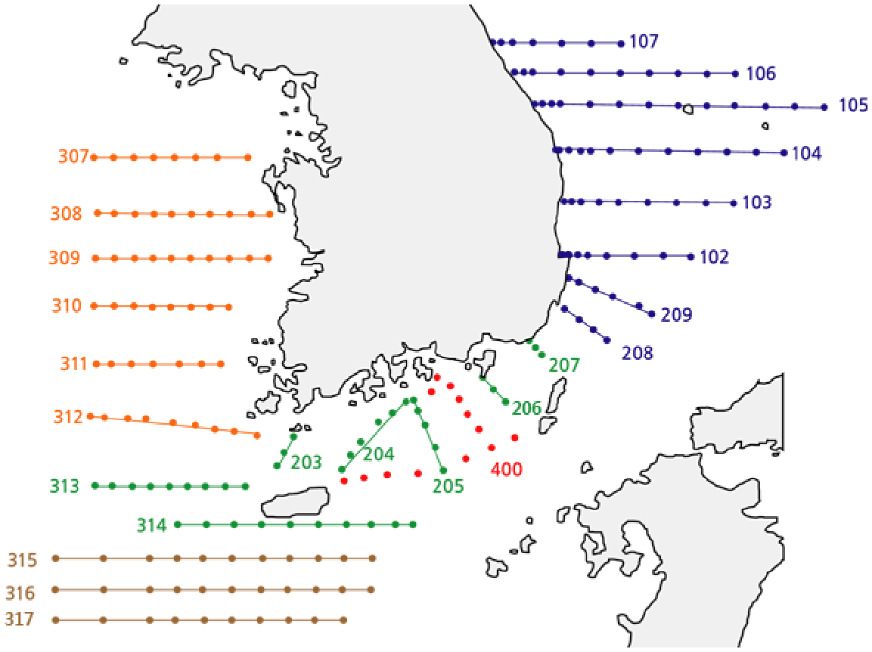

Fig. 5. Korea Serial Oceanographic Stations. The line numbers for Region K are 203, 204, 205, 206, 207 and 400.

2-3-3. Region J

Databases of oceanographic conditions (water temperature, salinity, dissolved oxygen, nutrient, etc), plankton including copepods, benthos are available to the public through internet (Appendix 1;

Fig. 6). Fisheries-independent data are not available. Japanese fisheries statistics on catches of 54 taxa from Region J for 1964-2004 are available. Socio-economic data were not available. Dozens of scientific papers published in English are available (Appendix 1).

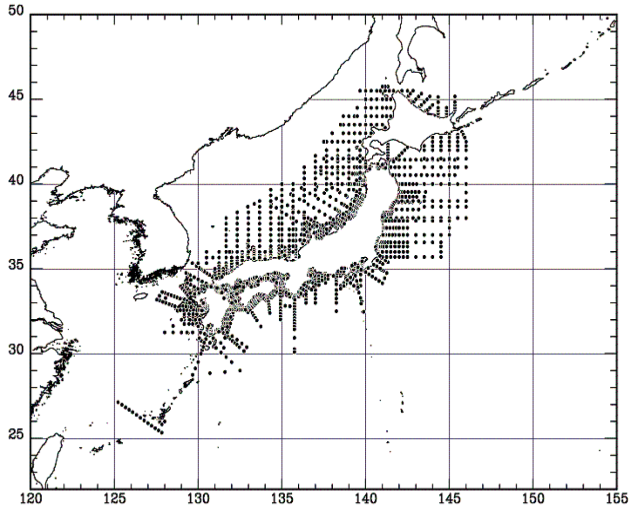

Fig. 6. Monitoring stations organized by Fisheries Research Agency and local fisheries research institutes in Japan since early 1950s.

2-3-4. Region R

2-3-4-1. Oceanographic data

Russia maintains regular oceanographic observations in Region R and adjacent area of the North-West Pacific (Fig. 7). The most active researches are conducted by Pacific Fisheries Research Center (TINRO, Vladivostok) and its Amur branch (Khabarovsk) that organize annually several large-scale research expeditions; other institutions which conduct limited programs of oceanographic observations are Pacific Oceanological Institute of Russian Ac. Sci. (POI, Vladivostok) that works mostly in Region R and North-West Pacific, Far-Eastern Hydrometeorological Research Institute (Vladivostok), Sakhalin Research Institute of Fisheries and Oceanography (Yuzhno-Sakhalinsk), Kamchatka Research Institute of Fisheries and Oceanography (Petropavlovsk), Magadan Research Institute of Fisheries and Oceanography (Magadan), Far-Eastern Research Institute of Marine Fleet (Vladivostok), and Russian Navy.

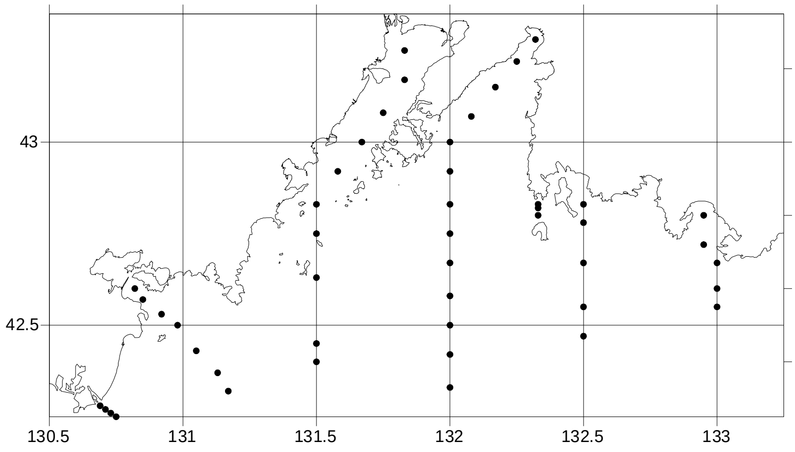

Fig. 7. Typical scheme of oceanographic survey in the coastal zone (RV MRS-5005, 2006-2008; RV Yantar 2009-2010)

The first Russian oceanographic observations in these waters were made in the middle of 19th century, the first large-scale surveys were made in the 1920-1950s, and since 1980s the surveys became rather regular, with interval from a season to 1-3 years (observations on some standard sections are more frequent: Table 1).

Common technique of observations in the period from 1920s to 1970s was the temperature measurements by Nansen thermometers and water sampling by Nansen bathometers with further measurements of salinity and oxygen in the samples by titration and nutrients – by colorimetry. After a transitional period of wide application of bathythermographers, oceanographic profilometers with temperature and salinity measurements *in situ* became the main technique of observations since 1980s, though the dissolved oxygen content and nutrients concentrations are still determined mostly by the same methods as decades ago.

The data of oceanographic observations in standard forms (for standard depths) are collected in several data bases organized in each agency, which little-by-little transmit them to national and international data bases, so theoretically all oceanographic data have to be accessible for a wide scientific society. In practice, the data are shared with a huge time lag, with only one exclusion: the data collected in Region R by Pacific Fisheries Research Center are provided annually, on the base of TINRO-NFRDI bilateral agreement, to Korean Oceanographic Data Center (KODC) and are available through the site of this Center. Metadata on Russian oceanographic surveys in Region R are distributed by NEAR-GOOS. The data from local archives of abovementioned institutes could not be shared or exchanged without special official agreements, but could be used for research purposes by scientists working in those institutes or in collaboration with them.

Table 1. Long series of annual oceanographic data obtained by Russia in Region R

Data series	Data description	Unit	Period of regular observations	% of missing values	Maintenance of the series
Temperature of the Surface Subarctic water mass	Modal temperature of the surface layer in the deep-water part of the standard section along 132°E (41°30-42°20 N), for summer and winter	°C	1980-nowadays	0%	Zuenko Yury (TINRO)
Temperature of the Intermediate water mass	Modal temperature of the layer between seasonal thermocline and 200 m in the deep-water part of the standard section along 132°E (41°30-42°20 N), for summer and winter	°C	1950-nowadays	summer: 17% winter: 28%	Zuenko Yury (TINRO)
Temperature of the Surface Coastal water mass	Modal temperature of the surface layer in the shelf part of the standard section along 132°E (42°30-43°00 N), for summer	°C	1980-nowadays	0%	Zuenko Yury (TINRO)
Salinity of the Intermediate water mass	Annual mean salinity in the layer 350-1000 m averaged for the whole Sea	psu	1950-nowadays	0%	Rudykh Natalia (POI)
Salinity of the Deep water mass	Annual mean salinity in the layer 1000-2000 m averaged for the whole Sea	psu	1950-nowadays	7%	Rudykh Natalia (POI)
Ice cover	Portion of the Tatar Strait area covered by the sea ice, by 10-day periods	%	1960-nowadays	0%	Ustinova Elena (TINRO)

2-3-4-2. Plankton data

Russia collects plankton samples in Region R. The most active researches, in particular in the Bering and Okhotsk Seas, are conducted by Pacific Fisheries Research Center (Vladivostok) that organize annually several large-scale research expeditions; however zooplankton and ichthyoplankton samples only are collected in those surveys. Other institutions which conduct limited programs of the plankton research are Institute of Marine Biology of Russian Ac. Sci. (Vladivostok) – it is the only institution that collects and processes the samples of phytoplankton, Far-Eastern Hydrometeorological Institute (Vladivostok), Sakhalin Research Institute of Fisheries and Oceanography (Yuzhno-Sakhalinsk), Kamchatka Research Institute of Fisheries and Oceanography (Petropavlovsk), and Magadan Research Institute of Fisheries and Oceanography (Magadan).

Russian scientists started investigations of marine plankton in Region R in the early 20th century. Large-scale surveys of the all Far-Eastern Seas and the North Pacific were conducted in the 1950-1970s, and since 1980s the surveys became rather regular, with interval from a season to 1-3 years (Table 2).

Table 2. Long series of the data on zooplankton obtained by Russia in Region R.

Data series	Data description	Unit	Period of regular observations	% of missing values	Maintenance of the series
Zooplankton abundance in the deep-water sea	Zooplankton biomass and number and biomass of all zooplankton species in May-June averaged for the area 41^{o}00-42^{o}30 N 131^{o}00-134^{o}00	mg/m^3: ind./m^3	1986-nowadays	30%	Dolganova Natalia (TINRO)
Zooplankton abundance in the coastal zone	Zooplankton biomass and number and biomass of all zooplankton species in summer months averaged for the area of Peter the Great Bay	mg/m^3: ind./m^3	1988-nowadays	0%	Nadtochy Victoria (TINRO)

Phytoplankton samples are collected by bathometers from standard depths and processed after filtering, with accounting the phytoplankton cells and species definition. The high labor expenditures do not allow to get any long time series for phytoplankton in Russian waters. Zooplankton samples are collected by standard Jeday net, usually from the upper layer 0-100 or 0-200 m. Other layers (the upper mixed layer, or intermediate layers) are towed only for special purposes. The samples are processed by two methods: classical one with total accounting and measurement of all organisms in each sample and further recalculation of each species number to the biomass using standard weights depending on species and size, and volumenometric express-method with dividing the sample onto 3 size fractions, definition the total biomass of each fraction, and sharing it to mass species. In both cases, the coefficients of catchability for Jeday net are applied for recalculation of the wet weight of each species in the sample to its real biomass *in situ*. Usually the samples are not stored after the processing. Ichthyoplankton samples (fish eggs and larvae) are collected by larger ichthyoplankton nets with both horizontal and vertical towing and are processed with accounting the eggs and larvae of certain species only (usually mass commercial species), because the species definition of eggs and larvae is rather difficult.

Data of the plankton samples composition are stored in standard form in personal or laboratory archives. The data of plankton surveys are generalized, analyzed, and published by planktonologists, but never included in any data bases for public access. They could be used by other scientists only in collaboration with their holders.

2-3-4-3. Benthos data

Russia investigates benthos in all shelves of the Russian EEZ and in the most part of deep-water zone of the Far-Eastern Seas (Fig. 8). The benthic surveys are conducted by Pacific Fisheries Research Center (Vladivostok) and Institute of Marine Biology of Russian Ac. Sci. (Vladivostok).

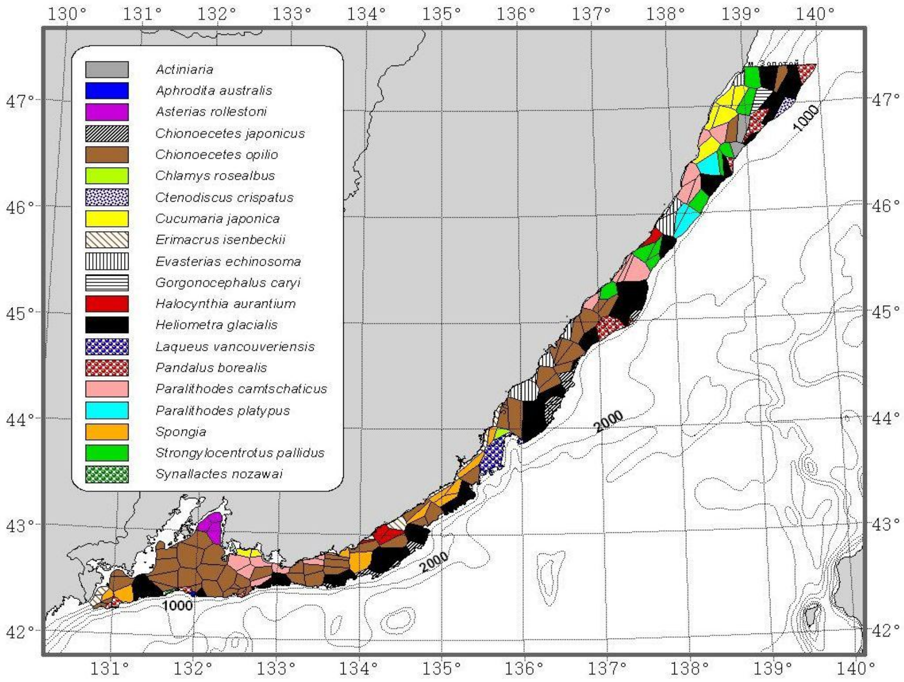

Fig. 8. Study areas for benthos in the shelf and slope of Primorye by RV Buhoro bottom trawl survey conducted in 2011.

Russian scientists started investigations of marine benthos in Region R in the 1920s. Large-scale surveys of the all Far-Eastern Seas and shelf areas of the North Pacific were conducted in the 1930-1970s, and since 1980s the surveys in certain areas (as Peter the Great Bay, for example) became rather regular, with interval of several years.

The samples of benthos are collected by two main sampling gyres: a bottom sampler that cut a certain portion of bottom sediments with all animals dwelling in it (Ocean is the standard sampler in Russia), and a dredge that collects the animals from the bottom surface – the latter technique is considered as a nonquantitative one. All benthic samples are totally processed with definition, accounting, and weighting of all species.

Data of the benthic samples composition are stored in standard form in personal or laboratory archives. The data of benthic surveys are generalized, analyzed, and published by benthologists, but never included in any data bases for public access. They could be used by other scientists only in collaboration with their holders.

2-3-4-4. Fisheries-independent fish data

Russian fisheries science is traditionally based on fisheries-independent data on fish resources, mainly on the data of direct fish accounting *in situ* (Fig. 9). The main research method is trawl surveys. Other fishing gyres, as longlines, drifting nets, traps, and jiggers are used sometimes for certain species. Acoustic surveys are conducted in parallels with traditional accounting, but usually their results are considered as additional information only. All surveys of fish resources are conducted by the institutes of the Federal Agency on Fisheries of Russia: Pacific Fisheries Research Center (Vladivostok) and its Amur (Khabarovsk) and Chukotka (Anadyr) branches that organize annually several large-scale surveys in all Far-Eastern Seas and the North-West Pacific, and Sakhalin Research Institute of Fisheries and Oceanography (Yuzhno-Sakhalinsk) that explores Region R.

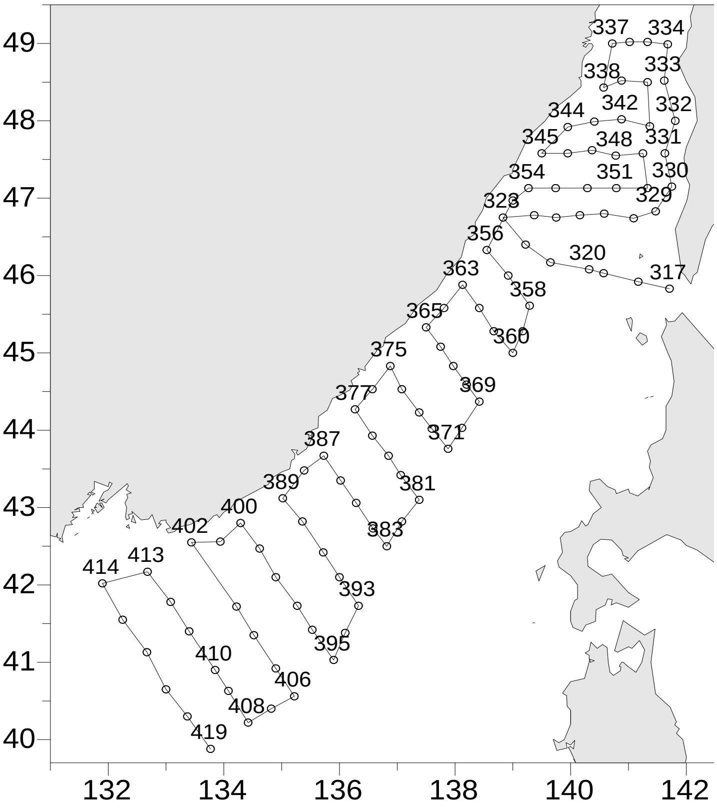

Fig. 9. Typical scheme of trawl survey over the whole EEZ of Russia (RV Professor Kaganovsky, 2003)

Russian scientists started investigations of marine fish resources in Region R in the 1920s. Large-scale surveys of commercial species in all areas of Region R were conducted in the 1930-1950s, and since 1980s the surveys with total accounting of all nekton species are organized regularly in Region R and the North-West Pacific, annually or with interval of several years.

Trawl surveys are made by standard research trawls, either pelagic or bottom in dependence on studied ichthyocenes. The catches are totally processed with definition of all species, their accounting and weighting, and biological analysis of mass species. On the base of these data, biomass and total allowable catch are estimated for all commercial species (Table 3).

Data of the catches composition are stored in standard form in archives of the institutes and the Federal Agency, besides, they are transferred to the regional data base that is maintained in TINRO. The data of surveys on fisheries resources are considered as commercial ones and their free distribution is strictly prohibited. However, these data are generalized, analyzed, and published by ichthyologists, and partially presented on annual bilateral meetings between Russian, Japanese, Korean, and Chinese fish scientists.

Table 3. Examples of long series of commercial fish biomass estimations in Region R.

Data series	Data description	Unit	Period of regular observations	% of missing values	Maintenance of the series
Walleye pollock biomass	Total biomass of pollock in the western part of Region R (at the continental coast)	10^6 t	1978-nowadays	0%	Nuzhdin Vladimir (TINRO)
Arabesque greenling biomass	Total biomass of greenling in the western part Region R (at the continental coast)	10^3 t	1958-nowadays	0%	Vdovin Alexander (TINRO)

2-3-4-5. Fisheries-dependent fish data

Fisheries statistics in the Far East of Russia began from the salmon fishery in the Amur Liman in the late 19 century and now it covers all kinds of fisheries in any marine area. All fishing vessels and enterprises, whether Russian or foreign, are required to report every day to the authorities of Federal Agency on Fisheries about the weight and species composition of their catch. These data are not completely reliable, but at least they are numerous and regular, that allows to trace seasonal or interannual dynamics of fisheries. Could they be used for monitoring of fish populations? It depends mostly on fishing efforts, and if the population is hardly exploited – it is possible. However, only for few commercial species the total allowable catch is completely used by Russian fishery, as for pollock or red king crab. Many species are underfished, so their annual catches depend mostly on fishing effort but not on state of the stock. In these cases, the stock dynamics could be characterized by dynamics of CPUE or the catch normalized to a standard fishing effort. Using the data on catch normalized to fishing effort, the year-class strength could be calculated (summary catch of generation in the whole period of its life) that is the best estimation of recruitment (Table 4).

Table 4. Examples of long series of estimations the year-class strength for commercial fish species in Region R.

Data series	Data description	Unit	Period of regular observations	% of missing values	Maintenance of the series
Walleye pollock year-class strength	Total catch of pollock generations in the age 3+ and elder by Russian fleet at Primorye coast	10^6 ind.	1952-2003	0%	Nuzhdin Vladimir (TINRO)
Saffron cod year-class strength	Total catch of saffron cod generations in the age 2+ and elder in Peter the Great Bay, normalized to the standard fishing effort (180 hoop-nets)	10^6 ind.	1965-2006	0%	Chernoivanova Ludmila (TINRO)
Pacific herring year-class strength	Total catch of herring generations in the age 3+ and elder by Russian fleet at Primorye coast	10^6 ind.	1950-2004	0%	Chernoivanova Ludmila (TINRO)

The data on daily catch of each species are summarized within statistical areas (large parts of the seas, much larger than the statistical areas in other countries) and by months, quarters, and years. These data are delivered to foreign partners of the Federal Agency on Fisheries and to international organizations, so generally the raw data on catch are easy accessible. However, the results of calculation CPUE, normalized catch, or year-class strength are not collected in any data base and are stored in personal or laboratory archives only – they could be used by other scientists only in collaboration with their authors and holders.

Annual catch data from 1983 to 2011 for pollack, saffron cod, Pacific cod, greenling, herring, flatfishes, sculpins and skates from Primorye were provided to this project by Russian experts.

2-3-4-6. Socio-economic data

Economical studies for fisheries industry in the Far East of Russia are traditionally conducted by Pacific Fisheries Research Center (TINRO). The main directions of these studies are concerned to economical substantiation of models for the fisheries industry development and enhancing of the marine biological resources management. The socio-economic data on the fisheries industry in the Far East of Russia are collected in statistical reports for every of 9 administrative regions located eastward of Lake Baikal which are published annually since 1959, where the data on the regions population, its dynamics, employment in fisheries industry, the fisheries industry output, etc. are presented (Table 5). The reports are widely distributed and easy available.

Table 5. Contents of the annual statistical report on socio-economic situation in the fisheries industry of Russian Far East (published by administrative regions)

Data series	Data description	Unit	Period of published data	% of missing values	Source
Population	Total population size	10^6 ind.	1959-2011	0%	Federal Service of the State Statistics
Natural dynamics	Increase or decrease of the population per 1000 ind. per a year	ind.$\cdot 10^{-3}$ ind.	1959-2011	0%	Federal Service of the State Statistics
Migration	Number of people migrated between regions of Far East and in/out of Russian Far East from/to other regions of Russia or other countries	%	2000-2011	0%	Federal Service of the State Statistics
Able-bodied citizens	Total number of the able-bodied citizens	10^6 ind.	1959-2011	0%	Federal Service of the State Statistics
Employment in fisheries industry	Number of laborers in fish industry, including both fishing and fish processing	10^3 ind.	1990-2011	0%	Yeruchimovich V.B. (TINRO)
Annual landings	Total annual catch of all species of marine and fresh-water resources	10^3 ton	1980-2011	0%	Yeruchimovich V.B. (TINRO)
Fishery enterprises	Total number of enterprises engaged in fishing	enterprise	1980-2011	0%	Yeruchimovich V.B. (TINRO)

Dozens of scientific papers published in English or Russian are available (Appendix 1).

3.0 Results & Discussion

3-1. Region Y

Over the last 50 years, Yellow Sea ecosystem has large changes in biodiversity and productivity. For example, due to species shifted in dominance, the commercially important long-lived, high trophic level, piscivorous bottom fish have been replaced by the low-valued shorted-lived, low trophic level, planktivorous pelagic fish (Fig. 10).

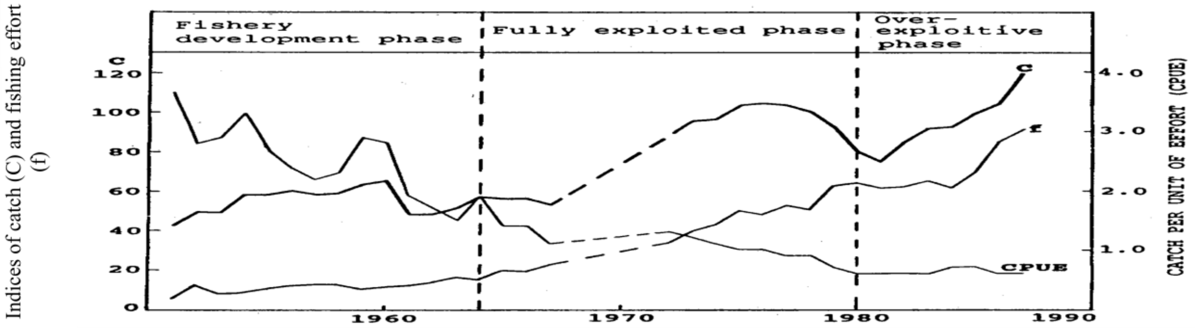

Fig. 10. Trends in catch and effort for Yellow Sea fisheries, 1950-1980s and a generalized history of the fisheries in Region Y (Tang, 1989).

Using long time series fishery survey data and the relative environmental variables, the variations in species regime shifts were reported by Jin (2003)and Xu and Jin (2005), and species composition, biomass variations and biological characteristics of some species in Region Y were closely related to temperature variations (Figs. 11-13). During warm period, the biomass of warm water species (anchovy), warm temperate species (small yellow croaker) increased, adversely, the biomass of cold water species (Pacific herring, Pacific cod) decreased, and vice versa; the sharp increase of SST also had a negative impact on some species (small yellow croaker, *Lophius litulon*), caused the decline of these population (Li et al., 2011). In addition, the tropical water species, false killer whale, which had not been observed before 2004, was found in the Yellow Sea. Qiu et al (2008; 2010) identified the responses of fish production to climate variability (land precipitation, monsoon wind speeds, and a proposed index of tropical cyclone influence). The results suggested that river runoff, monsoon circulation and tropical cyclone impacts are the physical forcing factors dominating the catch variations, and the effects are largely through controlling the nutrient supply for biological production.

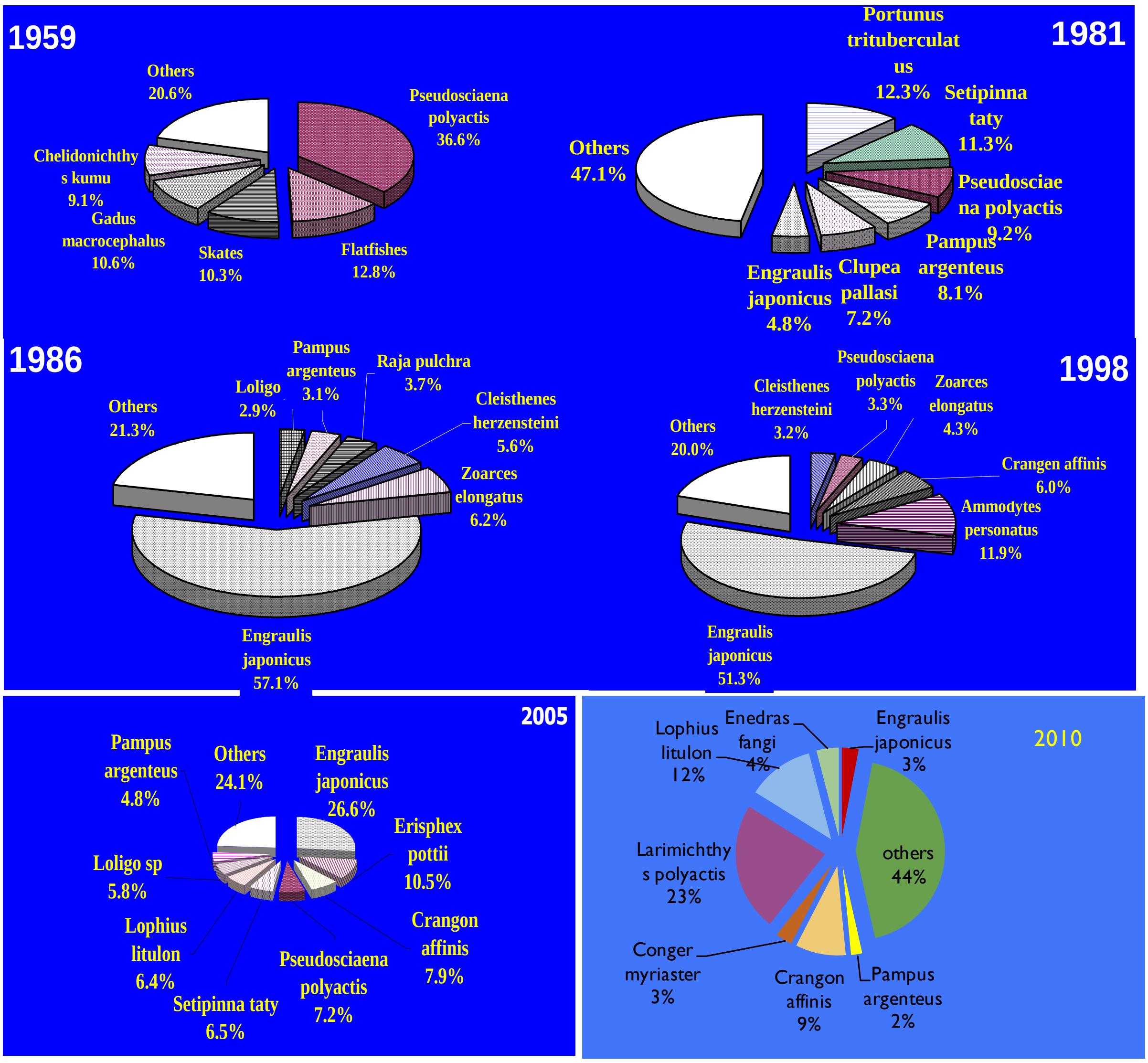

Fig. 11. Biomass composition of major species in Region Y in 1986, 1998, 2005 and 2010.

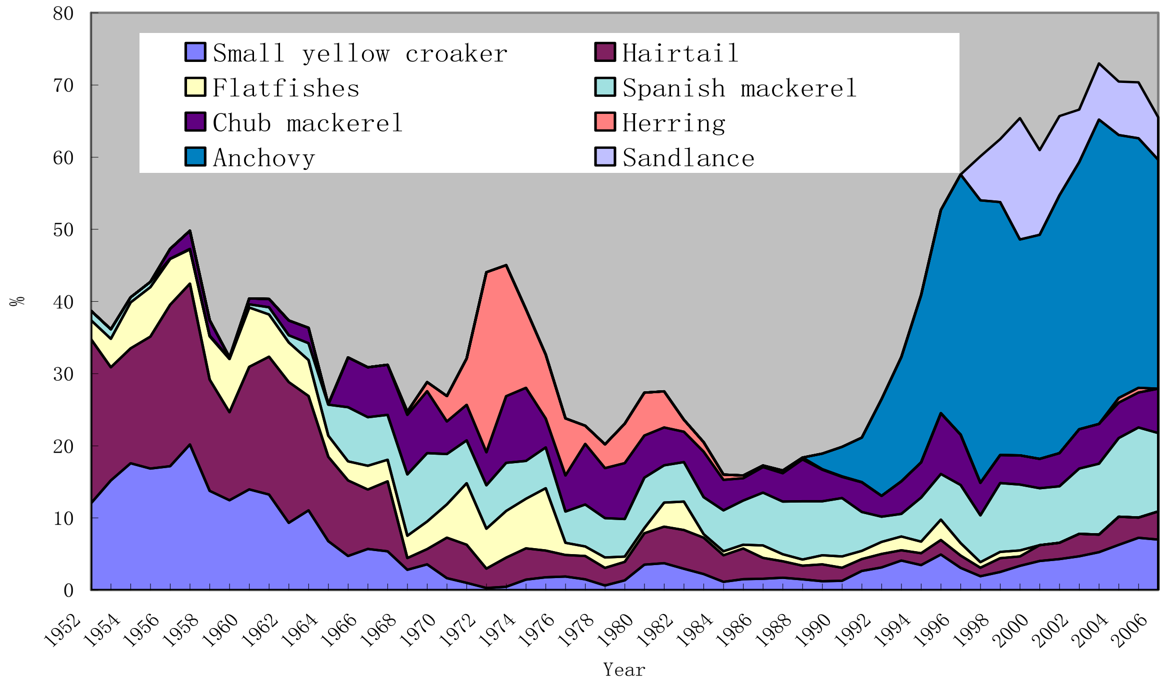

Fig. 12. Biomass composition of major fisheries species in Region Y from 1952 to 2007.

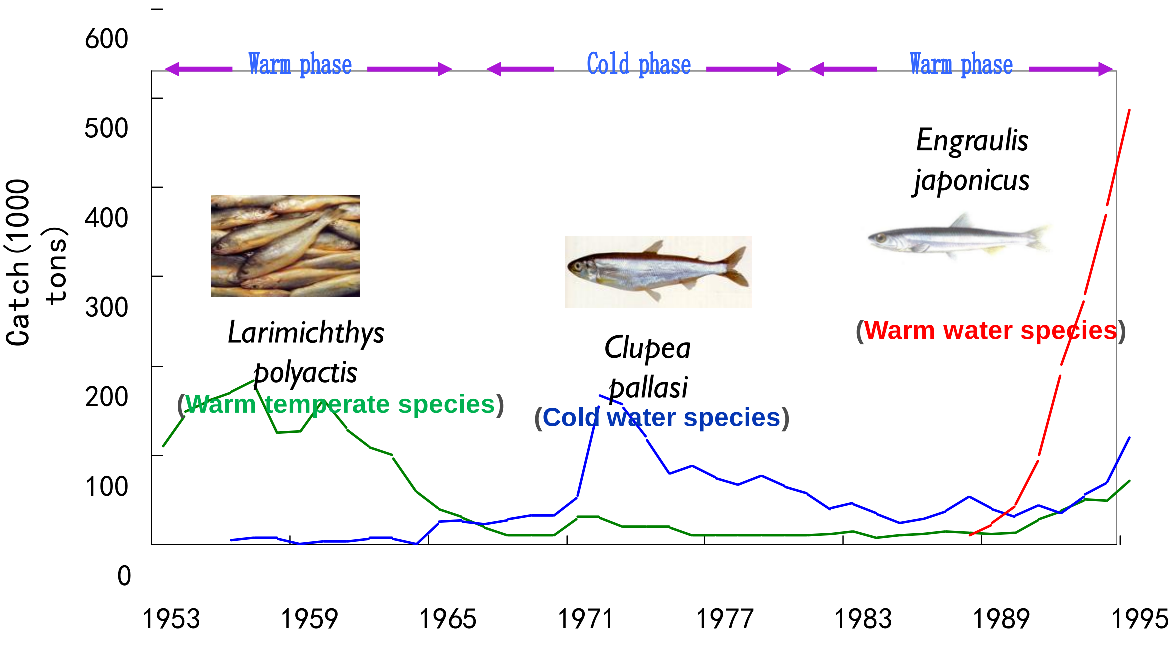

Fig. 13. Different temperature-type species and climate changes in Region Y (Tang et al., 2003).

The fishery abundance is also closely related to the climate changes (e.g. ENSO). Many fishery species production showed a regular fluctuation during ENSO events (Fig. 14). The higher production of small yellow croaker was found during ENSO and 1-2 years after ENSO events (Li et al., 2011). There was a relationship between periods of abundance and dryness and wetness which was associated with the southern oscillation (Tang, 1981). A new study identified four SST regimes in

Region Y over the past 138 years: a warm regime before 1900, a cold regime from 1901 to 1944, a warm regime with a cooling trend from 1945 to 1976, and a warm regime with a warming trend from 1977 to 2007. SST regime shifts and fluctuations in herring abundance in the Yellow Sea showed a very good match.

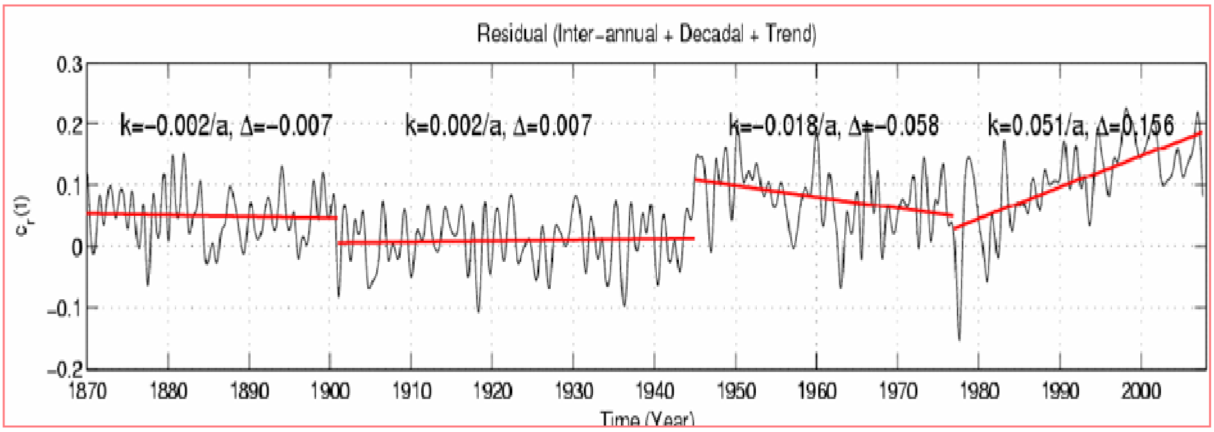

Fig. 14. Four SST regimes are indentified in Region Y over the past 138 years, namely, the warm regime (W) before 1900, cold regime (C) from 1901 to 1944, warm regime with cooling trend (WC) from 1945 to 1976, and warm regime with warming trend (WW) from 1977 to 2007.

3-2. Region K

3-2-1. Oceanographic conditions

Spatially-explicit, retrospective analyses on air temperature in the southern part of Korean peninsula and hydrological conditions in Region K showed that global warming have apparently increased land surface temperatures by 1.376^{o}C from 1968 to 2007 (Jung, 2008b), at least for the urban areas, and consequently sea surface temperatures of Region have increased by 0.99^{o}C from 1968 to 2010. The estimated rate of linear increase of air temperature in South Korea, 0.035^{o}C yr^{-1}, is 2.7 times higher than the linear warming trend of 0.013^{o}C yr^{-1} for the past 50 years reported by the Intergovernmental Panel on Climate Change (IPCC, 2007a). The rate of linear increase of sea surface temperature in Korea sea waters from 1968 to 2010, estimated by this project, was 0.024^{o}C yr^{-1} (Table 6). The warming sea surface temperature in Korean coastal and offshore sea areas were already reported by past studies (Min and Kim, 2006; Jung, 2008b). The linear rate estimated for coastal sea surface temperatures from 1969 to 2004, which have been measured at lighthouses along the coastline of Korea, was 0.020^{o}C yr^{-1} (Min and Kim, 2006), which is lower by 0.004 than our estimate for offshore areas. However, the increasing trend of the sea water temperatures diminished with waters depths up to 100 m (Table 6).

In Region K, an increasing shift in water temperature was detected in 1987-1988 at all of the standard depths (Fig. 15) except 100 m (the graph is not shown). Particularly at 0 and 10 m, an additional increasing shift was detected in 2007. Thus, overall from 1984 to 2010, water temperature has linearly increased at 0-20 m water depth, but not at 30-100 m depth. However, at 30, 50 and 100 m, a decreasing shift was detected in 2000 or 2002. At 75 m, no additional shift was detected after 1988. Annually-averaged salinity in Region K showed more complicated pattern depending on the water depth, but showed the lowest value in 2006 and rebounded thereafter at all of the standard depths (Fig. 16). At 0 and 10 m, it showed two decreasing shifts in 1998 and 2010, thus a linearly decreasing trend. At 20 and 30 m, it showed an increasing shift in 1979, followed by decreasing shifts after 1997. At 50 - 100 m, it showed a major decreasing shift in 2005. Confined to the period of 1984-2010, the depth-specific salinities have linearly decreased.

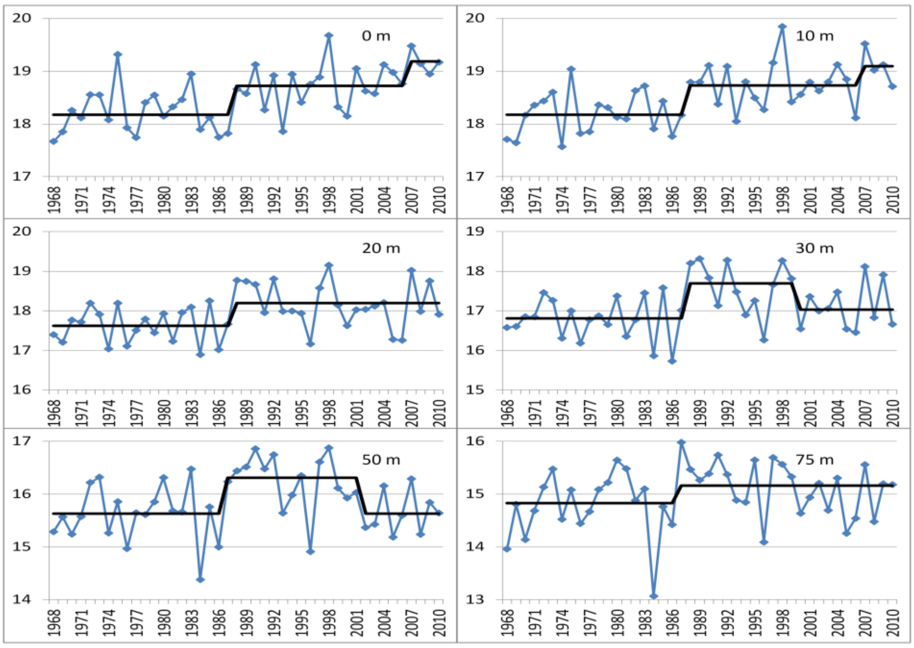

Fig. 15. Annually-averaged, depth-specific water temperatures from 1968 to 2010 at 0, 10, 20, 30, 50 and 75 m in Region K (126°20’ -129°20’ E, 33°30’ -35°00’ N).

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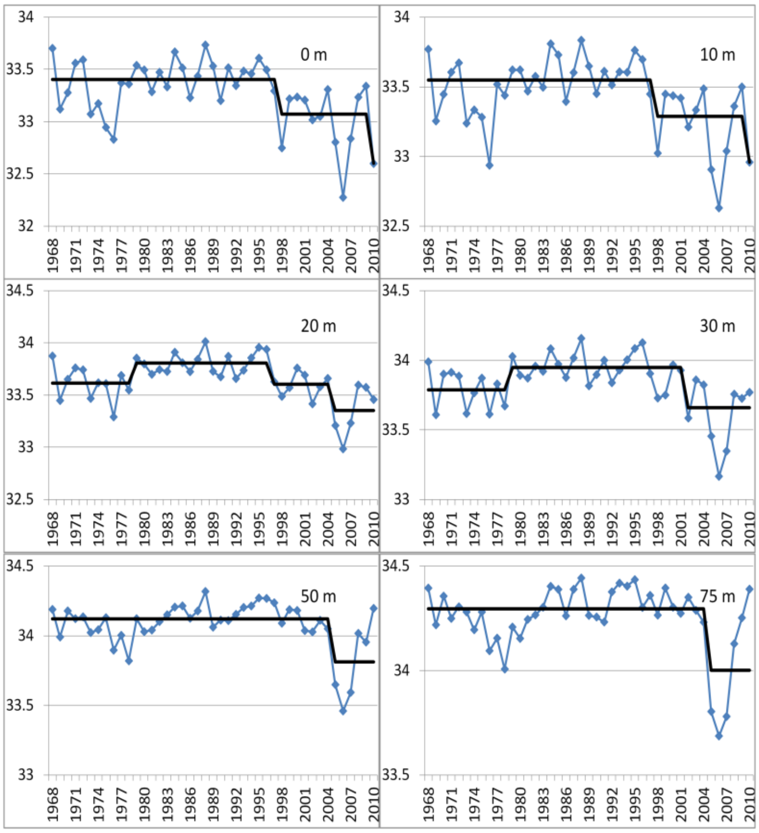


vi.

Fig. 16. Annually-averaged, depth-specific salinity from 1968 to 2010 at 0, 10, 20, 30, 50 and 75 m in Region K (126°20’ -129°20’ E, 33°30’ -35°00’ N).

Table 6. The linear rates of land climate and depth-specific hydrological factors in Region K from 1968 to 2010.

Factor	Depth (m)	Rate(yr^{-1})	SE(yr^{-1})	p-value	Increase
Temperature (oC)	0	0.0235	0.0052	<.001	0.99
	10	0.0240	0.0052	<.001	1.01
	20	0.0164	0.0066	0.018	0.69
	30	0.0138	0.0079	0.087	0.58
	50	0.0061	0.0070	0.391	0.26
	75	0.0078	0.0070	0.27	0.33
	100	-0.0061	0.0068	0.379	-0.26
	Bottom	0.0051	0.0068	0.456	0.21
Salinity	0	-0.0100	0.0035	0.007	-0.42
	10	-0.0072	0.0031	0.024	-0.30
	20	-0.0052	0.0025	0.046	-0.22
	30	-0.0042	0.0024	0.085	-0.18
	50	-0.0031	0.0021	0.153	-0.13
	75	-0.0026	0.0020	0.218	-0.11
	100	-0.0031	0.0021	0.14	-0.13
	Bottom	-0.0056	0.0022	0.013	-0.23
DO	0	-0.0002	0.0028	0.94	-0.01
	10	-0.0041	0.0026	0.123	-0.17
	20	-0.0071	0.0028	0.018	-0.30
	30	-0.0087	0.0030	0.007	-0.37
	50	-0.0133	0.0032	<.001	-0.56
	75	-0.0094	0.0031	0.005	-0.40
	100	-0.0092	0.0035	0.014	-0.39
	Bottom	-0.0088	0.0032	0.009	-0.37

Contrary to the depth-specific sea water temperatures, dissolved oxygen content (DO) and its saturation level have generally decreased, which is expected because gas solubility decreased with increasing water temperature (Pörtner and Knust, 2007). However, the decreasing trend of DO and its saturation level became greater with water depths, which is opposite to temperature trend in which warming trend diminished with water depth. In deep water, in addition to decreased solubility of oxygen due to warming sea water *per se*, we speculate that warming mixed layer may have strengthened the degree stratification between the surface and bottom layer of the water column, inhibiting oxygen supply to deep water and intensified the DO decrease in deeper water. Together with climate-driven changes, anthropogenic factors such as eutrophication and water-quality deterioration in coastal areas of Korea (Smith, 2003; Lee and Lim, 2006) could have accelerated the decreasing trend of DO.

Although sea surface salinity was reported to have increased in Region Y (Lin et al., 2001), our analysis for the 1968-2010 period in Region K showed that depth-specific salinity has linearly decreased from 0 to 100-m depth (Table 6). As the decreasing trend of salinity was pronounced in the mixed layer, we speculate that it is probably related to the annual variations in Changjiang diluted water (Kim et al., 2009).

3-2-2. Zooplankton

Annual mean biomass of zooplankton abruptly increased in 1997 and 2005 (Fig. 17). Bimonthly mean biomass of total zooplankton was generally lowest in February and highest in October (Kang et al., 2012). However, high values were observed mainly in October and December after the late 1980s, but were later found mainly in June and August after the mid-1990s.

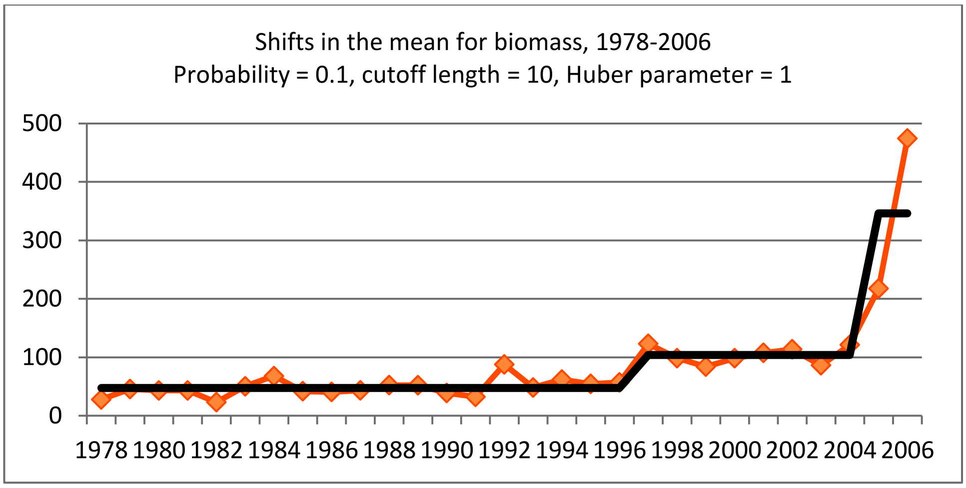


Fig. 17. Annually-averaged biomass (mg m^{-3}) of meso- and macro-zooplankton in Region K.

Monthly and annual variation of annual mean abundance density were similar between amphipods and chaetognaths, but distinctive in copepods and euphusiids (Fig. 18). Copepods dominated year around. Amphipods and chaetognaths tended to increase in August and October; whereas euphausiids in April. Abundances of copepods, amphipods, and chaetognaths increased after the later 1990s (1998, 1996, and 2000, respectively). Abundance of euphusiids increased in 1992 and then suddenly decreased in 2006. The ordinations of the years from 1978 to 2006 generally showed a step-by-step shift, but the magnitude of the shift varied and was greater in some years (the bottom panel of Fig. 18). Greater shifts occurred in 1979-1982, 1995-1996, 1997-1998, and 2005.

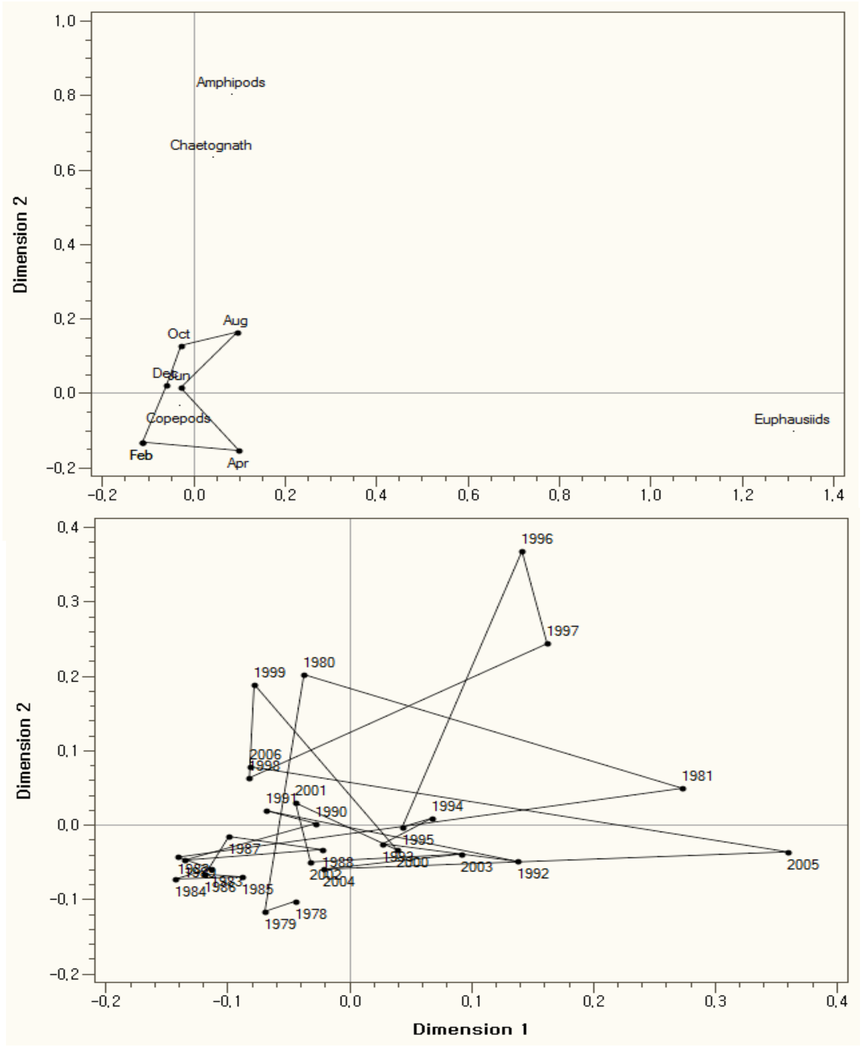


Fig. 18. Correspondence analysis on the numerical taxonomic composition of the four meso-and macro-zooplankton groups (copepods, chaetognaths, amphipods, and euphausiids) collected bimonthly in Region K from 1978 to 2006 in relation to month (top panel) and year (bottom panel). The scales of dimensions 1 and 2 are the same for the two panels, but group labels were omitted for display purposes in the bottom panel.

Canonical correspondence analysis (CCA) on the taxonomic compositions of zooplankton in relation to depth-specific water temperatures and salinities up to 100-m depth in Region K from 1978 to 2006 showed that both salinities and temperatures were significantly correlated with changes in zooplankton abundance, especially with Dimension 2 (Fig. 19). Depth-specific temperatures were opposite to that of salinities in the CCA plot (Fig. 19). As water temperatures increased and salinity decreased, abundance of chaetognaths and amphipods generally increased, but abundance of copepods decreased. As bottom salinity decreases, abundance of all 4 groups of zooplankton increased ($p < 0.05$).

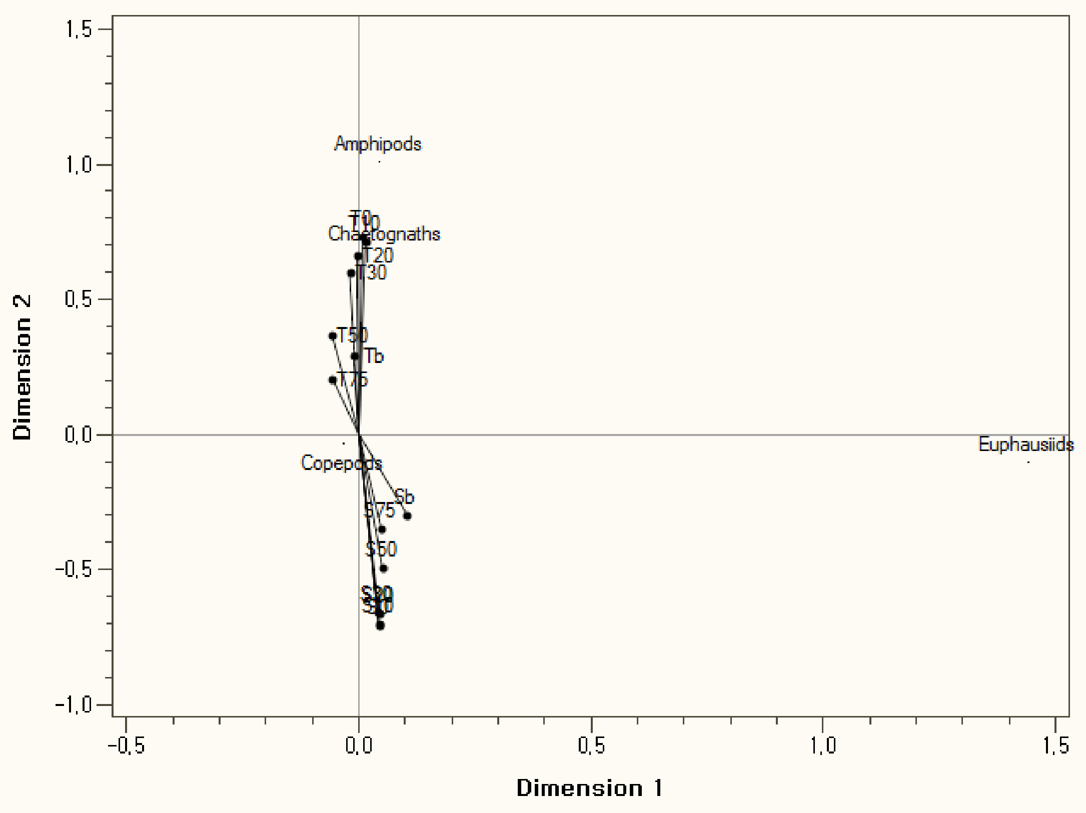


Fig. 19. Canonical correspondence analysis on the taxonomic compositions of meso- and macro-zooplankton in relation to depth-specific water temperatures (T) and salinities (S) up to 100-m depth in Region K from 1978 to 2006. The two digits denote depth (m) and ‘b’ denote bottom (the deepest depth at which the CTD was deployed).

3-2-3. Fish

By applying the same CCA, four regimes and their characteristic commercial fish species could be defined for fisheries-dependent data from 1968 to 2010 in Korean waters (covering parts of Regions Y, K and J): (1) saury (1968-1974); (2) pollock (1975-1982); (3) sardine (1983-1990); and (4) common squid (1991-2010) (Fig. 20).

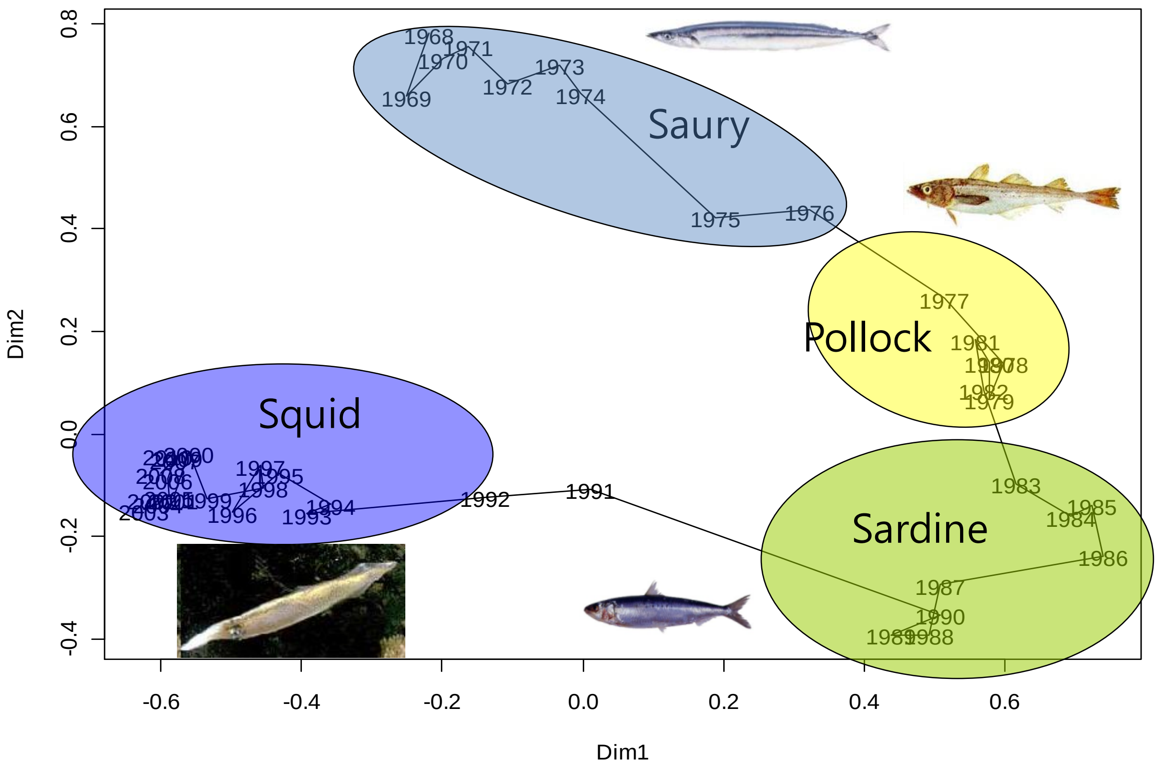


Fig. 20. Correspondence analysis of species composition in fishery catch from Korean sea waters from 1968 to 2010. Column variable was year and row variable was fish species. Points of fish species are not shown, but the characteristic species representing the four distinct periods are illustrated.

Because these four species have been caught mostly in the Tsushima Warm Current (TWC) region, we analyzed seasonal and annual variations in volume transports of the TWC, but could not detect any significant shift. To detect shifts in the dimension 1 and 2 extracted from CA, Bayesian Markov switching models and the sequential t-test regime-shift detection method were applied. Markov switching models detected shifts in 1976, 1983 and 1991 (Fig. 21), whereas the sequential t-test method detected shifts in 1976-1977, 1983, 1988, 1991 and 1995 (Fig. 22).

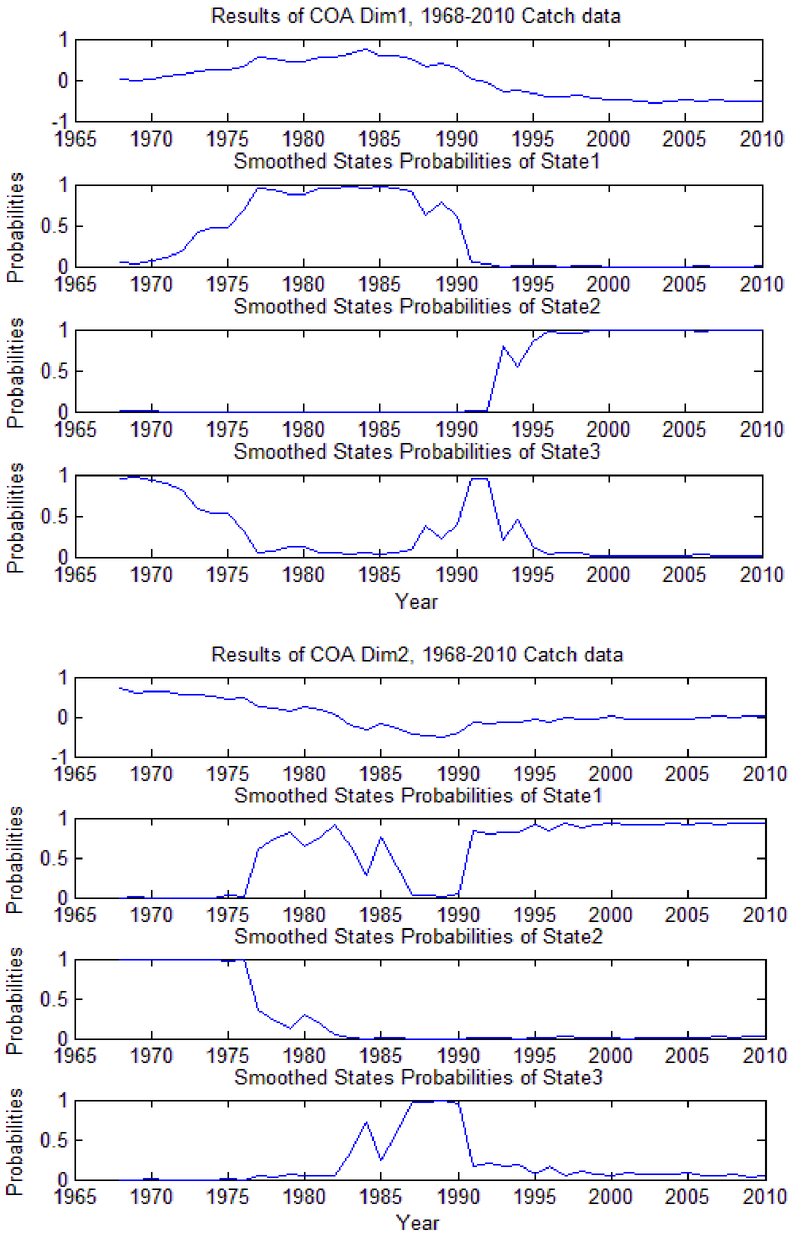


Fig. 21. State probablities estimated by applying Bayesian Markov switching models to the dimension 1 and 2 extracted from correspondence analysis on fisheries species compostion in Korea from 1968 to 2010.

Confined to Region K, correspondence analysis (CA) showed that species composition in weight of commercial catches in the period of 1986-2010 dramatically shifted between 1987 and 1993 (Fig. 22-a). CA also nicely summarized annual changes of each species. In the graphics showing ordination of fish species (Fig. 22-b), the points of species positioned in the left side from the origin denote that those species became dominant in fisheries catch in 1993-2010 whereas those points positioned in the right side indicate that the corresponding species once dominant in 1986-1992, but decreased after 1987. The degree of change from 1986 to 2010 is generally proportional to the horizontal distance between the point of each species and the origin. In other words, those species positioned to the rightmost (e.g., sardine and filefish) were most greatly decreased after 1987; whereas those positioned to the leftmost (e.g., squid, Spanish mackerel, yellow croaker, yellowtail, and anchovy) were mostly greatly increased after 1993. Those species positioned close to the origin (e.g., chub mackerel and horse mackerel) were relatively stable throughout the period in their contribution to the annual total fisheries catch.

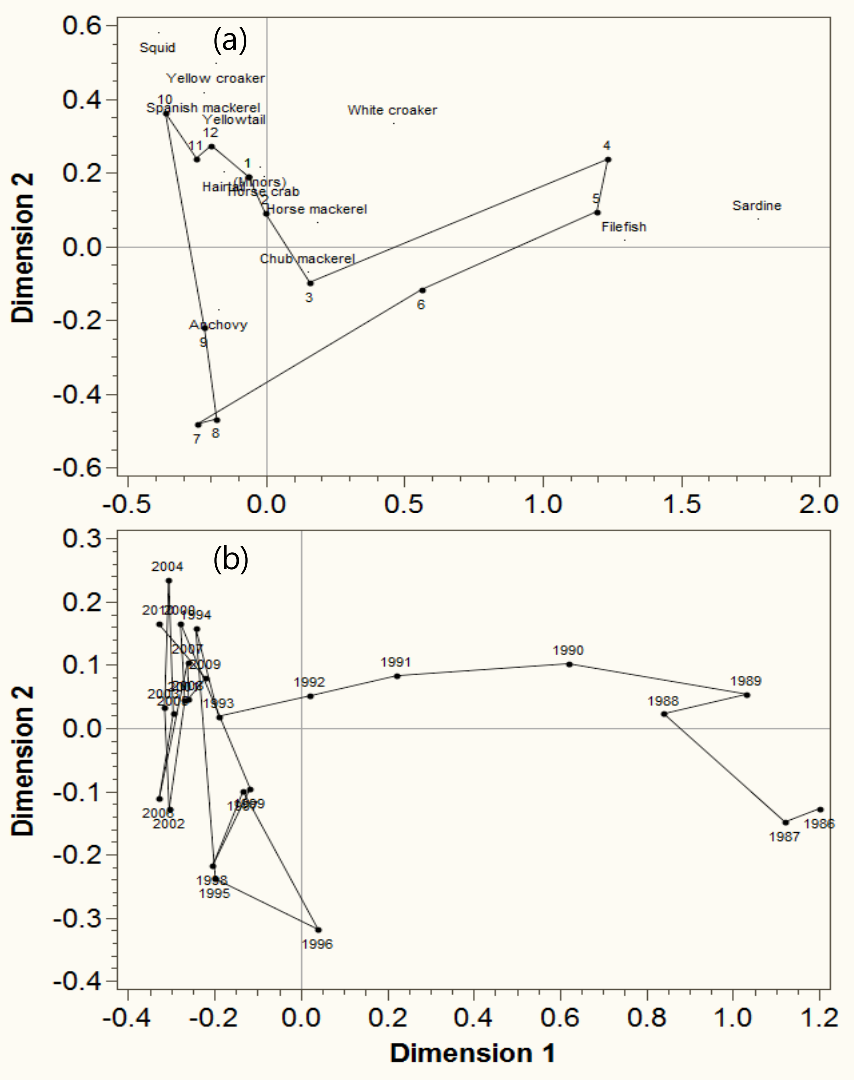


Fig. 22. Correspondence analysis on the taxonomic biomass composition of 12 major fisheries species caught by Korean fishers in Region K from 1986 to 2010 in relation to month (a) and year (b). The digits in (a) denote month. The scales of dimensions 1 and 2 are the same for the two panels, but group labels were omitted for display purposes in the bottom panel.

Fig. 23 also confirms and details the annual changes in commercial catch of each species. In 1986-1990, anchovy was most dominant (36.6%), followed by sardine (17.7%), filefish (16.0%), chub mackerel (11.2%) and hairtail (5.7%). In 1991-2010, catch of sardine and filefish dramatically decreased, and anchovy became more dominant (55.8%), and common squid (7.4%) became one of dominant species together with chub mackerel (10.3%) and hairtail (6.3%). Thus, collapse of sardine and filefish fishery was the main feature of the shift observed in the late 1980s and early 1990s.

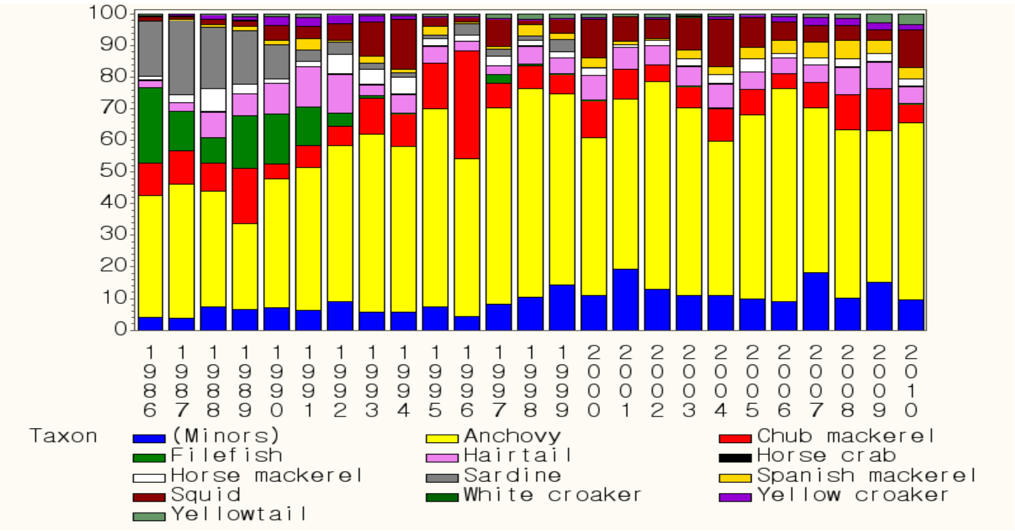


Fig. 23. Species composition in biomass of fisheries catch in Region K by Korean fishers from 1986 to 2010. Data were provided by the National Fisheries Research & Development Institute.

To evaluate and project their range shifts based on climate-driven hydrographic changes simulated by a general circulation model under a climate change scenario, we selected 12 major fisheries species in Region K. The criteria of selection were 1) that the duration of provided time-series of each species was longer than 5 years, and 2) that their major fishing ground is Region K, not Region Y or J. We grouped these species into 3 categories based on their body size and preferred water-depth range: 1) small pelagic species (anchovy *Engraulis japonicus*, chub mackerel *Scomber japonicus*, Pacific sardine *Sardinops sagax*, horse mackerel *Trachurus japonicus*, Pacific herring (*Clupea pallasii*), Pacific sardine *Sardinops sagax*, and common squid *Todarodes pacificus*), 2) large pelagic species (Spanish mackerel *Scomberomorus niphonius* and yellowtail *Seriola quinqueradiata*), and 3) demersal or bentho-pelagic species (hairtail *Trichiurus lepturus*, yellow croaker *Larimichthys polyactis*, filefish *Thamnaconus modestus*, and red horsehead *Branchiostegus japonicas*).

The biomass-weighted mean latitudes of catch distribution showed strong seasonality for all 12 fish species (Fig. 24). However, the long-term trends fit by LOESS differed with fish group, but mostly showed an oscillating trend at decadal scale. Mean latitude of small pelagic species showed decadally oscillating, but stationary trends in the long-term for the period of 1984-2010. An exception was Pacific anchovy, which showed a gradual southward shift until the late 1990s, followed by a stationary trend thereafter. In the case of Pacific sardine, because catch was greatly reduced after 1991, monthly-aggregated catch sometimes became nearly zero, generating outliers or missing values in its mean latitude. The two large pelagic species, Spanish mackerel and yellowtail, showed a long-term trend of poleward movement with oscillation at decadal scale. The poleward shift was more obvious in Spanish mackerel. Three of the 4 demersal and bentho-pelagic species selected in our analysis (hairtail, yellow croaker and red horsehead) showed a long-term trend of poleward shift with decadal oscillation. Like sardine, fishery of filefish was collapsed after 1991, and its mean latitude showed a trend of southward shift thereafter.

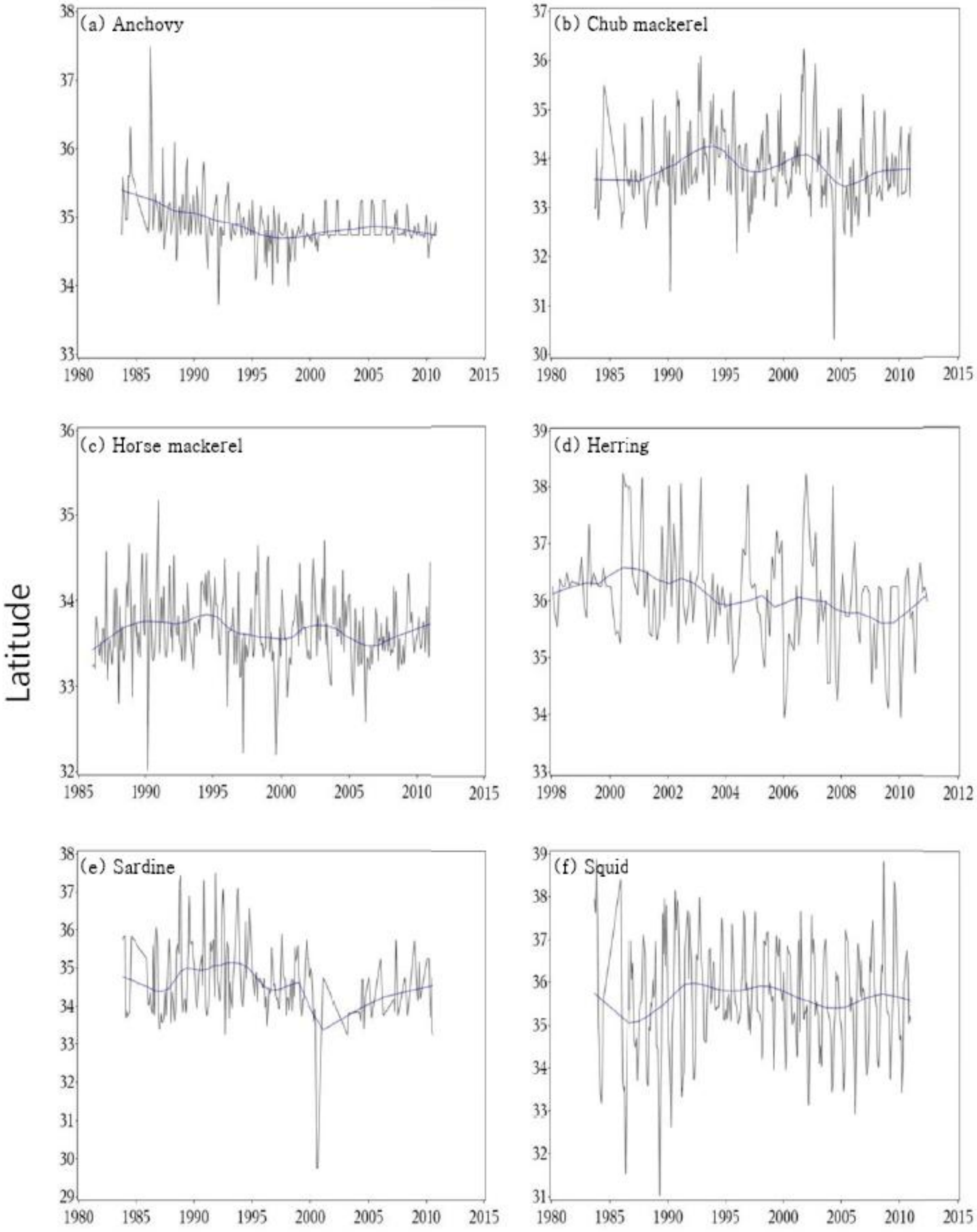
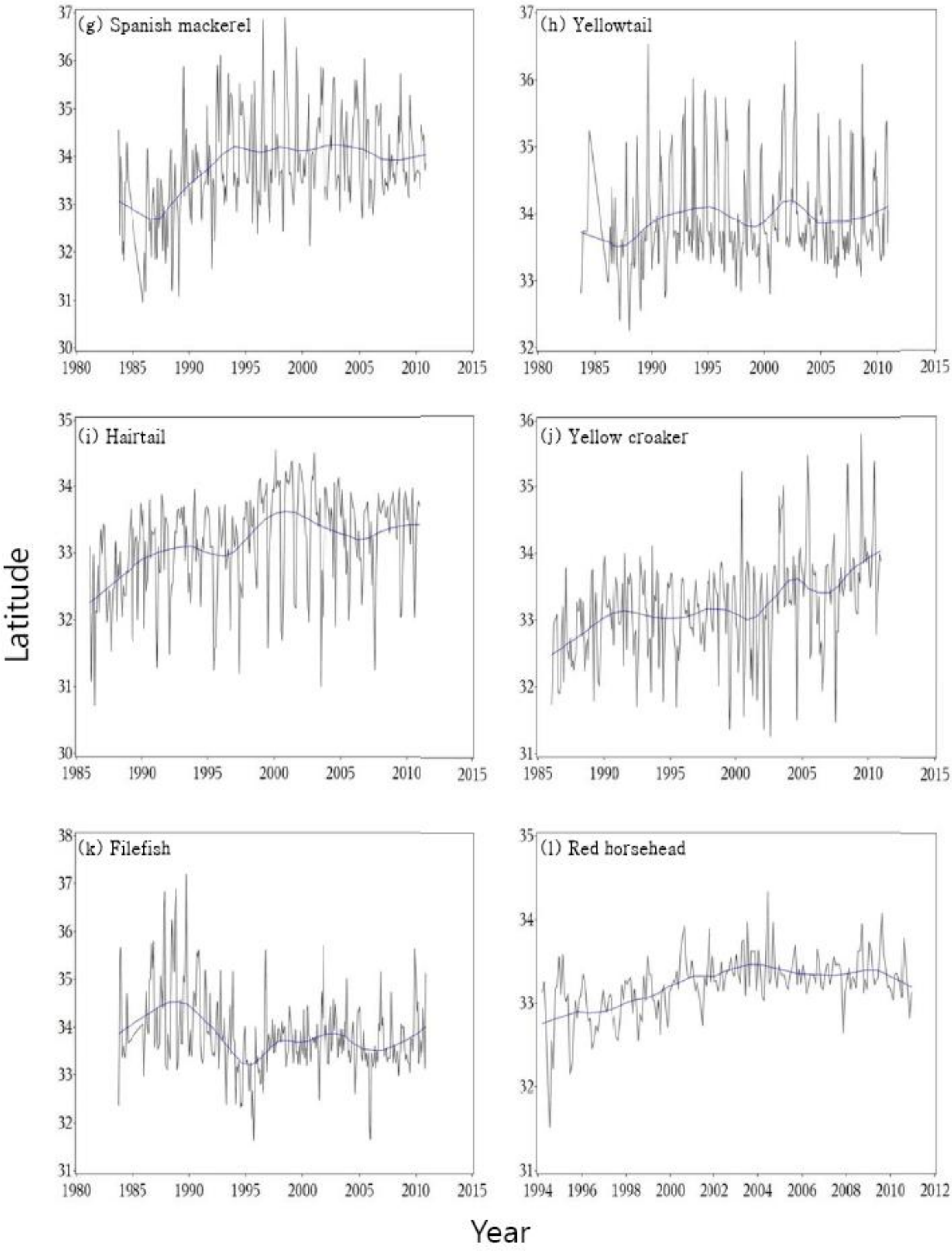


Fig. 24. Biomass-weighted, monthly mean latitudes of catch distribution of fishes from 1984 to 2010: (a) anchovy, (b) chub mackerel, (c) horse mackerel, (d) Pacific herring, (e) Pacific sardine, (f) common squid, (g) Spanish mackerel, (h) yellowtail, (i) bighead hairtail, (j) small yellow croaker, (k) filefish, (l) red horsehead. The overlaid line denote the long-term trend smoothed by LOESS (locally-weighted scatterplot smoothing). Continued in the next page.



3-3. Region J

Using more than 100 long time series including climatic, oceanic, biological and fisheries data, Tian et al (2006; 2008; 2011) identified a regime shift, characterized by an abrupt change from a cool to warm conditions, occurred in Region Y under influence of the Tsushima Warm Current (TWC) in the late 1980s.

3-3-1. Oceanographic conditions

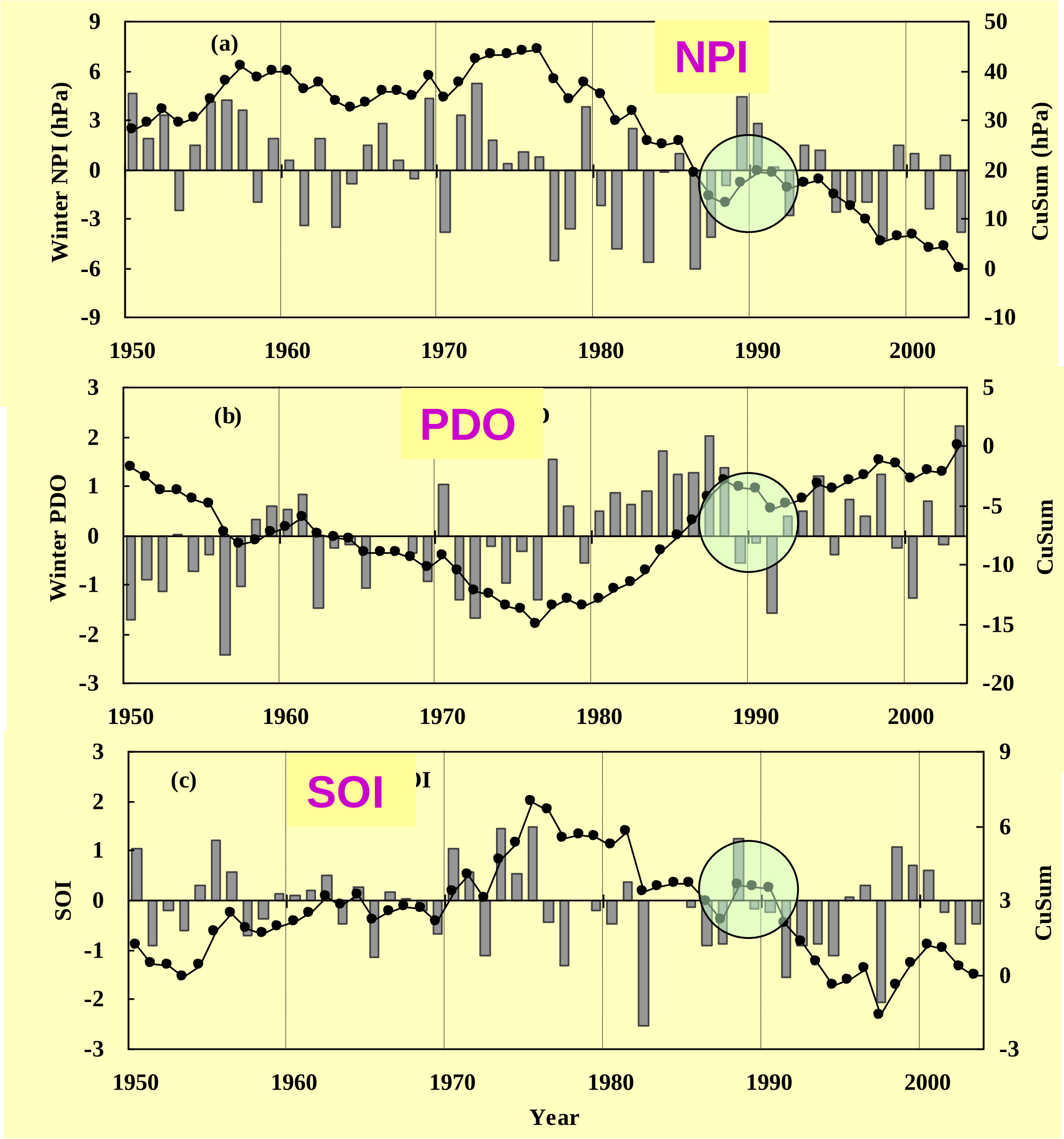


Fig. 25. Annual anomalies of the three global climate indices (PDO, AO, and ENSO) from 1950 to 2004.

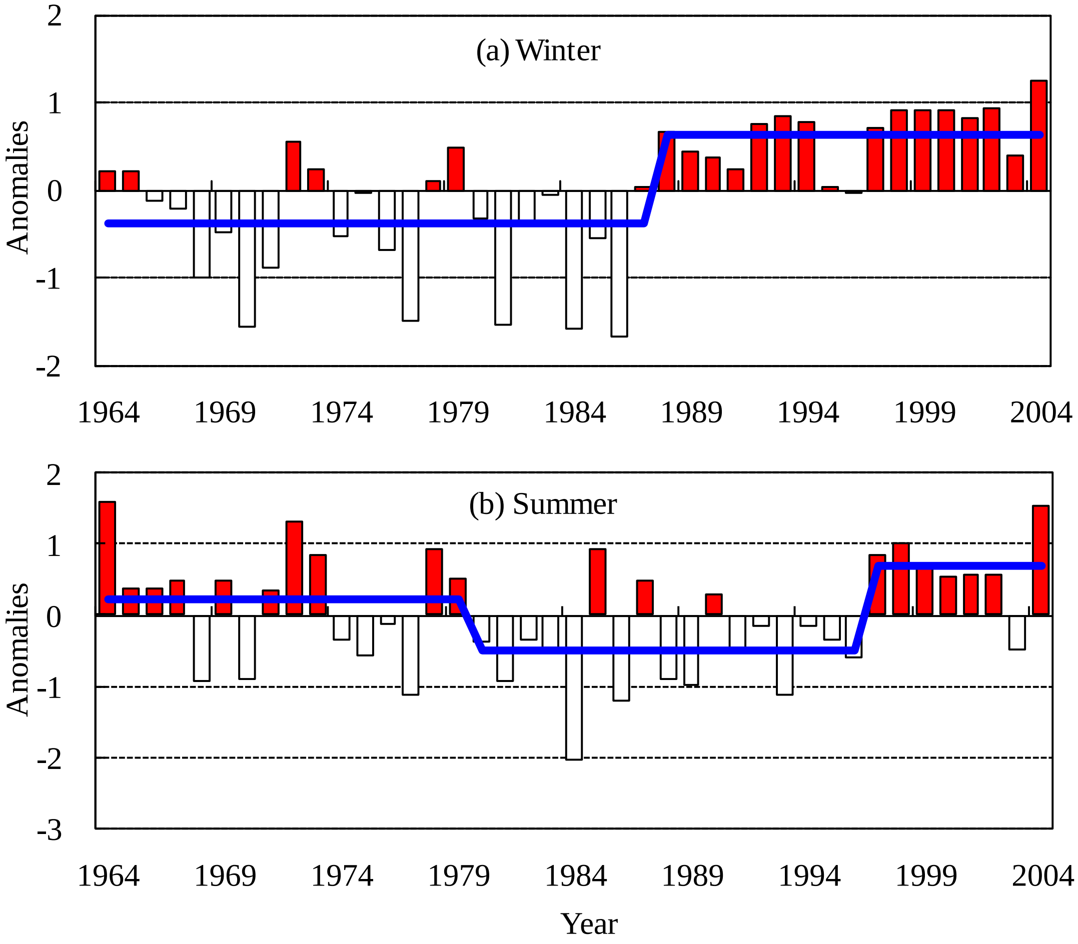


Fig. 26. Annual anomalies of winter and summer water temperatures at 50-m depth along the Tsushima warm current from 1964 to 2004.

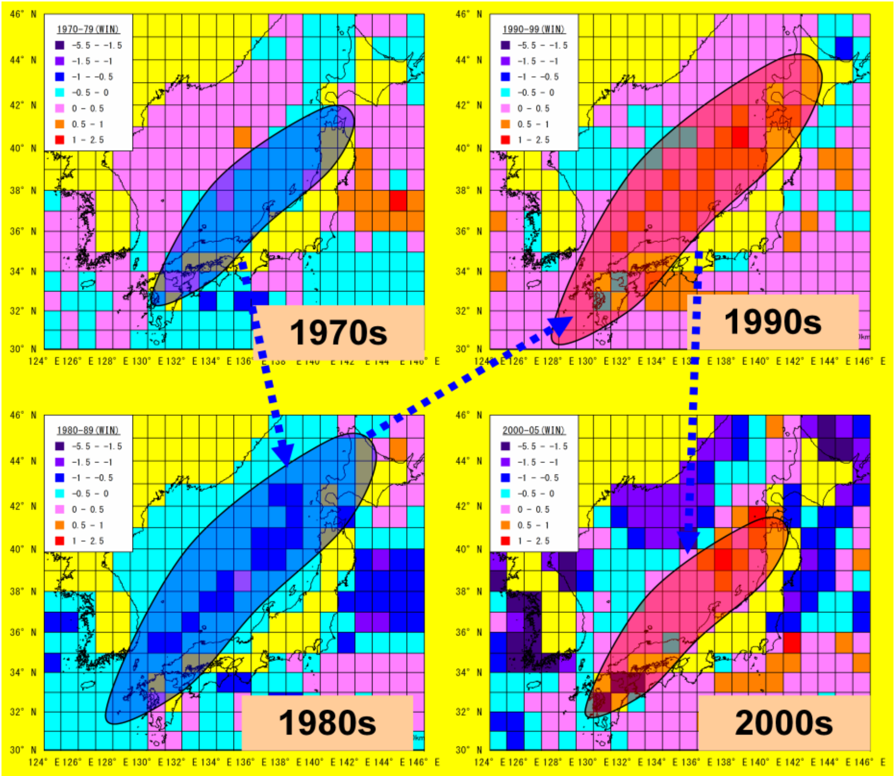


Fig. 27. Decadally-averaged sea surface temperatures in the NOWPAP area.

3-3-2. Phytoplankton

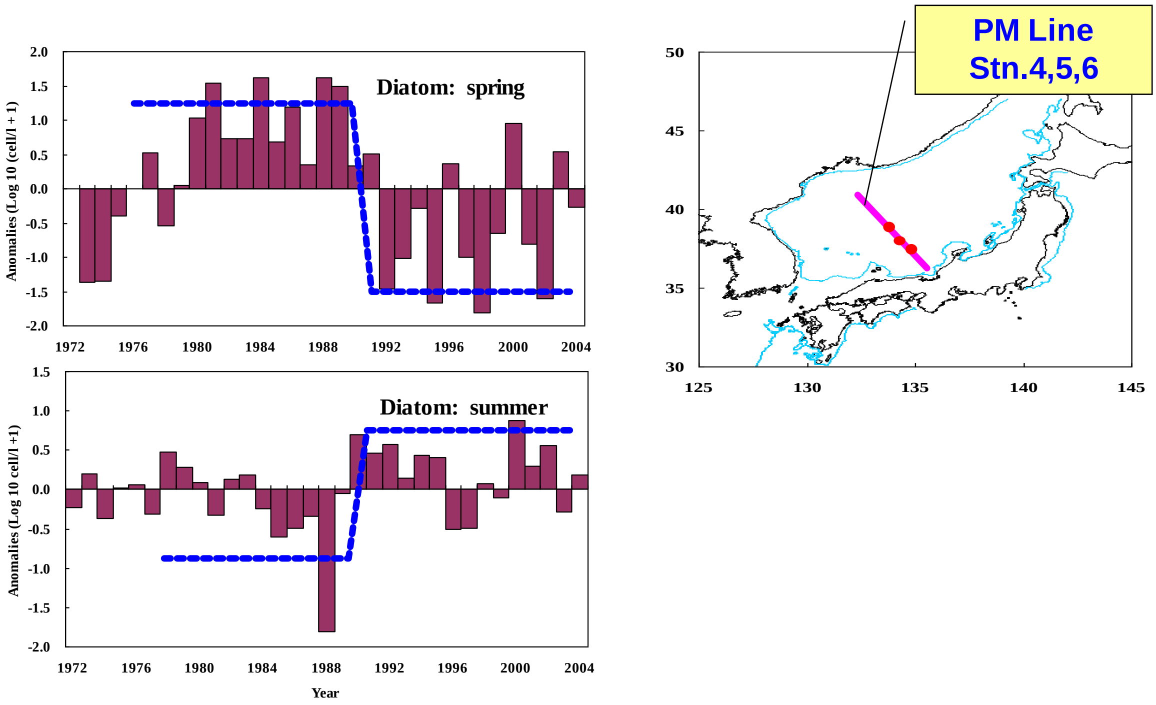


Fig. 28. Annual anomalies of diatom abundance from 1972 to 2004 along the PM Line.

3-3-3. Zooplankton

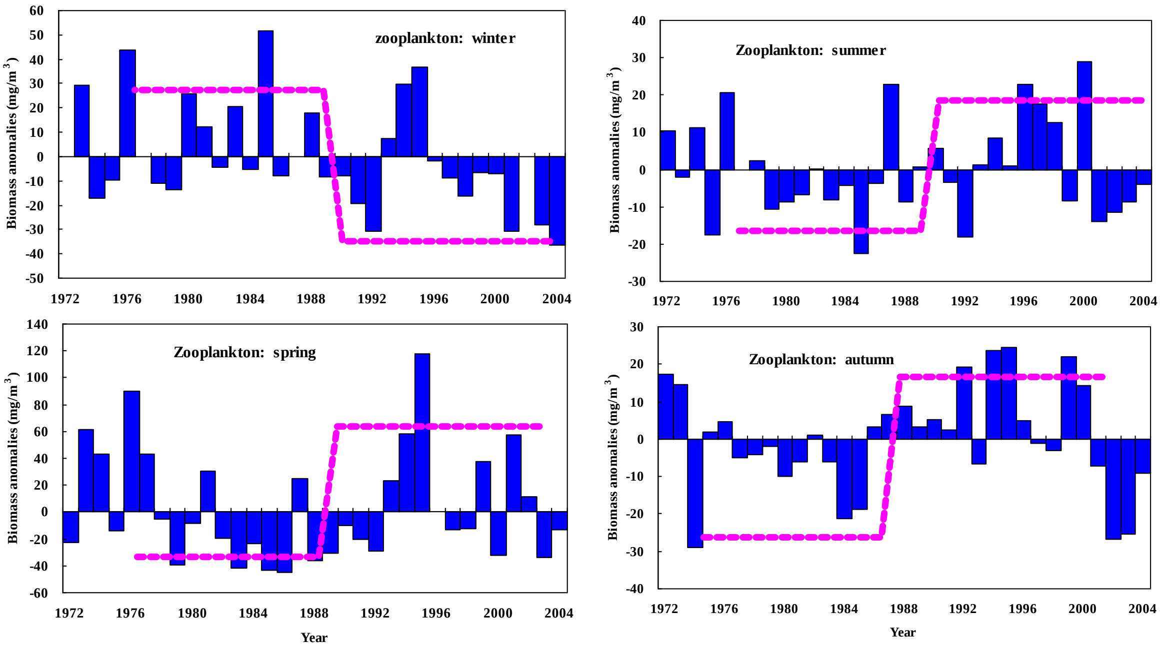


Fig. 29. Mean biomass of zooplankton in wet weight (mg m^{-3}) by season in Region J from 1972 to 2004.

3-3-4. Fish

The fish community in the TWC region responded strongly to the climate regime shift. Response patterns are different between warm- (pelagic) and cold-water (demersal) species (Fig. 30). The scores of the two principal components (PC1 and PC2) extracted from principal component analysis on biomass compositions of target species by Japanese single- and pair- trawlers were significantly correlated with winter and summer water temperatures in Region J (Fig. 31). Cold-water species (*e.g.*, walleye pollock, Pacific cod) decreased (increased) both in biomass and distribution during the warm (cold) regime (Fig. 32), while warm-water (*e.g.* yellowtail) species increased in biomass and/or distribution during the warm 1990s. Different response pattern to the regime shift and different forcing (winter and summer water temperature) between cold- and warm-water species resulted in the complexity of the variability in the fish community and increased the difficulty toward to ecosystem-based management in the TWC. A small number of indicator species (most of small pelagic species) suggested recent changes occurred around 2004/05, and related to climate changes (Fig. 33). These indicator species are useful to identify the changes in the fish community, and suggested a cold regime occurred in the TWC around 2004/05.

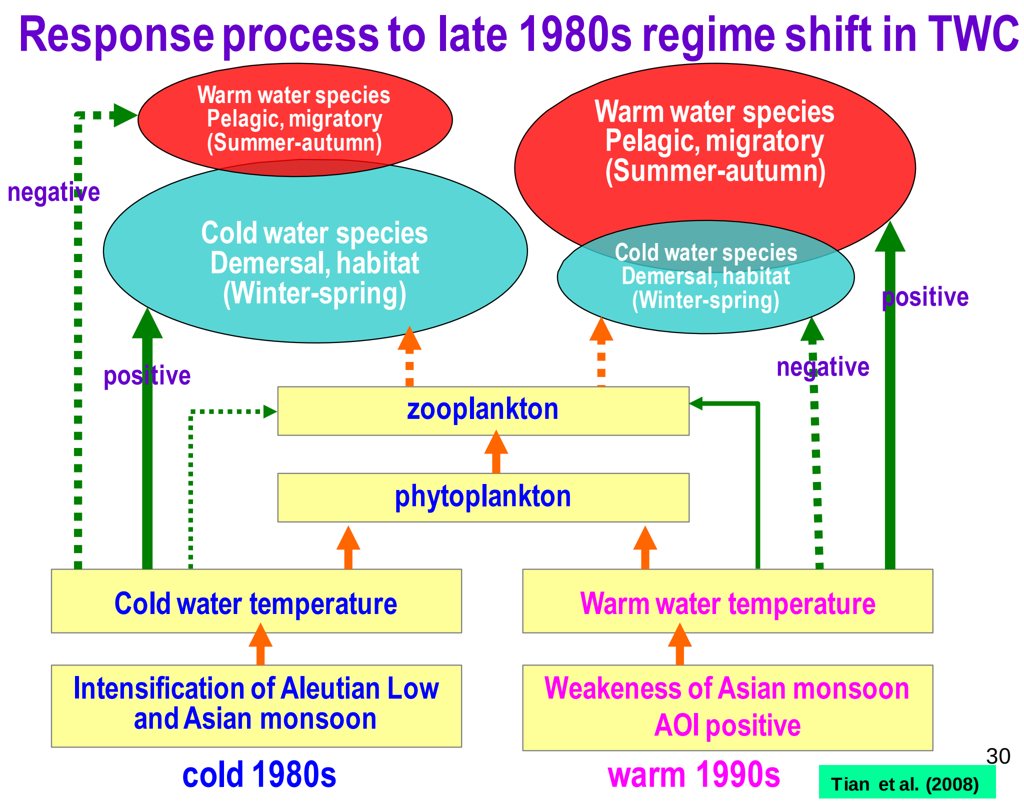


Fig. 30. Scheme of response process to late 1980s regime shift in Region J.

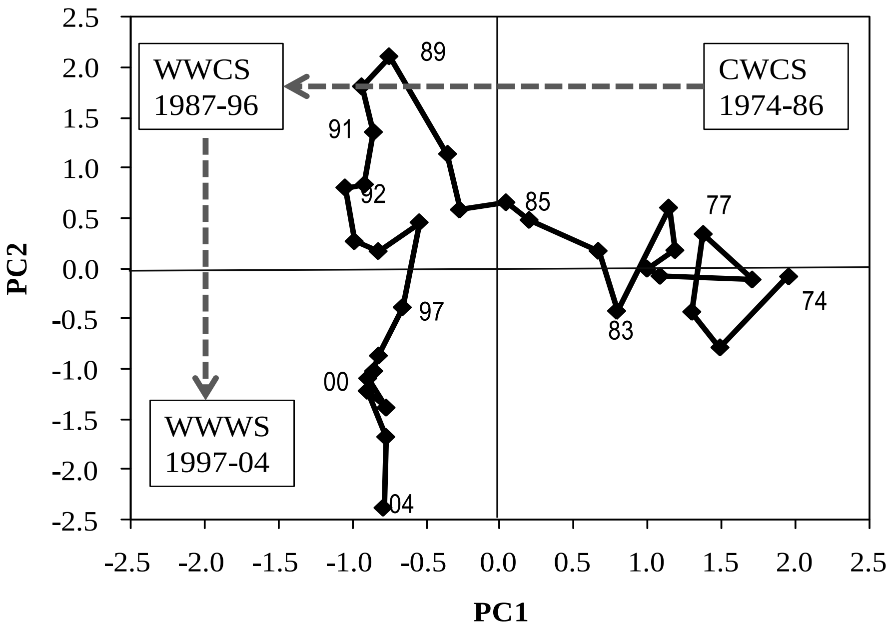


Fig. 31. Phase trajectory for principal component 1 and 2 (PC1 and PC2) extracted from principal component analysis on biomass compositions of target species by Japanese single-trawler in Region J.

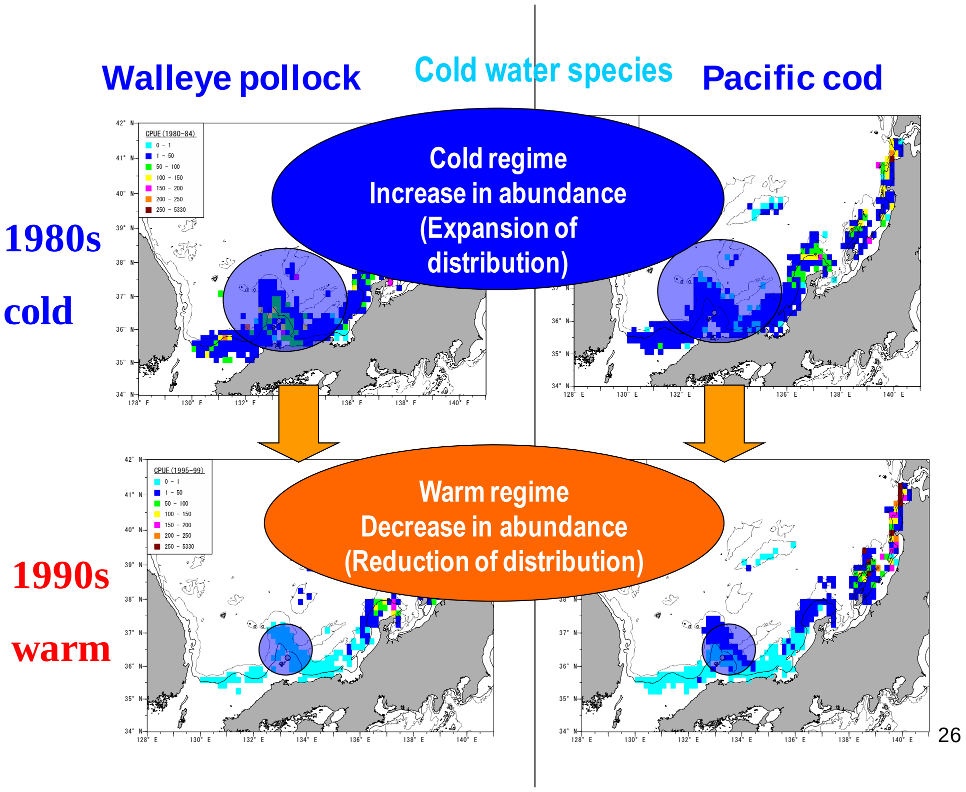


Fig. 32. Contraction of habitat ranges of walleye Pollock and Pacific cod in Region J between 1980s and 1990s.

The biological production in the ocean is closely related to the long-term variation of climate (e.g. PDO, AO, ENSO). Many fishery important species (sardine, anchovy, saury etc.) are known to perform large scale fluctuation of their stocks (Fig. 33). During ‘80s, the level of stock of sardine was extremely high and it declined drastically during ‘90s. The mechanism of such fluctuation has not been revealed perfectly, but the timings of the phase change of the stock were similar to the regime shift of the climate change. Yatsu et al. (2005) reviewed the relationship between the productivities of fishery important species and climate change. Tian et al.(2003; 2004) reviewed population dynamics of Pacific saury in relation to climate/oceanic regime shifts.

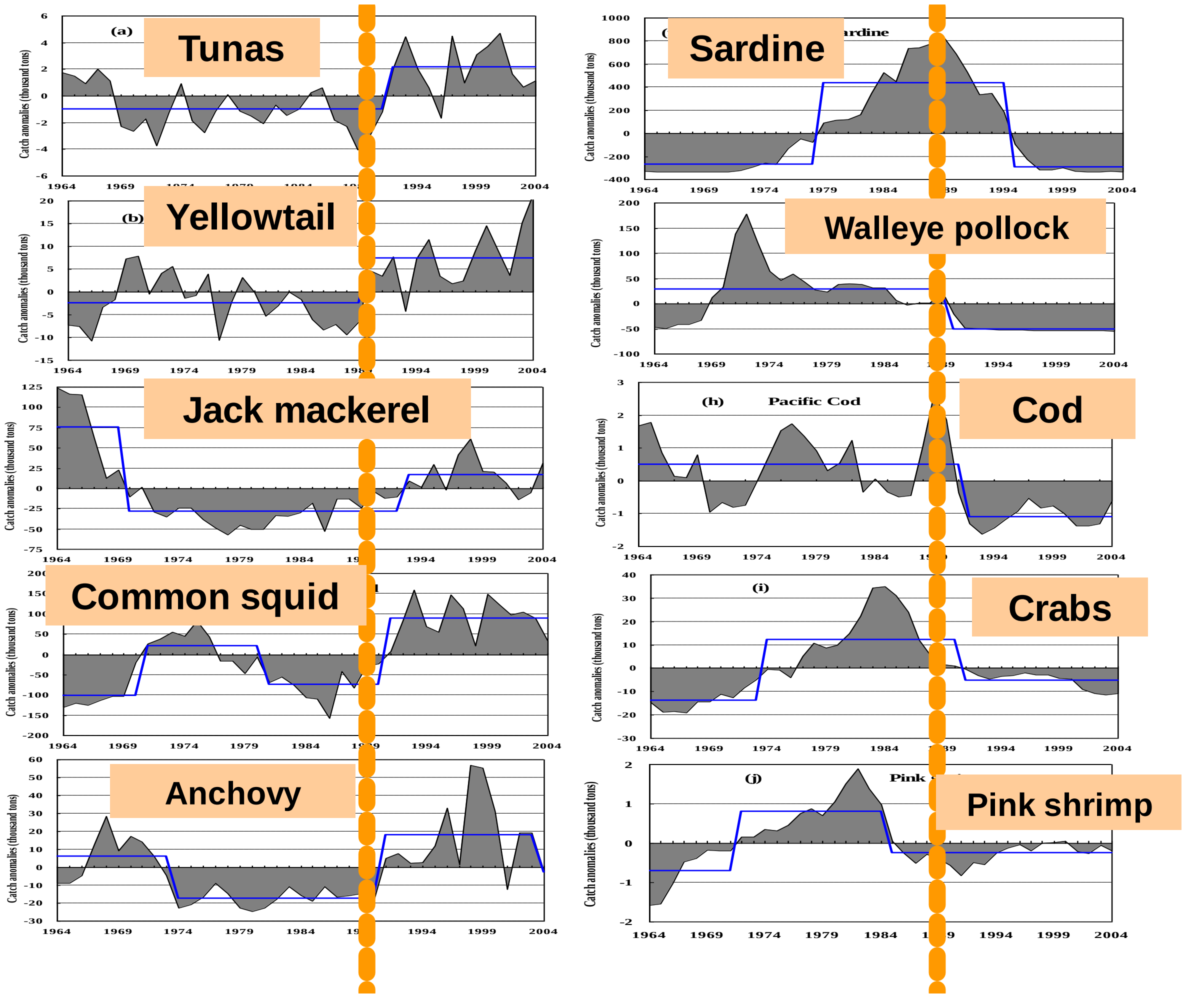


Fig. 33. Annual catch of indicator fish species in Region J from 1964 to 2004. The regime shift year, 1989, is marked by the thick dashed vertical line.

3-4. Region R

3-4-1. Oceanographic conditions

Northern, north-western winds prevail over Region R in autumn and winter (September-April). They transport cold and dry air masses from the continent. Recently, the winter monsoon indices (SHI, MOI) show the tendency to its weakening since the late 1970s (Fig. 34).

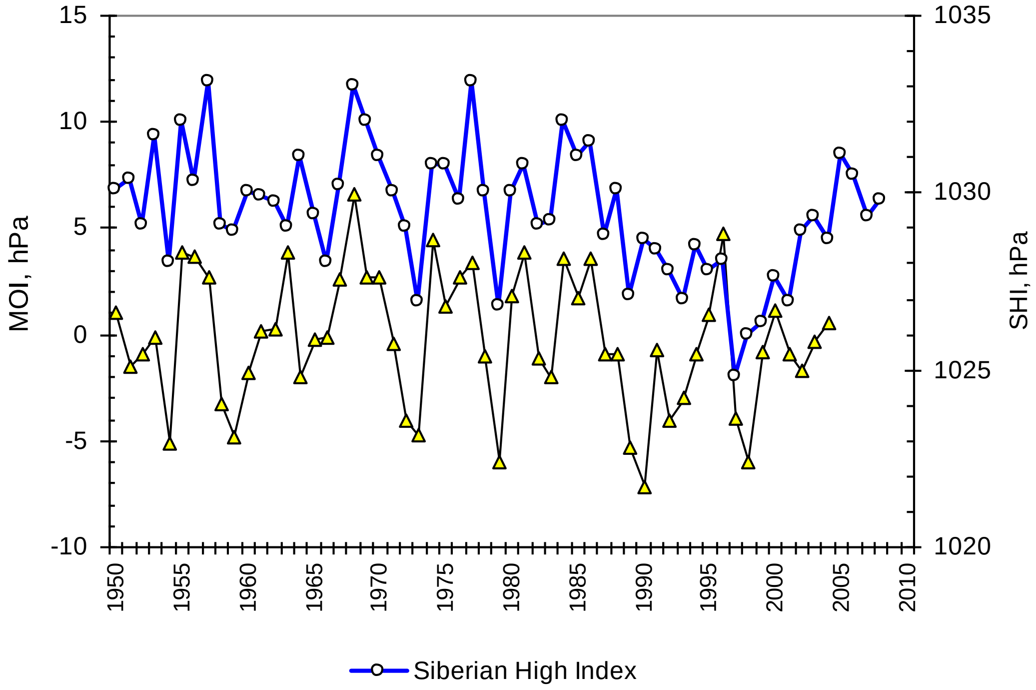


Fig. 34. Year-to-year change of the winter monsoon indices: SHI – Siberian High Index (Panagiotopoulos et al., 2005); MOI – Winter Monsoon Index (Tian et al., 2008).

Interdecadal fluctuations exist, as well: the monsoon was stronger in 1980s and 2000s and was weaker in 1990s Climate change is the change with time scale >3 decades. Comparing the recent state of ecosystem in Region R with the 1980s, prominent changes could be seen. The sea waters became warmer in all layers: the highest warming (>0.02 o/year) occurred in the surface layer of its northern part in winter (Fig. 35), but even deep and bottom waters had visible rise of temperature (Fig. 36). The process of deep and slope convection became weaker – that's why the difference between the Intermediate and Deep water masses became stronger, and the Bottom water partially lost its extreme parameters: low temperature, high salinity, and relatively high oxygen content. Because of the same reason, the nutrients burial in the deep layers occurred that theoretically had to cause decreasing of biological productivity.

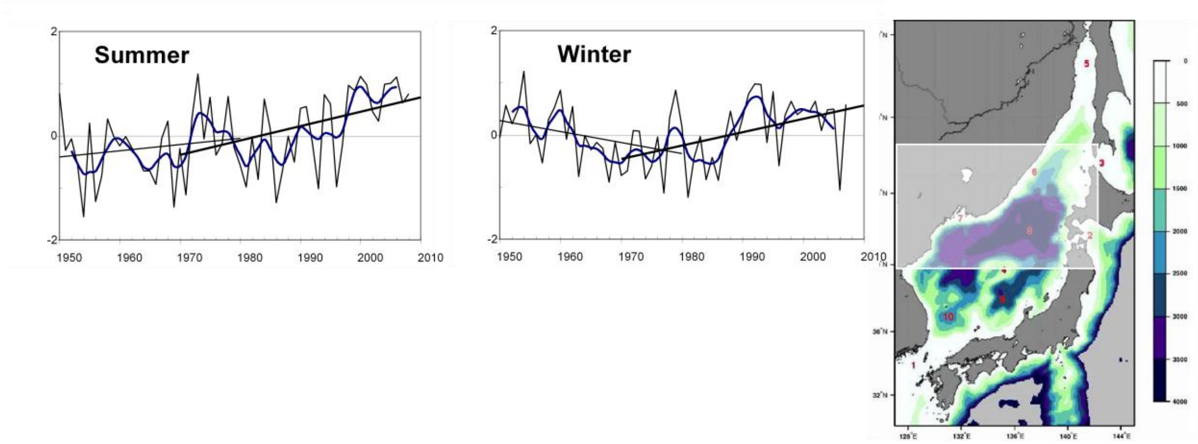


Fig. 35. Annual anomalies of sea surface temperature in Region R (the boxed area in the map) from 1950 to 2008.

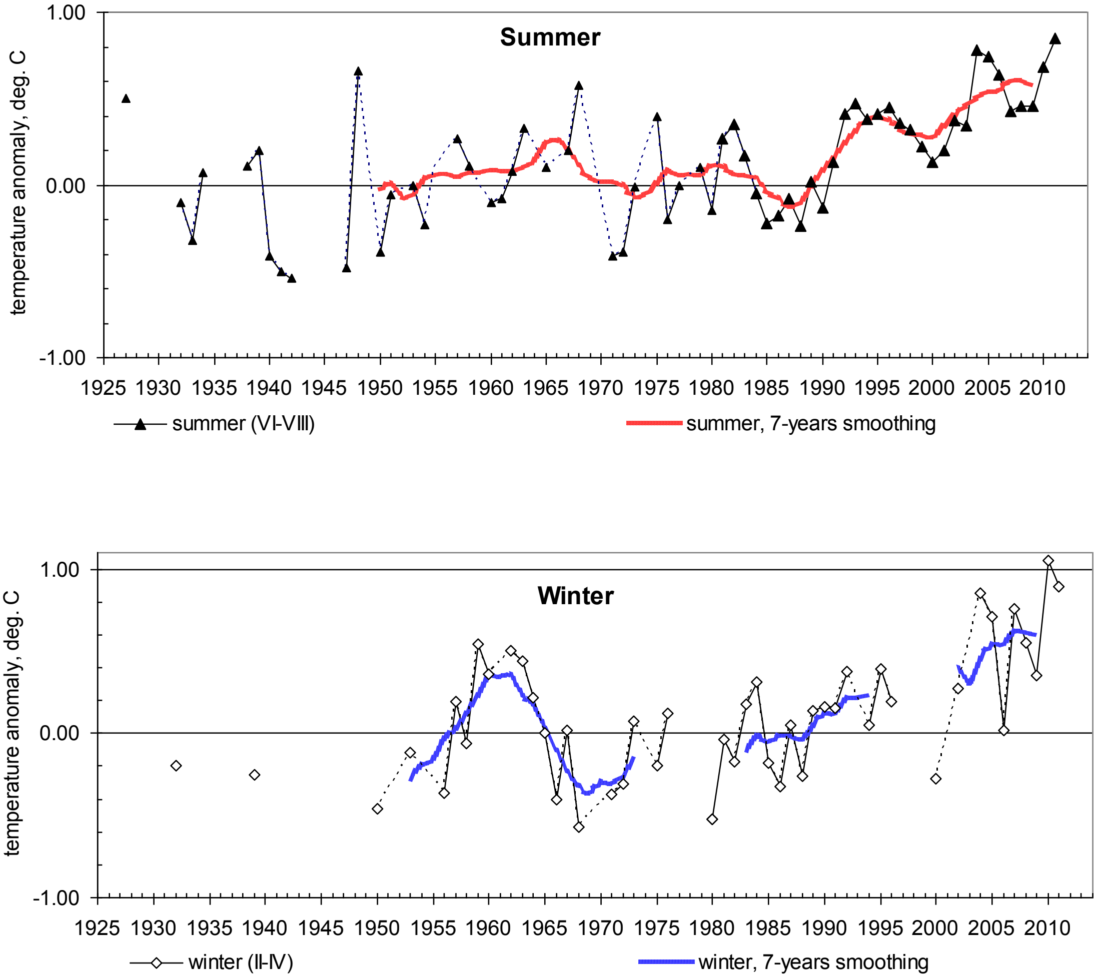


Fig. 36. Temperature anomalies in the layer from thermocline to 200 m at the standard section along 132° E. Top – winter, bottom – summer.

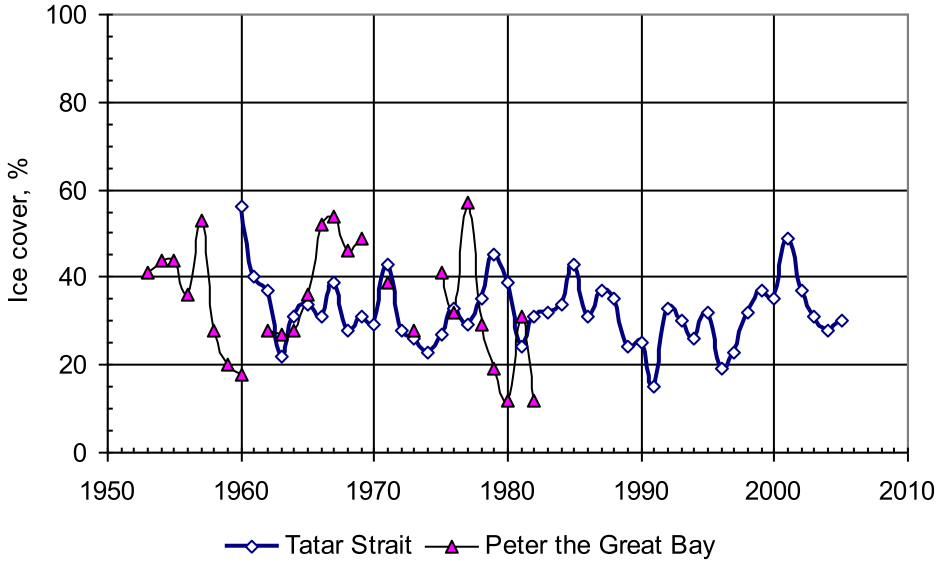


Fig. 37. Year-to-year fluctuations of ice cover in the Tatar Strait and Peter the Great Bay averaged for January-April (Khen et al., 2006)

3-4-2. Plankton

The monthly mean biomass of zooplankton in Region R was highest in May before the mid-1990s, while high in June after the mid-1990s (Kang et al., 2012). Annual mean anomaly shifted generally from positive to negative after the mid-1990s. Annual anomaly variations in the means of May and June were similar in copepods, euphausiids, amphipods and chaetognaths, showing a downward trend after the late 1990s, particularly in 1997 or 1998 (Kang et al., 2012). However, there are no clear evidences of phytoplankton concentration or production decreasing, and concentration of zooplankton became higher. Zooplankton abundance in summer has no significant long-term tendency but has interdecadal changes controlled by summer monsoon changes (Fig. 38).

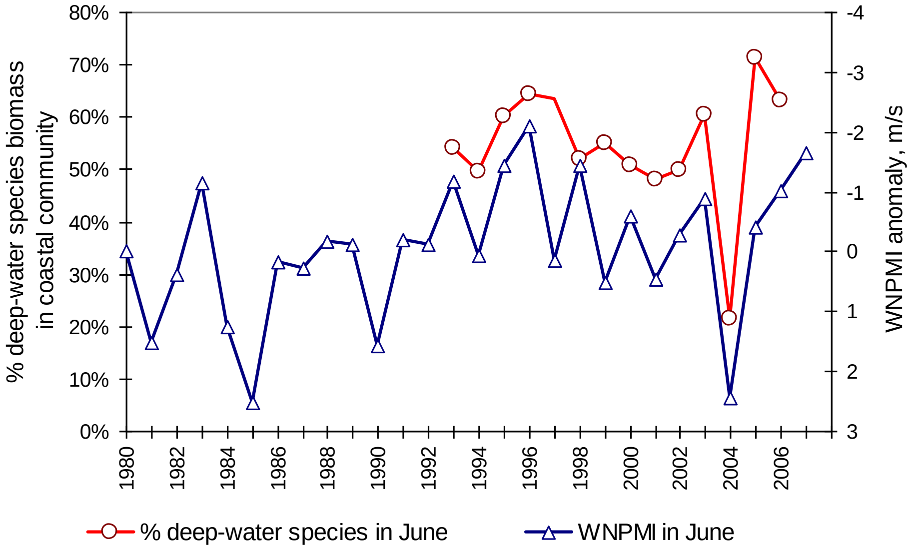


Fig. 38. Changes of the summer monsoon index WNPMI (blue) and percentage of deep-water species in zooplankton of Peter the Great Bay (red) from 1980 to 2007.

3-4-3. Fish

Indeed, the total biomass of nekton became significantly lower, but mostly because of decreasing of only one species stock – Japanese sardine (Fig. 39). Abundance of some cold-water species, as pollock (Fig. 40) and saffron cod, became lower, as well, but some other, as pacific cod and herring, became more abundant. Wide expansion of warm-water species is observed, some of them (spanish mackerel) became important commercial species. The sardine domination in the nekton community changed to domination of common squid. Generally, the reconstructions in ecosystem of Region J look as its gradual transition from high-productive subarctic ecosystem with low efficiency of primary production utilization to low-productive but highly efficient subtropic ecosystem.

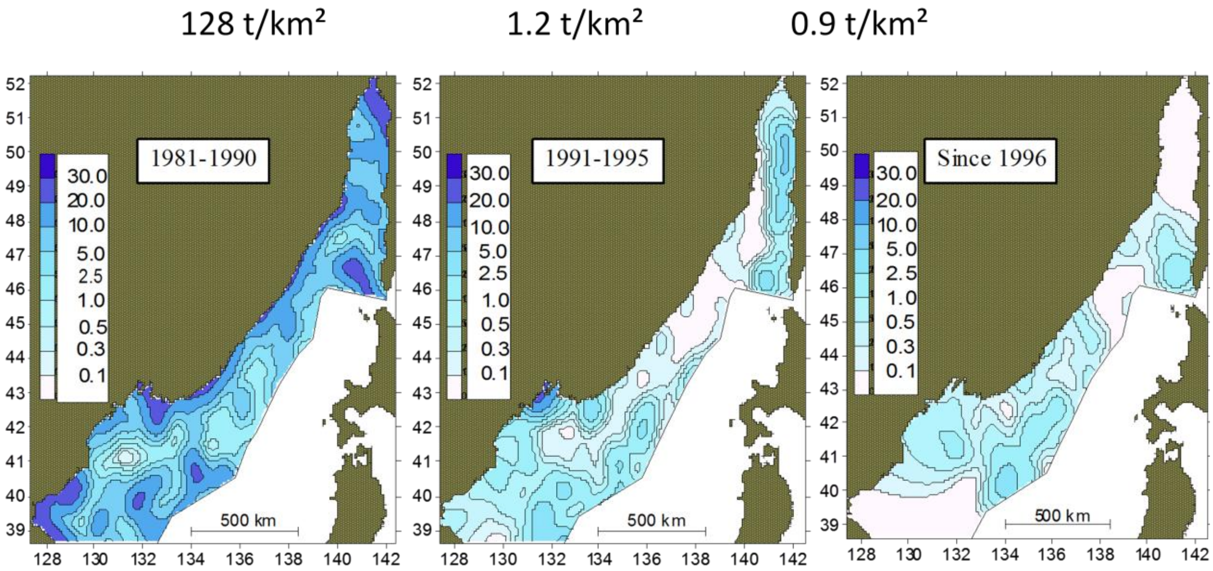


Fig. 39. Distribution of total nekton biomass in the periods 1981-1990, 1991-1995, and since 1996, t/km² (from Sukhanov, Ivanov, 2009)

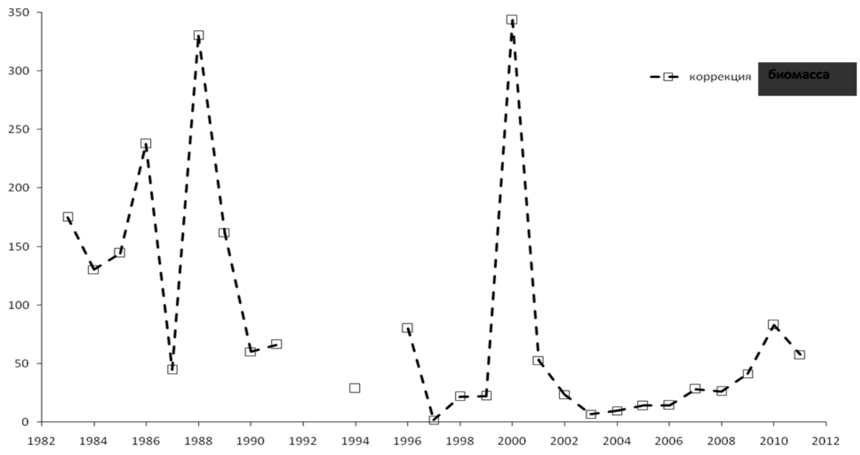


Fig. 40. Biomass of walleye pollock in Peter the Great Bay in 1000 t (from S. Solomatov, A. Nuzdin)

3-5. Synthesis

3-5-1. Oceanographic conditions

Sea surface temperatures have increased in all regions in the NOWPAP area, especially in the mixed layer. In the mixed layer, water temperature suddenly increased in 1987-1989. An annual index of the volume transport by the Korea Strait Bottom Cold Water displayed a sudden intensification in 1992-1993, accompanied by decreased water temperature and increased water density in the deep water. The results suggest that climate-driven oceanic changes and the subsequent ecological impacts can occur asynchronously, often with time lags of several years, between the upper and the deep layer.

3-5-2. Plankton

Time-series data of zooplankton biomass indicated regional differences in responses to basin-wide climatic changes (Kang et al., 2012). Annual mean anomalies of zooplankton showed an upward trend after the early 1990s in Region K and J and after the mid-1980s in Region Y, despite low values in 1998 and 2004 (Kang et al., 2012). On the other hand, in Region R, zooplankton biomass showed a stationary trend after the mid-1990s, although the data were limited to May and June.

The other specific trend in time series of zooplankton biomass in Region J was abrupt increases after the late 1990s (green line of Fig. 41). The sharp increase of zooplankton biomass in the 2000s may be a result of decreasing salinity and longer warming periods. Winter warming is known to enhance primary production and zooplankton production (Kang et al., 2002; Miller et al., 2004; Rebstock and Kang, 2003; Chiba et al., 2008; Tian et al., 2008), and extending the warming period to late spring was found to prolong the period of and thereby increase primary production (Tian et al., 2008).

Chiba et al. (2008) and Yoo et al. (2008) suggested that seasonal variations tend to be larger in amplitude than do annual mean variations in the lower trophic levels, and cautioned that time-series analyses based on annual means alone can sometimes lead to erroneous outcomes. In Region Y and J, zooplankton biomass showed an upward trend after the late 1980s (Tian et al., 2008; Kang et al., 2012). Yoo and Kim (2004) also noted that the spring bloom of phytoplankton was closely related to the variability in the volume transport and direction of the TWC, which is the major input to Region K and J. On the other hand, an upward trend of zooplankton biomass in the 1990s was detected in the Bohai Sea located in Region Y (Rebstock and Kang, 2003; Tang et al., 2003) and in Region J (Kang et al., 2002; Rebstock and Kang, 2003; Chiba et al., 2008; Tian et al., 2008; Yoo et al., 2008). In Region R, larger-size cold-water copepods became more abundant in conditions of the intermediate layer warming, where they mature and spawn, possibly because of higher fecundity (Zuenko et al., 2010).

3-5-3. Fish

3-5-3-1. Sardine

Sardine *Sardinops melanostictus* is characterized by highly-variable multi-decadal fluctuations in its stock size. The stock of sardine increased from the early 1970s, peaking at 10 x10^6 tons in 1988. Thereafter it declined drastically to 10^6 t in 1995 and under 10,000 t in 2001. The stock began to increase slightly since 2004 and reached 10,000 t in 2005 and 28,000 t in 2009. Its total catch in the NOWPAP area was very high (>10^6 t annually) in 1981-1992 but declined drastically to 1,000 t in

2001. Annual catch recently increased to > 5,000 t. The stock of sardine is currently at extremely low level, but shows a sign of recovering trend. Sardine is caught by purse seine, set nets and trawls.

3-5-3-2. Anchovy

Anchovy *Engraulis japonicus* is a ubiquitous species in the NOWPAP area. The adult anchovies migrate north from the warm and deep ocean to spawn in coastal waters of Region K in April-August (Kim and Lo, 2001). Anchovy forms aggregations at the coast when water temperature reaches 13-15^{o}C, and its schools then migrate northward following the warming of water. Anchovy is caught by purse seine, set nets and drag nets, stow nets, lift nets, set nets, and gill nets. The main fishing grounds of anchovy are located in Region Y, K and southern part of Region J. In Region K, the highly concentrated anchovy yield in the confined shallow area < 20 m suggests that drag nets of small-scale boats dominate anchovy fisheries and those boats seldom pursue anchovies in deep offshore water, because income would not cover the expense, especially soaring prices of oil fuel (Jung, 2008a). Total catch of anchovy by Japan and South Korea was high (> 100,000 t/yr) in the late 1990s and decreased in the last decade. Russian landings were insignificant

3-5-3-3. Herring

Pacific herring *Clupea pallasii* distribute in the whole cold sector of the NOWPAP area, but forms several populations with separate spawning grounds. They spawn in winter. Before the spawning season, they usually aggregate at the bottom and move toward the spawning grounds to breed. Eggs hatch in 1 month. All herring populations were very abundant in the past. For example, in the Sakhalin-Hokkaido, annual catch once reached ca 100,000 t. However, the abundance of all populations decreased since the 1950s, and no more than 1-2 thousand tons have been caught until the late 1990s (Gavrilov, 1998; Naumenko, 2001). Another feature of the changes was northward shifts of the spawning grounds, the most considerable being in the 1920-1950s. Recently the populations in Region R are still in depression. The largest spawning stock in Region R is located at southwestern Sakhalin and its estimated size is ca. 10,000 t. Recently catch in Region K and western part of Region J has dramatically increased in the late 2000s, together with Pacific cod. Trophic interactions between Pacific cod and herring were suggested.

3-5-3-4. Chub mackerel

Chub mackerel *Scomber japonicus* distributes widely from the East China Sea to waters at Hokkaido and Sakhalin (Yukami et al., 2009, 2010). It spawns in the East China Sea and the Region K in February-June (Yukami et al., 2009) and migrates to Region Y and J in summer. Chub mackerel is caught mainly by purse seine (Yukami et al., 2010). Its catch increased in the 1970s, but decline in the 1980s. Negative correlation between recruitment and SST at spawning grounds indicates that warming may be unfavorable for reproductive success of chub mackerel (Yukami et al., 2010). Therefore, the warming Tsushima Current since the late 1980s and the increasing summer SST since the late 1990s could be a cause of its decline in catch.

3-5-3-5. Jack mackerel

Like chub mackerel, jack mackerel *Trachurus japonicus* distribute widely from the East China Sea to the waters at Hokkaido and Sakhalin (Yoda et al., 2010). They spawn in the East China Sea in January-March and at the coast of Japan in February-June (Sassa et al., 2004; Yoda et al., 2010). Its juveniles migrate northward in late spring following the isopleths of SST at 16^{o} (Shimura et al., 2009). Jack mackerel is caught mainly by purse seine (Shimura et al., 2010). Recently most of the catch in

Region J was reported to be <1 yr age classes, suggesting the jack mackerel fisheries were intensified in the 1990s by the collapse of sardine in Region J. The portion of adult was lower in the 1990-2000s than in the 1970s and before (Yoda et al., 2010; Enami, Hotta, 1974). Annual catches were high in the 1960s and the late 1990s but low in the 1970-1980s. It seems that warming sea water is favorable for the jack mackerel recruitment and its northward migration (Tian et al., 2008).

3-5-3-6. Common squid

Common squid *Todarodes pacificus* is commercially the most important cephalopod species in the NOWPAP area. This species lives up to one year. Its fecundity ranges from 300,000 to 500,000 eggs per female. The stock of common squid is composed of 3-4 different seasonal spawning cohorts (Araya, 1967; Okutani, 1983). They are caught in Japan and South Korea mostly by jigging and trawling, though set nets and purse seine nets take a small percentage of the catch. The total annual catches of Japanese and South Korean fishers were about 100,000 t until 1950, then increased with the development of jigging fishery to 0.25-0.6 x 10^6 t in the 1950-1960s, but decreased to 0.15-0.2 x 10^6 t in the 1970-1980s with the minimal catch about 0.1 x 10^6 t in 1986. Then the catches rebounded to 0.4-0.6 x 10^6 t because of the stock growth and expansion of South Korean fishery to 0.21-0.23 x 10^6 t in the mid 2000s.

3-5-3-6. Pacific cod

Pacific cod *Gadus macrocephalus* distribute in most of the NOWPAP area, but two or more distinct stocks exist among Region Y, K, J and R. The stock in Region J usually inhabit 200-400 m depth in the continental slope and matured cod moves to the shelf for spawning in November-March with the peak of spawning in January (Moiseev, 1953; Mishima, 1984; Lee et al., 2005; Cha et al., 2007). The stock in Region R spawn in deep-water areas or at the continental slope in late winter and spring (Kim, 1998; Vdovin, 2004). Cod fishery has a long 600-year history that began in Korea. It is caught by trawls and gill nets, mostly the 4-6 years old fish with length 50-70 cm in the period of spawning migration. The main fishing grounds of cod are located in coastal areas of Region Y, K, J and R. This species was among the most important commercial objects in the first decades of 20th Century when its annual catch at south-west Sakhalin had achieved to 53,800 t. Later the catches fluctuated from 10 to 30 x 10^3 tons for the population at southwestern Sakhalin and were much less for other fishing grounds. The decreasing tendency of the cod stocks was connected with water cooling in the middle of 20th century accompanied by herring population declining, as its prey (Kim, 1998). Fluctuations on the background of this negative trend are caused by random appearance of strong year-classes, such as the year-classes of 1984 and 1992 at northern Honshu.

3-5-3-7. Walleye pollock

Walleye pollock *Theragra chalcogramma* was once a ubiquitous species in the NOWPAP area. The largest stock of pollock is in the East-Korean Bay, other populations with their own spawning grounds are located (in order of stock decreasing) at Hokkaido and northern Honshu, at southern Primorye including Peter the Great Bay, and at Sakhalin, though the last one was more important in the past (Ogata, 1956; Gong, Zhang, 1986; Fadeev, 2005). Different populations of pollock were distinguished by different seasons of spawning: autumn-winter (December-March, peaking in January-March) in the East-Korean Bay and at Hokkaido but spring at southern Primorye and Sakhalin (Zverkova, 2003). Generally, the life span of pollock from these populations is shorter than in the Okhotsk and Bering Seas and does not exceed 10-12 years and age classes of 2-6 yr dominate stock biomass. Fecundity of walleye pollock is 0.25-1.0 x 10^6 eggs per female. Length at 50 % group maturity is estimated as 34 cm that corresponds to the age 3 years. The pollock populations in the NOWPAP area showed bi-decadal cycle: the stocks were high in the early 1960s, late 1970s – early 1980s, and early 2000s. In addition to environmental changes that caused its recruitment decreasing, excessive fishing of immature fish by indiscriminate fishing gears is considered as the reason of the decline. History of pollock fishery has more than three centuries in the East-Korean Bay. It is caught mainly by trawls, Danish seine and gill nets in Korea, by trawls, longlines and gill nets in Japan, and by trawls in Russia. The main season of the pollock fishery in Region J is January-March. Highest catch in Region J was reached in 1980-1981, and thereafter catch has drastically decreased. The decreasing trend was more severe for warm-water populations or southern periphery of populations. Therefore, the pollock was virtually collapsed in Region K, southern part of Region J, and Sakhalin of Region R in the early 2000s. However, its fisheries still continue with very low landings at Hokkaido and Primorye of Region R.

3-5-3-8. Small yellow croaker

Small yellow croaker (*Pseudosciaena polyactis*) is an important commercial fish species in Korea and Japan. It migrates out to the East China Sea in winter and returns to the Yellow Sea to spawn in spring. It was cited as an example of overfished species in Region Y (Tang, 1993) and its annual catch by Chinese and Korean fisheries also indicated a significant long-term decrease. However, its catch by Korean fisheries has recently increased to 34 x 10^3 tons in 2007, which is comparable to the catch levels in the 1950s, suggesting that environmental variability has been the major cause of fluctuation in its catch (Kim et al., 1997). Biomass of small yellow croaker increased with sea surface temperature, but a sharp increase of SST could negatively impact small yellow croaker (Li et al., 2011). In early 1990s, scientists reported a long term southward-shifting trend for the period between the 1950s and the 1980s with respect to its fishing grounds from Region Y to the southwestern area of Jeju Island and the East China Sea. However, based on catch reports by Korean fisheries, its fishing ground showed a poleward shift from the 1980s to 2000s, probably driven by warming sea waters.

3-5-3-9. Bluefin tuna

Bluefin tuna recently became an important commercial fish species in Region K, as its catch level dramatically increased in 2000s. There are circumstantial evidences showing that the range of this species is shifting north closer to Korean waters and its catch level dramatically increased in 2000s (Shomura et al., 1993; Kitagawa et al., 2002; Kwon and Yoo, 2010), despite low recruitment of their preferred prey, Pacific sardine (Polovina, 1996).

3-5-4. Ecosystem regime shifts

Previous studies suggested that regime shift occurred in the Pacific during the mid-1970s (Chavez et al., 2003) and late 1980s (Zhang et al., 2000). Our study tried to determine regime shifts in Region K and J. In Region Y and R, similar analysis has not yet been conducted. In Region K, an increasing shift in water temperature was detected in 1987-1988 at all of the standard depths from 0 to 75 m (Fig. 15), but not in the mid-1970s. In Region J, an increasing shift in 1987-1988 was detected for winter water temperatures at 50-m depth.

The suggested regime shift in late 1980s was not detected in zooplankton data from Region K (Figs. 17 and 18), but detected in Region J for diatom and zooplankton (Figs. 28 and 19) (Zuenko et al., 2010). On the other hand, correspondence analyses indicated that abundance compositions of the four zooplankton groups in Korean waters shifted dramatically in 1982-1983 (Kang et al., 2012), probably related to the 1982 El Niño event (Wolter and Timlin, 1998); this shift was preceded by another significant shift in 1981-1982. The shift in 1982-1983 reflected the change in numerical taxonomic composition, in which copepods became more dominant while the relative abundance of euphausiids decreased. The shift was most pronounced in Region Y, where the influence of river discharges on salinity is most pronounced (Kang et al., 2007), followed by Region K; the shift was least apparent in Region J.

Our analyses suggested that shifts in fish assemblages occurred in 1976, 1983 and 1991 in Korean waters (Figs. 20 and 21), and between 1987-1993 in Region K (Fig. 22). It is notable that fish communities in Region J also detected the 1987-1988 shift, but did not detect the shift in the mid-1970s (Fig. 31). The dramatic change between 1987 and 1993 in the fisheries species compositions in Region K (Fig. 22) seems to match the 1989-1990 shift of mesozooplankton communities suggested by Rebstock and Kang (2003) and Kang et al. (2012). Although past studies had not examined this feature, our CA indicated that the El Niño event of 1982-1983 influenced fisheries species in the NOWPAP area (Figs. 20 and 21), but no significant shift was detected in the other Regions.

Based on annual anomalies of zooplankton biomass, Region K and J seem to have responded to the 1989 regime shift, but Region Y and R have not.

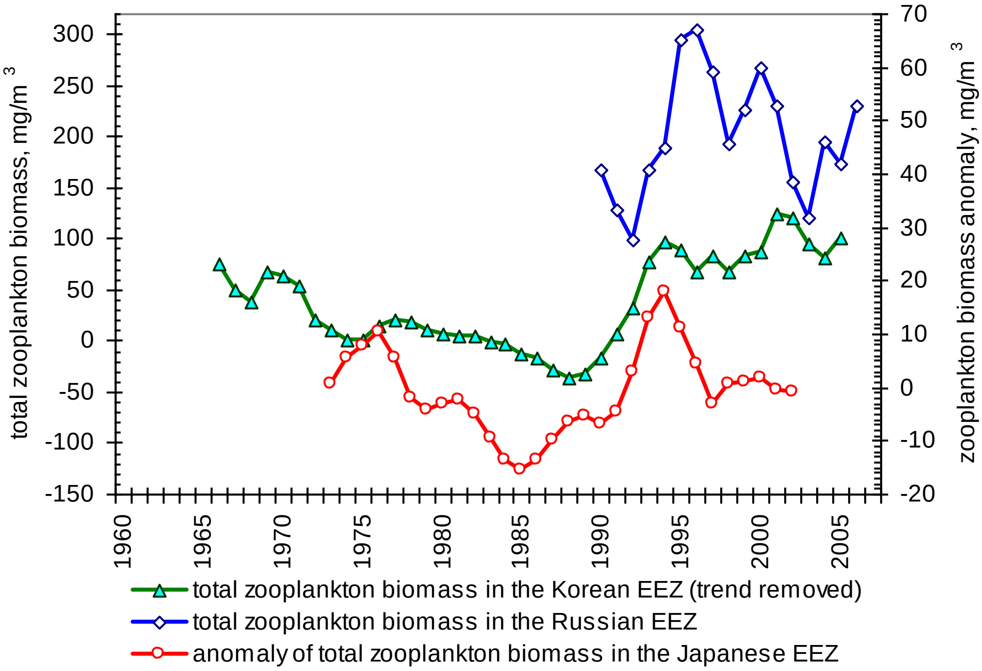


Fig. 41. Zooplankton abundance in Region R estimated by Russia (blue), and Region J estimated by Korea (green) and Japan (red).

Four zooplankton groups (copepods, euphausiids, chaetognaths and amphipods) showed regional differences in responses to the 1989 and 1998 regime shifts (Kang et al., 2012). In both Region J and K, their abundance gradually increased after the late 1980s and then sharply increased after the late 1990s with negative values around 1997-1998, corresponding to the 1989 and 1998 regimes. In contrast, in Region Y, copepods, amphipods and chaetognaths have decreased since the late 1990s with the exception of high values in 2002 and 2006. In Region R, abundances of the four zooplankton groups deceased after the early 2000s.

Other interesting trends were identified in Region J and K. In both regions, the four zooplankton groups showed very low values in 1997-1999 (Kang et al., 2012). The 1997-1999 trends in these zooplankton groups seemed to be a result of the 1997/98 El Niño. Hong (2008) reported that extreme cooling of Region J occurred in response to the 1997/98 El Niño, and this cold state likely caused a decrease in zooplankton production.

Results of correspondence analyses on fish species composition in the NOWPAP area suggested that climate-driven oceanic changes can occur asynchronously between the upper and deep layer of Region J and K (Jung, 2014). The dominant species of Region J and K were once sardine in the epi-pelagic ecosystem in the 1980s, and filefish in the deep water ecosystem (Jung and Cha, 2013). The warming of the upper layer replaced sardine with anchovy and chub mackerel after the late 1980s; whereas the intensified KSBCW and cooling of the deep water replaced filefish with herring and cod. However, the detailed mechanisms involved require further researches regarding the interactions of oceanographic processes between the two layers and temperature-related physiology and recruitment processes of fishes both in the laboratory and in the field (Takasuka et al., 2007; Takasuka et al., 2008; Pörtner and Peck, 2010).

3-5-5. Outlook of the NOWPAP area marine ecosystems and fisheries

3-5-5-1. Region Y

Based on the suggested physical forcing factors and their controlling mechanisms, Qiu et al (2010) predicted that increasing climate changes are likely to result in an increase in fish production. Variation in habitat and migration patterns of fishery species were changed by climate change, then changed the species composition, predator-prey interaction (Shan et al., 2011; Zhang et al, 2009), further led to the variations in fishing grounds and fishery catch (He et al., 1995; Shang et al., 2002; Zhou, 2005), e.g. the boundary of Pacific cod distribution migrated northward 0.5° latitude (Li, 2011).

Multi-decadal alternations between cold and warm regime in SST not only greatly contributed to the variations in physiological process of fishery species, such as development, reproduction and growth, but also played a key role in population dynamics, seasonal migration, predator-prey interaction, further led to the variations in biomass of fishery species with different optimal temperature adaptation. Therefore, the response of fishery species to marine environment varied with different species, with the global climate change, three options for fishery species might be met in the future: (1) local species extinction; (2) species migration; (3) species genetic adaptation. In addition, fishery industry changed the population structure, and temporal and spatial distribution, which caused simplification of fishery populations in the ecological and physiological characteristics, further leading to the sensitive response of fishery species to climate change.

3-5-5-2. Region K

A numerical ocean model, ROMS (Regional Ocean Modeling Systems) (Shchepetkin and McWilliams, 2005) was used to project changes in oceanographic conditions in the NOWPAP area in 2030-2039. Two model runs were conducted. One was the present reanalysis run for 2000s (2000-2009), and the other was the future climate change run for 2030-2039 (2030s), which was conducted using the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) model result (IPCC, 2007b) (Fig. 42).

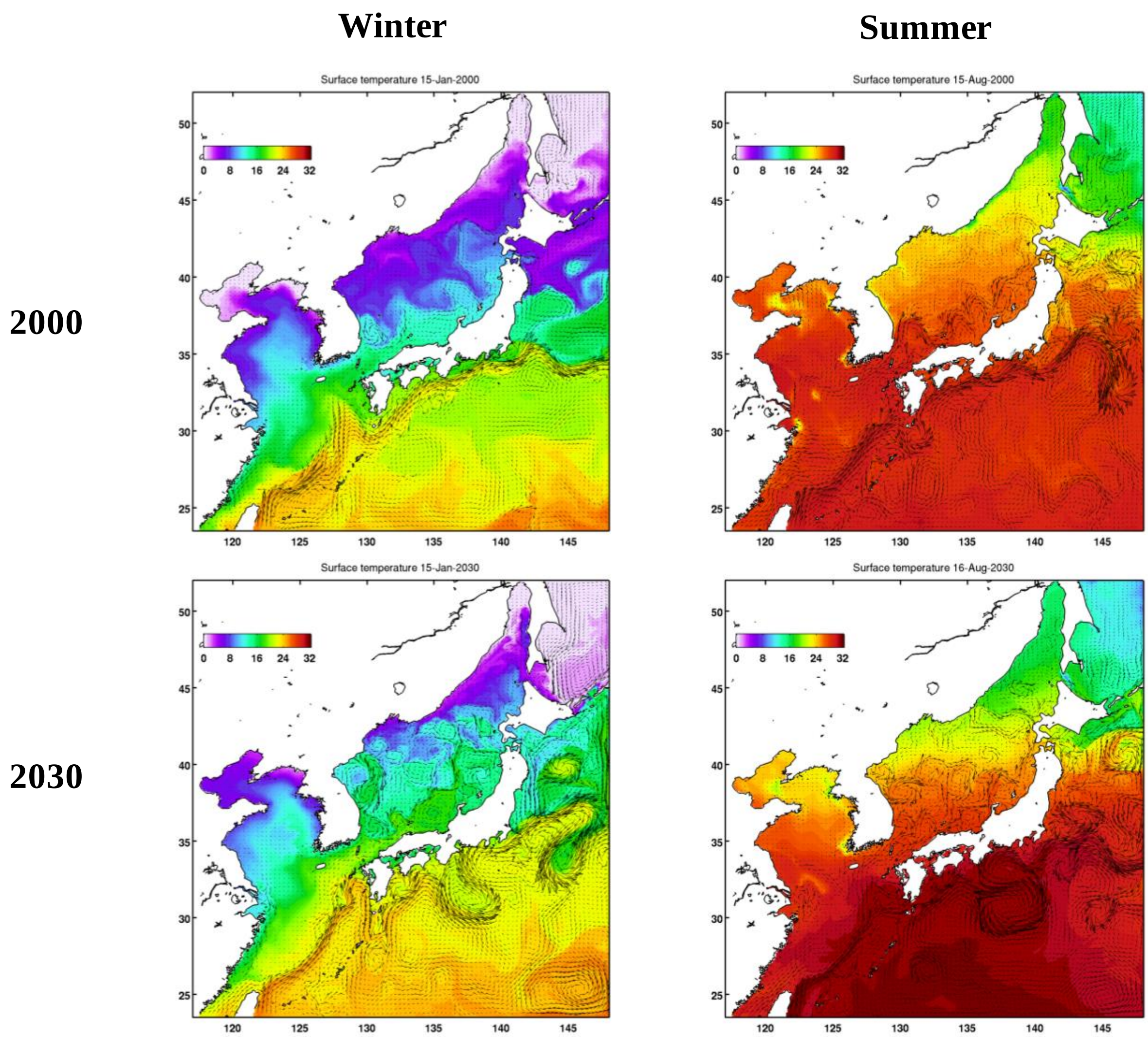


Fig. 42. Sea surface temperatures of the NOWPAP area hindcast and projected by the ocean circulation model for 2000 and 2030.

Our ROMS projections showed that vertical temperature differences in Region K would not exist in 2030s (Table 7). Thus, while the estimated linear rate of ocean warming from 1968 to 2010 in Region K diminished with water depth, our ROMS generated an opposite trend for 2030-2039: warming was greatest in deep water and least in the surface layer (0-10 m) (Table 7). This may be explained by two local phenomena that can weaken vertical temperature stratification of Region K in 2030s. First, we speculate that, by global warming, the western boundary current will be shifted poleward, and the Tsushima Warm Current (Fig. 3) will be strengthened, weakening vertical temperature gradients in Region K. Second, the Yellow Sea Bottom Cold Water (YSBCW; Fig. 3), which currently intrudes into Region K, and strengthens vertical temperature gradients, can be shrunk by global warming.

Table 7. Depth-specific mean temperature (^{o}C) of the Korea Strait predicted for 2000s and projected for 2030s based on IPCC A1B scenario by the general circulation model and observed for 1968-2010.

Depth	2000-	2030-	Differen	Rate	Observ	Factor

(m)	2009 (A)	2039 (B)	ce (B – A)	(^{o}C yr^{-1}) (C)	ed rate (1968-2010) (^{o}C yr^{-1}) (D)	(C ÷ D)
1	19.18	20.75	1.57	0.052	0.024	2.2
10	18.20	19.75	1.55	0.052	0.024	2.2
20	17.17	19.50	2.33	0.078	0.016	4.9
30	16.51	19.52	3.01	0.100	0.014	7.2
50	16.13	19.59	3.46	0.115	0.006	19.2
75	16.12	19.72	3.60	0.120	0.008	15.0

Among 12 species included in our analysis, a half of species showed significant relationship with water temperatures after filtering out the effects of non-climatic factors. Three species (Pacific herring, hairtail and yellow croaker) showed significant correlations with water temperatures, but the relationship was no longer significant when removing the effects of non-climatic factors. Water temperatures also showed significant correlations with annual catch and the two dimensions from our correspondence analysis (CA), implying that warming temperatures have driven changes in both fish and fisheries. Although we did not include the 3 species for projecting the range shift, it is still possible that water temperatures played a role in range shift of these 3 species, but it was difficult to evaluate the effects of water temperature separated from socio-economic factors. Standard deviations of catch distribution (range) showed significant relationships with water temperatures for chub mackerel, horse mackerel and yellow tail, indicating that their distributional range tend to expand with warming sea surface. The standard deviations mostly showed negative correlations with oil prices, suggesting that the travel distance of fishing vessels tend to shorten with soaring fuel prices. On the other hand, the mean latitude of common squid did not show any significant correlation with water temperatures, but did show significant relationships with water temperatures after removing the effect of catch amount. This implies that the travel distances of fishing vessels can change dramatically depending on recruitment levels of common squid, and other 3 species (anchovy, herring and hairtail), that showed significant correlations with catch. Crude oil price was significantly correlated with the mean latitude of catch distribution for herring and yellow croaker. Changes in fishery type were important in determining the mean latitude of fishing grounds of 5 species (anchovy, chub mackerel, horse mackerel, hairtail, and yellow croaker).

The estimated speeds of shift in mean latitude ranged from 0.63 to 2.37 km yr^{-1} (Table 8; average = 1.26 km yr^{-1}) while sea surface temperature increased by 1.05^{o}C in Region K. Based on a dynamic bioclimate envelope model, Cheung et al. (2009) rates of shifting of range limits across climate change scenarios for 1066 exploited marine fish and invertebrates. Their projected global median rate between 2001-2005 and 2040-2060 ranged from 45 to 59 km per decade, which is equivalent to 4.5-5.9 km yr^{-1}.and > 3 times faster than our estimated average of 1.26 km yr^{-1}. However, our estimated speed is still twice faster than the global estimate, 0.61 km yr^{-1}, reported based terrestrial 99 species of birds, butterflies and alpine herbs (Parmesan and Yohe, 2003).

Table 8. Poleward latitudinal shift of fishes from 2000s to 2030s, estimated by multiplying 1) regression coefficient of depth-specific water temperature on mean latitude of fish, and 2) temperature change projected by the general circulation model based on IPCC A1B scenario.

Fish	Predictor temperature depth	Regression coefficient (degree $^{\circ}C^{-1}$)	Projected temperature change ($^{\circ}C$)	Projected poleward shift (km)	Speed (km yr^{-1})	Speed (km $^{\circ}C^{-1}$)
Anchovy	10 m	-0.13	1.55	-23	-0.75	-14.5
Chub mackerel						
Horse mackerel	30 m	0.08	3.01	26	0.86	8.6
Pacific herring						
Pacific sardine	75 m	0.05	3.60	19	0.63	5.3
Common squid	10 m	0.29	1.55	50	1.65	32.0
Spanish mackerel	1 m	0.41	1.57	71	2.37	45.3
Yellowtail	1 m	0.22	1.57	39	1.30	24.8
Hairtail						
Yellow croaker						
Filefish						
Red horsehead						

In addition to the 12 species included in our analyses, Walleye pollock *Theragra chalcogramma* and Pacific cod *Gadus macrocephalus* are notable. Pacific cod and Walleye pollock have been traditionally important commercial fish species in Korea. We excluded these 2 species in our analyses, because Walleye pollock is no longer caught in Korean water, and Pacific cod is mostly caught by gill nets and their location of fishing is not reported by fishermen. The two species are similar in that they were once major commercial fish species in Korea, and are deep-water species that spawn at cold temperatures during the winter. Since the late 1990s, bottom temperatures of Region K during the winter spawning season have significantly decreased, favoring the recruitment of Pacific cod whose eggs are demersal and hatch at 5-12 $^{\circ}C$ (Lee et al., 2007). Recruitment of cod seemed to decrease from the 1950s to the 1990s, as catch levels were lower compared with the 1920-1940s. Since 1998, however, catch has continued to increase from 0.5 x 10^{3} metric tons in 1998 to 7.2 x 10^{3} tons in 2007, reaching a record high. In contrast to Pacific cod, catch of Walleye pollock reached a record high (166 x10^{3} metric tons) in 1981, but has steadily decreased since 1990, reaching a record low in 2007 (< 0.1 x 10^{3} tons). Distribution of Pacific cod, known as cold-water demersal species, extended southward since the late 1990s, which seems to be related with intensified episodic penetration of deep waters from Region J into Region K (An, 1974; Cho and Kuh, 1998; Johnson and Teague, 2002; Kim et al., 2006b; Min et al., 2006).

Among 6 species that showing significant relationship of their mean latitude with water temperatures, only anchovy indicated southward shift (Tables 1 and 2). It fishing ground was once extended to Region J, but it was shrunk to Tongyeong area (the red contour area near 34.30°E, 129°E of Fig. 1) after late 1990s, probably mainly by non-climatic factors. Even after removing the non-climatic effects, mean latitude of anchovy revealed significantly negative correlation with water temperatures of Region K. The time-series of egg-density-weighted mean sea surface temperature estimated in Japanese waters (Takasuka et al., 2007) generally showed a decreasing trend from 1984 to 2004, implying a southward shift of anchovy. The reported optimum temperature for growth of larval anchovy is 22.0^{o}C (Takasuka et al., 2007), and we speculate that too warm water temperature may be unfavorable.

For the other small pelagic species, we expect that common squid and horse mackerel will respond to warming ocean in their distribution range, but the magnitude of distance would be less than the large pelagic species (Table 6). Although thermal tolerance windows can be narrow in early life stages of both small and large pelagic fish species (Pörtner and Peck, 2010), we speculate that generally recruited small pelagic fishes can be acclimated to varying temperatures more easily than juveniles and adults of large pelagic species. Although Pacific sardine showed significant relationship in their mean latitude with water temperature at 30-m depth, but it is highly uncertain whether their distribution range will shift poleward, because their catch level in Korea waters became nearly zero after 2001 (Kim et al., 2006a).

All of the 2 large pelagic species (Spanish mackerel and yellowtail) showed strongest relationships between their mean latitude and sea surface water temperatures (Table 2). Together with the circumstantial evidence of northward shift in range of northern bluefin tuna, we conclude and expect that large pelagic species will most sensitively respond to warming oceans in their distribution range.

Although demersal and bentho-pelagic fish species did not show significant relationship in their mean latitude with water temperatures after filtering out the non-climatic factors, we speculate that the variation in the Tsushima warm current and the counteractive episodic intrusion of cold water from the East to Region K could be important in explaining in oscillations in distribution range of demersal and bentho-pelagic species (Hwang and Jung, 2012).

The relatively greater fluctuation in dominant fisheries species along the Tsushima current suggests that basin wide climate change, which was transmitted by the Kuroshio current, may be a major cause of changes in species composition and recruitment and migration pattern of major species in Region K (Zhang et al., 2000; Lehodey et al., 2006; Tian et al., 2006; Kim et al., 2007; Takasuka et al., 2007; Watanabe, 2007).

The three pelagic species such as common squid, anchovy and chub mackerel (Fig. 5) seem to be productive and resilient against environmental impact and fishing pressure (Hutchings, 2000; Jung, 2008a), and, despite their greater annual fluctuation, their biomass and production level has been relatively stable in the long-term during the past 60 years. These three pelagic species have been dominant in fishery catches in both Korea and Japan since 1990 (Gong et al., 2006; Gong et al., 2007). Comparisons between Korea and Japan with respect to catch statistics of these three species compiled by Food and Agriculture Organization of the United Nations since 1950[1] suggests that the

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[1] http://www.fao.org/fishery/statistics/software/fishstat/en

long-term increases in Korean catch was primarily due to enhanced fishing power and technology (Hiyama et al., 2002; Gong et al., 2007; Gong and Choi, 2008).

Despite their greater decadal variability in recruitment, small pelagic species seem to be resilient to climate change in their distribution rage, compared with large pelagic species. Long-term plans need to be developed especially for large pelagic species to adapt related fisheries to climate change and global warming (e.g., vessels equipped with freezers for preserving tuna for more profitable marketing).

Although demersal/bentho-pelagic species did not show any significant correlation with water temperatures in our analyses, it seems that their distribution ranges fluctuate with other climatic factors such as the fluctuating Tsushima Warm Current. Both artisanal and industrialized fisheries exploit demersal and bentho-pelagic species. For example, artisanal and coastal fisheries are the major provider of hairtail, preferably in unfrozen but fresh state (ca. 300 million USD in 2010); whereas industrialized and offshore fisheries are the major provider of frozen yellow croaker (ca. 250 million USD in 2011). Recently in 2000s, the major fishing grounds of hairtail shifted northward closer to Jeju Island (Figs. 1 and 3-i), and the local coastal angling fishery benefited by greatly decreased fuels costs. We expect that artisanal and coastal fisheries, which have benefited from a capacity to quickly supply live or unfrozen fishes, will become less competitive than industrialized fisheries in adapting to possible climate-driven range shifts in their respective target species (Roessig et al., 2004).

3-5-5-3. Region J

Based on the retrospective analysis between SST and catch of yellowtail during the last century, Tian et al. (2012) assessed the potential effect of future global warming on the yellowtail in Region J, indicated that future global warming will extend the northward distribution of yellowtail in winter, and will consequently affect the southward migration pattern and fisheries structure. But responses to climate change are different by species (Tian et al., 2008, 2011), the impacts of global warming on fishes will be species-specific.

3-5-5-4. Region R

Long-term forecasting of the changes in fisheries resources in the North-West Pacific is rather difficult because future changes of environments are not clear so far as the results of climate models should be downscaled to regional and local scales. However, some outlooks are possible on the background of similarity between the climate changes in future and in recent past. The global warming of the last decades exhibited in the North-West Pacific mainly in winter when the monsoon became weaker, so the sea surface became warmer, winter convection became weaker, and so on. Changes in the summer atmosphere processes are not so prominent, but slight tendency to the summer monsoon weakening is observed, as well. The sea surface temperature in summer became higher because of less cooling in winter and calm weather in summer, that had certain consequences in the ecosystem.

Presumably, similar changes will continue in future, if the global warming will continue. In this case, the stratification strengthening and productivity lowering in Region R will continue. It is not favorable for the most of cold-water species, but some of them, as the mass copepod *Neocalanus plumchrus*, get better conditions for reproduction. High temperatures of the surface layer will attract more subtropical and tropical species into Region R. From the other hand, weakening of summer downwelling along the continental coast will provide cooling at the shelf bottom in summer, so a niche for bottom cold-water species will remain, as well. The most abundant species of Region R – sardine has ability to successful reproduction in both cold and warm environments, so its high stock can be restored in future. Generally, the ecosystem of Region R in future will be less productive but will be distinguished by high species diversity. The most important fisheries resources here will be mass subtropical species, as common squid, mackerels, maybe tunas, and in the years of high abundance of sardine – the sardine. Cold-water species, as pollock, cods, herring, will have only local importance for fisheries.

3-6. Discussion

3-6-1. Fishing vs. climate hypothesis

During the late 20th century, stock assessment for fisheries management was mostly based on surplus production and stock-recruitment models that usually treated climate and environmental fluctuations as a long-term constant with white noise (Gulland, 1983). 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, usually termed as 'overfishing' (Pontecorvo, 2008). However, recent multidisciplinary, international researches suggests that climate variability has been the major force in fluctuating fish population (Lehodey et al., 2006; Batchelder and Kim, 2008). In Korean fisheries, the 'overfishing' hypothesis has been popular among fisheries scientists and managers (Tang, 1993; McFarlane et al., 2009; Zhang et al., ; Zhang et al., In press), but recent studies including this paper suggest that basin-wide climate variability has been a major mechanism explaining fluctuating catches of major fisheries species in Korean sea waters (Kang et al., 2002; Zhang et al., 2004; Tian et al., 2006; Gong et al., 2007; Kim et al., 2007; Zhang et al., 2007; Gong and Choi, 2008). We agree that overfishing has certainly influenced ecosystems and fish communities in the long term (Pauly et al., 1998; Jackson et al., 2001; Mace, 2001), but we concluded that its magnitude has usually been overestimated because the environmental influence was not explicitly included in traditional stock-assessment models.

Regarding the major cause of decline in Atlantic cod, the related paradigm seemed to have recently shifted from the 'fishing' to the 'environmental' hypothesis (Cook et al., 1997; Rothschild, 2007; Halliday and Pinhorn, 2009; Drinkwater). We suggest that regional policy makers and scientists may consider implications of potential long-term climate changes driven by natural and human forces when developing ecosystem and fishery management plans (King and McFarlane, 2006; Pontecorvo, 2008; Joshua, 2009; Haltuch et al., In Press). Like weather forecasts, fisheries scientists and oceanographers should able to forecast climate-driven regime shifts by monitoring oceanic conditions to warn and advise fishermen and managers to prepare for a sudden shift in species changes in fisheries catch, minimizing potential socioeconomic impacts.

For Pacific anchovy, its annual catch reported in Japanese fisheries statistics (FAO, 2007) showed more stable pattern in the long term (figure is omitted here) compared with Korean anchovy, although its annual catch has linearly increased since the early 20th century by enhancing fishing technology. In both Korea and Japan, annual catch of anchovy has increased since the 1990s, suggesting that warming sea water can enhance anchovy recruitment and production (Takasuka et al., 2003; Takasuka et al., 2007). In the Chinese side of the Yellow Sea, the standing stock biomass of anchovy was suggested to have decreased dramatically since 1999, probably by overfishing (Zhao et al., 2003; Wang et al., 2006). However, in the Korean side, the fishing mortality on anchovy was evaluated to be marginal compared with natural mortality (Jung, 2008a; Jung et al., 2008), ruling out the overfishing hypothesis, at least in Korean sea waters. The recent studies on Pacific anchovy in Korea and Japan suggest that natural oceanic change has been the major force on recruitment fluctuation of anchovy rather than overfishing.

Common squid probably benefits by warming sea water and increased zooplankton biomass off the Korean peninsula, because zooplankton biomass and abundance of major zooplankton groups (Figs. 2 and 3) were significantly cross-correlated with commercial catch of common squid in Region J for the 1978-1998 period (Kang et al., 2002). The historical trend of annual catch level of common squid since 1920s show that it rebounded in the 1990s far more in the Tsushima-current areas than in the seas off Japanese northeastern coast (Gong et al., 2006; Gong et al., 2007), suggesting a northward shift in spatial distribution of recruited squids, probably driven by warming sea waters.

3-6-2. Range shift

The estimated speeds of shift in mean latitude ranged from 0.63 to 2.37 km yr^{-1} (Table 5; average = 1.26 km yr^{-1}) while sea surface temperature increased by 1.05°C in Region K. In the North Sea, the estimated speeds of shift in center of distribution of 15 demersal fish ranged from 2.0 to 16.8 km yr^{-1} (average = 7.2 km yr^{-1}) while sea water temperature increased by 1.05°C from 1977 to 2001. This comparison suggests that our estimated speeds of shift in center of distribution are slower by a factor of 5 than those in the North Sea. We note the geomorpholgical difference between our study area and the North Sea. The boundary between the land and the ocean in our study area is the upside-down shape of the North Sea (i.e., the inverted “U” vs. the “U” shape): The North is opened only poleward to be connected to the Norwegian Sea, whereas the ocean of our study area is opend southward, but closed poleward and westward by the Asian continent and eastward by the Japanese archipelago, except the 3 narrow straits connected northeast to the Okhotsk Sea (Tsugaru, La Perouse and Tartary Strait). This implies that marine organisms in the western North Pacific have geographic limitation in poleward shift driven by warming oceans. In evolutionary history, fish stocks that could not be acclimated well to the warming ocean of our study area might have survived less than those in the North Sea (Pörtner and Peck, 2010). Thus, we speculate that the fish stocks in our study area have been acclimated to warming ocean better, but have been less flexible in meridional shift in their distribution, at least partially explaining our far slower estimates of range shift compared with the North Sea.

4.0 Conclusions

Scientists of the four countries involved in this project have compiled an amazingly ample set of physical and biological data sets from the area of investigation. Naturally, the joint analysis suffers from the fact that these data have been collected uncoordinatedly and separately by the different countries. Consequently, in a further step, these data sets should be analyzed in an amalgamated way and a corresponding synthesis should be presented. The project focuses on two oceanic regions: (i) the Yellow Sea and (ii) Region R and J. There is comparatively little information available from the Yellow Sea, whereas the other region is well covered. Three country reports deal with Region R and J, but cover mainly the areas adjacent to their coasts. A joint analysis of this data would lead to a much better understanding of the entire NOWAP region.

The goal of the project is to evaluate the impact of global warming in the NOWAP region. To do so, first, the impact of natural climate variability has to be documented by retrospective analysis, as is attempted in this report. In contrast to many other regions in the world, the impact of climate drivers such as the Siberian High and the East Asian Winter Monsoon, are clearly visible, but have been only cursory treated. For example, temperature and population dynamics of zooplankton and fish seem to be strongly affected by these climate drivers probably causing regime shifts, as demonstrated by the data sets from Korea, Japan and Russia, and this could be analyzed in much more depth. Climate impact would become much clearer when the results from the different sub-areas, for example sea temperature, would be presented in a single graph. Also, the country reports should be harmonized and presented in a more uniform way: for example, with respect to oceanographic data, the Korean report shows an extensive analysis, the Russian report gives a short description and the Japanese report shows only figures without any description. Similarly, the information on fish is presented in different ways making comparisons difficult.

A strong climatically induced ecosystem regime shift has occurred in the NOWAP region in the late 1980s. Corresponding analysis was conducted for regions K and J, but not for regions Y and R and, consequently, it is stated that regions K and J responded to the climatic regime shift, but regions Y and R did not. However, the information given in the reports on regions Y and R clearly shows it is highly likely that there were also ecosystem regime shifts. Fig. 12 and 13 demonstrate dramatic changes in the region Y fish community and Fig. 35 and 36 show a considerable temperature increase in region R which has probably also resulted in community changes in region R. The regime shift hypothesis should be studied further integrating all four regions.

The synthesis of the report should include the results of the joint retrospective analysis of the four regions.

5.0 Future Directions

Mechanisms of climate change effects on marine fish and invertebrate populations can be considered at four interlinked levels of biological organization (Pörtner and Peck, 2010): (1) organismal-level physiological changes in response to changing environmental variables such as temperature, dissolved oxygen and ocean carbon dioxide levels; (2) Individual-level behavioral changes such as the avoidance of unfavorable conditions or movement into suitable areas; (3) Population-level changes through changes in mortality, growth, reproduction, and retention or dispersion of early life stages by ocean currents; (4) Ecosystem-level changes in productivity and food web interactions. However, our analyses and projections were based on empirical relationships between distribution range of fish and water temperatures, but cause-and-effect understanding is needed to reliably project the effects of global warming on commercially important marine species (Pörtner and Peck, 2010). For this, relationships between ambient water temperature and fish habitat range need to be studies based on chemical and physiological principles. Second, we are currently developing spatially-explicit, biophysical coupling models to understand and project how warming ocean and changing currents will effect on distribution range of marine fishes in Korean waters. In addition, to understand effects of climate change on temperature tolerance of marine fishes and invertebrates, southern and northern boundaries of fish distribution need to be analyzed with respect to long-term changes in summer and winter temperatures in our study area.

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Appendix

Conferences/Symposia/Workshops

1st workshop: Jeju, Republic of Korea, March 22-24, 2012

2nd workshop: Jeju, Republic of Korea, July 9-14, 2012

3rd workshop: Jeju, Republic of Korea, November 10-13, 2013

Agenda/Programme (including title, date and venue)

1st workshop:

i. Present the research status and data availability of the participating countries with respect to climate change and fisheries
ii. Discuss directions, obstacles and outputs of the project
iii. Arrange other experts who can contribute to our APN project
iv. Plan the 2nd workshop.

2nd workshop:

v. Synthesize past studies and available data from each participating countries
vi. Project changes in biomass and habitat range of major fisheries species
vii. Complete national reports
viii. Comparison between N. Pacific and N. Atlantic in climate change and fisheries
ix. Plan activities for the 2nd phase project (2012-2013)

3rd workshop:

x. Synthesize past studies and available data from each participating countries
xi. Combine and synthesize national reports
xii. Complete draft of the final report

Participants list

1st workshop: Hiroya Sugisaki (FRA, sugisaki@affrc.go.jp), Gennady V. Khen (Tinro, gennady1@tinro.ru); Xianshi Jin (YSFRI, jin@ysfri.ac.cn); Dohoon Kim (NFRDI, delaware310@pknu.ac.kr), Sangjin Lee (NOWPAP, sangjin.lee@nowpap.org), Young Cheol Park (Ecocean21, ypark115@yahoo.co.kr), Suam Kim (Pukyoung Univ, suamkim@pknu.ac.kr), Sukgeun Jung (Jeju Nat's Univ, sukgeun.jung@gmail.com), Igchan Pang (Jeju Nat's Univ, pangig@jejunu.ac.kr), Byung-Gul Lee (Jeju Nat's Univ, leebg@jejunu.ac.kr), Sang Rul Park (Jeju Nat's Univ, srpark@jejunu.ac.kr), Joon Ho Lee (Jeju Nat's Univ, ocean0510@gmail.com), Hye Ung Ko (Jeju Nat's Univ, stepano1228@fira.or.kr), Jaehwan Kwak (Jeju Nat's Univ, kjh790319@fira.or.kr), Seok-Beom Hong (Jeju Nat's Univ, honga198@fira.or.kr)

2nd workshop: Russa: Gennady V. Khen (Tinro, gennady1@tinro.ru), Yury Zuenko (Tinro, zuenko_yury@hotmail.com) , Sangjin Lee (NOWPAP, sangjin.lee@nowpap.org), Sukgeun Jung (Jeju Nat's Univ, sukgeun.jung@gmail.com), Byung-Gul Lee (Jeju Nat's Univ, leebg@jejunu.ac.kr), Hye Ung Ko (Jeju Nat's Univ, stepano1228@fira.or.kr), Jaehwan Kwak (Jeju Nat's Univ, kjh790319@fira.or.kr), Seok-Beom Hong (Jeju Nat's Univ, honga198@fira.or.kr), Jürgen Alheit (juergen.alheit@io-warnemuende.de)

3rd workshop: Jürgen Alheit (juergen.alheit@io-warnemuende.de), Hanna Na (Hokkaido University, hanna.ocean@gmail.com), Yongjun Tian (FRA-Japan, yjtian@affrc.go.jp), Gennady V. Khen (Tinro, gennady1@tinro.ru), Zuenko Yury (Tinro, zuenko_yury@hotmail.com), Shan Xiujuan (YSFRI-China, shanxiujuan@gmail.com), Lan Kuowei (Taiwan Ocean Nat's Univ, kwlan422@gmail.com), Byung-Gul Lee (Jeju Nat's Univ, leebg@jejunu.ac.kr), Suam Kim (Pukyoung Univ, suamkim@pknu.ac.kr), Sung Yong Kim (KAIST, syongkim@kaist.ac.kr), Sangjin Lee (NOWPAP, sangjin.lee@nowpap.org), Seungmok Ha (Jeju Nat's Univ, ums0818@naver.com), Kyunghwan Lee (Jeju Nat's Univ, kyunghwan034@naver.com), Jinsu Jang (Jeju Nat's Univ, rivers1215@naver.com)

Funding sources outside the APN

Activity	**Organisation**	**In-Kind (US$)**	**Cash (US$)**
Workshop	Ieodo Research Center		5,000
Workshop	Jeju Sea Grant		3,500
Workshop	Jeju National University		8,500
Administration Support	Industry-Academic Cooperation Foundation, Jeju National University	17,200	
Development of bio-physical coupling models for fishes	National Fisheries Research & Development Institute		150,000
	Total	**17,200**	**167,000**

List of Young Scientists

Joon Ho Lee (Jeju Nat's Univ, ocean0510@gmail.com), Hye Ung Ko (Jeju Nat's Univ, stepano1228@fira.or.kr), Jaehwan Kwak (Jeju Nat's Univ, kjh790319@fira.or.kr), Seok-Beom Hong (Jeju Nat's Univ, honga198@fira.or.kr), Seungmok Ha (Jeju Nat's Univ, ums0818@naver.com), Kyunghwan Lee (Jeju Nat's Univ, kyunghwan034@naver.com), Jinsu Jang (Jeju Nat's Univ, rivers1215@naver.com)

Glossary of Terms

APEC-LME: Asia-Pacific Economic Cooperation - Large Marine Ecosystems

APN: Asia-Pacific Network for Global Change Research

AR5: Fifth Assessment Report

CA: Correspondence analysis

CCA	Canonical correspondence analysis
EEZ	Exclusive Economic Zone
ENSO	El Niño–Southern Oscillation
FAO	Food and Agriculture Organization of the United Nations
ICES	International Council for the Exploration of the Sea
IPCC	Intergovernmental Panel on Climate Change
KODC	Korea Oceanographic Data Center
LOESS	Locally weighted scatterplot smoothing
NEAR-GOOS	The North-East Asian Regional Global Ocean Observing System
NFRDI	National Fisheries Research & Development Institute, Korea
NOWPAP	Northwest Pacific Action Plan
PICES	North Pacific Marine Science Organization
POI	Pacific Oceanological Institute of Russian Academy of Science, Vladivostok
TINRO	Pacific Fisheries Research Center, Vladivostok
TWC	Tsushima Warm Current
YSBCW	Yellow Sea Bottom Cold Water

Power Point Slides of conference/symposia/workshop presentations

1. ICES annual science meeting in Gdansk, Polland (September 2011), 2 oral presentations
2. PICES annual meeting in Khabarovsk, Russia in (October 2011), 2 oral presentations
3. APEC-LME Workshop on Marine Ecosystem Assessment Management in Seoul, Korea (January 2012)
4. 2nd International Symposium “Effects of climate change on the world’s ocean” in Yeosu, Korea (May 2012)), 2 oral presentations
5. Asian Fisheries Acoustics Society in Busan, Korea (November 2012)
6. 10-th Asian Fisheries and Aquaculture Forum in Yeosu, Korea (May 2013)

Electronic supplementary materials

1. Published papers
2. Power Point Slides of conferences
3. Photos of workshop