1 Introduction

Regime shifts have been observed and described for both, the North Atlantic and the North Pacific, and were the subject of Theme and Topic sessions on the annual meetings of ICES and PICES. In the marine realm, the term regime was first used by Isaacs (1976) to describe distinct climatic and/or ecosystem states and, as early as 1989, Lluch-Belda *et al*. (1989) stated that regime shifts are transitions between different regimes. There is no universally accepted definition. Lees *et al*. (2006) listed several, but none of them is quantitative. Criteria for definition are: sudden, high-amplitude, infrequent events, the number of trophic levels impacted by the shift and bio-physical impacts (Lees *et al*., 2006). A practical definition has been suggested by deYoung *et al*. (2004): *regime shifts are changes in marine system function that are relatively abrupt, persistent, occurring at large spatial scales and observed at different trophic levels. It is important to note that the duration of the shift itself is much shorter than that of the regime following the shift.* Regime shifts have occurred in all oceans and their occurrence has been widely accepted, however, the concept of regime shifts remains controversial (Hsieh *et al*., 2005; Lees *et al*., 2006; Beaugrand, 2009). The mechanisms underlying these observed changes are largely unknown (deYoung *et al*., 2008). Integrated physiological and ecological studies should be promising approaches to elaborate cause and effect (Alheit and Pörtner 2011). A better understanding of the nature of regime shifts is required so that they can be taken into account in the movement towards ecosystem-based management of living resources and their environments. Regime shifts may be caused by natural (climate, internal community dynamics) and by anthropogenic forcing (fishing, pollution, habitat destruction). Both groups of drivers might act synergistically and it is often difficult to disentangle them (Planque *et al*., 2010). Here we focus on climatic drivers aiming to clarify the contribution of climate forcing. During the last decade, many papers on regime shifts in marine ecosystems have been published, particularly in relation to climate variability in the North Atlantic and, the North and South Pacific (for example: Beaugrand, 2004; Benson and Trites, 2002; Alheit and Niquen, 2004). This is in part due to several long-term sampling programmes reaching an age of 40 and more years and, in the wake of climate change, an increasing interest in their results. The successful international GLOBEC programme (1992-2009) contributed in an important way to our understanding of regime shifts. Theoretical concepts of regime shifts stem largely from freshwater (lake) studies (Scheffer *et al*., 2001). However, they are not easily transferable to marine systems, as regime shifts in lakes are much easier to understand because they occur in closed systems and are usually much smaller in extent.

Detection of regime shifts is difficult. Until now, they have only been defined by retrospective analyses of long time-series that included a number of abiotic and biotic variables. For example, in several large marine ecosystems in the Northern Hemisphere substantial changes have been observed around the late 1980s, but it took about 10 years before scientists working on the North Sea became aware of the shift (Reid *et al*., 2001) and, in the case of the Baltic Sea, it took about 15 years (Alheit *et al*., 2005). It was suggested by deYoung *et al*. (2008) that a shift like that in the late 1980s in the North Sea, as it was caused by a change in mean climate, might be predictable, given an improvement in knowledge and the application of new prognostic atmosphere-ocean climate models. Although it is important to search for a better understanding of drivers and the causative mechanisms for changes in marine communities, as this is the key to predict how ecosystems might react to regime shifts associated with climate (Lees *et al*., 2006), the prospects for realistic predictions in the near future appear poor. The main stumbling block is that sudden shifts in the climate system, the knowledge of which would be essential for forecasting the reaction of marine communities, apparently cannot be predicted at present. Especially during the late 1980s, regime shifts have been observed in several northern hemisphere marine ecosystems in the Atlantic and the Pacific such as the Baltic Sea (Alheit and Möllmann 2005, Möllmann et al. 2009), the North Sea (Beaugrand 2004), the Mediterranean Sea (Conversi et al. 2010), the Gulf of Alaska/Northern California Current (King 2005), the Oyashio-Kuroshio system (Yatsu et al. 2008) and the Japan/East Sea (Tian et al. 2008). All these systems have important small pelagic resources such as anchovy, sardine, herring, or sprat. It was assumed that these regime shifts in the two northern hemisphere oceans in the late 1980s were based on climatic teleconnection patterns between these ecosystems which are widely separated from each other (Alheit et al., in prep.).

A workshop similar to NORCLIM focusing only on European ecosystems was organized in 2010: EUR-OCEANS workshop on "*Comparative analysis of European marine ecosystem reorganizations – a largescale approach to develop the basis for an ecosystem-based management of marine resources*" in Hamburg, Germany (Möllmann et al. 2011). This workshop intended to conduct retrospective studies that analyse, and synthesize existing information using a comparative approach. It compared the effects of climate change and anthropogenic forcing on regime changes in marine ecosystems. By applying this comparative approach to a wide range of different marine systems the workshop tried to identify large-scale synchronies and regional expressions in regime shift patterns and their underlying causative agents and mechanisms. The NORCLIM workshop focused on NW Pacific ecosystems and aimed at investigating and comparing these their regime shifts in a quantitative way. Long-term time series of physical, chemical and biological variables from these regional ecosystems were compared and analysed by a team of experts from PICES and ICES countries using multivariate statistics. In particular, the tasks were to assemble multivariate data sets of long-term time series of physical, chemical and biological variables from regional ecosystems and to identify trends and abrupt changes (i.e. regime shifts) in the regional data sets using multivariate statistical and discontinuity analyses. These studies yielded further insight into how ecosystems change state, as, for example, the rates and magnitudes of change are not the same for the different systems reflecting regional specific differences in the forcing factors. In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing pressures appear to be at greater risk to this phenomena.

2 Methods

Recently a series of studies were published analysing the status and temporal development of large marine ecosystems (LMEs) including the occurrence and timing of regime shifts (*e.g.,* Beaugrand and Reid 2003, Conversi *et al.* 2010, Friedland and Hare 2007, Hare & Mantua 2000, Kenny *et al.* 2008, Litzow 2006, Mantua 2004, Molinero *et al.* 2008, Petersen *et al.* 2008, Solow and Beet 2005). However, no standardized approach was used to diagnose multivariate sudden changes and reveal the responsible drivers and mechanisms of ecosystem reorganizations. The frequently applied analytical techniques each have their own conceptual or statistical problems, and their suitability is a current source of debate. In general, methods need to deal with time series and multivariate data, illustrate gradual changes and/or abrupt transitions between states, identify breakpoints in the dataset, be robust and easy to use, and enable cross-comparisons between datasets and systems. To start the analysis within this Workshop, a suite of methods was suggested that were used in many of the above listed publications and ICES Working and Study Groups (REGNS, WGIAB, WGHAME, WGINOSE).

1. Ordination: Principal Component Analysis (PCA) based on the correlation matrix of all variables and data subsets, using the PC-scores of the first and second axis to visualise the time-trajectory of the system
2. Discontinuity time-series analyses (identify sudden changes): (1) Chronological Clustering (Legendre et al., 1985) (using all time series) and (2) Sequential Regime-Shift Detection Method (STARS, Rodionov, 2004) (using single variables and PC-scores)
3. "Traffic light plot" (Link et al., 2002) to show the status and temporal development of the system and of all variables (Quintiles of metrics are colour-coded and variables are sorted according to their subsequently derived PC1 loadings)

A code was developed in R (R Development Core Team, 2007) to perform a PCA and get the related plots. This should facilitate the application within workshops and easily produces comparable results and graphs for different data series. The output of the analysis was illustrated by using a multivariate data set from the Central Baltic Sea (CBS), previously analysed in the ICES/ HECLOM Working Group on Integrated Assessment of the Baltic Sea (WGIAB). This dataset consisted of 59 biotic response and abiotic driving variables covering a period from 1975 to 2008. The selection of variables was based on a number of criteria: (i) length of the investigated period, (ii) number of missing data points, (iii) representativeness for a specific ecosystem component, and (iv) low cross-correlation with other variables. All available dataseries were compiled to one value per year and the number of variables per functional type and the number of drivers and response variables was balanced as far as possible. For methodological reasons when applying PCAs, missing values need to be replaced *e.g.* by the average of the four nearest datapoints. To improve linearity between variables, and to reduce the relationship between the mean and the variance, most of the biological time-series and nutrient values need to be ln(x+1) transformed.

In the traffic light plot, variables are sorted according to their loading on the first Principal Component, which results in a pattern with variables at the top showing an increasing trend over time and variables at the bottom showing a decreasing trend (Fig 1). Even though structural breaks might become visible within such a plot, we would not recommend using it as an analytical, but rather as an illustrative tool. Because each variable is separated into quintiles (indicated by different colours), the temporal development of a single variable in relation to other variables can be deduced without necessarily going back to the original data or anomaly plots.

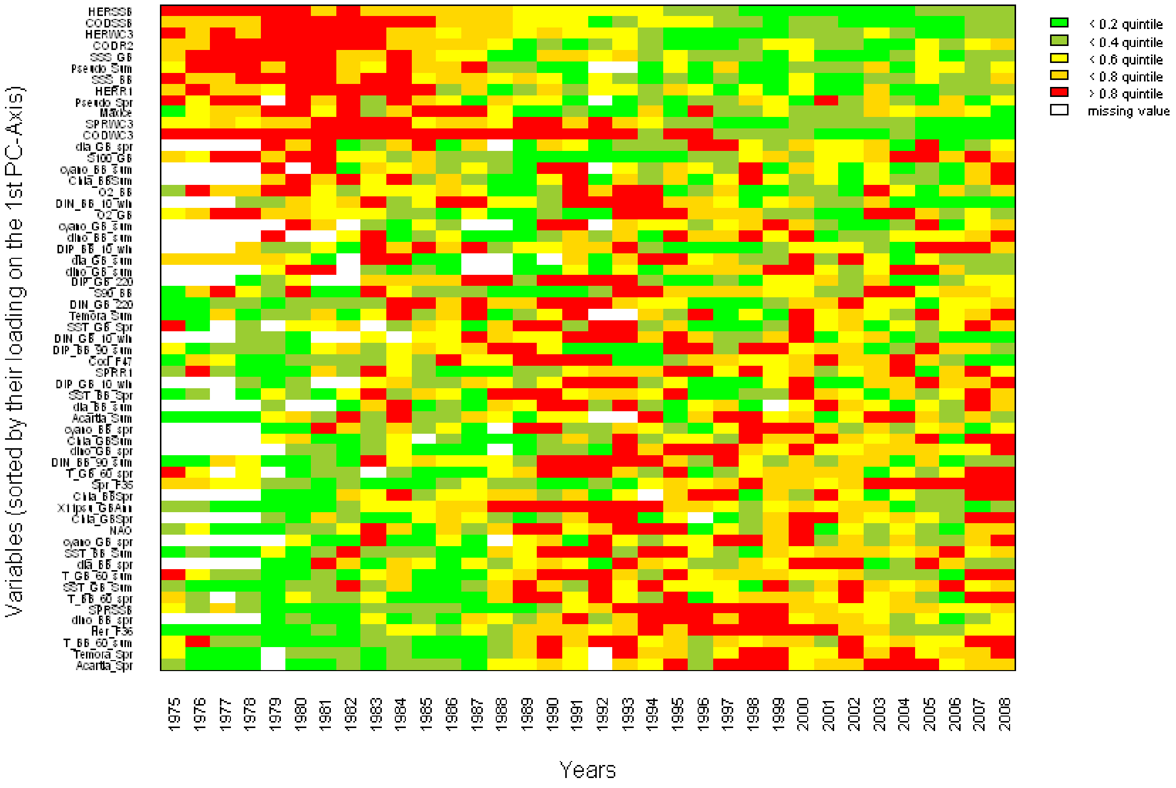

Fig. 1: Traffic-light plot of the temporal development of Central Baltic Sea time-series. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component.

In addition to the numerical result of the PCA (based on the correlation matrix) various plots are produced. First, the PC scores of the first and second axis (further axes can be shown if necessary) are plotted against time (Fig. 2) and against each other (Fig. 3). The latter results in a time trajectory, as consecutive years are linked to each other by a line. Like in other ordination methods, the closer two points (years) stand to each other, the more similar they are according to the behaviour of their underlying variables. Therefore, continuous as well as sudden changes can be graphically shown. For completeness, a biplot (Fig. 4) can be also produced, showing vectors for variable loadings and the year scores in the back.

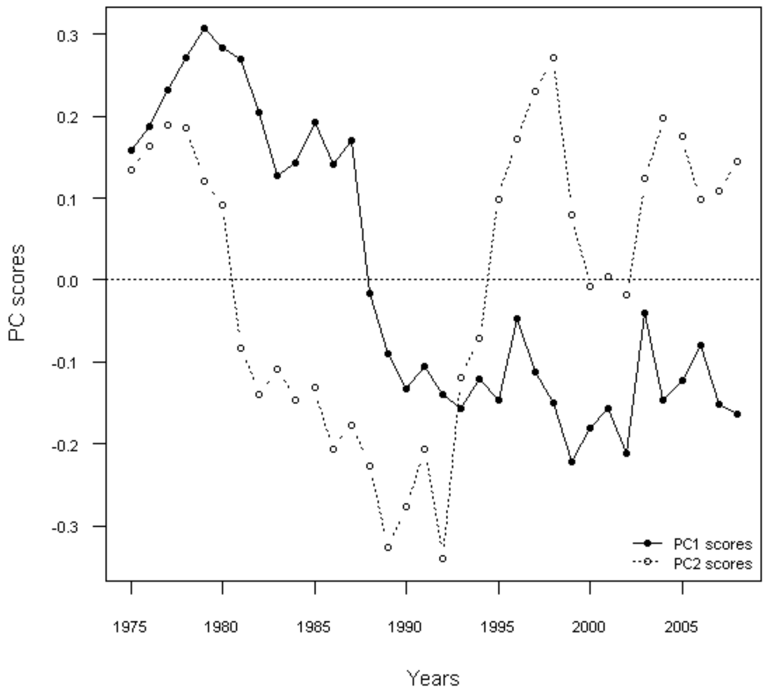

Fig. 2: Results of the standardized principal component analysis using all 59 variables assembled for the central Baltic Sea showing PC1 (black circles) and PC2 scores (white circles) against time.

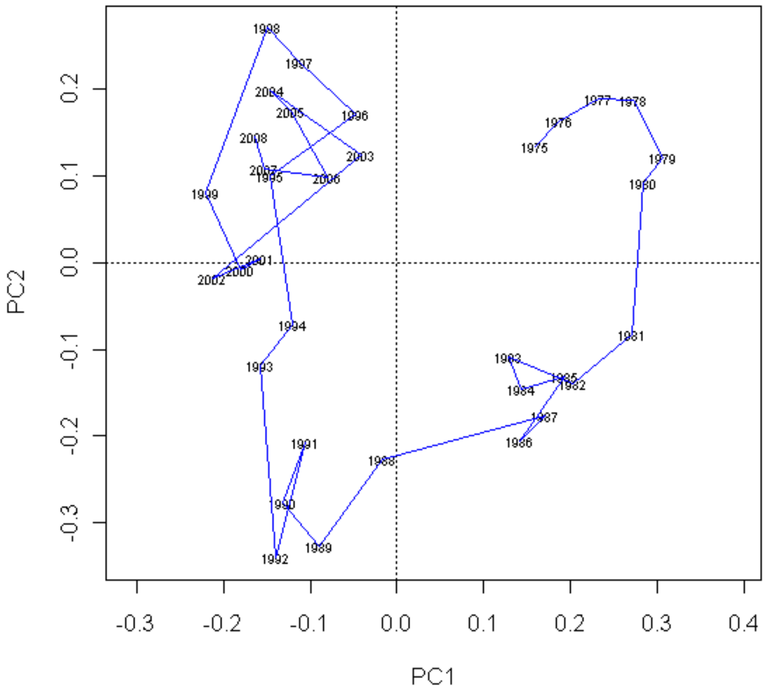

Fig. 3: Results of the standardized principal component analysis using all 59 variables assembled for the central Baltic Sea showing the time trajectory on the first factorial plane (PC1 vs. PC2).

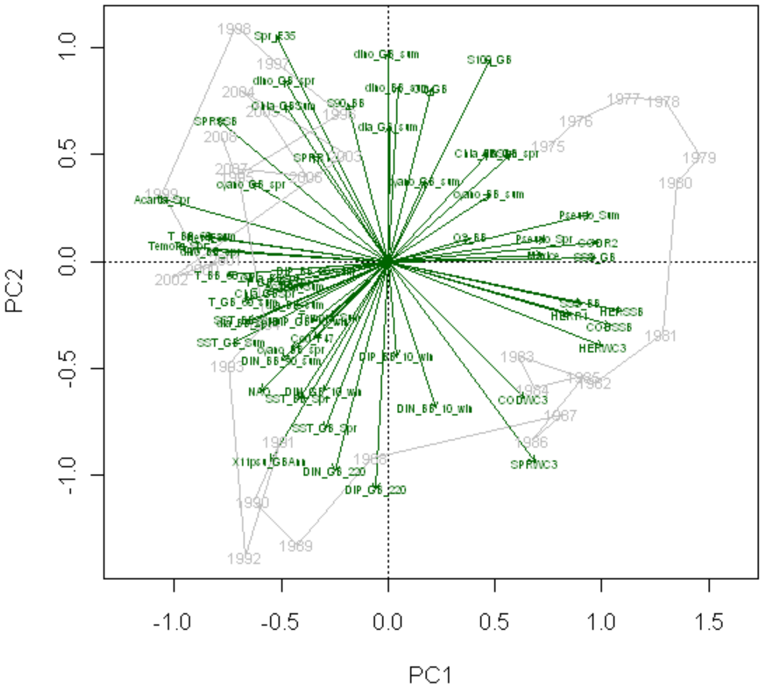

Fig. 4: Results of the standardized principal component analysis using all 59 variables assembled for the central Baltic Sea showing the variable loadings on the first factorial plane (for orientation: time trajectory from Figure 3 in light grey).

Finally, discontinuity analyses were applied to objectively identify abrupt changes in single datasets or in multivariate time series. Two independent types of analyses were used. First, Chronological Clustering was applied on the normalised dataset. In accordance with the use of the correlation coefficient in the PCA, the Euclidean distance function was calculated to determine similarity between years. Structural breaks in the multivariate dataset were analysed for different significance levels, with the smallest ☐=0.01 identifying o strongest shifts in the dataset. Second, STARS (Rodionov, 2004) was applied on single time series or on the first and second PC scores, and thus taking not the entire variability in the dataset into account. The test is based on a sequential *t*-test, and the two parameters controlling the magnitude and scale of the regimes to be detected need to be set. For the Baltic Sea dataset the significance level (☐-off length (*l*) was set to 0.05, after w was set to 8 years. The latter defines the minimum length of the time period (regime) to be identified by the test. However, shifts with a high magnitude can still be detected for shorter periods.

3 Results

Naturally, the time available at the workshop was not sufficient to completely analyse the vast data sets. The preliminary results are presented in four Annexes. It is planned to compare the results in a second workshop.

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Annex2: Terms of reference

2010/2/SSGEF07 An **ICES/PICES Workshop on the Reaction of Northern Hemisphere Ecosystems to Climate Events: a Comparison** (WKNORCLIM), chaired by Jürgen Alheit*, Germany; Christian Möllmann*, Germany; Sukgeun Jung*, Rep. of Korea; and Yoshiro Watanabe*, Japan, will meet in Hamburg, Germany, 2–6 May 2011 to:

a) Assemble multivariate data sets of long-term time series of physical, chemical and biological variables from regional ecosystems;

b) Identify trends and abrupt changes (i.e. regime shifts) in the regional data sets using multivariate statistical and discontinuity analyses;

c) Identify the region-specific importance of climate events relative to anthropogenic forcing factors such as eutrophication and exploitation;

d) Conduct a meta-analysis of ecosystem trends and their potential drivers over all northern hemisphere ecosystem.

WKNORCLIM will report by 1 July 2011 (via SSGEF) for the attention of SCICOM and to the PICES POC and MONITOR Committees.

Supporting Information

Priority	This workshop will conduct a meta-analysis of changes in ecosystem structure and function over several northern hemisphere ecosystems in relation to climate and other anthropogenic drivers. It contributes to the priority areas of the ICES Science Plan “Understanding ecosystem functioning” (research topics 1.1, 1.3) and “Understanding human interactions with ecosystems” (research topic 2.1)
Scientific justification	Regime shifts have been observed, espcially during the late 1980s, in several northern hemisphere marine ecosystems in the Atlantic and the Pacific such as the Baltic Sea, the North Sea, the Mediterranean Sea, Gulf of Alaska/Northern California Current, the Oyashio-Kuroshio System and the Japan/East Sea which all have important small pelagic resources. A respective multi-authored manuscript has been drafted by an earlier joint ICES/PICES workshop describing the associated climatic teleconnection patterns between these ecosystems which are widely separated from each other. The present workshop will extend this descriptive exercise in a quantitative way. Long-term time series of physical, chemical and biological variables from these regional ecosystems will be compared and analyzed by a team of experts from PICES and ICES countries using multivariate statistics. These studies will yield further insight into how ecosystems change state, as, for example, the rates and magnitudes of change are not the same for the

	different systems reflecting regional specific differences in the forcing factors. In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing pressures appear to be at greater risk to this phenomena).
Resource requirements	Assistance of the Secretariat in maintaining and exchanging information and data to potential participants. Assistance of especially the ICES DATA CENTER to collect and store relevant data series
Participants	The WK will be attended by 15–20 participants, incl. members from the Mediterranean Sea.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to advisory committees	Relevant to the work of ACOM and SCICOM
Linkages to other committees or groups	SSGEF, SSGSRP, WGNARS, WGHAME, all SG/WGs related to Baltic Sea issues.
Linkages to other organizations	PICES Physical Oceanography Committee (POC) and the MONITOR Committee will receive the workshop reports. HELCOM, OSPAR, NAFO

Annex 3: Agenda

ICES/PICES Workshop on the Reaction of Northern Hemisphere Ecosystems to Climate Events: a Comparison (WKNORCLIM)

Hamburg, Germany, 2–6 May 2011

Monday

10:00-12:30	Coffee Informal chats
12:30-13:30	Lunch
13:30-14:00	Introduction to workshop and first results of a North Atlantic Meta-Analysis of ecosystem changes *Christian Möllmann*
14:00-14:30	Introduction into planned statistical analyses *Rabea Diekmann*
14:30-15:00	Detection of regime and other shifts in marine time series – the new shiftogram approach *Joachim Gröger*
15:00-15:30	Climatic teleconnections NW Pacific – NE Atlantic *Jürgen Alheit*
16:00-16:30	Data presentation Japan/East Sea, incl. brief description of area *Yongjun Tian*
16:00	Coffee Break
16:00-16:30	Data presentation Japan/East Sea, incl. brief description of area *Yury Zuenko*
16:30-17:00	Data presentation Japan/East Sea, incl. brief description of area *Sukgeun Jung*
17:00-17:30	Data presentation Kuroshio/Oyashio region, incl. brief description of area *Motomitsu Takahashi*
17:30-18:00	Data presentation, salmon *Skip McKinnell*
After 18:00	Fun with wine and food

Tuesday, Wednesday, Thursday

09:00-18:00	Joint Analysis

Friday

09:00-17:00	Presentation of results Wrap up Report

Annex 4: Japan/East Sea (Yury Zuenko)

Introduction

The Japan/East Sea (called “Japan Sea” in most of countries, but named “East Sea” in North and South Korea; PICES recommends to use “Japan/East Sea” or JES) is a mediterranean sea, one of the marginal seas of the North Pacific. Its main feature is its relative isolation from the open ocean; it is connected by a few shallow sounds only (Fig. 1). The maximal depth of the Sea is 3700 m. Its water column is divided onto all water layers usual for the World Ocean: Surface, Subsurface, Intermediate, Deep, and Bottom; but its water masses have mainly local origin because of its isolation from the open sea at the depths >200 m. Another important feature of the JES is its great meridional extent (> 2000 km); that is why its conditions are very diverse, and it is called a “miniature ocean” (Ichiye, 1984). The JES includes different climate zones: Subarctic and Subtropic, which are divided by the Polar Front, a part of the planetary Subarctic Front.

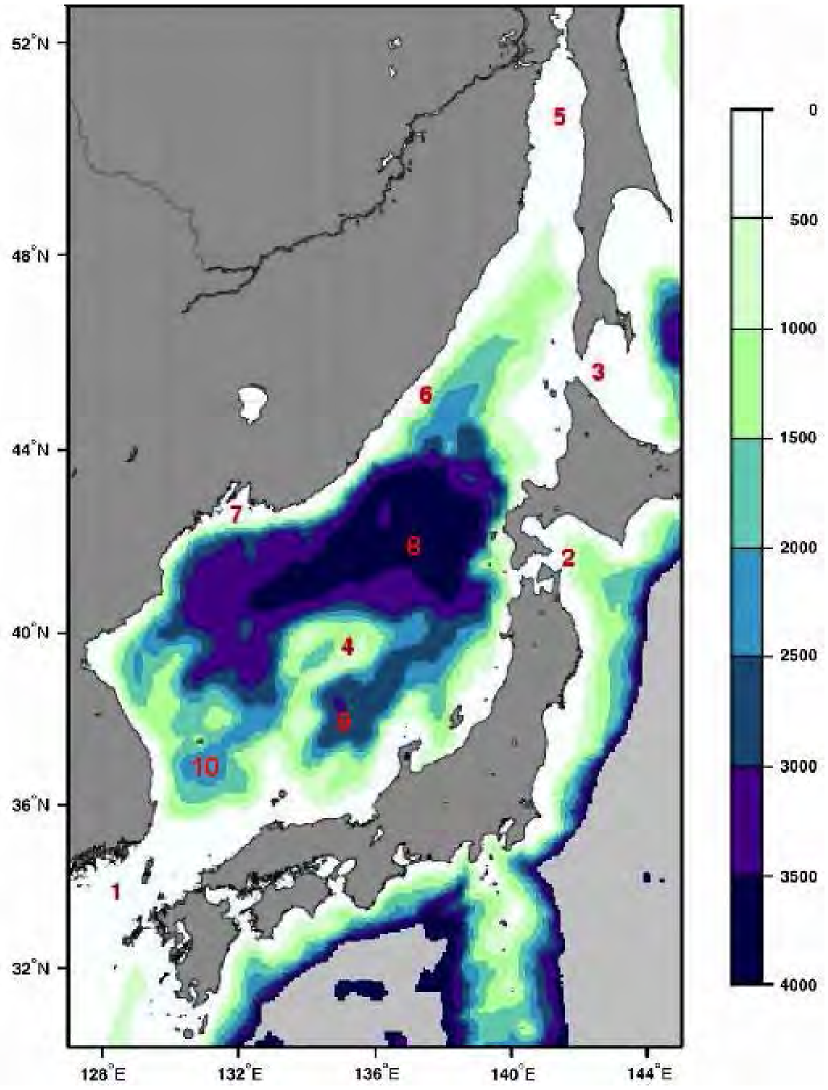


Fig. 1. The Japan/East Sea relief. 1 – Korean (Tsushima) Strait; 2 – Tsugaru (Sangarsky) Strait; 3 – Soya (LaPerouse) Strait; 4 – Yamato Rise; 5 – Tatar Strait; 6 – Primorye shelf; 7 – Peter the Great Bay; 8 – Japan Basin; 9 – Yamato Basin; 10 – Ulleung (Tsushima) Basin

Climate of the JES has strong monsoon features. Northerly, north-westerly winds prevail here in autumn and winter (September-April) that transport cold and dry air masses from the continent, and southerly, south-easterly winds prevail in summer that transport cool and wet air masses from the Pacific. Recently, the winter monsoon tends to weaken (since the late 1970s). Its intensity exhibits interdecadal fluctuations as well: the monsoon was stronger in 1980s and 2000s and weaker in 1990s (Fig. 2). Summer monsoon has no significant trend on the climatic scale, but it strengthened in 1990s and weakened in 2000s. Winter air temperature increases over the whole sea; the trend of summer air temperature is slightly positive, as well. In the last four decades, SST in the JES increased by 0.02-0.03^{o}/year, both in winter and summer, with the exception of the southern part of the sea in summer. Rising water temperature can be observed in deeper layers, as well, with respect to the Intermediate, Deep, and Bottom water masses which are formed within the sea in winter by the processes of deep and slope convection and subduction; e.g. the Intermediate Water temperature increased by 0.01-0.02^{o}/year and the Bottom Water temperature – on 0.001^{o}/year (all mentioned trends are significant at $p = 0.01$ level). The most rapid changes of thermal parameters happened in the late 1980s, a process which is considered usually as a “climate shift”. On the other hand, there are no data on any tendency in long-term changes of water circulation, and even the sea ice cover has no any significant trend, because the southern limit of the sea ice distribution is determined by the intensity of warm currents.

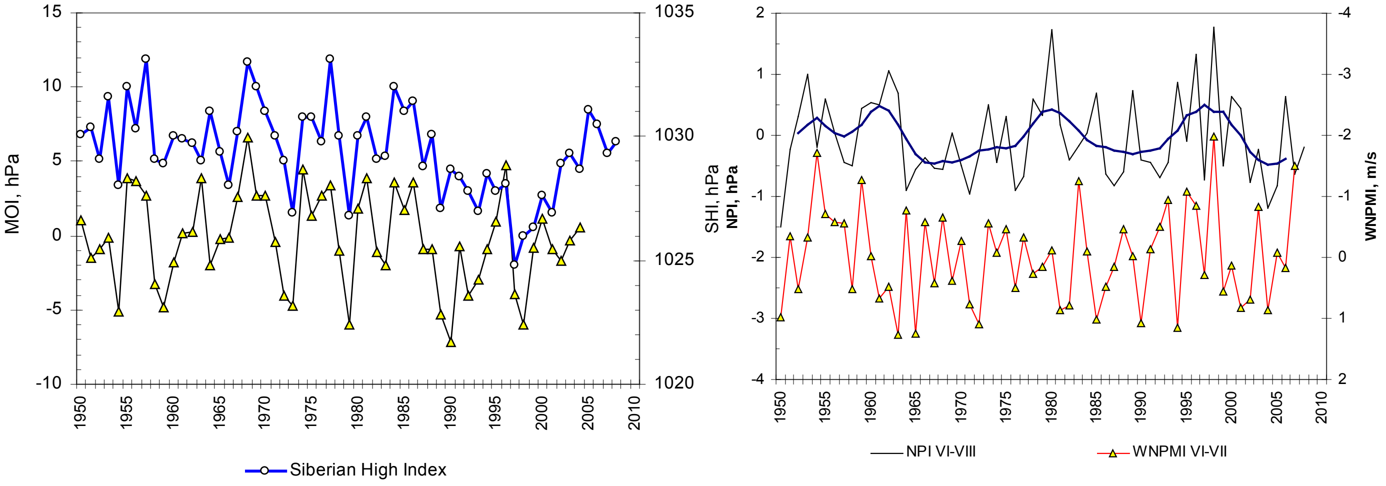


Fig. 2. Year-to-year changes of some climatic indices of the North Pacific: Siberian High Index (SHI) Panagiotopoulos et al., 2005, with additions) Winter Monsoon Index (MOI) (Tian et al., 2008) North aPcific Index (NPI) for June-August (http://www.cgd.ucar.edu/cas/hurrel/Data/) West-North Pacific Monsoon Index (WNPMI) for June-August (http://iprc.soest.hawaii.edu/)

Theoretically, the weakening of the convection should promote a decrease of the annual primary production. In a biogeochemical model (Zuenko, 2009), the recent reduction of the convective layer to 400 m causes a two-fold decrease of the yield. However, there are no significant long-term changes in the observed data of the phytoplankton biomass or Chl *a* concentration, though the timing of the spring bloom shifted insignificantly (10-15 days) to earlier dates after the climate shift in the late 1980s (Zuenko, Pershina, 2011).

Incontrast, fluctuations of zooplankton abundance show visible long-term dynamics with the tendency to increase in the late decades (Fig. 3). So far, large-sized copepods dominate the zooplankton community in all areas of the JES and they spend the main part of their life in the Intermediate Water. The warming of this water mass is considered to be the reason of their increased abundance (Zuenko et al., 2010).

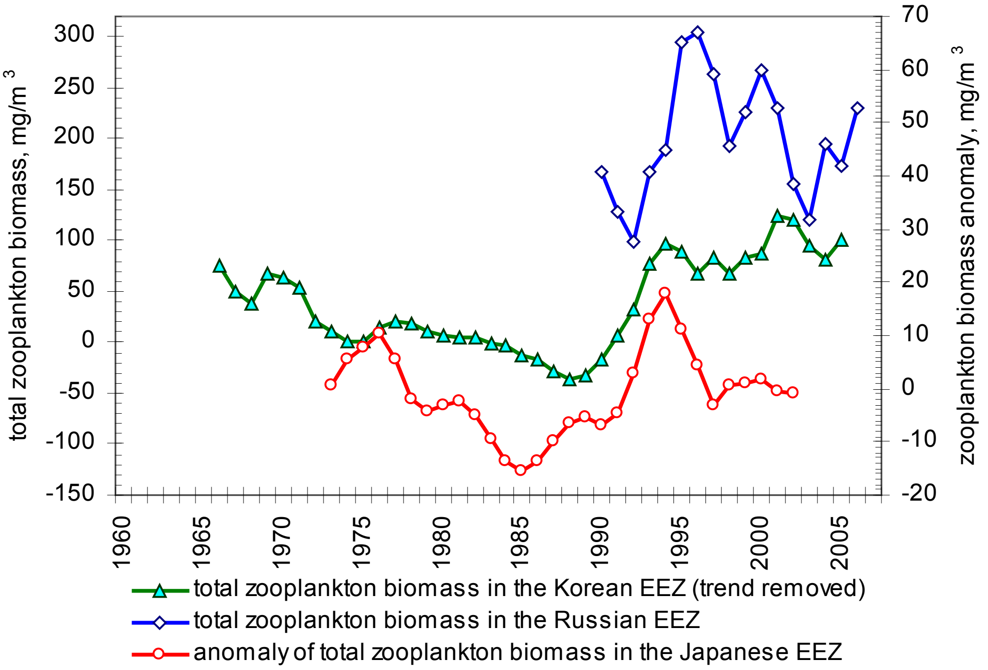


Fig. 3. Annual mean total zooplankton abundance smoothed by a 3-years running window in three deep-water areas of the Japan Sea (Zuenko et al., 2010)

Nekton populations have obviously diverse dynamics. Well-known is the phenomenon of the “sardine disaster”, when the stock of the Japanese sardine in the JES and North-West Pacific collapsed several years after the climate shift in the late 1980s and the annual catches of this highly important commercial species fell in the JES from 1.5 million t to zero (Fig. 4).I believe, the fluctuations of this subtropical species are caused by decadal variability of its reproduction conditions, not by environmental changes at the climatic scale. Strong year-classes of sardine were formed in the years when the peak of its spawning preceded to the peak of the spring bloom (1971-1984); recently it spawns too early because of warm winters (Zuenko, 2011).

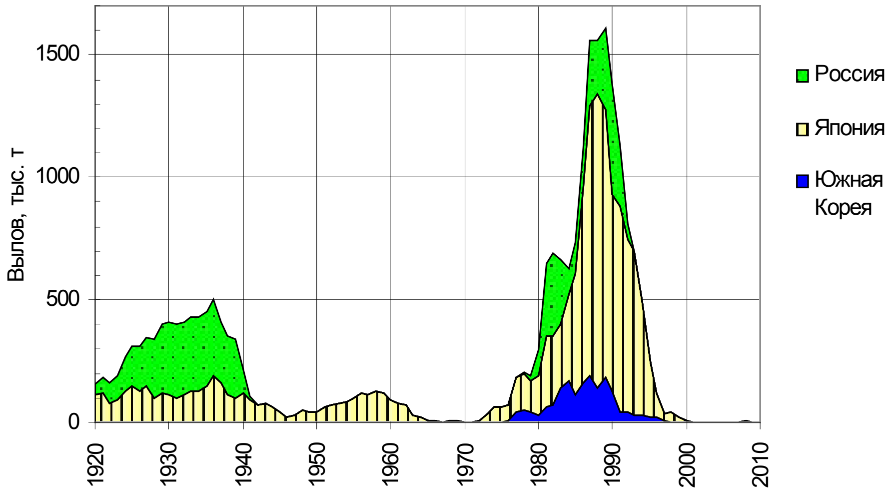


Fig. 4. Dynamics of the annual catch of Japanese sardine in the Japan/East Sea by countries, 10^3 t

Fluctuations of another leading nekton species, walleye pollock, are different – the stock of this cold-waters species has a long-term tendency to decreasing in the last decades (Fig. 5). It is known that warmer conditions for reproduction are favorable for pollock in the JES, as in other seas (Zuenko, 2008). But here the negative impact of warming on pollock dominates, possibly because of a stronger competition for prey with warm-water predators.

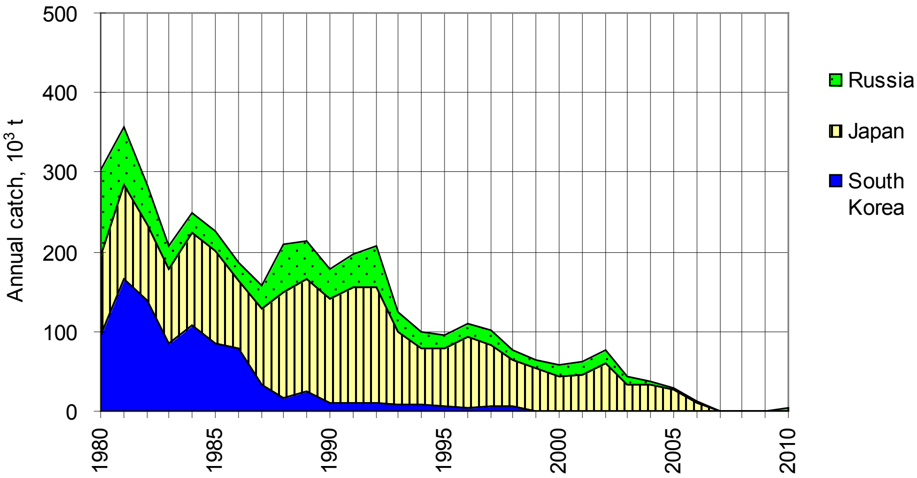


Fig. 5. Dynamics of the annual catch of walleye pollock in the Japan/East Sea by countries

After the collapse of the sardine and pollock populations, the main nekton species of JES in the last two decades is the Japanese common squid. Its stock rose qauickly after the climate shift in the late 1980s and is still very high (Fig. 6). There could be several reasons for the increase of this species in the1990s, such as weakening of winter storms (Sakurai et al., 2000) or increase of zooplankton abundance (Zuenko, 2008).

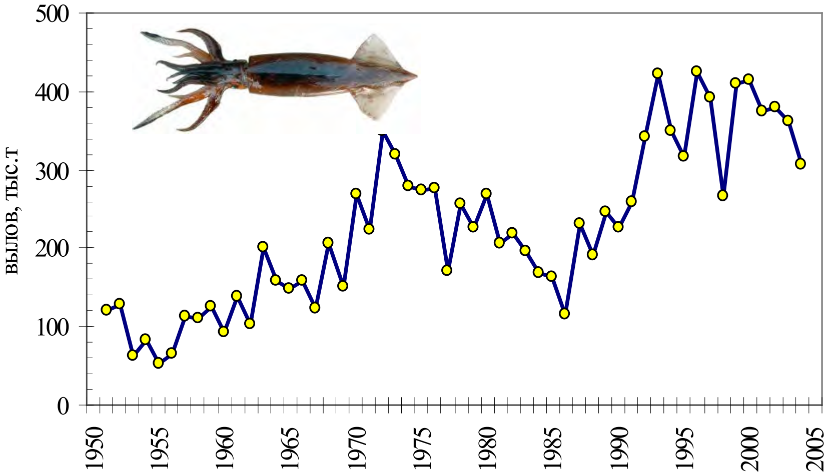


Fig. 6. Dynamics of the annual catch of japanese common squid in the Japan/East Sea by Japan and South Korea (Russian fishery is insignificant)

Data

Two data sets were prepared for analysis.

The first one (TINRO data set; “TINRO” is the Russian abbreviation for Pacific Fisheries Research Center) is based on Russian data, mainly from the northwestern part of the sea, and on data which are open for general use (published or available in Internet). After removing the redundant information (i.e. variables which described the same subjects or processes by means of different parameters), it consists of 29 variables, including climate indices (4), physical (air and water temperature, water salinity, ice cover) data for winter and spring seasons (11), data on zooplankton abundance and biomass (5), and data on the main nekton and benthos species (year-class strength, numbers or biomass of stock, catch) (9) (Tab. 1). Although some time series are very long, the time period is limited to 1979-2008, because of the lack of zooplankton data from earlier periods. Data are available for the S. Korean EEZ since 1979 and for the Russian EEZ since 1985. (in the latter case the time series was extrapolated by extending the value of 1985 to the years 1979-1984).Also, 1-5 values were extrapolated by the same way for the recent years for some temperature, salinity, and fish data series. There were a few missing values within the rows. These values were extrapolated by averaging their four neighbor values. When checking the distribution law for all variables, some of the biological ones (amphipoda, euphausia, laminaria, sardine, pollock, saffron cod, herring, greenling, saury) turned out to be far from normally distributed. They were ln- or lg-transformed by recommended methods.

Table 1

Metadata information for TINRO data set

Variable	Abbre-viation	Unit	Area	Season	Method Gear	Source Weblink
Arctic Oscillation Index	AO	hPa	Northern Hemisphere	Dec.-Feb.	barometer	http://jisao.washington.edu
Siberian High Index	SHI	hPa	North-East Asia	Dec.-Feb.	barometer	J. Climate (Panagiotopoulos et al., 2005)
North Pacific Index	NPI	hPa	North Pacific	June-Aug.	barometer	http://www.cgd.ucar.edu/cas/hurrell/Data
West-North Pacific Monsoon Index	WNPMI	m/s	North-West Pacific	July-Aug.	calculated from pressure field	http://iprc.soest.hawaii.edu/
Air temperature in winter	Ta winter	°C	Vladivostok	Dec.-Feb.	termometer	http://climexp.knmi.nl
Air temperature in summer	Ta summer	°C	Vladivostok	June-Aug.	termometer	http://climexp.knmi.nl
SST anomaly in winter	ATw winter	°C	northern JES	Dec.-Feb.	termometer	http://goos.kishou.go.jp
SST anomaly in summer	ATw summer	°C	northern JES	June-Aug.	termometer	http://goos.kishou.go.jp
SST anomaly at Russian coast in winter	ATw Rus. winter	°C	Peter the Great Bay	Jan.-March	termometer	http://goos.kishou.go.jp
Intermediate Water temperature anomaly in winter	ATw SS winter	°C	northwestern JES (standard section)	Feb.-Apr.	termometer	TINRO* (Zuenko)
Intermediate Water temperature anomaly in summer	ATw SS summer	°C	northwestern JES (standard section)	June-Aug.	termometer	TINRO* (Zuenko)
Sea surface salinity	Sw 0	psu	Tatar Strait	Jan.-Dec.	conductometer	POI* (Rudykh)
Intermediate Water salinity	Sw Int	psu	JES	Jan.-Dec.	conductometer	POI* (Rudykh)
Deep Water salinity	Sw Deep	psu	JES	Jan.-Dec.	conductometer	POI* (Rudykh)
Ice cover	Ice cover	%	Tatar Strait	Jan.-Apr.	satellite image	TINRO* (Ustinova)
Copepods abundance	Copepods	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	Progr. Oceanogr. (Rebstock, Kang, 2003)
Amphipods abundance	Amphipods	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	Progr. Oceanogr. (Rebstock, Kang, 2003)
Chaetognaths abundance	Chaetognath	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	Progr. Oceanogr. (Rebstock, Kang, 2003)
Euphausiids abundance	Euphausias	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	Progr. Oceanogr. (Rebstock, Kang, 2003)
Total zooplankton biomass	Zooplankton	mg/m^3	southern part of Russian EEZ	May	towing, Jeday net	Pacific Oceanogr. (Zuenko et al., 2010)
Laminaria stock	Laminaria	10^3 t	Primorye shelf	annual	diving	TINRO* (Krupnova)
Japanese sardine year-classes strength	Sardine	10^6 ind.	JES and ECS**	annual	fishery statistics	Fish. Oceanogr. (Ohshimo et al., 2009)
Pollock year-classes sterngth	Pollock	10^6 ind.	northwestern JES	annual	fishery statistics	TINRO* (Nuzhdin)
Saffron cod year-classes strength	Saffron cod	10^6 ind.	northwestern JES	annual	fishery statistics	TINRO* (Chernoivanova)
Herring year-classes strength	Herring	10^6 ind	northwestern JES	annual	fishery statistics	TINRO* (Chernoivanova)
Arabesque greenling stock	Greenling	10^3 t	northwestern JES	annual	trawl surveys	TINRO* (Vdovin)
Japanese anchovy catch	Anchovy	10^3 t	EEZ of S. Korea and Japan	annual	fishery statistics	TINRO* (Zuenko)
Saury catch	Saury	10^3 t	EEZ of S. Korea and Japan	annual	fishery statistics	TINRO* (Zuenko)
Japanese common squid catch	Squid	10^3 t	EEZ of S. Korea, Japan and Russia	annual	fishery statistics	TINRO* (Zuenko)

* – unpublished data of Pacific Fish. Res. Center (TINRO) and Pacific Oceanogr. Inst. Of Russian Ac. Sci. (POI)

** – East China Sea

The second data set was a combination of the first one with some data presented by Dr. Y. Tian (fisheries statistics for the Japanese EEZ and also water temperature and plankton, including phytoplankton, from the same area) and the data on zooplankton presented by Dr. S.-G. Jung (Tab. 2). Climate indices were not included. The combined data set (45 variables) is a better represention of the whole ecosystem, as it includes more data on primary producers, and even some data on mammals (whales). On the other hand, most of the Japanese data on fish are not biological but fisheriesdata. Consequently, they are distorted by changes in fishing activities. Moreover, they were not checked for normal distribution. The same applies for the new zooplankton data. The period for the combined data set is 1978-2004, limited by the absence of zooplankton data before 1978 and the fisheries data after 2004.

Table 2

Metadata information for combined data set

Variable	Abbreviation	Unit	Area	Season	Method Gear	Source* (initial data set)
Oceanographic parameters						
Air temperature in winter	Ta winter	°C	Vladivostok	Dec.-Feb.	termometer	TINRO
Air temperature in summer	Ta summer	°C	Vladivostok	June-Aug.	termometer	TINRO
SST anomaly in winter	ATw winter	°C	northern JES	Dec.-Feb.	termometer	TINRO
SST anomaly in summer	ATw summer	°C	northern JES	June-Aug.	termometer	TINRO
Subsurface Subtropic Water temperature in winter	Tw SST winter	°C	southeastern JES (standard section)	Dec.-Feb.	termometer	JSNFRI
Subsurface Subtropic Water temperature in winter	Tw SST summer	°C	southeastern JES (standard section)	June-Aug.	termometer	JSNFRI
Intermediate Water temperature anomaly in winter	ATw SS winter	°C	northwestern JES (standard section)	Feb.-Apr.	termometer	TINRO
Intermediate Water tempe-rature anomaly in summer	ATw SS summer	°C	northwestern JES (standard section)	June-Aug.	termometer	TINRO
Sea surface salinity	Sw 0	psu	Tatar Strait	Jan.-Dec.	conductometer	TINRO
Intermediate Water salinity	Sw Int	psu	JES	Jan.-Dec.	conductometer	TINRO
Ice cover	Ice cover	%	Tatar Strait	Jan.-Apr.	satellite image	TINRO
Phytoplankton and phytobenthos						
Undaria pinnatifida catch	S56NW	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Gelidium spp. catch	S57NW	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Hizikia fusifirmis catch	S58NW	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Laminaria japonica stock	Laminaria	10^3 t	Primorye shelf	annual	diving surveys	TINRO
Anomaly of Diatomea biomass in spring	Diatom_spr	mg/m^3	southeastern JES (standard section)	spring (?)	unknown	JSNFRI
Anomaly of Diatomea biomass in autumn	Diatom_aut	mg/m^3	southeastern JES (standard section)	autumn (?)	unknown	JSNFRI
Zooplankton and zoobenthos						
Anomaly of total zooplankton biomass	Zooplankton	mg/m^3	southeastern JES (standard section)	Jan.-Dec.	towing, Norpac net	JSNFRI
Copepods abundance	Copepods	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	NFRDI
Amphipods abundance	Amphipoda	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	NFRDI
Chaetognaths abundance	Chaetognath	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	NFRDI
Euphausiids abundance	Euphausia	ind./m^3	S. Korean EEZ	Jan.-Dec.	towing, Norpac net	NFRDI
Pink shrimp catch	Pink shrimp	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Tanner crab catch	Tanner crab	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Red snow crab catch	Red snow crab	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Sea urchins catch	Sea urchin	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Sea cucumber catch	Sea cucumber	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Plankton and benthos eaters						
Japanese sardine year-classes strength	Sardine	10^6 ind.	JES and ECS**	annual	fishery statistics	TINRO
Saffron cod year-classes strength	Saffron cod	10^6 ind.	northwestern JES	annual	fishery statistics	TINRO
Herring year-classes strength	Herring	10^6 ind	northwestern JES	annual	fishery statistics	TINRO
Arabesque greenling stock	Greenling	10^3 t	northwestern JES	annual	trawl surveys	TINRO
Japanese anchovy catch	Anchovy	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Japanese common squid catch	Squid	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Round herring catch	Round herring	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Horse mackerel catch	Horse mackerel	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Chub mackerel catch	Chub mackerel	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI

Japanese sandfish catch	Sandfish	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Fish and squid predators						
Pollock year-classes sterngth	Pollock	10^6 ind.	northwestern JES	annual	fishery statistics	TINRO
Bluefin tuna catch	Bluefin tuna	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Albacore catch	Albacore	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Sharks total catch	Sharks	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Yellowtail catch	Yellowtail	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Spanish mackerel catch	Spanish mackerel	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Pacific cod catch	Pacific cod	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI
Mammals						
Whales total catch	Whales	10^3 t	Japanese EEZ	annual	fishery statistics	JSNFRI

* – Iniitial data sets: TINRO collected by Y. Zuenko; JSNFRI collected by Y. Tian; NFRDI collected by S.-G. Jong

** – East China Sea

For a balanced representation of the ecosystem, the data set is divided into 6 groups of variables which are comparable by size and correspond to different trophic levels:

- oceanographic parameters (11 variables: air temperature in winter and summer, water temperature and salinity for certain water masses in winter and summer, ice cover);
- primary producers (6 variables: different populations of seaweed species and phytoplankton biomass in spring and autumn);
- zooplankton and benthos (10 variables: total zooplankton biomass in Korean EEZ, zooplankton abundance by groups of species in Korean EEZ, and annual catch of some shrimps, crabs, sea urchins, and sea cucumbers);
- planktophages and benthophages (10 variables: annual catches of small pelagic fish and squids, greenling biomass, herring and saffron cod year-class strength);
- predators (7 variables: annual catches of predatory fish species from cod to shark, walleye pollock year-class strength);
- mammals (1 variable: annual catch of all whales).

Results

The time series of many single variables have definite trends, decadal fluctuations, and shifts (see Figs. 1-6 and Fig. 7).

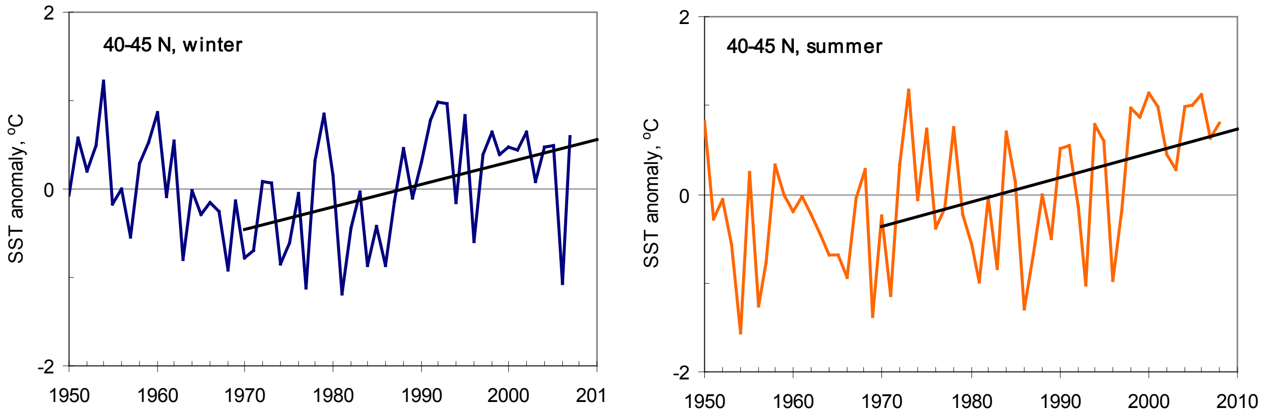


Fig. 7. Year-to-year changes of SST anomalies in winter (Dec.-Feb.) and summer (June-Aug.) averaged for the northern part of the Japan Sea between 40-45°N. Linear trends for the period after 1970 are shown (inclination 0.026 and 0.027°/yr, correspondingly). The regime shift in the late 1980s is visible for the winter series

Principal components analysis was conducted for both data sets, separately for the entire data set, and for the subsets of biotic and abiotic data. For all subsets, the three most important components contribute >50 % of variation (Tab. 3). However, the summary contribution of PC-1 and

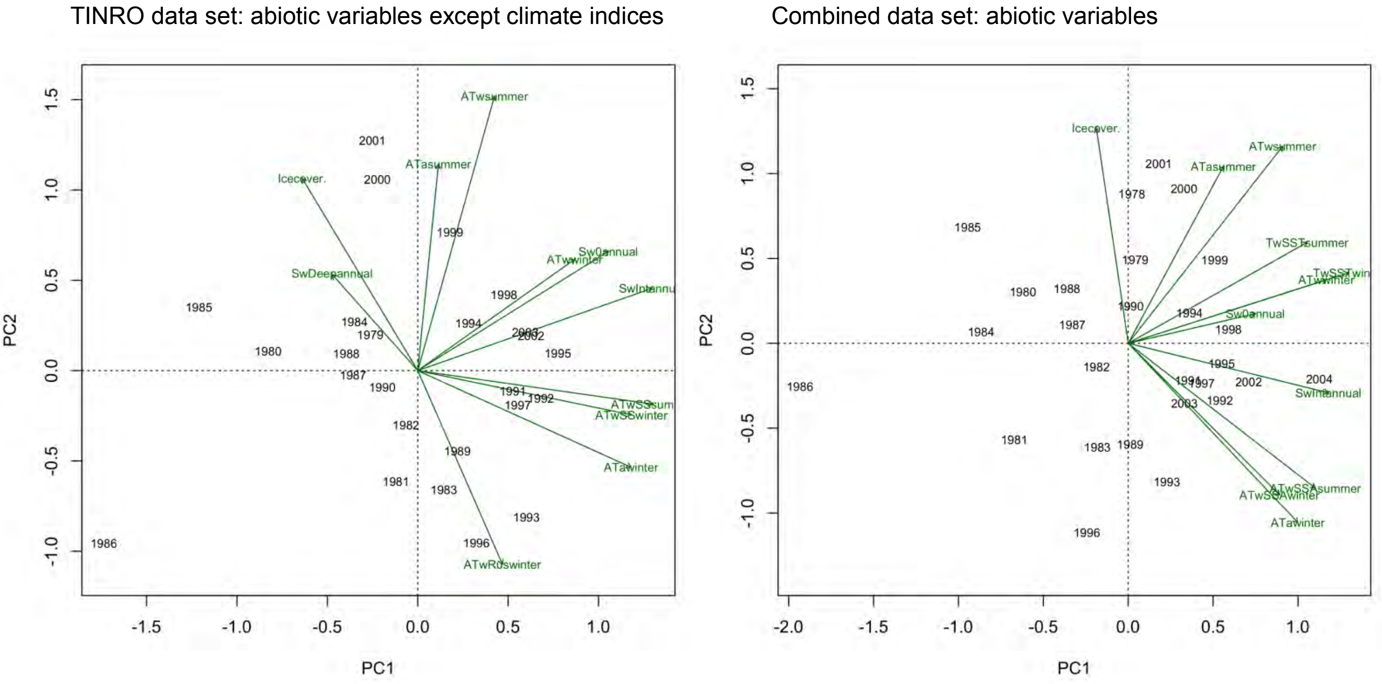
PC-2 prevails for separated data subsets only (both biotic and abiotic), with the maximal contribution of biotic subset of combined data set (58 %).

Table 3

Eigenvalues contribution for certain data subsets

Data set	Data subset	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7
TINRO	All variables (29)	0.279	0.159	0.102	0.073	0.064	0.056	0.051
	All variables except climatic (25)	0.293	0.171	0.098	0.071	0.068	0.058	0.052
	Abiotic variables only (11)	0.312	0.218	0.122	0.097	0.076	0.049	0.040
	Biotic variables only (14)	0.369	0.160	0.139	0.103	0.068	0.049	0.039
Combined	Abiotic variables only (11)	0.371	0.195	0.129	0.094	0.060	0.052	0.036
	Biotic variables only (34)	0.395	0.187	0.094	0.050	0.042	0.039	0.030

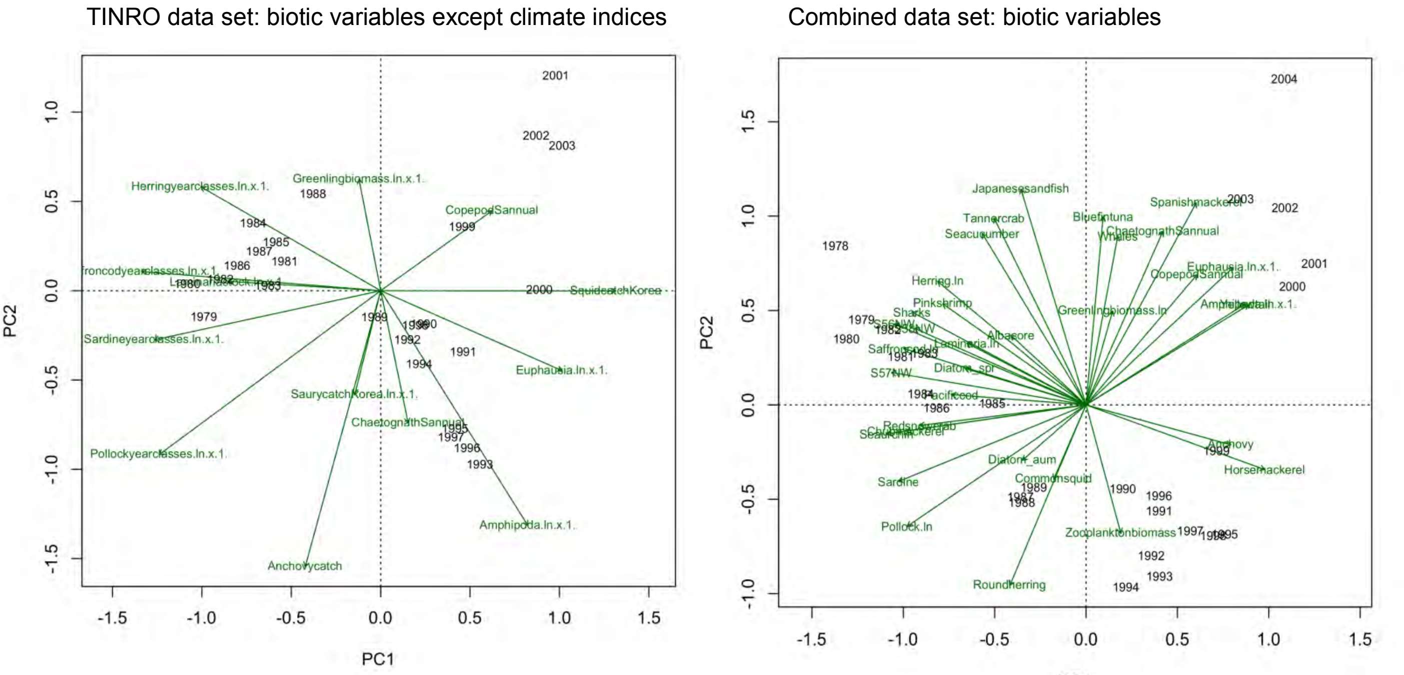
PC-1 of the abiotic variables of both data sets correlates well with the parameters describing winter conditions in the JES (Ta winter, ATw winter, ATw SS winter, Tw SST winter) or depends on them (ATw SS summer, Tw SST summer, Sw 0, Sw Int) – they form a group of right-directed beams on the PC-1,2 diagrams (Fig. 8). Other abiotic variables correlate better with PC-2 – they refer to summer conditions at the sea surface (Ta summer, ATw summer), as well as the ice cover and coastal water SST in winter (ATw Rus winter), and form the group of up-directed (Ta summer, ATw summer, Ice cover, Sw Deep (with low score)) or down-directed (ATw Rus winter) beams in Fig. 8. The high PC-2 scores of the ice cover (positive) and ATw Rus winter (negative) need some explanation. So, we can conclude that winter and summer processes are independent for the JES, and the influence of the winter variables dominates here.


TINRO data set: abiotic variables except climate indices

Combined data set: abiotic variables

The PC scores of biotic variables are more diverse (Fig. 9). First of all, some of them have a weak correlation with both, PC-1 and PC-2 (Diatom_aut, Greenling, Saury, Albacore), which means that their variability is not related with these principal components or is stochastic. Some variables show different relations with PC-1 and PC-2, depending on the data set, obviously because of different sources of these data (amphipoda, chaetognatha, euphausia, squid). So, they also cannot be analyzed. The other 27 species show definite relationships with PC-1 or PC-2, which allows to to speculate about the nature of their variability. The group of variables which are well correlated with PC-1 for both data sets includes all primary producers (Diatom_spr, Laminaria and all other seaweeds), as well as small benthic and pelagic species (pink shrimp, red snow crab, sea urchin, sardine, herring, saffron cod, chub mackerel, horse mackerel, yellowtail) and some predators (Pacific cod, sharks); all of them, except horse mackerel and yellowtail, are negatively related with PC-1 (left-directed beams). The variables well-correlated with PC-2 are found for the combined data only: zooplankton and round herring correlate with PC-2 negatively and sea cucumber, Tanner crab, sandfish, Spanish mackerel, bluefin tuna, and whales correlate with PC-2 positively. Two variables are well-correlated with both PC-1 and PC-2: copepods (positively with both) and pollock (negatively with both).

Thus, most of the biotic variables depend mainly on PC-1 which is natural. The correlation between all of them, except horse mackerel, is based on primary production which is also natural. So far, as the main physical process influencing primary production in the JES is winter convection (as in all subarctic seas), I suppose that PC-1 of the biotic subsets describes the variability of winter conditions, the same as for abiotic ones, though with opposite sign. That means that cold winters are favorable for all these species and pollock, but warm winters are advantageous for copepods, horse mackerel and yellowtail. The positive relationship of large-size cold-water copepods abundance with water temperature in the JES is already known (Zuenko, 2010), and the cases of horse mackerel and yellowtail have to be analyzed on the base of knowledge of these species biology.


TINRO data set: biotic variables except climate indices

Combined data set: biotic variables

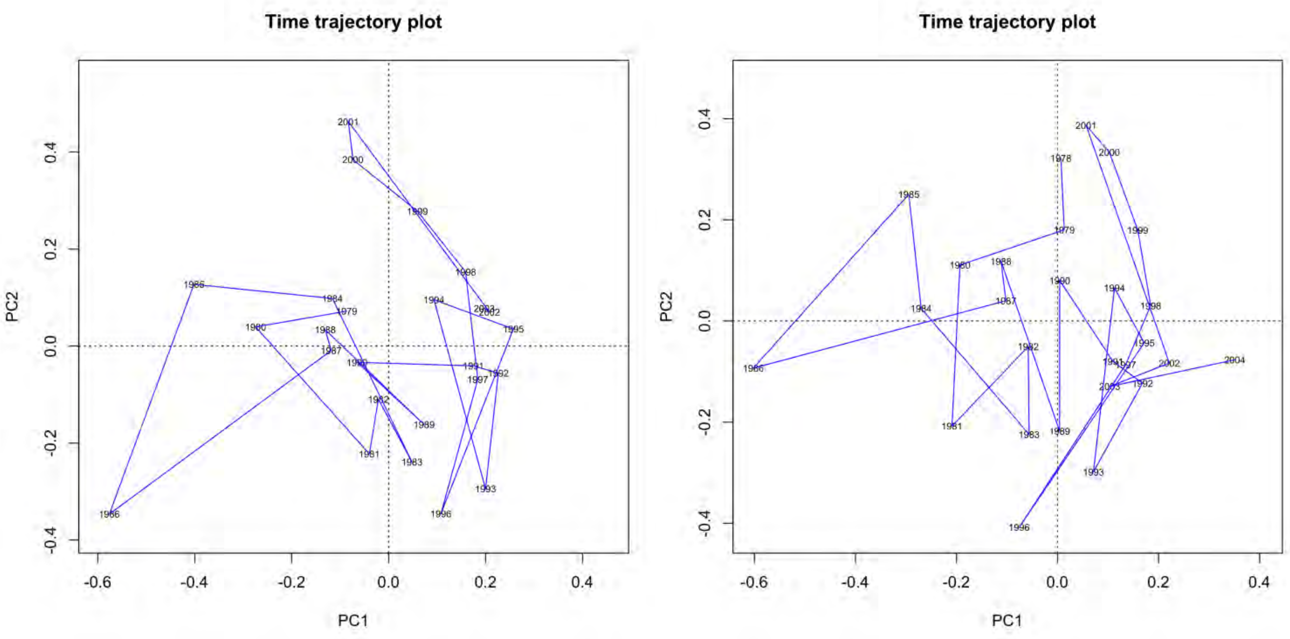
Fig. 9. PC-1 and PC-2 scores for biotic variables of two analyzed data sets

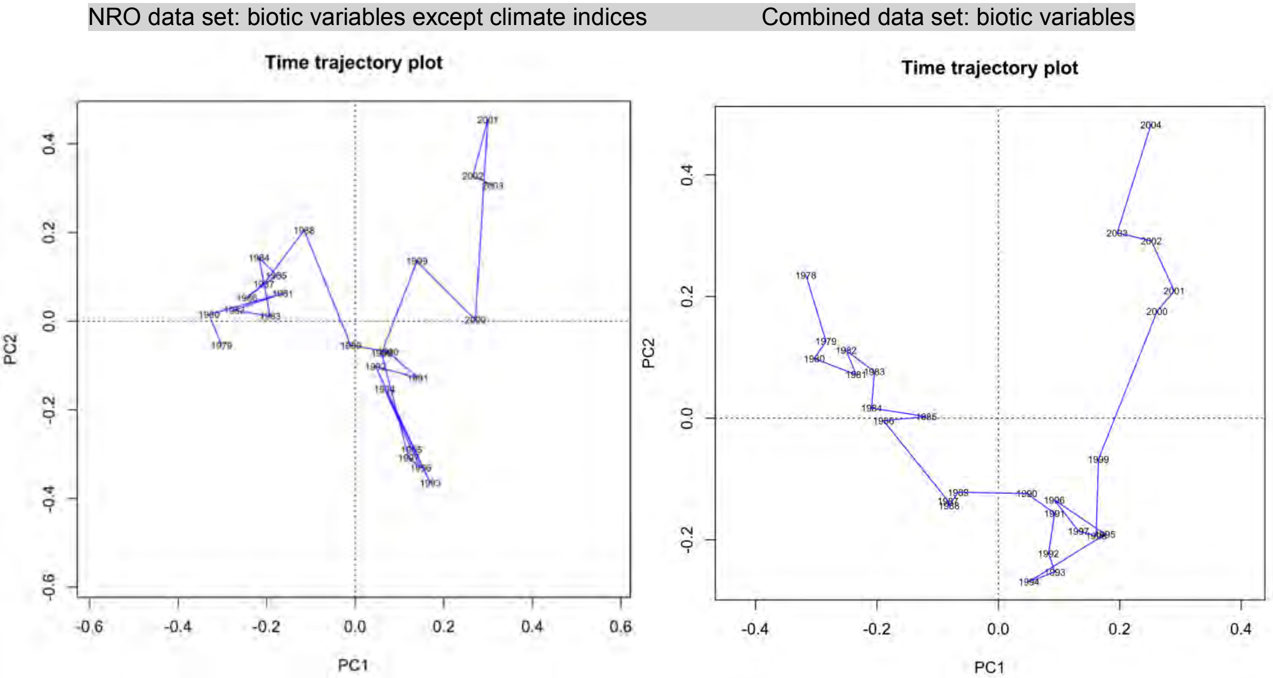
Other variables are less dependent on PC-1 (i.e. on winter conditions and productivity), but are negatively or positively dependent on PC-2, that describes some other process. As many of them reflect the state of the ecosystem in the subtropic section of the JES (including the total zooplankton biomass that, in contrast to zooplankton groups abundance, represents the southeastern part of the Sea), I assume that it is the process of warm subtropic waters advection into the Sea, mainly in summer. Thus, the catches of sea cucumber, tanner crab, sandfish, spanish mackerel, bluefin tuna, and whales, as well as copepods abundance in Korean EEZ, increase in the years with a warm summer, whereas the catch of round herring, the year-class strength of pollock, and the total zooplankton biomass in Japanese EEZ increase in the years with a cold summer.

A considerable portion of biotic variables have no strong correlation both with PC1 and PC2. This demonstrates that PCA is not quite good technique to analyze them. One of the main reasons, I believe, is the asynchronicity of relations between biotic time series caused by different life spans of species. The asynchronicity is less pronounced for abiotic time series, but exists, too.

Temporal changes of PC-1 and PC-2 look on the diagrams like loops with PC-1 increasing with more or less stable PC-2 until 1990s and then PC-2 increasing with more or less stable PC-1 (Fig. 10). The first stage corresponds to the process of the JES warming in 1980-1990s, the second one is not so well-known, but possibly it shows the warm currents intensifying in 2000s. The loop is “smoother” for biotic variables which means that biological variables smooth short-term fluctuations of environments.

TINRO data set: abiotic variables except climate indices Combined data set: abiotic variables




NRO data set: biotic variables except climate indices

Combined data set: biotic variables

Fig. 9. Time trajectory plots of PC-1 and PC-2 for abiotic and biotic variables of two analyzed data sets

Therefore, all time series are divided into two successive periods by chronological clustering. The abiotic time series are split in 1988-1989 and 1997-1998 for both data sets (Fig. 11). This grouping reflects the well-known regime shift in the JES, that was observed in the late 1980s, and another one in the late 1990s, not so well-known, but obviously related with PC-2.

The biotic subset from the TINRO data set shows a very similar chronological clustering with splits in 1992-1993 and 1998-1999 (Fig. 12). The small time lag is obviously determined by biota reaction to environmental changes. In contrast, the biotic subset from the combined data set is rather different and has one big group with a complicated structure and another very small group with a separation between them in 2000-2001. Note, that the combined data set includes mainly fishery data and many of them stem from species with a long life span, up to centuries for whales. That is why the results of chronological clustering for this data set are fuzzy, vague, and shifted to later periods.

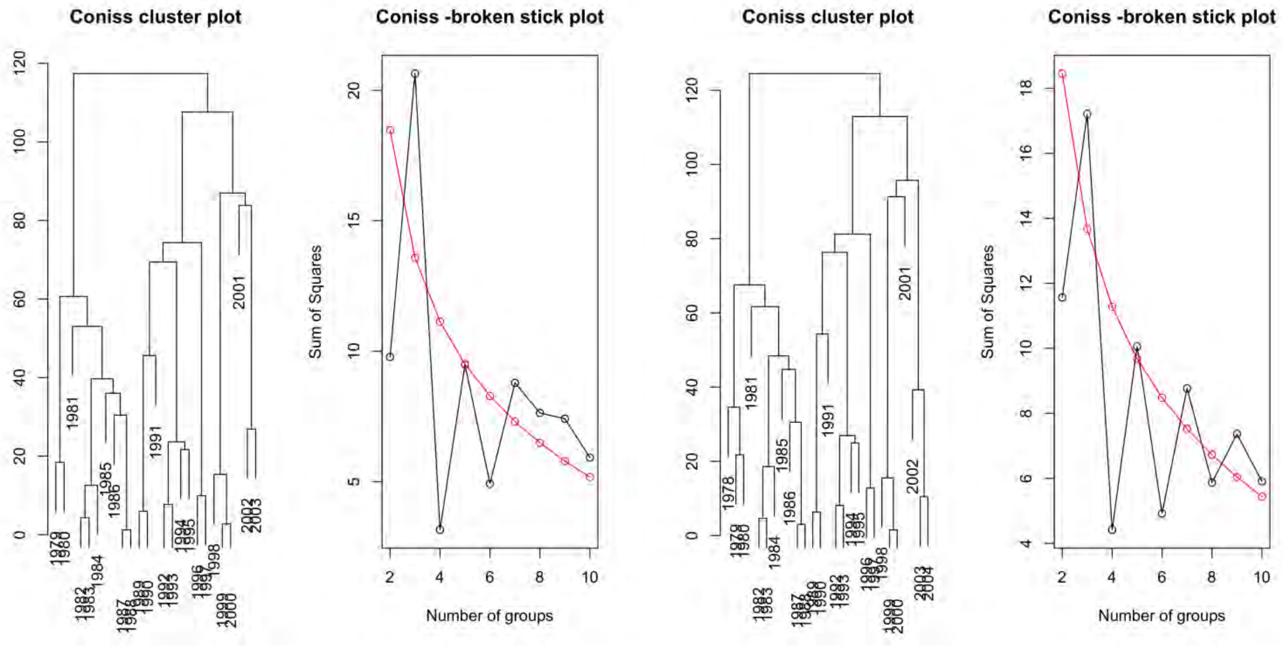


Fig. 11. Chronological clustering of abiotic subsets from TINRO data set (left) and combined data set (right)

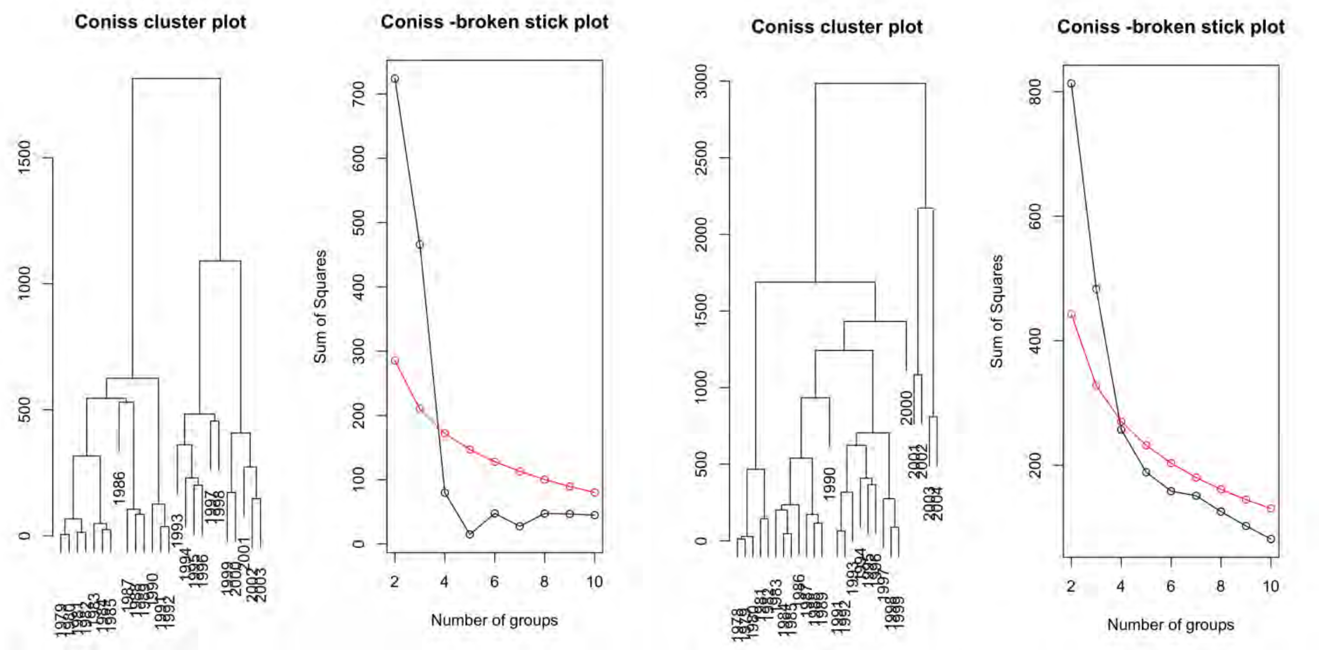


Fig. 12. Chronological clustering of biotic subsets from TINRO data set (left) and combined data set (right)

STARS analysis and constrained clustering were carried out for two principal components for the TINRO data set only (Table 4). The STARS shows results similar to chronological clustering, and the constrained clustering – the same shifts with a certain lag thatis difficult to interpret. Generally, two regime shifts are revealed: in the late 1980s and in the late 1990s; the former is connected with PC-1 and the latter with PC-2.

Table 4

Results of regime shifts research for TINRO data set

Subset	PC-1			PC-2		
	STARS	Chronological clustering	Constrained clustering	STARS	Chronological clustering	Constrained clustering
All variables	1989/1990	-	1992/1993	1999/2000	-	1998/1999
All variables except climatic	1989/1990	1988/1989	1992/1993	1999/2000	1997/1998	1998/1999
Abiotic variables	1991/1992	1988/1989	1988/1989	-	1997/1998	1997/1998
Biotic variables	1988/1989	1988/1989	1992/1993	2000/2001	1998/1999	1998/1999

Resumée

The comparison of the main principal components with climatic indices shows a good correlation of PC-1 with indices describing winter conditions (AO, and particular SHI). For biotic subsets, the best correlation is found with the time lag 1-3 years (Tab. 5). PC-2 has no significant correlation with any analyzed index. This is reasonable, if it describes the warm currents intensity.

Table 5

Coefficients of linear correlation between PC-1 for two data sets and Siberian High Index

Data set	Data subset	Time lag (PC after SHI)				
		No lag	1 year	2 years	3 years	4 years
Combined	Abiotic variables	0.69	0.48	0.50	0.49	0.44
	Biotic variables	0.56	0.62	0.69	0.72	0.67
TINRO	Abiotic variables	0.60				
	Biotic variables	0.52				

It is known that SHI and AO are intercorrelated: both of them describe air mass distribution over the Northern Hemisphere (Wu, Wang, 2002). This means, that winter conditions over the JES, depending on the regional SHI, reflect the state of atmosphere over the whole northern Hemisphere which is generally described by the planetary AO index. Ecosystems in other seas could be influenced by other regional processes, which, in turn, are interrelated with AO, as well. So, we could see good correlations of the main PCs for Georges Bank, North Sea, German Bight, Aegean Sea, Wadden Sea, and Oyashio with the AO. This is a background for teleconnections between ecosystems in the whole Northern Hemisphere.

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Annex 5: Tsushima Warm Current of the Japan Sea (Yongjun Tian)

1. Introduction

The Japan Sea is one of the marginal seas in the western North Pacific with characteristics of an ocean despite its small size and semi-enclosed geographical feature (Naganuma, 2000). The oceanographic structures are largely associated with the Tsushima Warm Current (TWC) and Liman Cold Current (Fig. 1), which are affected by sub-tropical and sub-arctic climate, respectively.

The fish community in the Japan Sea is diverse ranging from pelagic fishes such as Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), yellowtail (*Seriola quinqueradiata*) and tunas (*Thunnus* spp.) to demersal species such as Pacific cod (*Gadus macrocephalus*), flathead flounder (*Hippoglossoides dubius*) and snow crab (*Chionoecetes opilio*) (Naganuma, 2000; Tian et al., 2006, 2008, 2011). The Japanese waters of the TWC contribute more than 10 percent to the total fisheries production in Japan (Tian et al., 2006).

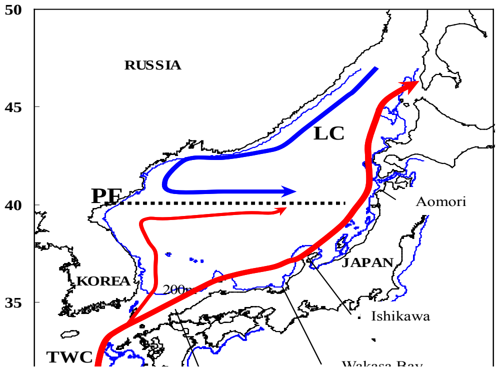


Fig. 1. Schematic diagram showing the oceanographic structures in the Japan Sea. Solid arrows indicate the Tsushima warm current (TWC) and Liman cold current (LC). The dotted line indicates the Polar front (PF). (Tian et al., 2006)

Using long-term data sets including climatic, oceanic and fisheries time series on the TWC, Tian et al. (2006, 2008, 2011) identified an evident regime shift which occurred around the late 1980s and affected the ecosystem of TWC including changes in the fish community structure from species composition to habitat distribution of species. Here, based on the previous studies on the ecosystem of the TWC, I will outline the changing pattern of the TWC ecosystem and its linkage with the late 1980s climatic regime shift, and discuss the control mechanism on the ecological process of the regime shift.

2. Data sets on the TWC and method

Data on the TWC includes climatic, oceanic, biological and fisheries long-term time series (Table 1). Principal component analysis (PCA) was applied to these datasets to identify the most important patterns of common variability in the time series (Hare and Mantua, 2000). Principal components (PCs) were extracted from the correlation matrix for all combined time series and for fisheries data sets. Standard correlation analysis was carried out to examine the relationships between climatic and biological indices (PC scores, CPUE, catch). STARS developed by Rodionov (2004) was applied to detect step changes in the time series.

Table 1 Data sets on TWC

Data Set	Species	Period	Reference (Data Source)	Notation
Fisheries	54 Taxa, annual catch	1964-2004	Tian et al. (2006, 2008)	Appendix 1
Fisheries	Two trawl fisheries, 16 and 27 taxa, catch,	1974-2005	Tian et al. (2008, 2011); Tian (2009)	Appendix 2,3

	CPUE			
Plankton	Diatom, zooplankton	1972-2004	JMA PM line data, Tian et al. (2008)	
Climate	PDO, AO, MOI, SOI	1950-present	Tian et al. (2004, 2006, 2008)	
Oceanic	SST, WT_at_50m, WT_at_200m	1964-2004	Tian et al. (2008,2011) Katoh et al. (2006)	
Others	Mesopelagic fish biomass index	1978-2005	Fujino et al. (2011)	

3. The late 1980s regime shift in the Japan Sea and its linkage with climate

The Japan Sea is one of the most rapidly warming large marine ecosystems in the world ocean; the SST increased by 1.09°C between 1982 and 2006 (Belkin, 2009). Based on data from the Japan Meteorological Agency (Fig. 2), the average SST in the northern part of the Japan Sea increased by 1.6°C over the last 100 years, which was the highest rate of increase in the waters around Japan, and largely exceeded the average of global warming (0.50°C/100years) of world oceans (Inoue and Hibino, 2007). However, if we focused on the period after the 1950, when the data already had a high precision, it showed decadal variability becomes evident rather than an increasing linear trend (Tian et al., 2010).

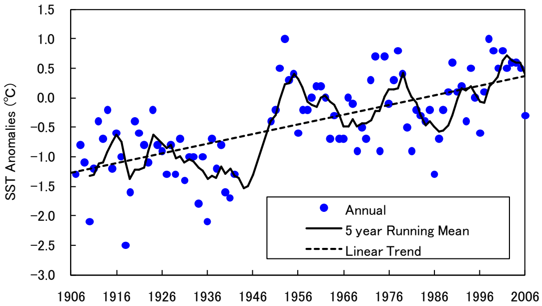


Fig. 2. SST anomalies in the Japan Sea during 1906-2006 (Data source: JMA).

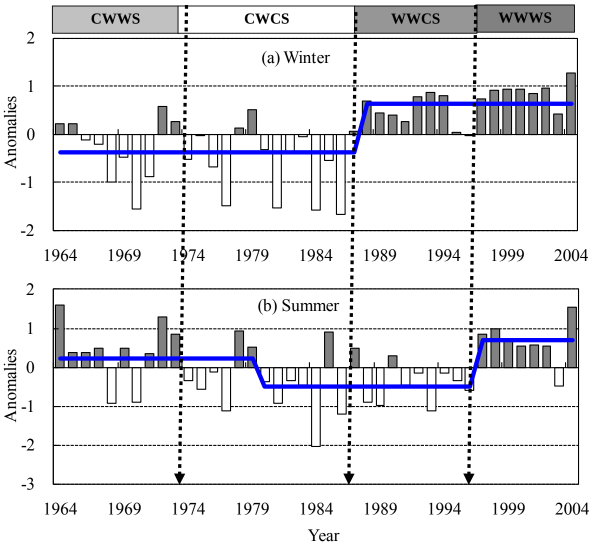


Fig. 3. Changes in water temperature at 50 m depth in the Tsushima Warm Current in the Japan Sea in winter (a) and summer (b). Bold solid lines and dotted arrows indicate STARS-defined trends in water temperature and the year of shift, respectively. CWWS, CWCS, WWCS and WWWS represent the periods of Cold-Winter and Warm-Summer, Cold-Winter and Cold-Summer, Warm-Winter and Cold-Summer, and Warm-Winter and Warm-Summer, respectively.

Oceanographic conditions in the Japan Sea, particularly in Japanese coastal waters, are greatly influenced by the TWC. Figure 3 shows changes in coastal water temperature (WT) at the 50 m depth in the Japan Sea, which is assumed to be an indicator for TWC (Katoh et al., 2006). The winter WT showed negative anomalies during 1966-1986 (-0.56°C) and positive anomalies during 1987-2004 (+0.62°C) indicating an abrupt change from a cold regime to a warm regime occurred around 1986/1987 in the TWC region. The pattern in summer (Jul.-Sep.) WT differed from that in winter; the WT was generally lower during the late 1970s to early 1990s but higher after the late 1990s. STARS analysis indicated regime shifts occurred in the winter temperature in 1986/87 and in the summer water temperature in 1996/1997. Four distinct regimes in the surface water were observed: 1964-1973 with cold winter and warm summer (CWWS), 1974-1986 with cold winter and cold summer (CWCS), 1987-1996 with warm winter and cold summer (WWCS), and 1987-2004 with warm winter and warm summer (WWWS). The periods for 1974-1987 and 1997-2004 can be defined as cold and warm years for all seasons, respectively.

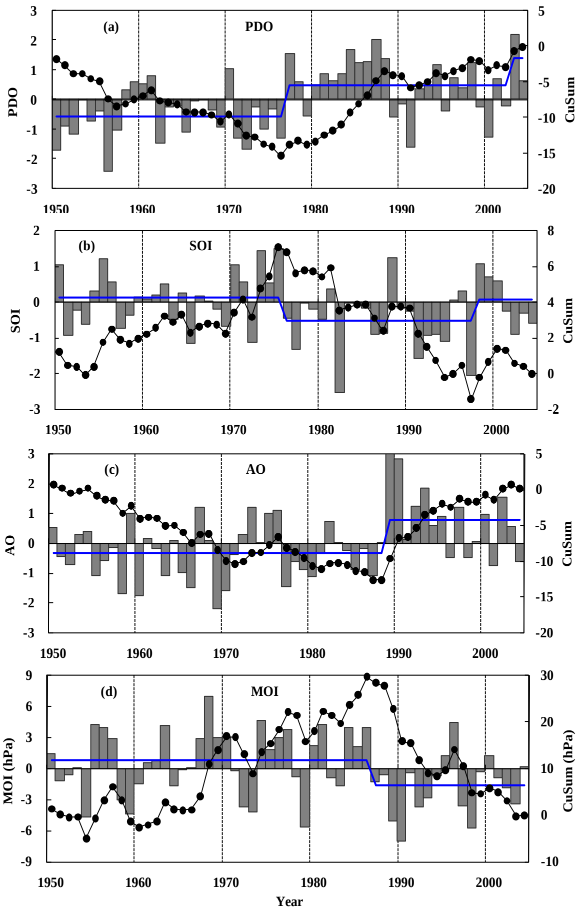


Fig. 4 Changes in four climate indices (PDO, SOI, AO, MOI) (Tian *et al.*, 2008)

It seemed that the variability in the oceanographic conditions in the TWC is linked with climate change. Among four typical climate indices (AO, PDO, MOI, SOI), STARS results indicated that a regime shift in SOI and PDO occurred in 1976/77, with a strong El Nino trend (negative SOI) and intensification of Aleutian Low (positive PDO). On the other hand, AOI and MOI showed a regime shift during 1987–1989 with large interannual variations, indicating a weakening Asian monsoon and intensified AO after 1989, but no distinct changes occurred in the mid-1970s.

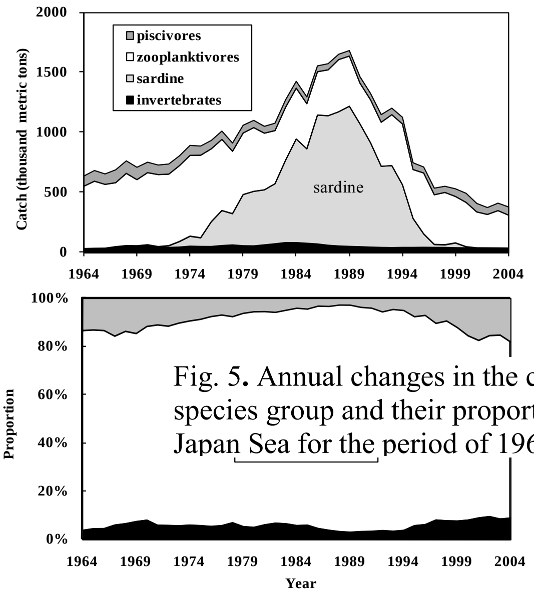


Fig. 5. Annual changes in the catch by species group and their proportions in the Japan Sea for the period of 1964-2004.

These results suggest that a distinct regime shift occurred in the oceanographic conditions, primarily in winter, in the Japan Sea particularly in the TWC region in the late 1980s, which was identified by changes in water temperatures from cool to warm waters and linked with MOI and AOI (Tian et al., 2006, 2008). On the other hand, the 1976/1977 regime shift in the global climatic indices such as PDO and SOI, seems not to be notable in the oceanographic indices of the TWC.

4. Response of fish community to the late 1980s regime shift in the TWC

Japanese catch for 54 taxa (26 pelagic and 28 demersal species) in the TWC has increased greatly since 1970 to a peak of 1.76 million t in 1989, and then decreased abruptly with the collapse of the Japanese sardine stock (Fig.5, Tian et al., 2008). The trend in the total catch in the TWC has depended largely on pelagic species (zooplanktivores group), and the trend was different between pelagic and demersal groups. The catch trend for demersal species is relatively stable compared with the large interannual fluctuations in the pelagic species. The proportion of demersal species to the total varied largely from over 30% during the late 1960s to about 7% in 1989, indicating that the fish community structure changed largely around the late 1980s (Tian et al., 2011).

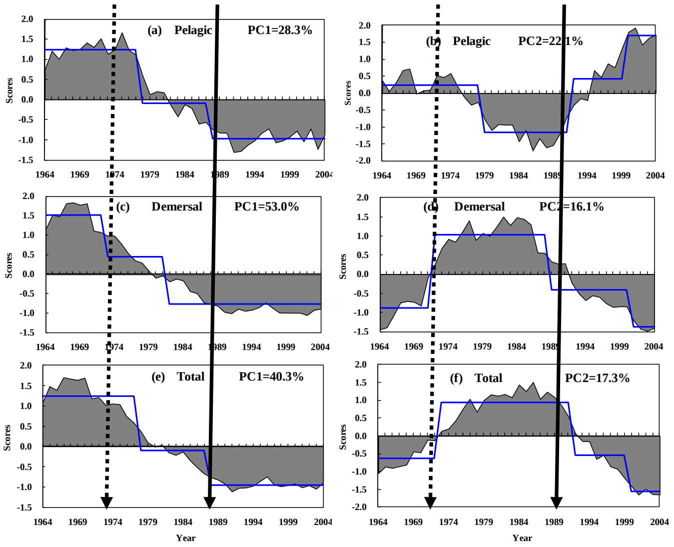
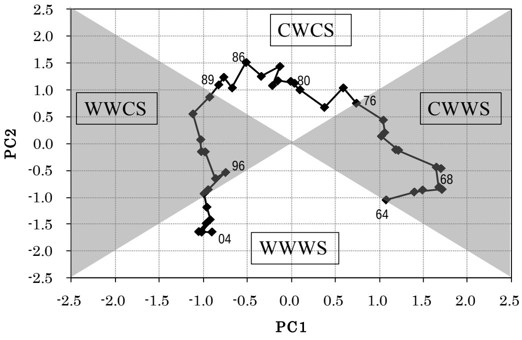


Fig. 6. The first two principal component (PC1-2) scores (shaded area) from the principal component analysis for the pelagic (top panels) and demersal (middle panels), and total (bottom panels) groups during 1964–2004. The solid bold lines represent the step changes estimated by STARS. (Tian et al., 2008)

Figure 6 shows the PCA results for pelagics, demersals and the total. The first two components (PC1-2) of PCA for the fisheries catches, which accounted for 50% and 69% of the total variance for the pelagic and demersal groups, respectively, shows decadal variation patterns. The PC1 for the two groups showed similar patterns with positive scores before the 1970s and negative values after the 1980s, indicating the most important change particularly in the demersal group (PC1 alone accounted for 53% of the total variance) which occurred during the late 1970s to early 1980s. The PC2 pattern seems to be the opposite between the pelagic and demersal groups, despite their synchronous changes around the late 1980s to the early 1990s. The PC1-2 for the entire group of 54 taxa were similar to PC1 in the pelagic group and PC2 in the demersal group, respectively.



PC2 from PCA for 54 taxa catch in the Japan Sea. (Tian, 2010)

STARS analyses for these PCs indicated that step changes occurred in the pelagic group in 1977/1978 (both PC1 and PC2) and in 1987/1988 (PC1), and in the demersal group in 1972/1973 (both PC1 and PC2), 1981/1982 (PC1) and 1988/1989 (PC2). PCA shows that both the pelagic and demersal fish assemblages show decadal variability with a step change in 1988 but different response patterns.

Figure 7 shows the trajectory of PC1 and PC2 for 54 taxa. The trajectory of points demonstrates that highest/lowest values for PC1 were found during 1964-1976 and 1990-1998 (shaded areas), whereas the periods from 1977-1989 and 1999-2004 (white areas) were characterized by variables with highest/lowest values on PC2. The phase change between the ordination dimension in PC1 and PC2 indicated three distinct regimes: 1964-1976 cluster with positive PC1, 1977-1986 cluster with positive PC2 and 1990-2004 cluster with negative PC1, which approximated the changing regimes in the 50m depth water temperature between summer and winter (Fig. 3). This suggests that variability in the fish community in the TWC was forced by the variation pattern in water temperature between summer and winter.

5. Variability in the demersal fish assemblages and its response to water temperature

Trawl (single- and pair-) fisheries data sets in the TWC have more and precise information than those in the catch statistics (Tian et al., 2011). PCAs for target species of both the single- and pair-trawler fisheries showed similar patterns with evident decadal variability (Fig. 8). The first two components, the PC1 and PC2 for the single-trawler fishery, which accounted for 37% and 17% of the total variance respectively, showed significant step changes around 1986/87 and 1996/97, respectively (Tian et al, 2011). The PC1 and PC2 for the pair-trawler fishery showed significant step changes around 1986/87 and 1994/95, respectively. It was notable that the decadal variation patterns and timings in the step changes were close between the single- and pair-trawlers, indicating the impact of environmental change.

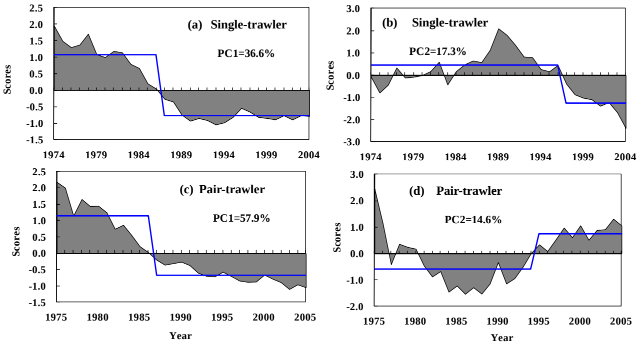


Fig. 8. The first two principal component (PC1-2) scores (shaded area) from the principal component analysis for the single (a, b) and pair (c, d) trawlers. The solid bold lines represent the step changes estimated by STARS. (Tian et al, 2011)

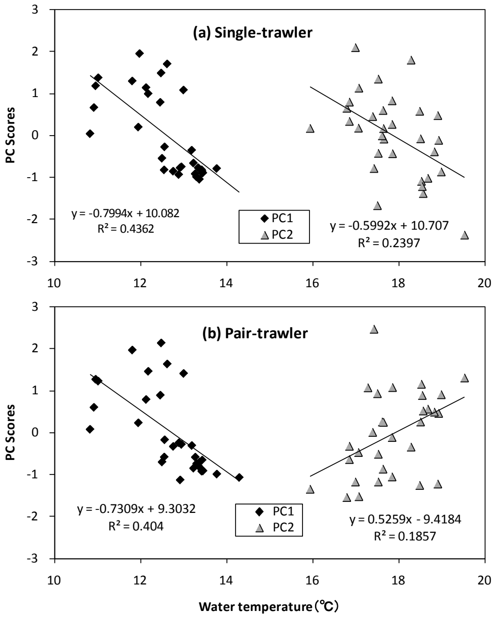


Fig. 9. Relationships between the first two PCs (PC1, PC2) and water temperature for single (a) and pair (b) trawler fisheries (Tian et al., 2011)

It is obvious that temporal variations in PC1 and PC2 for both the single- and pair-trawler fisheries corresponded well with the water temperatures in winter and summer, respectively. The PC1 changed from positive to negative around 1986/1987, and corresponded well and correlated significantly with winter temperature (Fig. 9). On the other hand, the PC2 changed around 1996/1997, and was associated closely with summer water temperature.

The dependence of the demersal fish assemblages on water temperature variability was also evident from a phase space plot between PC1 and PC2 for the single-trawler fisheries (Fig. 10). The trajectory of points shows that PC1 dominated during 1974-1986 with positive values and that PC2 changed largely from positive to negative during 1989-2004 with a slight change in PC1, indicating a PC2 dominated pattern. The phase change between the ordination dimension in PC1 and PC2 indicated three distinct regimes: a 1974-

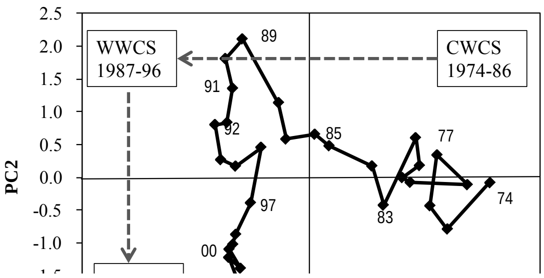


Fig. 10. Phase trajectory between PC1 and PC2 for the single trawler fisheries during 1974-2004. CWCS, WWCS and WWWS represent the periods of Cold-Winter and Cold-Summer, Warm-Winter and Cold-Summer, and Warm-Winter and Warm-Summer, respectively (as in Fig. 3). (Tian et al, 2011)

1986 cluster with positive PC1, a 1987-1996 cluster with negative PC1 and a positive PC2 and 1997-2004 cluster with negative PC1 and PC2 (Tian et al., 2011). The phase change corresponded well with the variation pattern in winter and summer WT as shown in Fig. 3. This pattern is also similar to that for the 54 taxa catch in Fig. 7.

Good correspondences between PCs in the two trawler fisheries and winter (summer) water temperature suggested that PC1 and PC2 were associated with warm- and cold-water species, respectively (Fig. 9). Figure 11 shows plots between PC1 and PC2 loadings for target species of the single-trawler fisheries as an example. Generally, most cold- (warm-) water species had high loadings on PC1 (PC2), indicating a PC1 (PC2) dominated variation pattern, which represents the influence of winter (summer) water temperature. This suggests that variability in the cold- and warm-water demersal fish assemblages in the TWC of the Japan Sea was forced by the variation pattern in water temperature between summer and winter. However, different variation pattern in summer and winter resulted in the complexity of the variability in the fish populations and community structure.

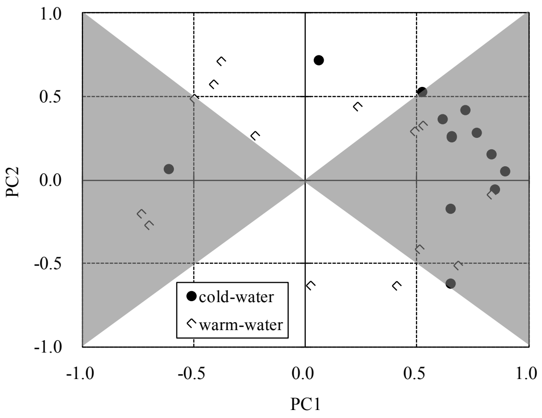


Fig. 11. Plots of PCs loading for target species of the single trawler fisheries. (Tian et al, 2011)

6. Ecological process of the late 1980 regime shift and the control mechanism

The above results from different data sets strongly indicated that 1) a regime shift in the fish community in the TWC occurred in the late 1980s which was associated with the winter climate change shown by MOI and AO. 2) The response to the late 1980s regime shift was different between cold- and warm-water species assemblages. 3) The PC1 and PC2 (the dominant patterns) were forced by winter and summer water temperature, respectively. Tian et al. (2008) illustrated the ecological process of the late 1980s regime shift in the TWC (Fig. 12). The decadal variability in both lower and higher trophic level ecosystems was directly linked with the climatic regime shift in the TWC region. During the cold regime in the 1980s, the Asian monsoon intensified and led to cold water temperature in the Japan Sea, particularly in the TWC region. This cooling resulted in increased recruitment and southward distribution for cold-water species while limiting the northward migration of warm-water species, which had reduced abundance in the TWC. With the shift from cooling to warming around the late 1980s, the pattern in the warm 1990s was opposite to that during the 1980s. The weaker Asian monsoon led to warmer winter water temperature and increased volume transport in the TWC. This had a negative impact on

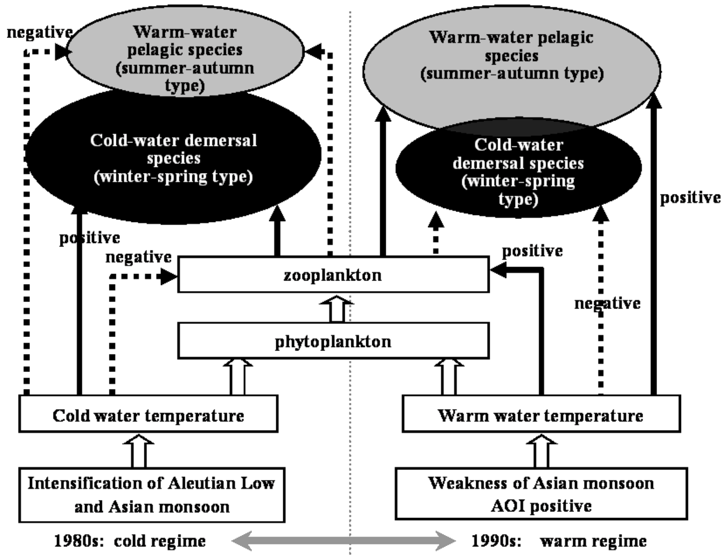


Fig. 12. Illustration showing the ecological response process to the late 1980s regime shift in the Tsushima Warm Current. (Tian et al., 2008)

the cold-water species, which were reduced in abundance and less widely distributed in the southwestern Japan Sea.

The mid-1970s regime shift and its impact on ecosystem were well documented in the North Pacific. However, no regime shift was detected in the TWC in the mid-1970s from our various data sets, although significant changes were identified in the early 1970s, and it seemed associated with ENSO (Tian, 2010). With the late 1980s regime shift, warm-water species such as yellowtail, tunas, anchovy, horse mackerel and common squid increased their abundances with northward extension in distributions, while cold-water species such as sardine, Pacific cod, walleye Pollack and spear squid reduced both the abundances and distributions (Tian et al., 2008; Tian, 2009). The changes in the early 1970s were opposite to those in the late 1980s: cold-water species such as sardine and Pacific cod increased, while warm-water species such as yellowtail, horse mackerel and anchovy decreased. Climate indices such as MOI, AOI and SOI changed around the early 1970s with several years scale, but no regime shift was was detected around the early 1970s in these climate indices. This indicates that changes in the TWC in the early 1970s aredifferent from what occurred in the North Pacific in the mid-1970s.

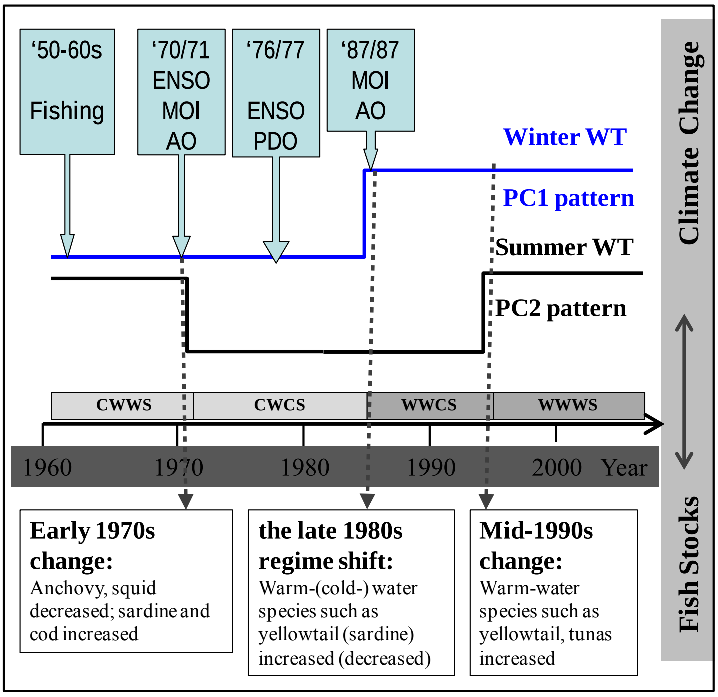


Fig. 13. Illustration showing the response of fish stocks in the Japan Sea to the climate changes. Modified from Tian (2010).

Figure 13 illustrates the impacts of climate changes on the long-term variability in the fish populations (Tian, 2010). The most evident change occurred around the late 1980s. This resulted from the late 1980s climate regime shift and is indicated as changes from cooling to warming in winter WT in the TWC. Details of the ecological respondse process to the late 1980s regime shift were described in Tian et al. (2008, 2010). The change in the early 1970s was clearly affected by summer WT as indicated by changes from warming to cooling around 1970/71, but it seems not to be a result of the well-known mid-1970 climate regime shift, which is indicated by PDO and SOI. The change in the mid-1990s was also forced by the summer water temperature in the TWC. After the mid-1990s, with the increase in summer water temperature, warm-water species, particularly migratory species with spawning grounds in the Eastern China Sea and tropical waters such as yellowtail, Japanese-Spanish mackerel (*Scomberomorus niphoonius)*, tunas and diamond squid (*Thysanoteutihis rhombus)* increased markedly in the TWC and showed northward movement. However, the linkage between the summer water temperature in the TWC and climate (index) and the response process of fishes were not determined yet in spite of a significant correlation between MOI and summer water temperature.

7. Resumée

A climate regime shift occurred in the TWC of the Japan Sea in the late 1980s, but no regime shift was identified in the mid-1970s. This indicats that the regime shift in the Japan Sea was different from that in the central and northeastern North Pacific, where the 1976/77 regime shift was most evident. The late 1980s regime shift was forced by winter water temperature, which is linked with AO and MOI. On the other hand, changes in the early 1970s and mid-1990s were forced by summer water temperature, but its linkage with climate is not clear. Decadal variability and different variation patterns in summer and winter water temperature are important for the fish stocks in the TWC.

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Appendix 1. Species List of Japanese Catch data (Modified from Tian et al., 2006)

Species Group	**English Name (main species)**	**Scientific Name**	**Trophic Level**	**Trophic Category**
Large	Bluefin tuna	*Thunnus thynnus*	4	P4
Predatory	Albacore	*Thunnus alalunga*	4	P4
Species	Yellowfin tuna	*Thunnus albacares*	4	P4
	Other tunas (Longtail tuna)	(*Thunnus tonggol*)	4	P4
	Swordfishes and billfishes	Xiphiidae and Istiophoridae	4	P4
	Frigate mackerel	*Auxis*	4	P4
	Sharks (Piked dogfish and Starspotted dogfishe)	(*Squalus acanthias, Mustelus manazo)*	4	P4
	Salmons	Salmonidae	4	P4
	Trouts	-	4	P4
	Yellowtail	*Seriola* spp.	4	P4
	Common dolphinfish	*Coryphaena* spp.	4	P4
	Japanese Spanish mackerel	*Scomberomorus niphonius*	4	P4
Small	Japanese sardine	*Sardinops melanostictus*	2.5	P3
Pelagic	Japanese anchovy	*Engraulis japonicus*	3	P3
Species	Round herring	*Etrumeus teres*	3	P3
	Pacific herring	*Clupea pallasii*	3	P3
	Horse mackerel	Carangidae	3	P3
	Mackerel (Chub mackerel)	Scombrini (*Scomber japonicus)*	3.5	P3
	Pacific saury	*Cololabis saira*	3	P3
	Japanese seabass	*Lateolabrax japonicus*	4	P4
	Flying fish	Exocoetidae	3	P3
	Mullet	Mugilidae	3	P3
	Pacific rudderfish	*Psenopsis anomala*	3	P3
	Pacific sandlance	*Ammodytes personatus*	2.5	P3
	Common squid	*Todarodes pacificus*	3.5	P3
	Golden cuttlefish	*Sepia esculenta*	3.5	P3
	Other squid (Loliginid squid)	*(Loligo bleekeri)*	3.5	P3
Demersal	Japanese sandfish	*Arctoscopus japonicus*	3	P3
Species	Bastard halibut	*Paralichthys olivaceus*	4	P4
	Flatfishes	Pleuronectidae	3.5	P3
	Arabesque greenling	*Pleurogrammus azonus*	3	P3
	Walleye pollock	*Theragra chalcogramma*	3.5	P3
	Pacific cod	*Gadus macrocephalus*	4	P4
	Deepsea smelt	*Glossanodon semifasciatus*	3	P3
	Croaker	Sciaenidae	3	P3
	Lizardfish	Synodontidae	4	P4
	Daggertooth pike conger	*Muraenesox cinereus*	4	P4
	Largehead hairtail	*Trichiurus japonicus*	4	P4
	Silver seabream	*Pagrus major*	3	P3
	Deepsea snapper and crimson seabream	*Evynnis japonica* and *Dentex tumifrons*	3	P3
	Skates and rays (Golden skate)	Rajiidae (*Bathyraja smirnovi*)	4	P4
Invertebrates	Pink shrimp	*Pandalus borealis*	2	P2
	Japanese shrimp	*Penaeus japonicus*	2	P2
	Other shrimps (Arctic argid)	(*Argis toyamaensis)*	2	P2
	Tanner crab	*Chionoecetes opilio*	3	P3
	Swimming crab	*Portunus trituberculatus*	2	P2
	Other crabs (Red snow crab)	(*Chionoecetes japonicus*)	2	P2
	Spiny top shell	*Bartillus cornutus*	2	P2
	Short-neck clam	*Ruditapes philippinarum*	2	P2
	Abalone	*Haliotis* spp.	2	P2
	Other shellfishes	(*Buccinum* spp.)	2	P2
	Octopus (North Pacific giant octopus)	*(Octopus dofleini)*	4	P4
	Sea urchin	Echinoidea	2	P2
	Sea cucumber	Holothroidea	2	P2
		Total 54 species items		

Appendix 2. List of target species of offshore single-trawler (From Tian et al., 2011)

No	Common name (main species)	Species name	Depth (m)	Life span (years)	Spawning season	Age at recruitment	Age at maturation	Age composition (main ages)	Current system	Habitat temperature
1	Pacific cod	*Gadus macrocephalus*	200-300	>12	Jan.-Mar.	1	4	1-5 (4-5)	CW	1-3 °C
2	walleye pollock	*Theragra chalcogramma*	100-500	>11	Dec.-Mar.	2	3	2-10 (3-5)	CW	1-8 °C
3	arabesque greenling	*Pleurogrammus azonus*	<200	7	Sep.-Nov.	0	2	0-3 (0-1)	CW	0-17
4	Japanese sandfish	*Arctoscopus japonicus*	300-500	5	Dec.-Jan.	1	2	1-4 (2-4)	CW	-
5	piked dogfish	*Squalus acanthias*	150-180	>10	Feb.-May	-	10	-	CW	2-10 °C
6	Owenton's rockfish	*Sebastes owstoni*	190-300	>10	-	-	-	-	CW	-
7	witch flounder	*Glyptocephalus stelleri*	200-300	>12	Jan.-Apr.	-	2	-	CW	1-10 °C
8	flathead flounder	*Hippoglossoides dubius*	150-500	>10	Feb.-Apr.	3	5	3-10 (3-5)	CW	1-10 °C
9	brown sole	*Pleuronectes herzensteini*	30-130	>10	Feb.-May	1	2	1-5 (3-4)	CW	0-15 °C
10	other righteye flounders (slime flounder)	Pleuronectidae (*Microstomus achne)*	50-400	10	Feb.-Apr.	1	3	-	CW	1-14 °C
11	pink shrimp	*Pandalus eous*	200-950	11	Feb.-Apr.	-	4	-	CW	0-11 °C
12	snow crab	*Chionoecetes opilio*	200-500	>10	Jun.-Jul.	5?	-	-	CW	0-5 °C
13	deepsea smelt	*Glossanodon semifasciatus*	<200	5	Spr. & Aut.	1	1	1-3 (2-3)	WW	10-18 °C
14	shotted halibut	*Eopsetta grigorjewi*	<140	>10	Feb.-Mar.	2	2	1-5 (1-2)	WW	10-20 °C
15	willowy flounder	*Tanakius kitaharai*	80-150	>10	Oct.-Jul.	1	2	1-5 (1-2)	WW	-
16	pointhead flounder	*Hippoglossoides pinetorum*	150-190	8	Jan.-Mar.	1	2	1-5 (2)	WW	-
17	bastard halibut	*Paralichthys olivaceus*	<150	>10	Mar.-Jun.	1	2	1-5 (2-3)	WW	5-25 °C
18	silver seabream	*Pagrus major*	<100	>10	Apr.-Jul.	1	3	1-5 (1-2)	WW	10-25 °C
19	crimson seabream	*Evynnis japonica*	30-130	>6	Jul.-Sep.	1	2	1-5 (1-2)	WW	10-20 °C
20	deepsea snapper	*Dentex tumifrons*	<200	>8	Spr. & Aut.	0	2	0-3 (1-2)	WW	10-20 °C
21	lizardfish	Synodontidae (*Saurida elongata*)	<150	>7	May.-Aug.	1	2	1-5(1-3)	WW	15-25 °C
22	croakers (silver croaker)	Sciaenidae (*Pennahia argentata)*	20-120	6?	Mar.-Jun.	-	2	-	WW	10-25 °C
23	redwing searobin	*Lepidotrigla microptera*	70-140	6	Feb.-Jun.	1	1	1-4	WW	-
24	largehead hairtail	*Trichiurus japonicus*	20-140	8	Apr.-Oct.	1	1	1-6 (1-2)	WW	10-22 °C
25	blackthroat seaperch	*Doederleinia berycoides*	80-150	10	Jul.-Aug.		2		WW	-
26	squids (golden cuttlefish)	*(Sepia esculenta)*	<200	<2	May-Jun.	1	1	1-2	WW	10-26 °C
27	octopus (North Pacific giant octopus)	(*Entroctopus dofleini*)	<200	5	Dec.-Nov.	1	2	1-3	WW	5-23 °C

Total 27 items

Appendix 3. List of target species of pair-trawler (From Tian et al., 2011)

No	Common name (main species)	Species name	Depth (m)	Life span (years)	Spawning season	Age at recruitment	Age at maturation	Age composition (main ages)	Current system	Habitat temperature
1	spear squid	*Loligo bleekeri*	0-200	1	Jan.-May.	0.5	0.8	0-1	CW	13-17 °C
2	swordtip squid	*Loligo edulis*	0-200	1	Apr.-Dec.	0.5	0.5	0-1	WW	12-27 °C
3	other squids (golden cuttlefish)	*(Sepia esculenta)*	<200	<2	May-Jun.	1	1	1-2	WW	-
4	silver seabream	*Pagrus major*	<100	>10	Apr.-Jul.	1	3	1-5 (1-2)	WW	10-25 °C
5	deepsea snapper	*Dentex tumifrons*	<200	>8	Spr. & Aut.	0	2	0-3 (1-2)	WW	10-20 °C
6	horse-head fish	*Branchiostegus japonicus*	<130	8-9	Jun.-Oct.	1	1	1-3	WW	15-24 °C
7	pointhead flounder	*Hippoglossoides pinetorum*	150-190	8	Jan.-Mar.	1	2	1-5 (2)	WW	
8	shotted halibut	*Eopsetta grigorjewi*	<140	>10	Feb.-Mar.	2	2	1-5 (1-2)	WW	10-20 °C
9	other righteye flounders (willowy flounder)	Pleuronectidae (*Tanakius kitaharai)*	<150	>10	Oct.-Jun..	2	2	1-5(1-2)	WW	-
10	blackthroat seaperch	*Doederleinia berycoides*	80-150	10	Jul.-Aug.	-	2	-	WW	-
11	Bluefin (redwing) searobin	*Triglidae* *(Chelidonichthys spinosus, Lepidotrigla microptera)*	70-140	6	Feb.-Jun.	1	1	1-4	WW	-
12	lizardfish	Synodontidae (*Saurida elongata*)	<150	>7	May.-Aug.	1	2	1-5(1-3)	WW	15-25 °C
13	largehead hairtail	*Trichiurus japonicus*	20-140	8	Apr.-Oct.	1	1	1-6 (1-2)	WW	10-25 °C
14	silver croaker	*Pennahia argentata*	<200	10	May-Aug.	1	1	1-5(2-3)	WW	15-27 °C
15	conger and pike eels	*Conger myriaster* *(Muraenesox cinereus)*	<150	>12	Apr.-Jul..	3-	8	3-12	WW	10-25 °C
16	deepsea smelt	*Glossanodon semifasciatus*	<200	5	Spr. & Aut.	1	1	1-3 (2-3)	WW	10-18 °C

Total 16 items

Annex 6: Waters around Korean peninsula (Sukgeun Jung)

Introduction

The land mass of Korea covers 220,843 km^2, and extends ca. 1,000 km in north-south direction. It is < 200 km wide (Fig. 1). The Korean peninsula belongs to the temperate zone, but broadleaved evergreen plants and bamboo grow in the south. The peninsula consists of a block of Pre-Cambrian granite covered by later sediments and granitic intrusions, which slopes down to the Yellow Sea in the west. Approximately 70% of the land surface is mountainous but rarely higher than 1,600 m. The mountain ranges are higher in the north and east. The mountains slope gently toward the south and west, ending in numerous islands and islets in the Yellow Sea. The major rivers also run toward the west and south. People have inhabited the peninsula since the paleolithic, *ca.* 500 thousand years ago (Nelson, 1993).

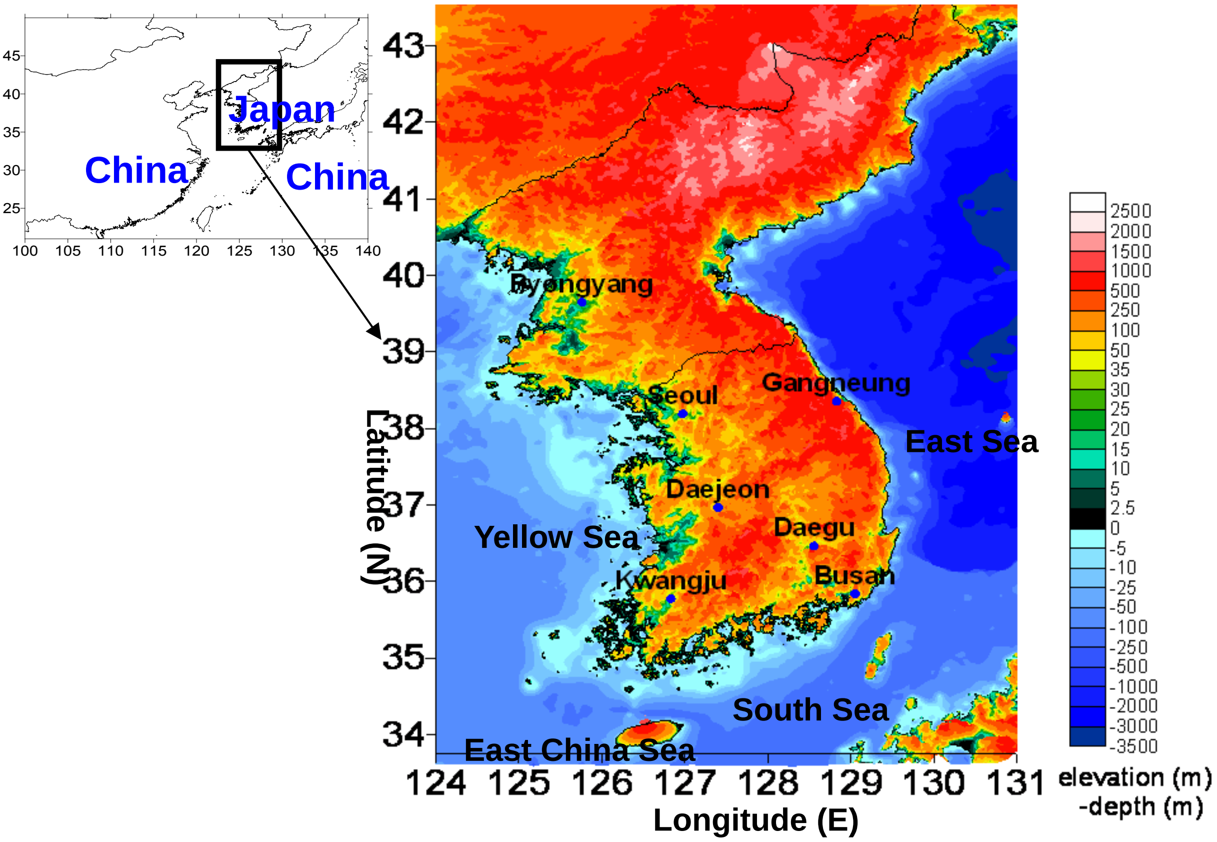


Fig. 1. Geomorphology of Korea (elevation and water depth at m).

The climate of the peninsula is continental, and prehistoric glacial activity is not evident in the Korean peninsula. The winters are cold and dry, while the summers are hot and subject to monsoon rain (McCune, 1956). Large deviations from the mean precipitation are a feature of Korean weather. Compared with the eastern coastal areas of China, changes in coastal lines due to alluvial sediments have been minimal in Korean coastal areas during the Holocene.

The Korean peninsula is surrounded by the three geomorphologically and ecologically distinctive seas, i.e., the East, Yellow and South Seas. The East Sea is a deep basin (the maximum depth = 4,049 m). The southern portion of the East Sea is influenced by the warm, saline Tsushima Warm Current, a branch of the Kuroshio Current. The North Korea Cold Current, a branch of the Liman Current, flows south along the Korean eastern coast. The Yellow Sea, or the West Sea of Korea, is a shallow, semi-enclosed shelf sea. The mean depth is 44 m. Shallow depths and strong tidal mixing result in high turbidity (Yoo and Park, 2007). Warm, saline water enters from the East China Sea episodically in winter (Lie *et al.*, 2001) and cooler, fresher water originating from rivers dominate the surface distribution of water properties (Chen *et al.*, 1994). The South Sea has intermediate geomorphology and ecology between the Yellow and East Sea. The Tsushima Warm Current enters the South Sea, flowing northeastward through the Korea Strait.

Data:

1. Oceanographic data

Korean Waters including Japan/East Sea: Depth-specific water temperature and salinity were measured bimonthly for the water columns at 175 fixed stations along 22 oceanographic lines in Korean waters from 1968 to 2009 by the National Fisheries Research & Development Institute (NFRDI) (Fig. 2) . Standard water depths are 0, 10, 20, 30, 50, 75 and 100 m.

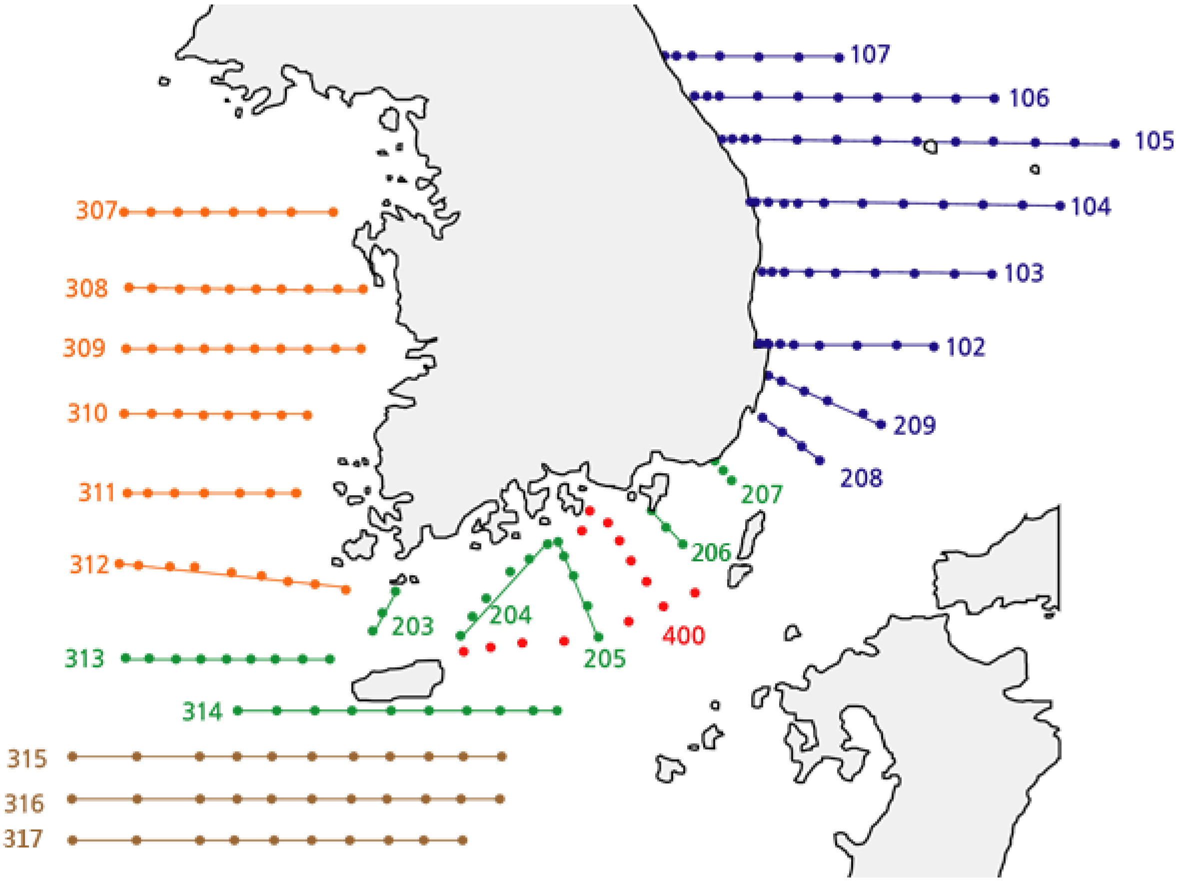


Fig. 2. Korea Serial Oceanographic Stations

Wtemp_mean.csv, Salin_mean.csv, Disoxy_mean.csv Dosat_mean.csv: month-, and depth-specific average water temperature, salinity, dissolved oxygen (mg/l), and oxygen saturation.

(these data sets were used for traffic-light plot)

Wtemp_y.csv, salin_y.csv, disoxy_y.csv, dosat_y.csv: annually-averaged depth-specific TSO.

These files were used for sequential regime shift detection. The output files were renamed and marked by the suffix "_stars.xlsx".

Kodc_TS.csv: temperature and salinity by month and depth

Kodc_TS_PCA.csv: Score of PCs from PCA

Number of variables: 43

Time period covered: 1968-2009

Variable name:

1st char: t → water temperature, s→ salinity

2nd digits: water depth (0, 10, 20, 30, 50, 75, 100 m)

3rd digits following 'm': month (2, 4, 6, 8, 10, 12)

The last var (43rd): Year

Data for 2010 were excluded because of possible problems in data quality control.

PCA and Chronological Clustering were applied for monthly-averaged depth-specific water temperature and salinity.

wtemp_y.xlsx (annually-averaged depth-specific water temperature), salin_y.xlsx (annually-averaged depth-specific salinity): output of the sequential regime shift detection considering autocorrelation (STARS2)

2. Meteorological data
3.

weather.csv

Year

Rainfall: average rain fall (mm/month)

Atemp: average air surface temperature (degree Celsius)

wtemp0y: average sea surface temperature

Weather_stars2.xlsx (annually-averaged air surface temperature, rainfall): output of the sequential regime shift detection considering autocorrelation (STARS2)

The Korea Meteorological Administration (KMA) provided daily time series of air temperature and precipitation that have been measured from up to 41 stations covering South Korea since 1904, but I included only data since 1968 when the nationwide number of stations reached 22 (Fig. 3). The meteorological variables were averaged or summed monthly for each station to compare them with oceanographic variables. At these 22 stations, monthly means of temperature and precipitation were available without any single missing value from 1968 to 2009, ruling out the possibility of potential biases due to differences in stations.

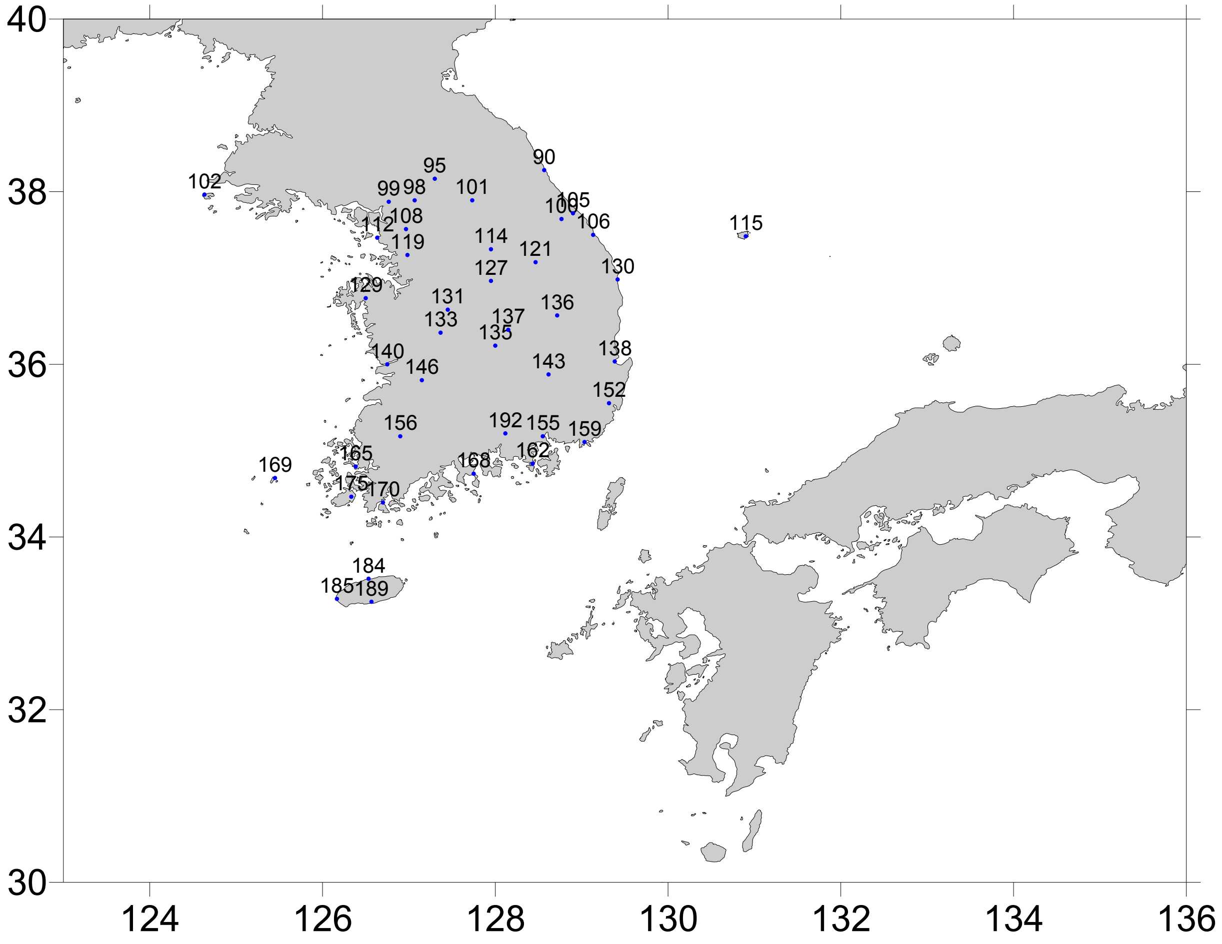


Fig. 3 Korea Meteorological Stations (n = 22)

4. Zooplankton Data

zoocoa.csv: Yearly scores of Dimension I and II from correspondence analysis on species composition

zoocoa_stars2.xlsx: Outputs of the sequential regime shift detection (STARS2, version 3)

zooplankton_log(biomass)_stars2.xlsx: Outputs of the sequential regime shift detection on log-transformed biomass of zooplankton.

ZoopBiomass_Korea_stars2.xlsx: Same as the above, except no log transformation.

Bimonthly samples of mesozooplankton have been collected since 1967 along the same 22 oceanographic lines of NFRDI in the Korean waters (Fig. 2). The samplings were from vertical tows from near the bottom to the 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 mesozooplankton. The zooplankton samples were used to estimate biomass as wet weight and to identify and enumerate taxonomic groups. The total biomass of mesozooplankton per tow was 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) are available for the period 1978–2006. Because the four zooplankton groups are the 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.

To identify climate-driven shifts in the zooplankton community structure, inter- and intra-annual changes in abundance compositions of the four mesozooplankton groups from 1978 to 2006 were summarized by applying correspondence analysis (CA).

The CA for summarizing annual changes in the zooplankton species composition was conducted using SAS (version 9.1, proc corresp and proc corr) (SAS, 1989).

5. Fisheries Data

Y_coa1968.csv: Yearly scores of Dimension I and II from correspondence analysis on species composition

FCOA_1968_stars.xlsx: Outputs of the sequential regime shift detection (STARS2, version 3)

In South Korea, fishery catch statistics have been compiled by the Korean central government since 1948. To evaluate the influence of oceanographic changes on marine ecosystems, species composition changes in the commercial fishery catches from Korean coaster waters from 1968 to 2010 were summarized by multiple correspondence analysis with the aim to investigate the regime-shift hypothesis.

The CA for summarizing annual changes in fisheries species composition was conducted using SAS (version 9.1, proc corresp and proc corr) (SAS, 1989).

Results

If feasible, show single variable time series or use the output of the R-code:

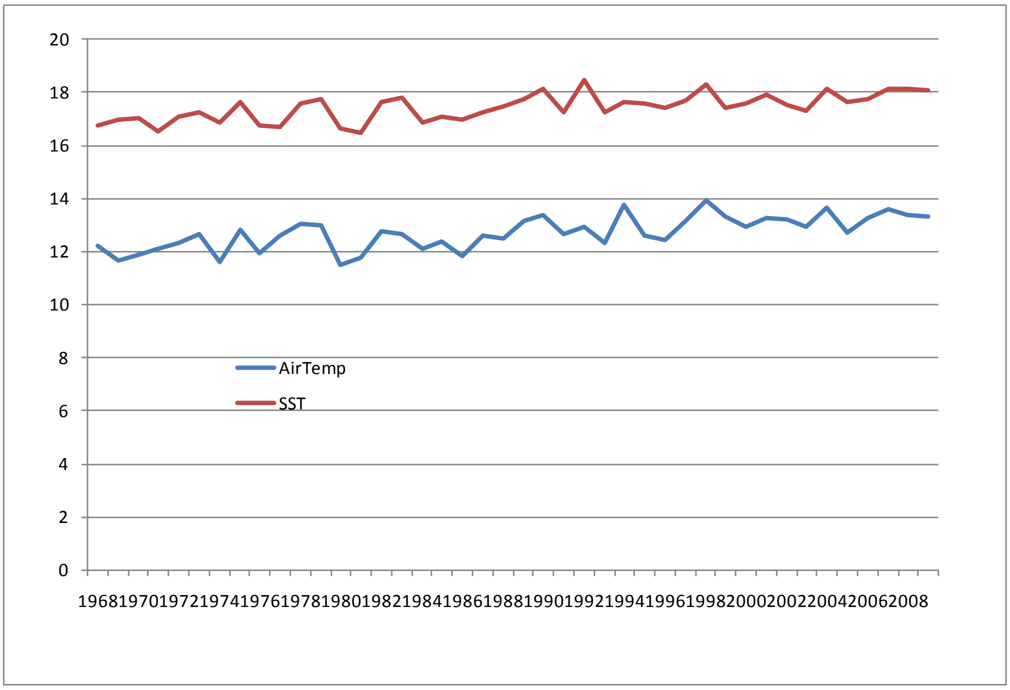


Fig. 4. Trends of Air Surface and Sea Surface Temperature from 1968 to 2009 in the southern Korean peninsula and its adjacent waters (ref. KODC station map).

- **Regime shift detections**

A shift was detected in the time-series of air surface temperature in the Korean peninsula for the period from 1968 to 2009 (Fig. 5). 1989, the year of the shift detected by the sequential t-test regime shift detection method, , is coincident with the well-established 1989 regime shift reported for the North Pacific.

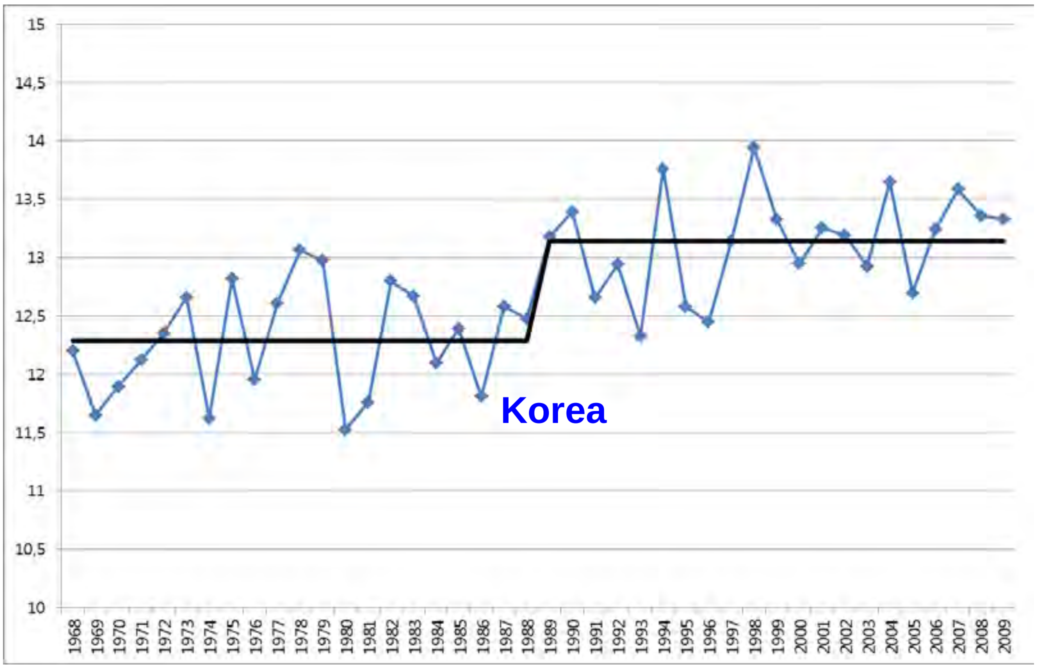


Fig. 5. Annually-averaged air surface temperature in the Korean peninsula for the period from 1968 to 2009. A major shift in 1989 detected by a sequential t-test is marked.

In the time-series of precipitation in the Korean peninsula for the period from 1968 to 2009, two shifts were detected in 1998 and 2008 (Fig. 6). The 1998 shift seemingly corresponds to the basin-wide 1997-1998 regime shift reported for the North Pacific marine ecosystems. Future time series data will verify whether the 2008 shift will be true.

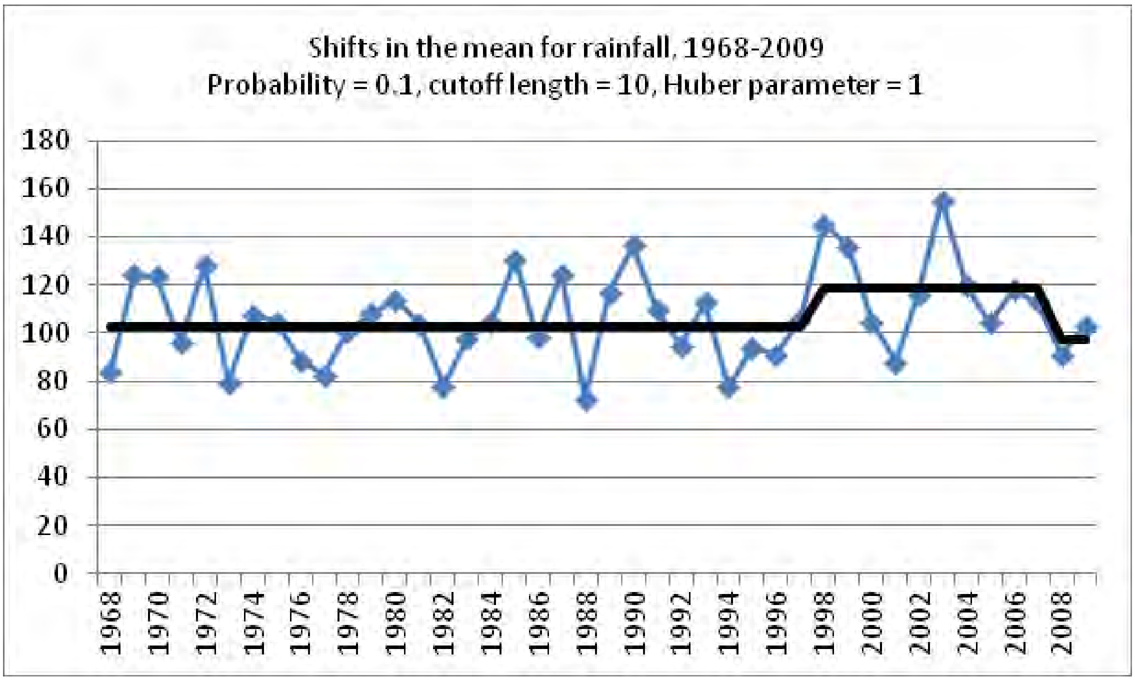


Fig. 6. Annually-averaged precipitation in the Korean peninsula for the period from 1968 to 2009. Two major shifts detected by a sequential t-test are overlaid with the thick black line.

The regime shift in 1988 was also detected in water temperatures at 0-50 m in Korean waters (Fig. 7). The 1997 shift was detected at 0-20 m depth.

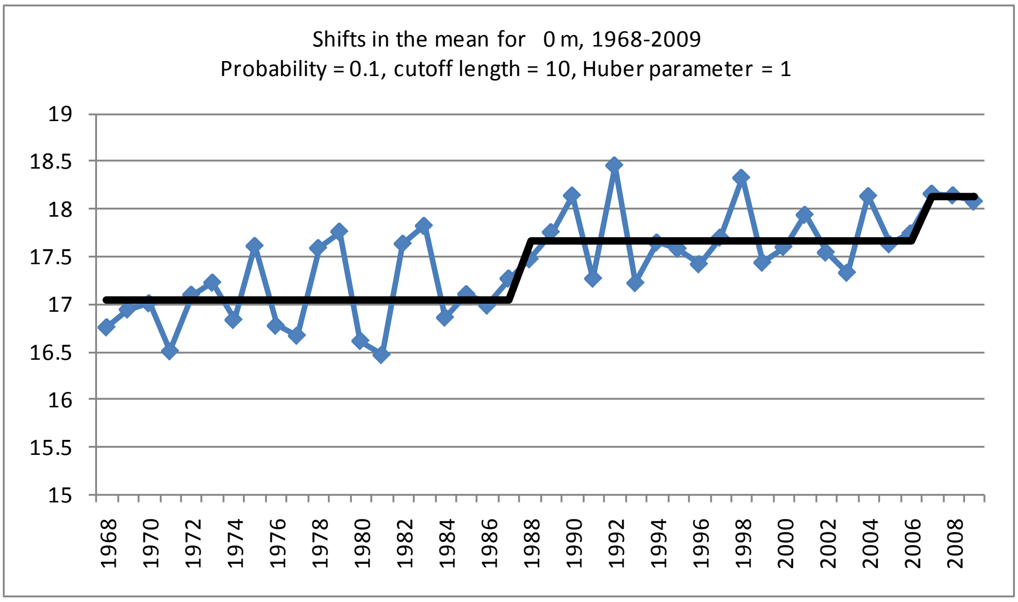


Fig. 7. Annually-averaged water temperature at 0-m depth in the Korean waters for the period from 1968 to 2009. Two major shifts detected by a sequential t-test are overlaid with the thick black line.

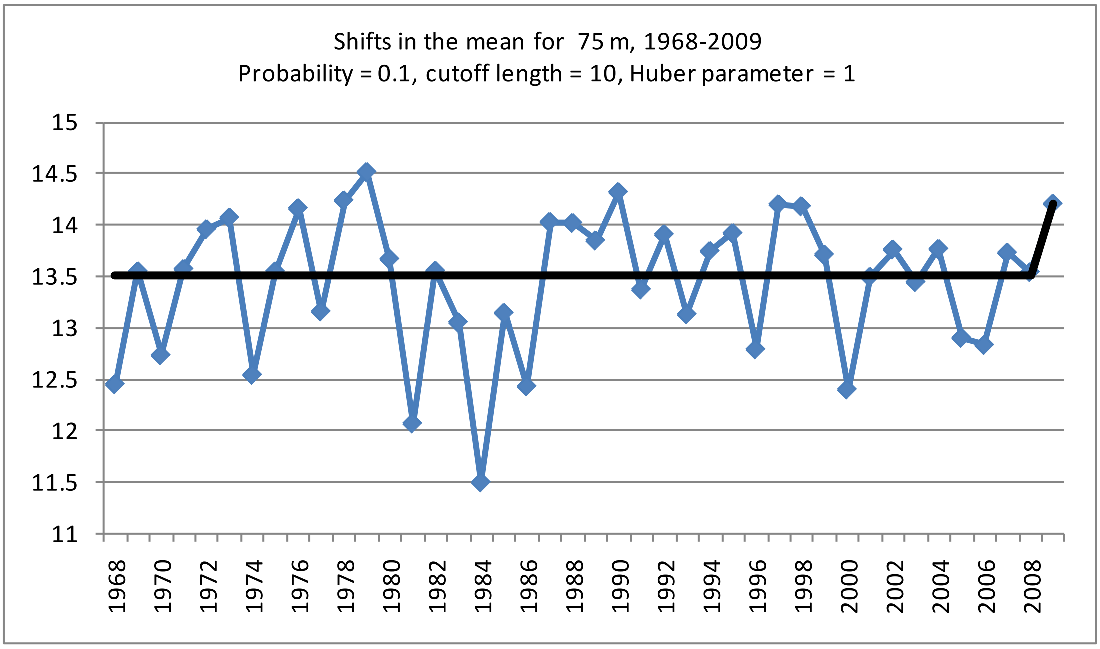


Fig. 8. Annually-averaged water temperature at 75-m depth in the Korean waters for the period from 1968 to 2009. A major shift detected by a sequential t-test is overlaid with the thick black line.

A major shift in annually-averaged salinity in Korean waters was detected in 1997-1999 (Figs. 9 and 10). Salinity at 0-50 m depths generally decreased after 1997-1999 (Figs. 9 and 10), whereas salinity at 75-100 m hardly changed from 1968 to 2009 (Fig. 11).

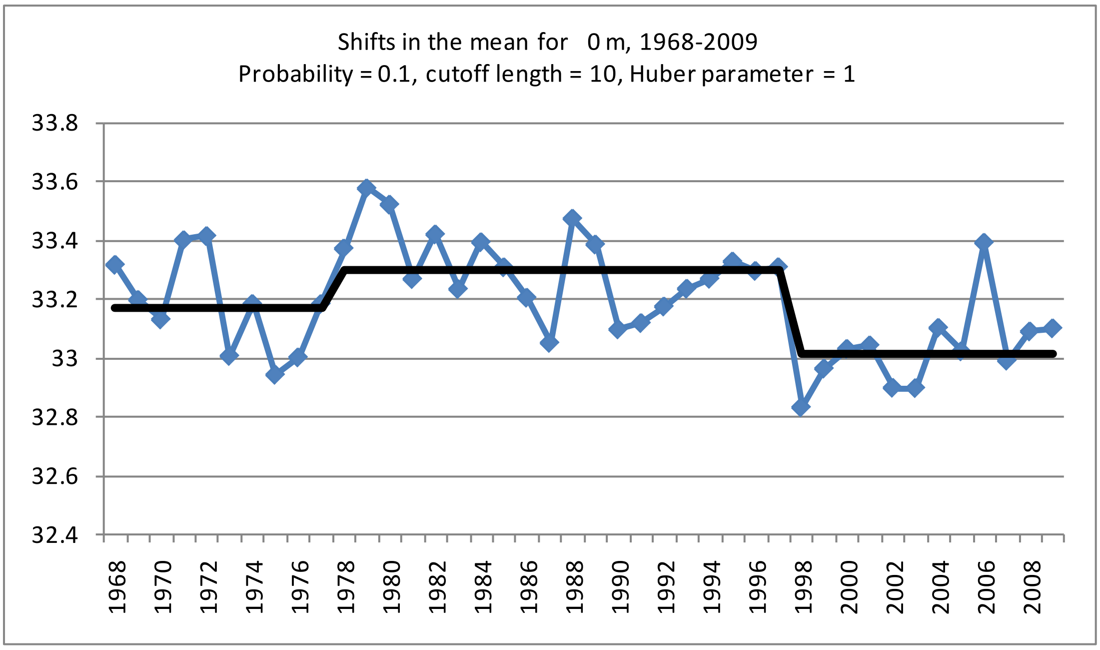


Fig. 9. Annually-averaged salinity at 0-m depth in the Korean waters for the period from 1968 to 2009. Shifts detected by a sequential t-test are overlaid with the thick black line.

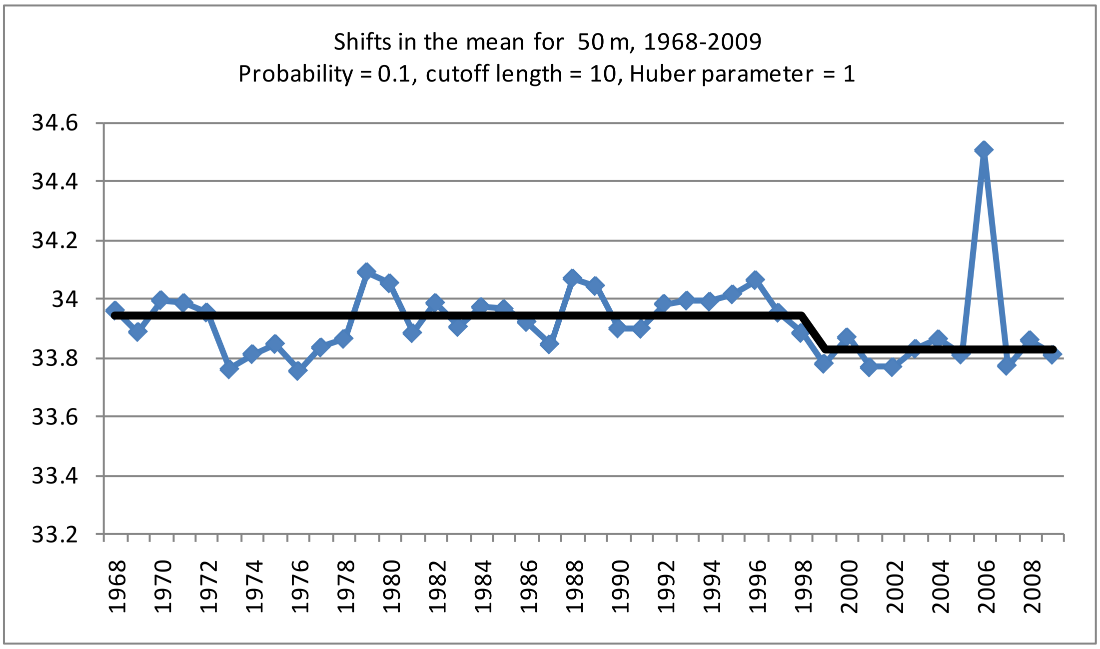


Fig. 10. Annually-averaged salinity at 50-m depth in the Korean waters for the period from 1968 to 2009. Shifts detected by a sequential t-test are overlaid with the thick black line.

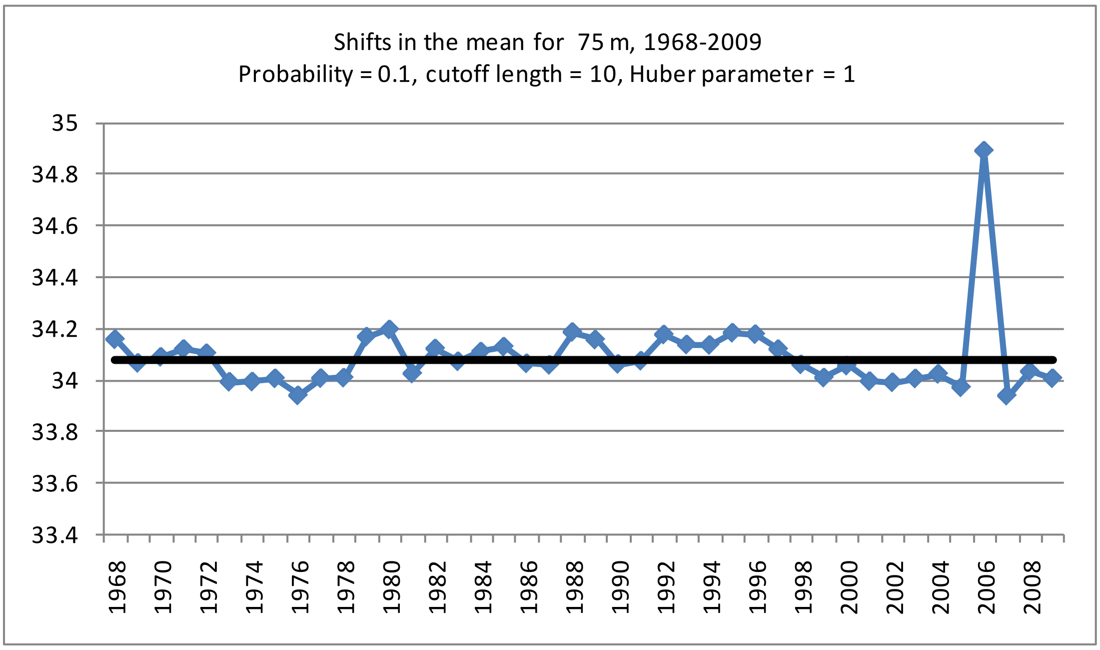


Fig. 11. Annually-averaged salinity at 75-m depth in the Korean waters for the period from 1968 to 2009. Shifts detected by a sequential t-test are overlaid with the thick black line.

- Correspondence Analysis and Sequential Regime Shift Detection

Kang et al. (in press) summarized regional, seasonal and annual changes in taxonomic compositions of mesozooplankton in Korean waters. Correspondence analysis (CA) of numerical compositions of the four mesozooplankton taxonomic groups by year, month and region revealed that the compositions varied annually, seasonally and regionally (Fig. 12). The first dimension (x-axis) explained 51% of the total inertia (variance in taxonomic composition) and the second dimension (y-axis) explained 27%.

Ordination of the taxonomic groups by CA showed that euphausiids and amphipods were similar in their spatio-temporal changes, but copepods and chaetognaths were distinctive with copepods positioned close to the origin. By month, CA ordination showed a step-by-step seasonal succession, except for June through August. The bi-monthly shift was greatest from June to August and smallest from August to October and from April to June. April to June was positioned opposite to August to October along the x-axis. Regionally, the NECS and SJES were similar, but they differed from the EYS which the ordination positioned in the direction opposite to that of the SJES (Fig. 12-A). Among the three regions, the NECS was closest to the origin.

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 (Fig. 12-B). The entire period could be broadly divided into two segments, 1978-1989 and 1990-2006, but the degree of the shift between two consecutive years was greatest in 1982-1983 (i.e., changes in the numerical compositions of the four zooplankton groups were greatest).

When applying a sequential regime shift detection method to the dimension 1 and 2 extracted from CA, a shift was detected in 1996 for the dimension 1 (Fig. 13)

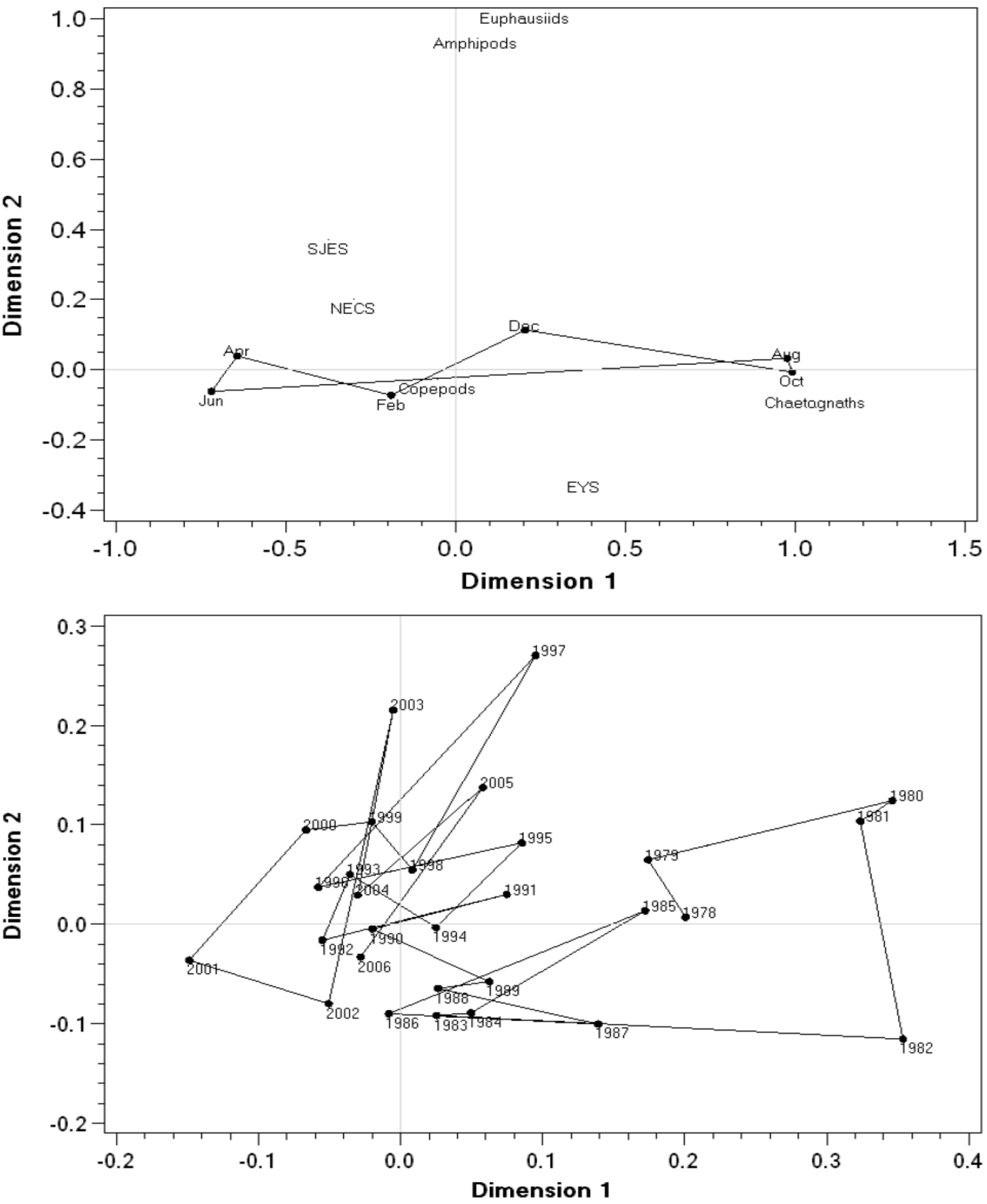
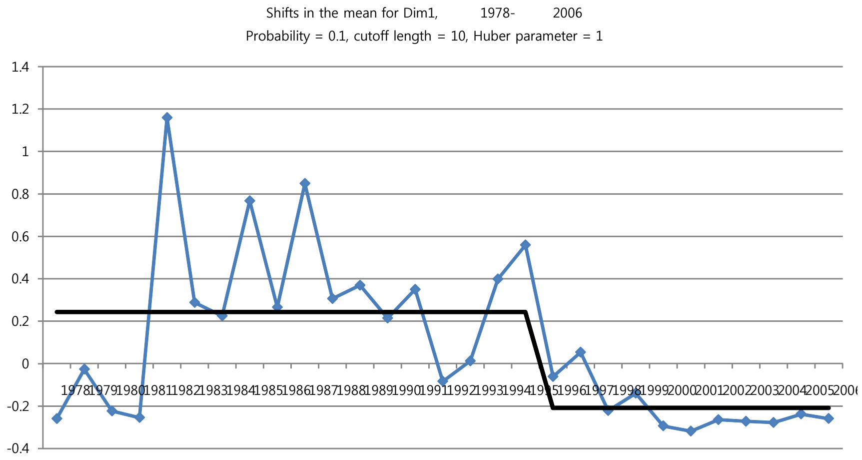


Fig. 12. Correspondence analysis on the numerical taxonomic composition of the four mesozooplankton groups (copepods, chaetognaths, amphipods, and euphausiids) collected bi-monthly from 88 stations along 20 lines in Korean seawaters from 1978 to 2006 in relation to (a) region and month, and (b) year. The scales of dimensions 1 and 2 are the same for the two panels, but group labels were omitted for display purposes in panel (b). Regions: EYS = eastern Yellow Sea, NECS = northern East China Sea, SJES = southwestern Japan/East Sea.

Zoop Dim 1 of COA



Zoop Dim 2 of COA

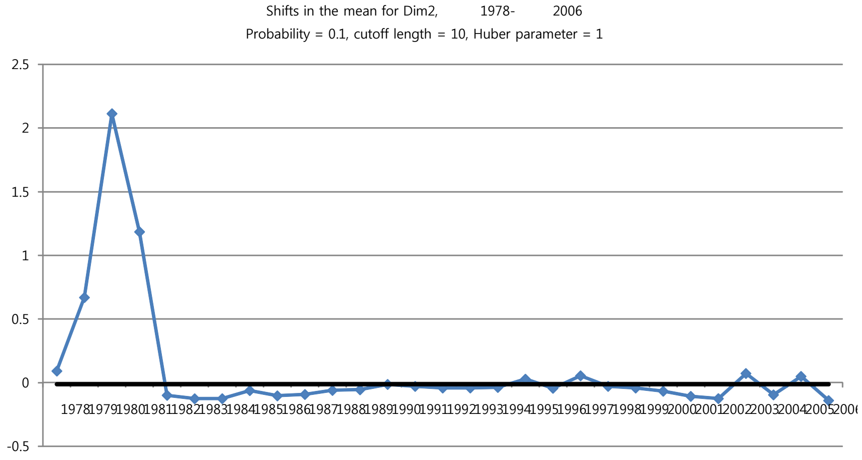


Fig. 13. Dimension 1 and 2 extracted from correspondence analysis on numerical taxonomic composition of mesozooplankton in Korean waters and shifts detected by STARS.

In the Japan/East Sea, a major shift was detected in 1999 for annually-averaged numerical density of major zooplankton groups (copepods, chaetognaths, amphipods and euphausiids) (Fig. 14). In general, the mean density of the four groups has steadidely increased since 1999.

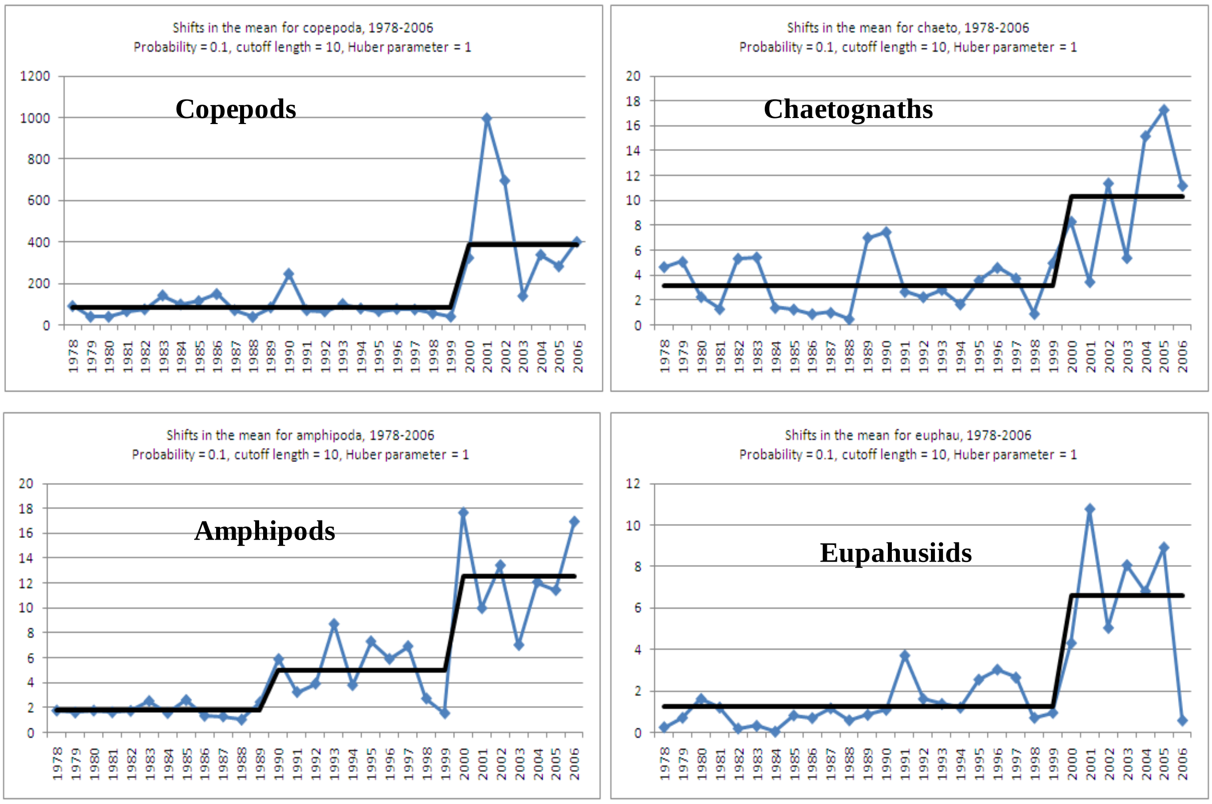


Fig. 14. Mean numerical density of major zooplankton groups in the Japan/East Sea from 1978 to 2006. Shifts detected by a sequential t-test are overlaid with the thick black line.

In Korean waters, annually-averaged biomass density of mesozooplankton has increased from 1968 to 2009, with three marked shifts in 1989, 1997 and 2005 (Fig. 15)

Fig. 15. Annually-averaged biomass density of mesozooplankton in the Korean waters from 1965 to 2006. Shifts detected by a sequential t-test are overlaid with the thick black line.

By applying categorical multivariate analyses and regime detection methods, four regimes and their characteristic commercial fish species could be defined: (1) saury (1968-1974); (2) pollock (1975-1982); (3) sardine (1983-1990); and (4) common squid (1991-2009) (Fig. 16). Because these four species have been caught mostly in the Tsushima Warm Current (TWC) region, I analyzed seasonal and annual variations in volume transports of the TWC, but could not detect any significant shift.

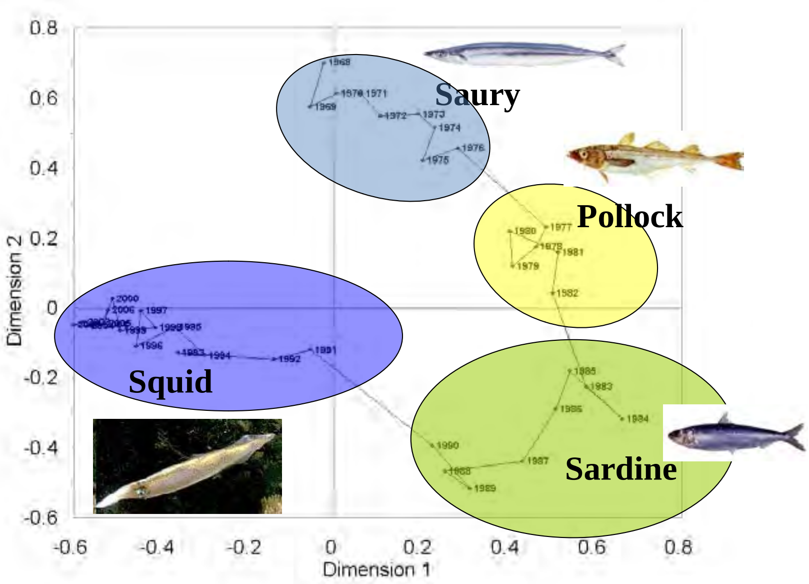
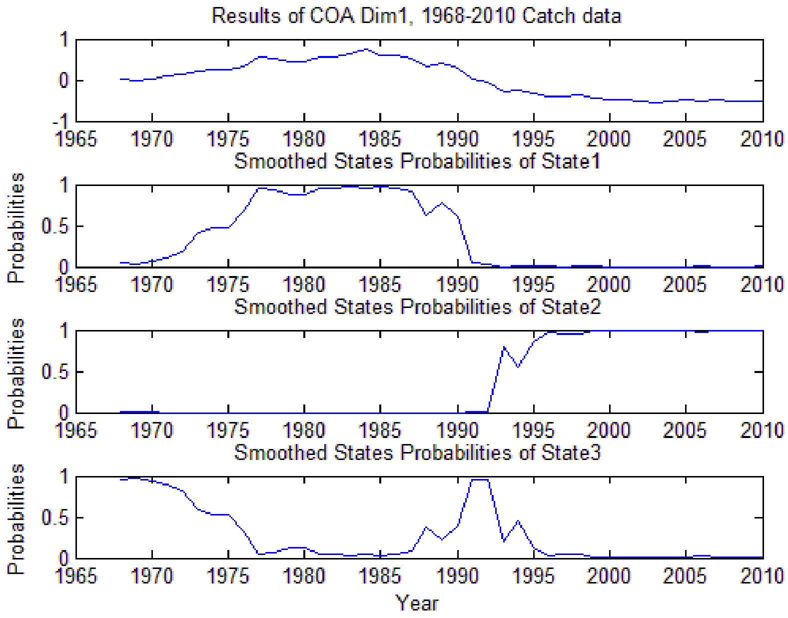


Fig. 16. Correspondence analysis of species composition in the fishery catch from Korean sea waters from 1968 to 2009. Column variable was year and row variable was fish species. Points of fish species are not shown, but the characteristic species representing the four distinct periods are illustrated.

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. 17), whereas the sequential t-test method detected shifts in 1976, 1983, 1988, 1991 and 1995 (Fig. 18).



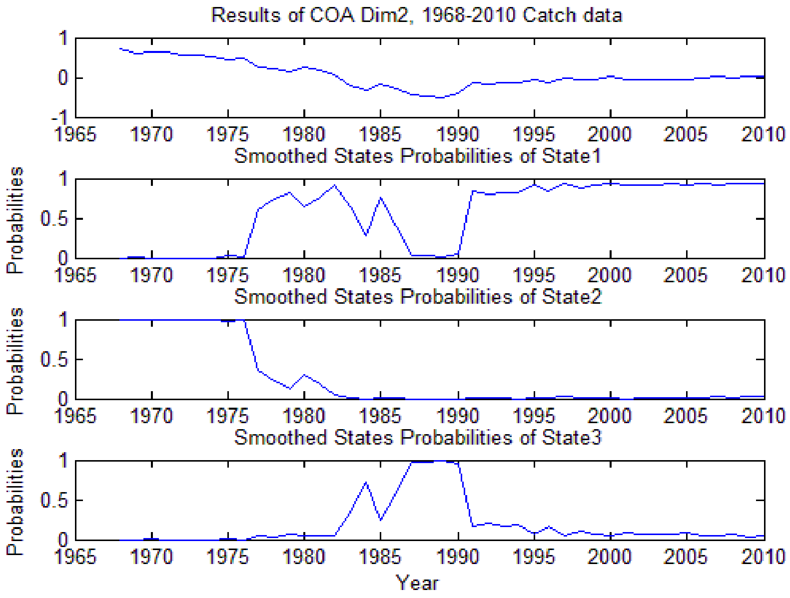
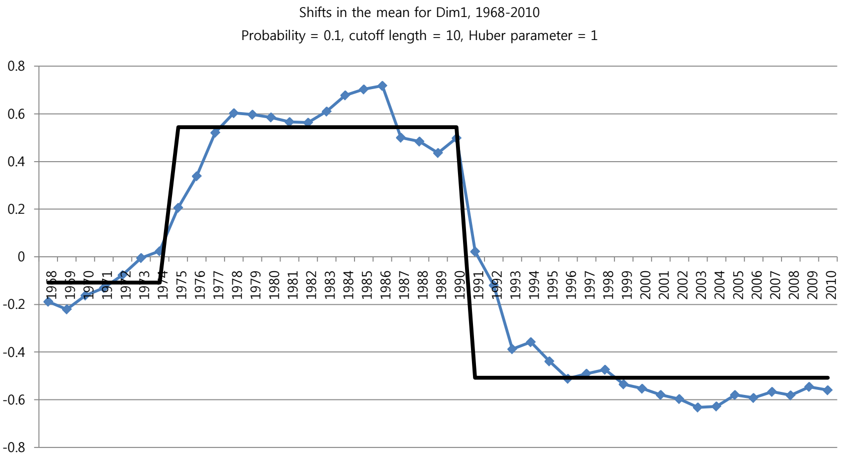


Fig. 17. State probablities estimated by applying Bayesian Markov switching models to the dimension 1 and 2 extracted from correspondence analysis on fisheries species composition in Korea from 1968 to 2010.

Fish Dim 1 of COA



Fish Dim 2 of COA

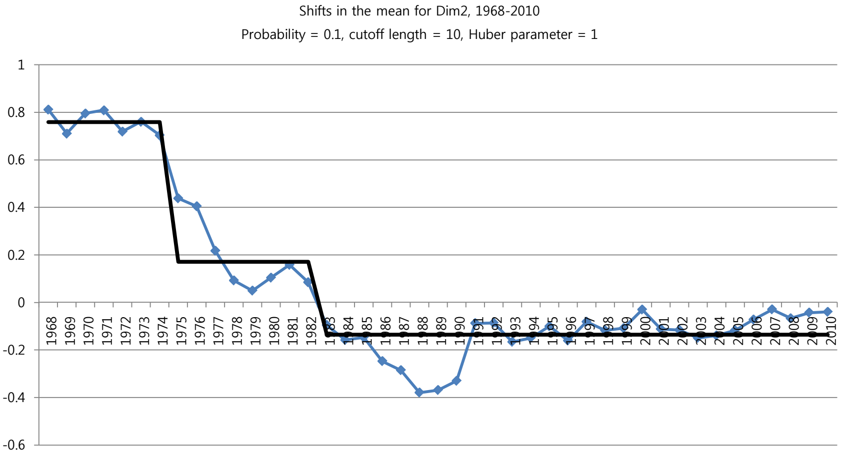


Fig. 18. Regime-shifts dected by applying a sequential t-test to the dimension 1 and 2 extracted from correspondence analysis on fisheries species composition in Korea from 1968 to 2010.

Résumée

To understand the mechanisms by which climate changes influence marine ecosystems, I analyzed the following spatially-explicit long-term time series data from 1968 to 2009: (1) meteorological and hydrographical conditions in the southern Korean peninsula and its adjacent waters, (2) zooplankton abundance/biomass, and (3) fisheries yields.

A major shift was detected in 1989 for air surface temperature, and in 1998 and 2008 for rainfall. Water temperatures, averaged for the entire Korean sea waters, have significantly increased in the mixed layer. Salinity has generally decreased since the late 1990s, especially in the mixed layer. Shifts were generally detected in water temperature and salinity at 0-50 m in Korean waters. The shifts were greatly weakened or not detected for 75-100 m. For water temperature, two major shifts were detected in 1988 and 2007. For salinity, two major shifts were detected in 1978 and 1998. It is notable that the shift in water temperature in 1988 preceeded the shift in air surface temperature in 1989.

In meso- and macro-zooplankton, mean biomass and numerical density has generally increased from 1965 to 2006. A major shift was detected for 1995 with respect to taxonomic composition. In terms of log-transformed annually-averaged biomass, shifts were detected for 1989, 1997, and 2005. The 1989 shift was probably related with the well-established 1988-89 North Pacific regime shift. Since 1989, zooplankton biomass has continued to increase with marked in 1997 and 2005.

Although the combined annual fishery catch has been relatively stable since 1980's, annual catch of individual fish species has fluctuated much more. By applying categorical multivariate analyses and regime detection methods, I could define four regimes and their characteristic commercial fish species: (1) saury (1968-1974); (2) pollock (1975-1982); (3) sardine (1983-1990); and (4) common squid (1991-2009). These four species have been caught mostly in waters along the southeastern Korean coast which is under the influence of the Tsushima Warm Current. The shift in 1991 could be linked to the 1988 shift in water temperature, considering a 2-3 yr time lag between spawning and fish recruitment. The other two shifts in 1975 and 1983 were not yet clearly linked to changes in oceanographic conditions in Korean waters, but seem to be related with strong El Ninos (ENSO). Further analyses are required in the near future.

Annex 7: Kuroshio/Oyashio System (Motomitsu Takahashi)

Introduction:

The subtropical Kuroshio and the subarctic Oyashio currents converge from the south and north in the eastern offshore waters off northern Japan (Fig. 1). The two currents form the Kuroshio-Oyashio transition region between the subarctic Oyashio front and the downstream jet of the Kuroshio, the Kuroshio Extension. Sea surface temperature (SST) showed synchronous rapid increases in 1987/88 in the Kurshio, the Kuroshio Extension, the Kuroshio-Oyashio transition region and the Oyashio

(Yasuda et al. 2000, Nakata and Hidaka 2003, Tian et al. 2003)

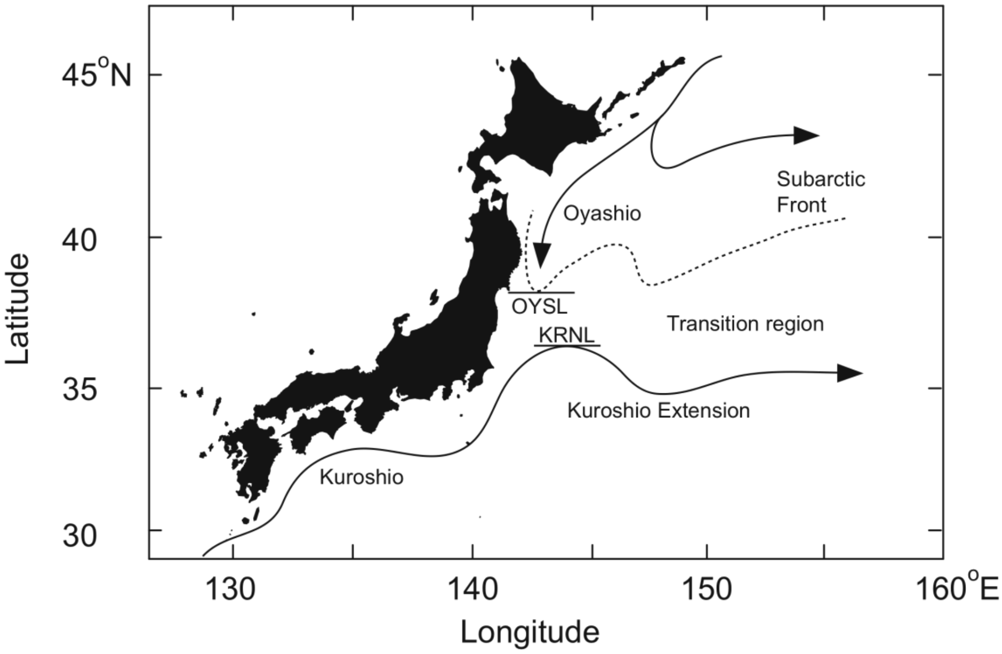


Fig. 1. Map of currents in the Pacific waters off Japan. KRNL and OYSL denote the northern limit of the Kuroshio Extension and the southern limit of the Oyashio.

The Kuroshio-Oyashio transition region is a nursery ground for multiple small pelagic fish species: Japanese sardine, Japanese anchovy, chub mackerel, Pacific saury. The larvae hatch in the Pacific coastal waters off Japan. They are transported eastward to the Kuroshio Extension region and grow up to the juvenile stage in the Kuroshio-Oyashio transition region. Frontal structures in the Kuroshio-Oyashio transition region have oscillated north- and southwards depending on the strength of the Kuroshio Extension and the Oyashio waters. Takahashi et al. (2009) demonstrated contrasting responses in growth rate during early life stages between Japanese anchovy and Japanese sardine to a shift of the frontal structures in the Kuroshio-Oyashio transition region. Many studies have focused on potential causes for population fluctuations in the fish species in the transition region.

Data:

The analysis included 13 variables, consisting of 3 climate indices, 5 physical indices, 2 series of zooplankton biomass and 3 series of fish abundances during 1963-2000 (38 yrs). The Pacific Decadal Oscillation (PDO), the Arctic Oscillation (AO) and the Southern Oscillation Index (SOI) were downloaded as large scale climate indices. Sea surface temperature (SST) was averaged for the Kuroshio (KR_SST, 30-35°N, 128-145°E), the Kuroshio-Oyashio transition region (KOTR_SST, 35-40°N, 140-160°E) and the Oyashio (OY_SST, 40-45°N, 140-160°E) regions taken from Tian et al. (2003). The latitudes of the northern limit of the Kuroshio Extension (KRNL) and the southern limit of the Oyashio front (OYSL) are representative of the two boundary current structures (Fig. 1). Mesozooplankton biomass in the Kurohio-Oyashio transition (ZPKOTR) and Oyashio (ZPOY) regions from June to August was taken from Yatsu et al. (2008). The number of age-0 recruits was from Yatsu et al. (2005) for Japanese sardine and chub mackerel and Tian et al. (2003) for Pacific saury. Biological indices were transformed into logarithm to achieve homogeneity.

Variable	Abbreviation	Unit	Area	Season/ Months	Source	Weblink
PDO	PDO					
AO	AO					
SOI	SOI					
SST	KR_SST	°C	Kuroshio	Winter	Tian et al. (2003)	
	KOTR_SST	°C	Transition region	Spring		
	OY_SST	°C	Oyashio	Summer		
North limit	KRNL	°N	Kuroshio	Winter	Yatsu et al. (2005)	
South limit	OYSL	°N	Oyashio	Winter		
Zooplankton	Log_ ZPKOTR	mg m^{-3}	Transition region	Summer	Yatsu et al. (2008)	
	Log_ ZPOY	mg m^{-3}	Oyashio	Summer		
Sardine	Log_Sardine	10^{6} fish	Pacific coastal waters		Yatsu et al. (2005)	
Mackerel	Log_Mackrel	10^{6} fish				
Saury	Log_Saury_large	10^{6} fish			Tian et al. (2003)	

Results

The PDO changed from negative to positive in 1976/77 and then changed to negative in the end of 1980s (Fig. 2a). The AO changed out of phase with the PDO. The SOI changed from positive to negative around the mid-1970s to 1980s. SST anomalies became negative in the early and mid-1980s and changed to positive in the late 1980s in the Kuroshio, the Kuroshio-Oyashio transiton region and the Oyashio, though trends in the 1960 and 1970s were different among the regions (Fig. 2b). The

Kuroshio Extension and the Oyashio fronts shifted southward (negative) from the 1970s to the 1980s and retreated to the north (positive) in the late 1980s (Fig. 2c). Zooplankton biomass in the Kuroshio-Oyashio and the Oyashio regions decreased from 1970s to 1980s and then increased in the mid-1990s (Fig. 2d). The number of recruits of Pacific saury gradually increased from the 1970s to the1990s, but those of chub mackerel changed vice versa (Fig. 2e). The Japanese sardine dramatically increased in the 1960s and 1970s, and then started to decrease in the end of the1980s.

Principle component analysis (PCA) was run for the following four data sets; full variables (13 variables), full variables without climate indices (10 variables), abiotic variables (5 variables), and biotic variables (5 variables). For the full variables set, PC1 scores explained 27.1 % of total variation. They were negative until late 1970s, changed to positive after 1980 and tended to decrease with large fluctuations in the 1990s (Fig. 3a). No significant shift was found in the constrained clustering (Fig. 3b, c), although chronological clustering showed significant shifts in 1966/67, 1976/77 and 1988/89 (figure not shown). The STARS analysis detected shifts in 1976/77 and 1998/99 (Fig. 3d). For the full variables set without climate indices, PC1 scores explained 26.7 % of total variation. They were negative until the mid-1970s and changed to positive during the period of the late 1970s to the early 1990s (Fig. 4a). Constrained clustering showed a significant shift only in 1972/73 (Fig. 4b, c), and chronological clustering in 1966/67 and 1972/73 (figure not shown). The STARS analysis detected a shift in 1972/73, 1980/81 and 1998/99 (Fig. 4d). For the abiotic variables, PC1 scores explained 40.0 % of total variation. They were positive until the end of the1970s and changed to negative in the early and mid-1980s (Fig. 5a). Constrained clustering showed significant shifts in 1992/93 and 1998/99 (Fig. 5b, c), meanwhile chronological clustering showed a significant shift in different years of 1980/81 (figure not shown). The STARS analysis detected shifts in 1980/81 and 1998/99 (Fig. 5d). For the biotic variables, PC1 scores explained 44.6 % of total variation. They were negative until the mid-1970s, changed to positive during the late 1970s to early 1990s, and then became negative in the mid- and late 1990s (Fig. 6a). Constrained clustering showed significant shifts in 1972/73 and 1987/88 (Fig. 6b, d), and chronological clustering in 1968/69, 1977/78, 1987/88, and 1992/93 (figure not shown). The STARS analysis detected shifts in 1972/73, 1980/81 and 1992/93 (Fig. 6d).

Résumée

An abrupt change in the full variables set without climate indices was found in 1972/73 in all statistical procedures. The shift in 1972/73 was detected only for the biotic indices, but not for the abioticones. A dramatic increase in abundance of recruits of Japanese sardine was responsible for the shift in the early 1970s. A shift in local abiotic indices was detected in 1980/81, corresponding with a southward shift of the Kuroshio Extension and the Oyashio fronts and a decrease in SST in the three regions. Large-scale climate indices, such as the AO, shifted in 1976/77 and may have caused the shift in local abiotic indices in the early 1980s. The growth rate during early life stages of the Japanese sardine was accelerated with the southward shift of the frontal structures with decreased SST in the late 1990s in the Kuroshio-Oyashio transition region (Takahashi et al. 2009), suggesting that environmental conditions in the early and mid-1980s were suitable for survival of juvenile Japanese sardines in the nursery grounds. Abrupt changes in the biotic indices were detected in 1987/88 and 1992/1993. They were considered to be responsible for the precipitous decline of the Japanese sardine population and the dramatic increase in zooplankton biomass, respectively. Population dynamics of chub mackerel and Pacific saury were out of phase in the survey periods. The instantaneous surplus production rate of chub mackerel in the late 1990s, however, was as high as in the 1970s, when the biomass was large (Yatsu et al. 2005), suggesting fishing pressure depressed the beginning of the population increase. Population dynamics of Japanese sardine had a stronger impact on the ecosystem than those of chub mackerel and Pacific saury in the Kuroshio/Oyashio systems.

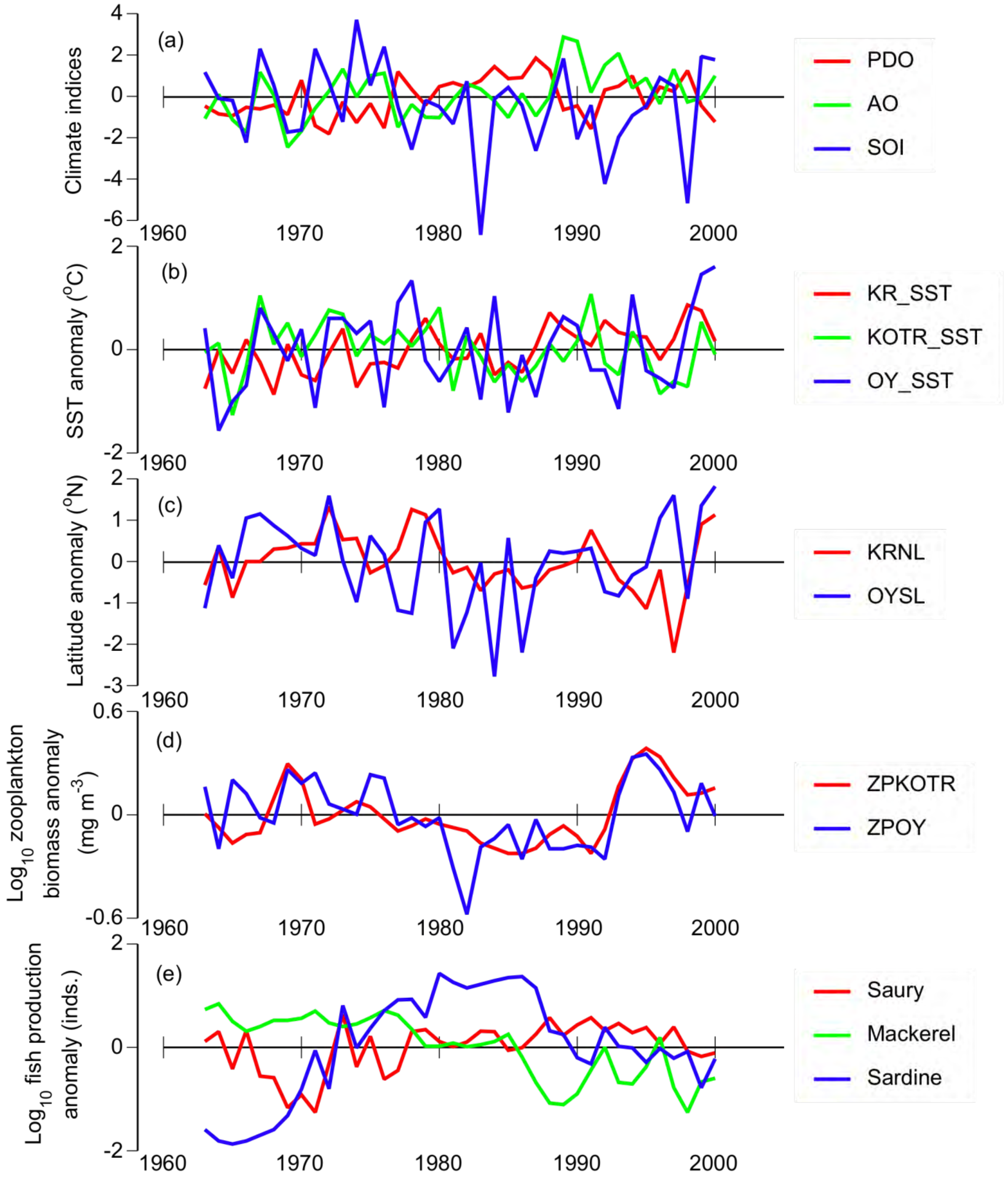


Fig. 2. Time series of large scale climate indices (a), anomalies of SST (b), anomalies of positions of northern and southern limit of the Kuroshio Extension and the Oyashio fronts (c), zooplankton biomass in the Kuroshio-Oyashio transition region and the Oyashio region (d), production of small pelagic fish species shown as individual number of recruits (e).

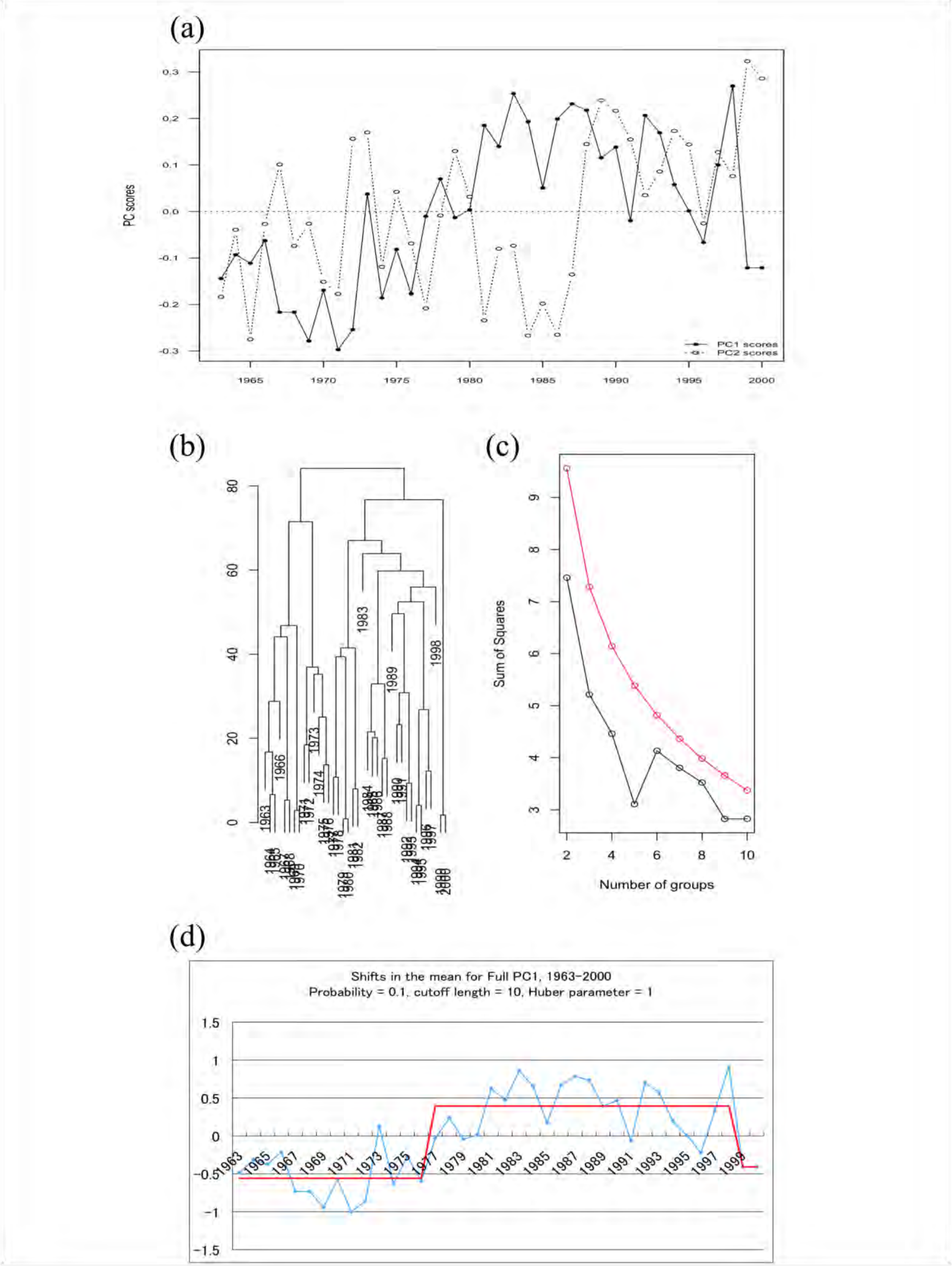


Fig. 3. Time series of PCA scores of full variables (a), constrained clustering (b, c) and a sequential t-test, STARS (d) for PC1scores.

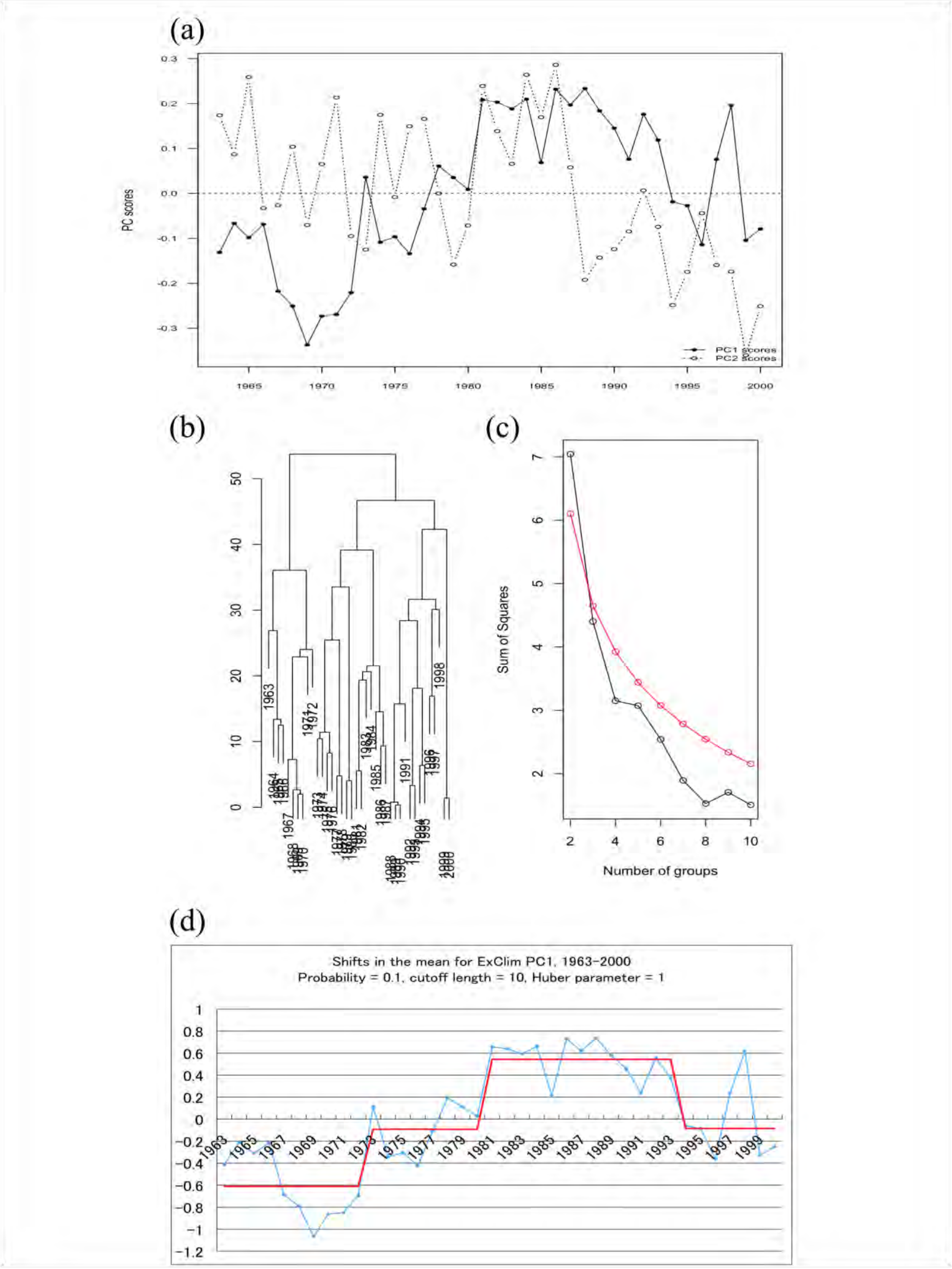


Fig. 4. Time series of PCA scores of full variables set without climate indices (a), constrained clustering (b, c) and a sequential t-test, STARS (d) for PC1scores.

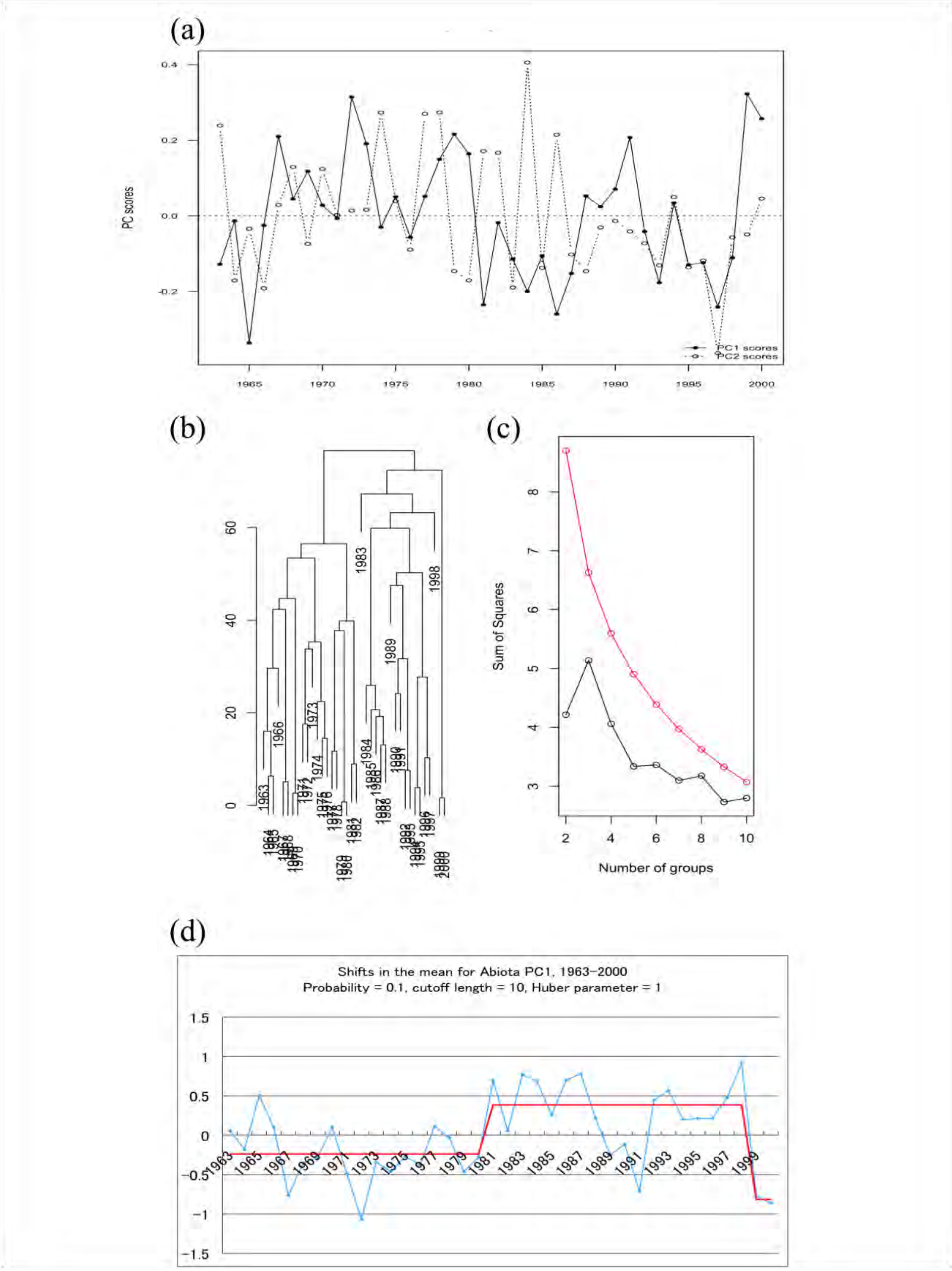


Fig. 5. Time series of PCA scores of abiotic variables (a), constrained clustering (b, c) and a sequential t-test, STARS (d) for PC1scores.

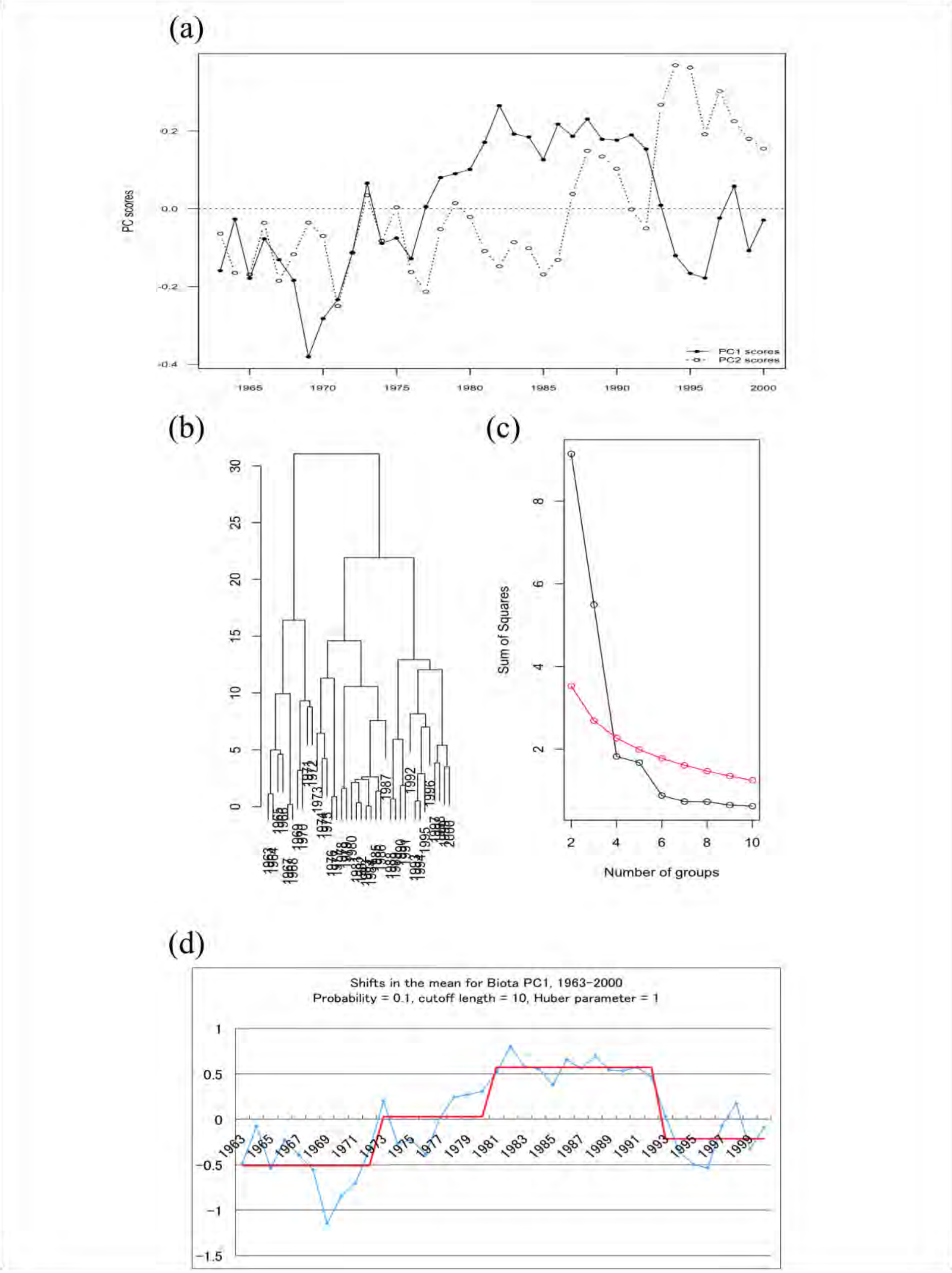


Fig. 6. Time series of PCA scores of biotic variables (a), constrained clustering (b, c) and a sequential t-test, STARS (d) for PC1scores.