# Recent climatic changes in the Japan/East Sea ecosystem on the tri-national data set

*Yury Zuenko, Yongjun Tian, Sukgeun Jung, and Rabea Diekmann*

**(from results of WG-FCCIFS Workshop in Hamburg, May 2011)**

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

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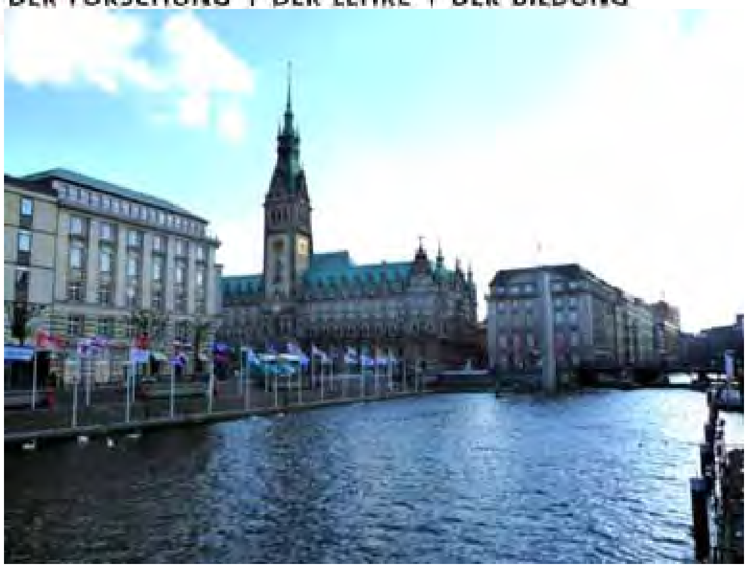

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# **ICES/PICES Workshop on the Reaction of Northern Hemisphere Ecosystems to Climate Events: a Comparison** (WKNORCLIM)

Tasks:

1. Data preparation (ecosystem balance, periods, gaps, independence, matrix)
2. Data assimilation (anomalies, transformation)
3. Principal components analysis
4. Chronological clustering
5. STARS (regime shifts revealing)
6. Comparing the results between ecosystems and with climatic indices for understanding the ecosystems reaction to climate events

## Combined data set

The combined data set includes the time series describing all the main components of marine ecosystem which are collected by scientists from Japan (JSNFRI, Niigata), Korea (NFRDI, Busan), and Russia (TINRO, Vladivostok).

In order to describe all trophic levels, length of time series is limited by period 1978-2004

| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **Oceanographic parameters** | | | | | | |
| Air temperature in winter | Ta winter | $^oC$ | Vladivostok | Dec.-Feb. | termometer | TINRO |
| Air temperature in summer | Ta summer | $^oC$ | Vladivostok | June-Aug. | termometer | TINRO |
| SST anomaly in winter | ATw winter | $^oC$ | northern JES | Dec.-Feb. | termometer | TINRO |
| SST anomaly in summer | ATw summer | $^oC$ | northern JES | June-Aug. | termometer | TINRO |
| Subsurface Subtropic Water temperature in winter | Tw SST winter | $^oC$ | southeastern JES (standard section) | Dec.-Feb. | termometer | JSNFRI |
| Subsurface Subtropic Water temperature in winter | Tw SST summer | $^oC$ | southeastern JES (standard section) | June-Aug. | termometer | JSNFRI |
| Intermediate Water temperature anomaly in winter | ATw SS winter | $^oC$ | northwestern JES (standard section) | Feb.-Apr. | termometer | TINRO |
| Intermediate Water tempe-rature anomaly in summer | ATw SS summer | $^oC$ | 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 |

## Combined data set: oceanographic parameters

| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **Oceanographic parameters** | | | | | | |
| Air temperature in winter | Ta winter | $^{o}C$ | Vladivostok | Dec.-Feb. | termometer | TINRO |
| Air temperature in summer | Ta summer | $^{o}C$ | Vladivostok | June-Aug. | termometer | TINRO |
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| Subsurface Subtropic Water temperature in winter | Tw SST winter | $^{o}C$ | southeastern JES (standard section) | Dec.-Feb. | termometer | JSNFRI |
| Subsurface Subtropic Water temperature in winter | Tw SST summer | $^{o}C$ | southeastern JES (standard section) | June-Aug. | termometer | JSNFRI |
| Intermediate Water temperature anomaly in winter | ATw SS winter | $^{o}C$ | northwestern JES (standard section) | Feb.-Apr. | termometer | TINRO |
| Intermediate Water tempe-rature anomaly in summer | ATw SS summer | $^{o}C$ | 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 |

Time series of oceanographic parameters are mainly Russian-made, but they represent both northern part of the Sea and the whole Sea, including Japanese and Korean EEZs. Similar data sets are available In Japan and Korea, too, because of active exchange by oceanographic data.

## Combined data set: phytoplankton and seaweeds

| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **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 |
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| 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 |

Data on phytoplankton are very limited. The only regular and long time series are obtained at the standard section in the southeastern part of the Sea conducted by Japanese scientists. Other data on primary producers concern the commercial seaweeds.

## Combined data set: zooplankton and zoobenthos

| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **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 |

The best time series on zooplankton are collected in bi-monthly surveys conducted by NFRDI, Korea.
Japanese and Russian time series are shorter, that's why we didn't use them.
The data on zoobenthos concern the commercial species, mostly crabs and shrimps.

## Combined data set: plankton and benthos eaters

| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **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 |

The data on non-predatory fishes are mainly received from fishery statistics, easy available in all three countries. The data on stock are available for the northern part of the Sea only, where regular trawl surveys are conducted by Russian scientists.

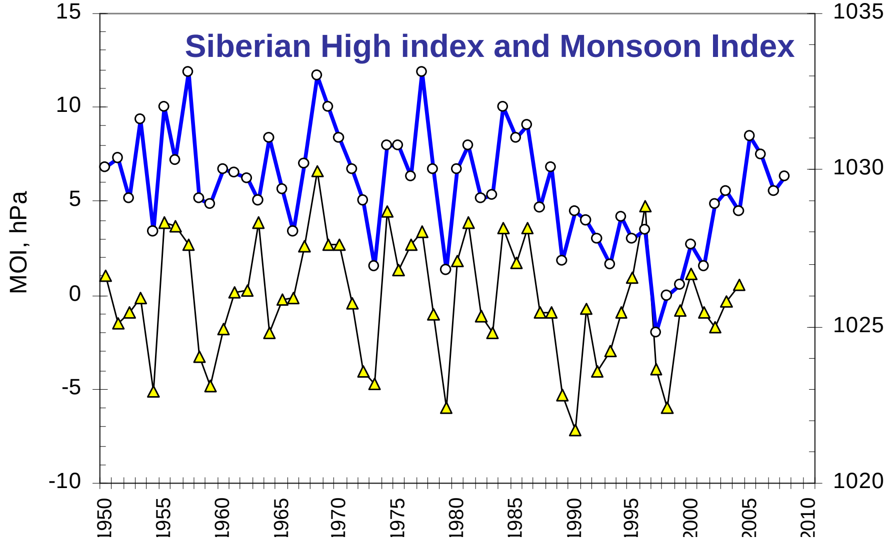
## Combined data set: fish and squid predators; mammals

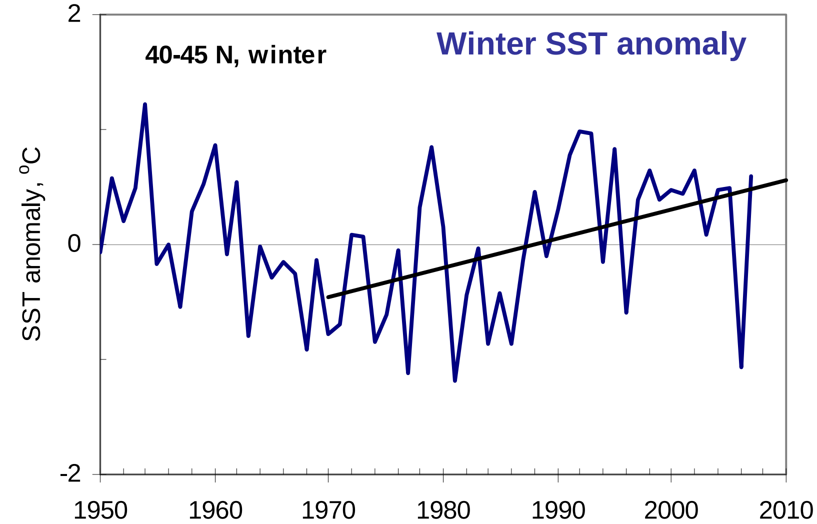
| Variable | Abbre-viation | Unit | Area | Season | Method Gear | Source* (initial data set) |
|---|---|---|---|---|---|---|
| **Fish and squid predators** | | | | | | |
| Pollock year-classes sterngth | Pollock | $10^6$ ind. | northwestern JES | annual | fishery statistics | TINRO |
| Bluefin tuna catch | 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 |

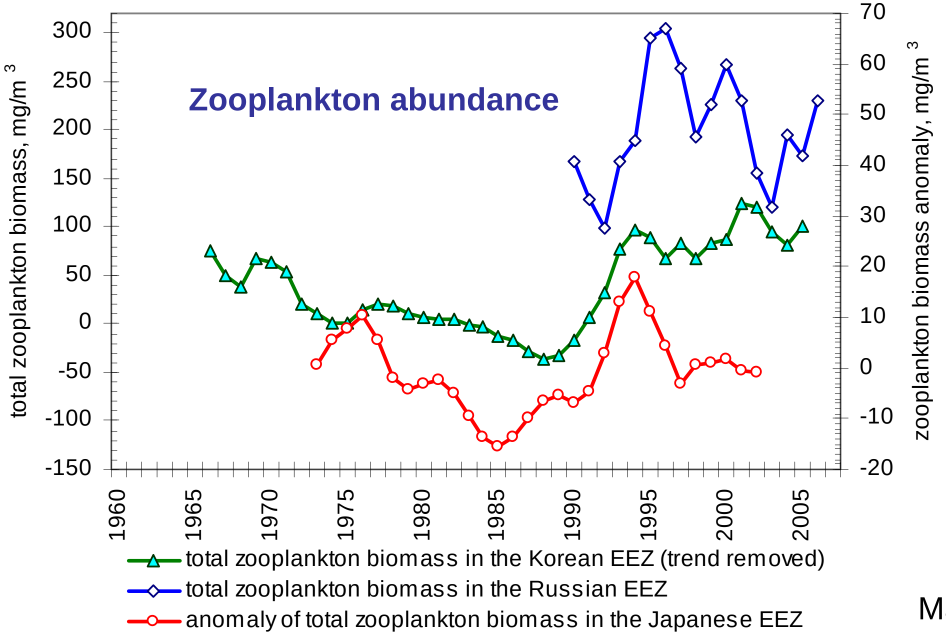
The most of predators dwell in the southern part of the Sea, so we used Japanese fishery statistics for their describing. The most important predator in the northern part is walleye pollock, which abundance is well monitored by Russian scientists.

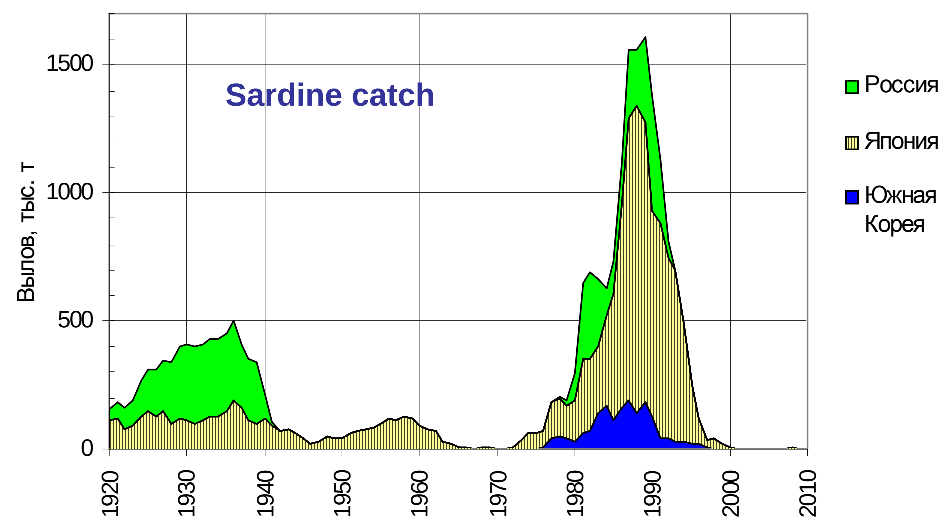
The data on whales are not quite good because of their few number.

# Variability of single variables




Many of the variables have obvious trends and long-term (decadal) variability in the last decades, he same as climatic indices.

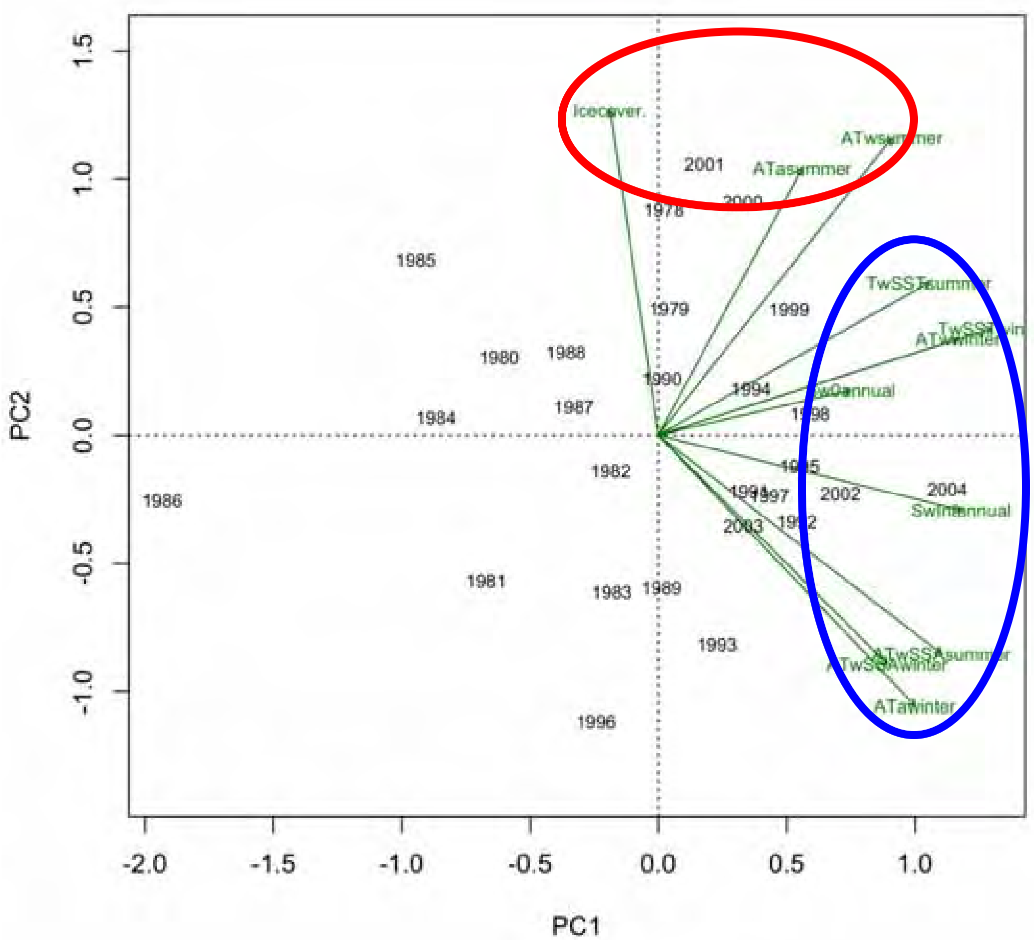
We need a complex description of the whole system variability that is possible by means of Principal Components Analysis (PCA)

## PCA: eigenvalues contribution

| Data set | Data subset | PC-1 | PC-2 | PC-3 | PC-4 | PC-5 | PC-6 | PC-7 |
|---|---|---|---|---|---|---|---|---|
| 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 and PC-2 contribute >50 % of variation for separate subsets of abiotic and biotic variables

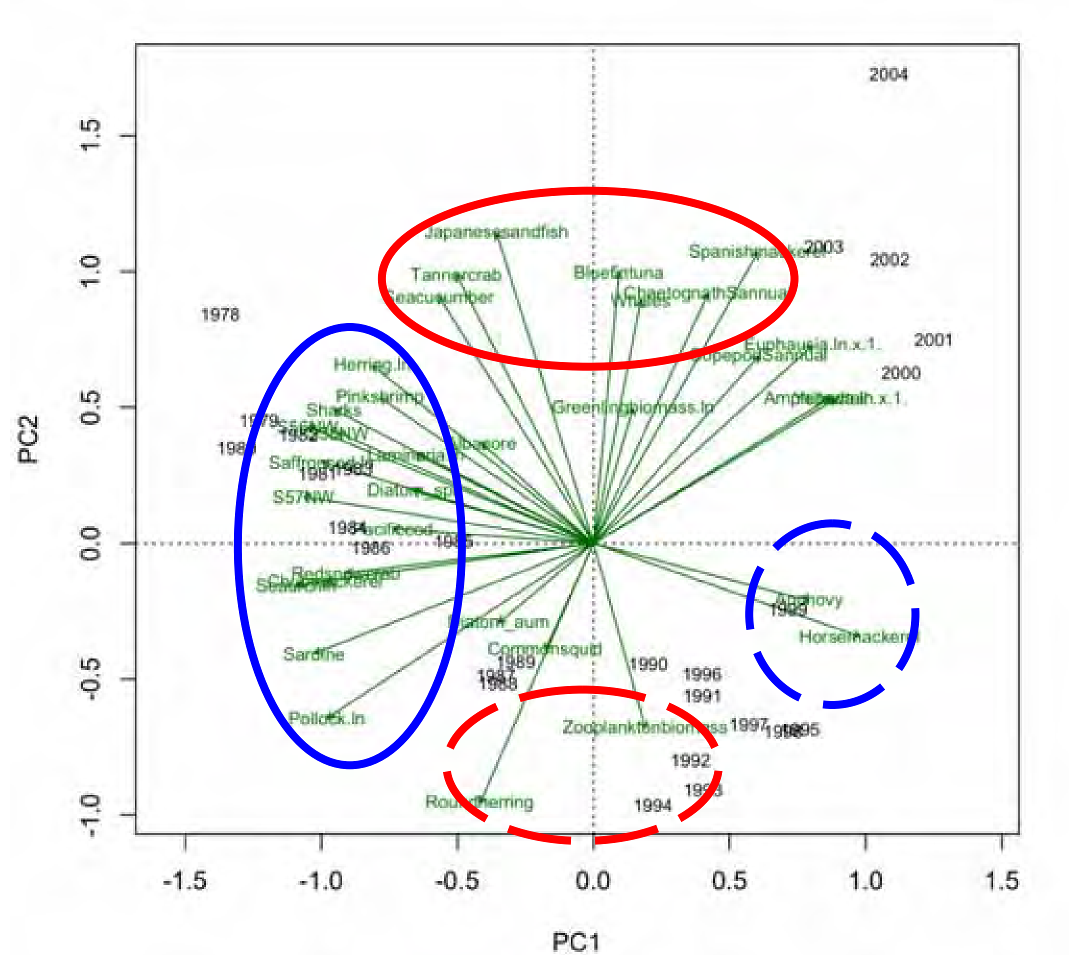
# PCA: scores of abiotic variables




PC-1 of abiotic variables correlates well with parameters describing winter conditions (Ta winter, ATw winter, ATw SS winter, Tw SST winter) or depended 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 diagram.

Other abiotic variables correlate better with PC-2 – they concern to summer conditions at the sea surface (Ta summer, ATw summer), as well as the ice cover (??), and form the group of up-directed beams. Supposedly, the PC-2 describes some parameters of summer conditions.

## PCA: scores of biotic variables



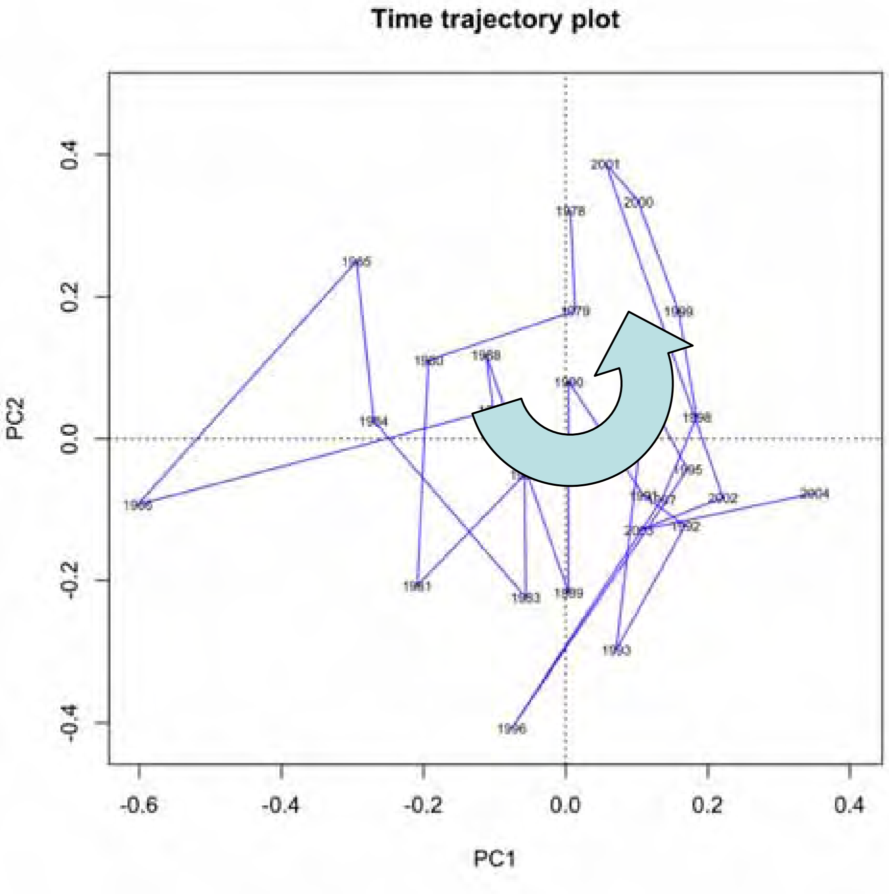

Some biotic variables have weak correlation with both PC-1 and PC-2 (Diatom_aut, Greenling, Saury, Albacore) that means that their variability is not related with these principal components or is stochastic.

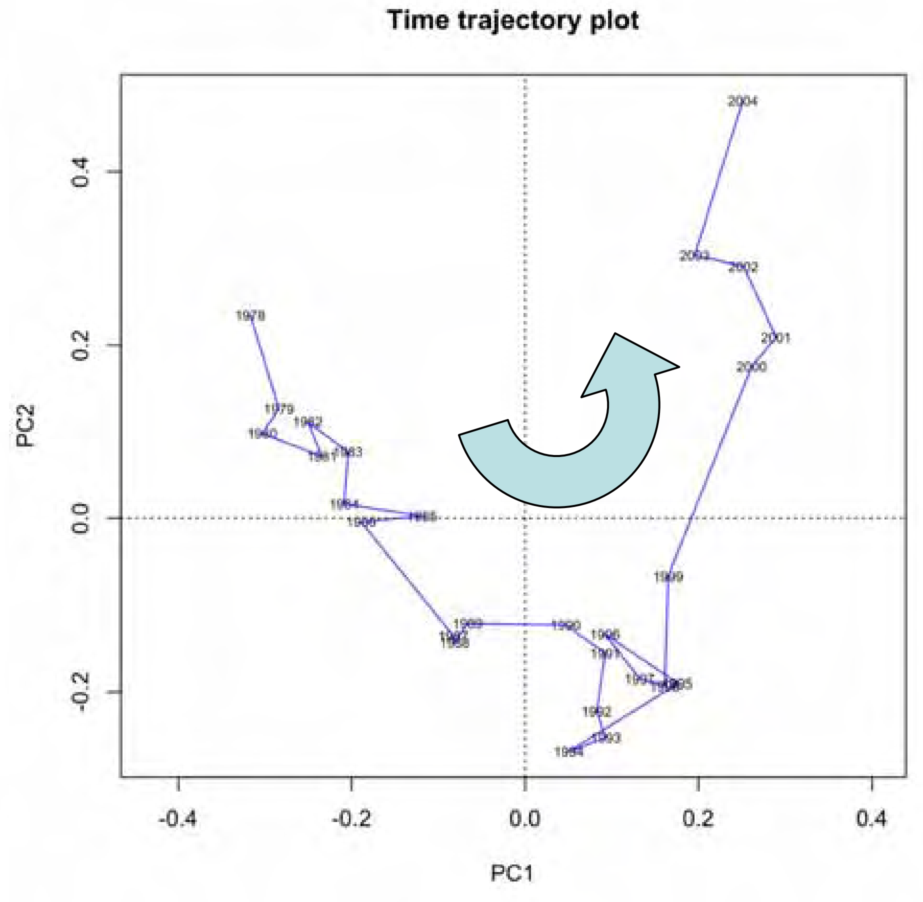
Other species show definite relationship with PC-1 or PC-2 that allows to assume nature of their variability.

**Well-correlated with PC-1:** all primary producers (Diatom_spr, all seaweeds), the most of small benthics and small pelagics (Pink shrimp, Red snow crab, Sea urchin, Sardine, Herring, Saffron cod, Chub mackerel, Horse mackerel, Yellowtail), some predators (Pacific cod, Pollock, Sharks) – all of them, except Horse mackerel and Yellowtail, are negatively related with PC-1 (left-directed beams).

**Well-correlated with PC-2:** Zooplankton and Round herring ( negatively) and Sea cucumber, Tanner crab, Sandfish, Spanish mackerel, Bluefin tuna, and Whales (positively). Pollock is negatively correlated with both PC-1 and PC-2.

# PCA: year-to-year trajectories

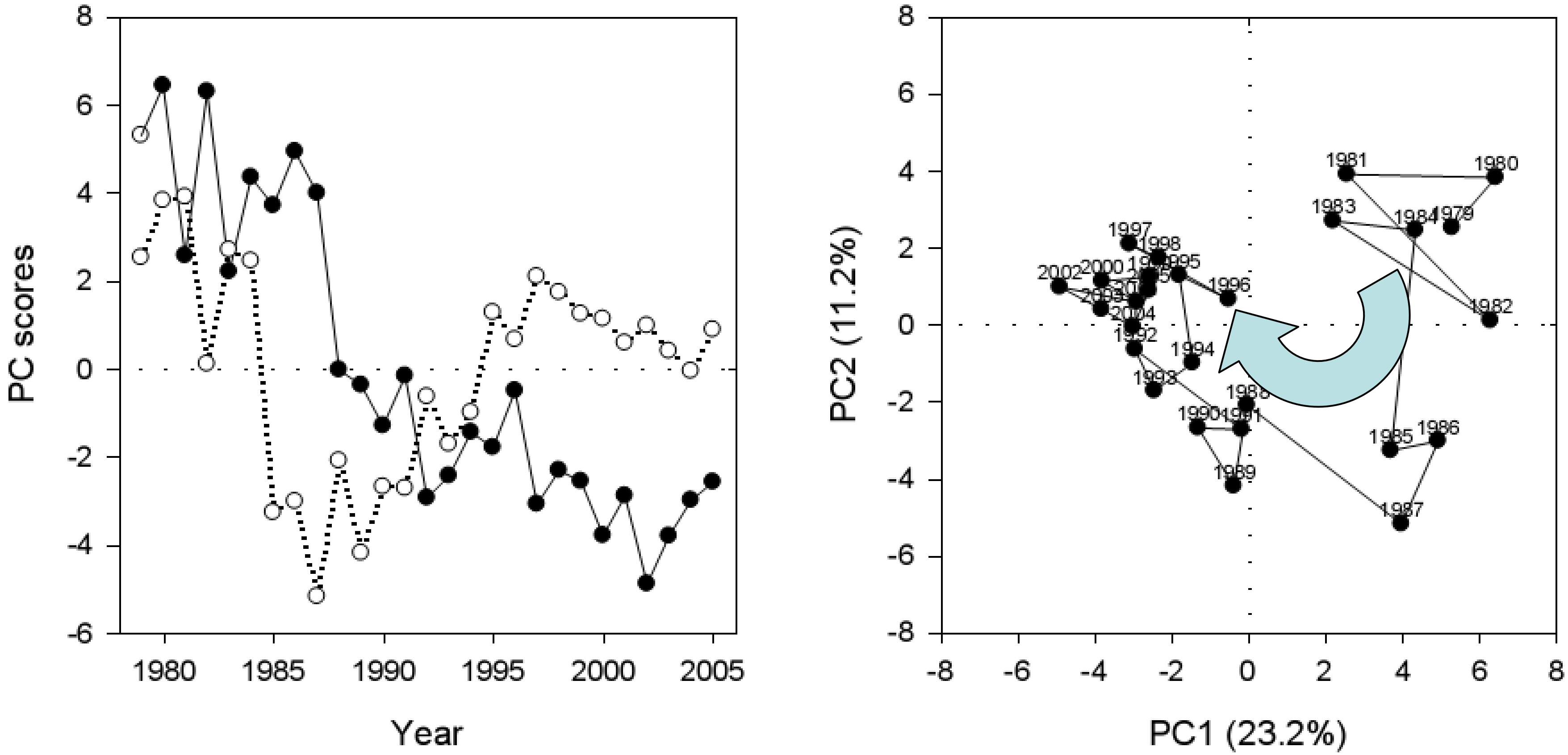



Temporal changes of PC-1 and PC-2 look on the diagrams for both abiotic and biotic variables as loops with PC-1 increasing and PC-2 decreasing until 1990s and then PC-2 increasing with more or less stable PC-1.

The first stage corresponds to the process of the Japan Sea warming in 1980-1990s, the second one relates to some summer processes change in 2000s, possibly warm currents intensifying

**PCA: year-to-year trajectories**




These changes are similar to changes in the ecosystem of the Baltic Sea and many other regional ecosystems of the North Hemisphere, in particular by PC-1 trend reasoned by winter warming in all these regions

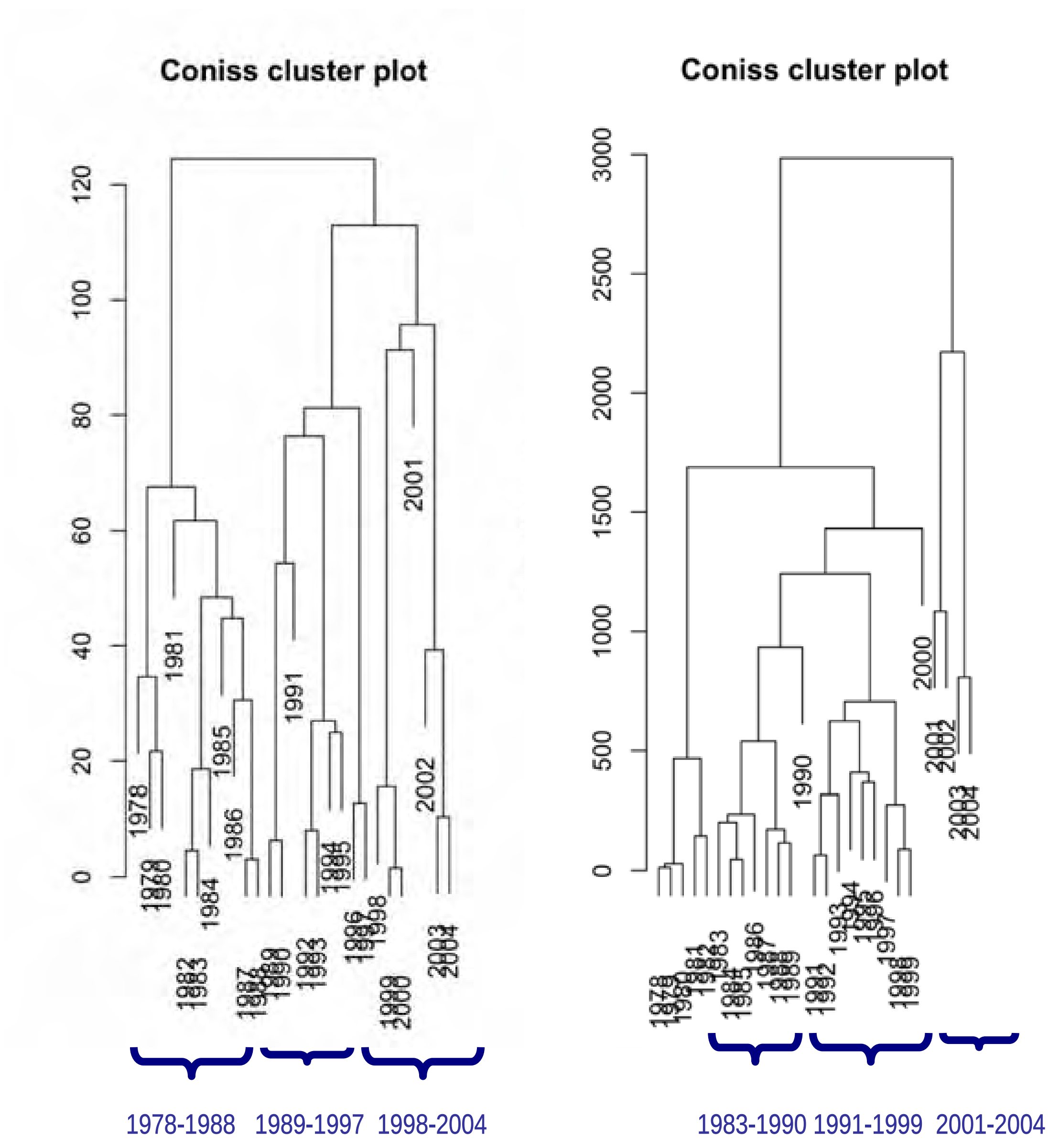
## PCA: chronological clustering

Chronological clustering allows to divide the time series to three successive periods, split in 1989-1990 and 1998-2000. Shifts of biotic variables always follow the shifts of abiotic ones.

The former regime shift in the late 1980s is well-known, and definitely it is reasoned by winter warming because of winter monsoon weakening.

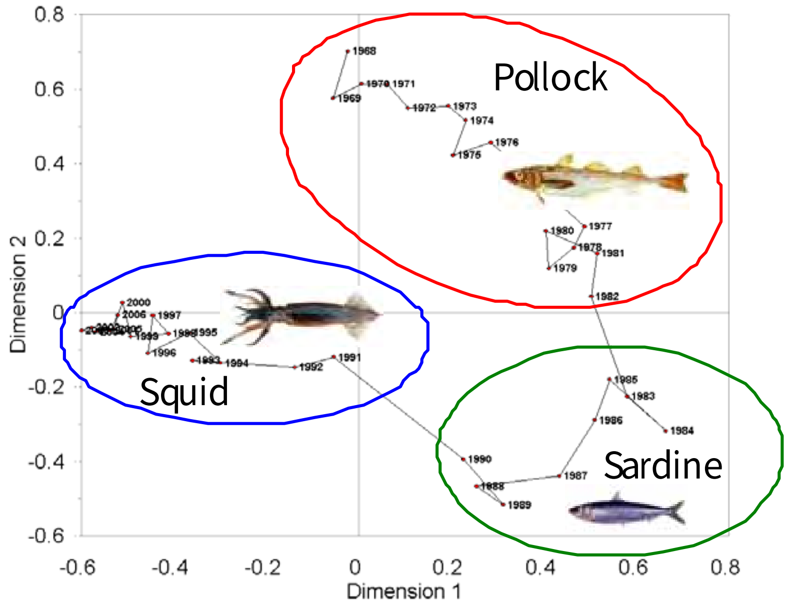
The latter regime shift in the late 1990s is not so well-known; it is related with PC-2 change that obviously reflects the changes of some summer processes.

**Abiotic variables** **Biotic variables**



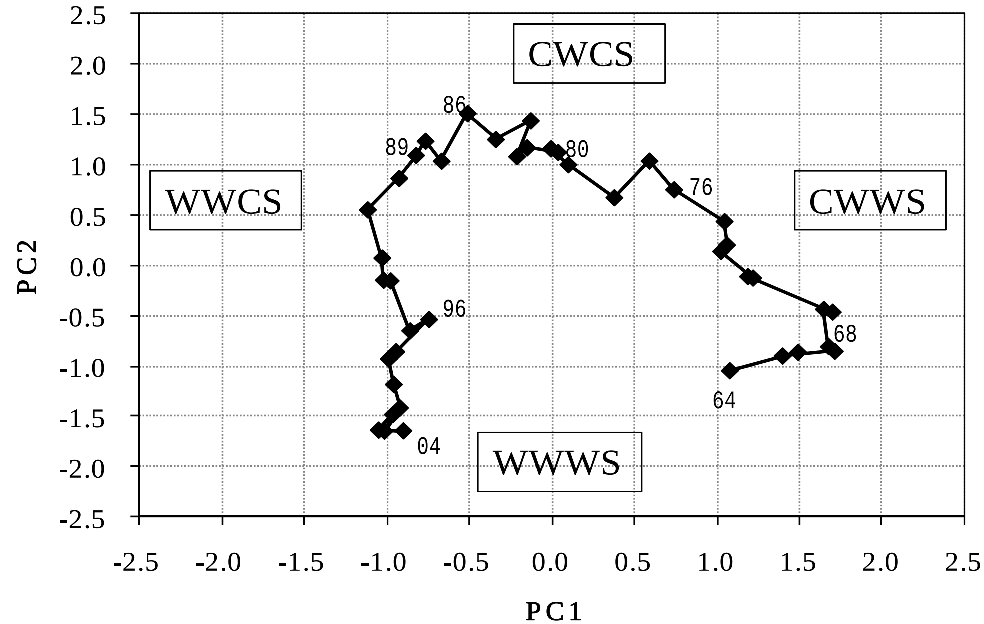
## PCA: chronological clustering

**Set of biotic and abiotic variables for the waters around S. Korea**




❖ Regime Shifts: 1976-1977, 1988-1989, 1997-1998

**Set of the data on commercial catches in EEZ of Japan**




Similar changes could be seen on national data sets, though some of them are longer and include 1960-1970s.

Generally, the period **before the climate shift in the late 1980s** could be characterized as “sardine times” and was distinguished by cold winter and relatively cold summer (CWCS);
the period **in 1990s, between the climate shifts,** could be characterized as “common squid times” and was distinguished by warm winter and relatively cold summer (WWCS);
**the modern period** is distinguished by warm winter and warm summer (WWWS); the stock of common squid is still very high, but abundance of warm-water migrants is rising in the southern part of the Sea

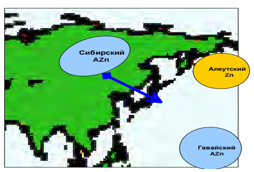
## PCA: relationship with climatic indices

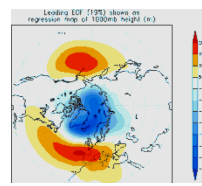
The PC comparison with climatic indices shows a good correlation of PC-1 with the indices describing winter conditions, as AO, and particular SHI. For biotic subset, the best correlation is found with the time lag 2-3 years. The nature of the relationship with SHI is obvious; AO influences on winter conditions in the Japan Sea via its link with Siberian High and zonal air transfer over Eurasia.

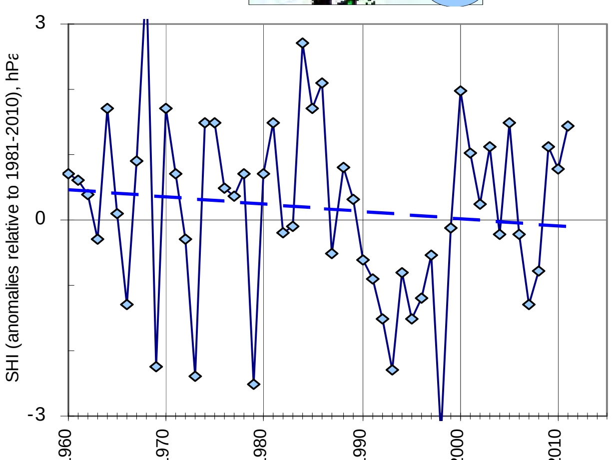
PC-2 has no significant correlation with any index of atmosphere that is reasonable if it describes the warm currents intensity.

*Table. Correlation coefficients between PC-1 for both data subsets and Siberian High Index*

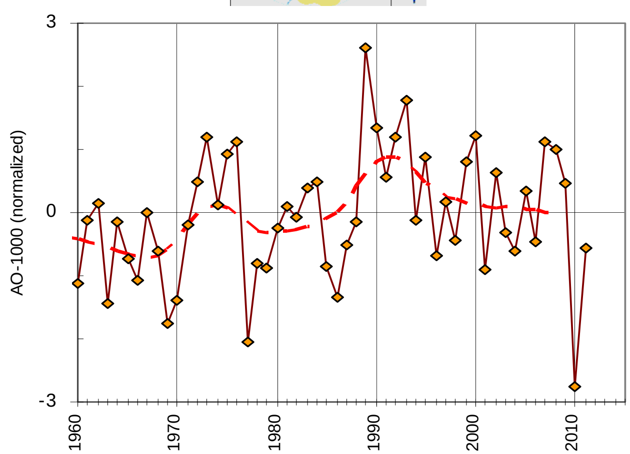
| Data set | Data subset | Time lag (PC after SHI) | | | | |
|---|---|---|---|---|---|---|
| | | No lag | 1 year | 2 years | 3 years | 4 years |
| Combined | Abiotic variables | 0.69 | 0.48 | 0.50 | 0.49 | 0.44 |
| | Biotic variables | 0.56 | 0.62 | 0.69 | 0.72 | 0.67 |



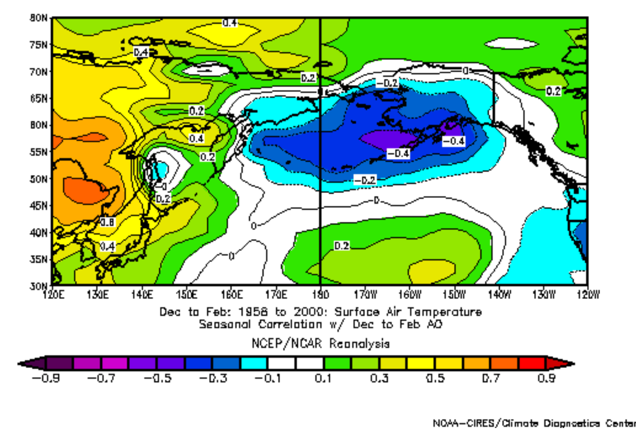





*Siberian High Index*
*(Panagiotopoulos et al., 2005,)*




*Arctic Oscillation index*
*(http://jisao.washington.edu/analyses0302/)*




*AO correlates well with air temperature over the Japan Sea (Wu, Wang, 2002)*

## Conclusion:

The state of the whole Japan Sea ecosystem, as well as its parts, is determined mainly by winter processes described well by regional index SHI that reflects the state of atmosphere over the whole Northern Hemisphere, generally described by the planetary AO index.

In the last decades, the most important reconstruction of the Japan Sea ecosystem, with replacement of its dominant species, happened in the late 1980s that was reasoned by winter monsoon weakening on the positive phase of Arctic Oscillation. At the same time, strong changes happened in marine ecosystems of many other regions of Northern Hemisphere.

Fluctuations of summer conditions are important mainly for the southern part of the Sea. Mechanism of this relationship is still not clear; possibly it concerns the warm currents intensity.