Integrating spatial processes into ecosystem models for sustainable utilization of fish resources
INSPIRE

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Lead Partner for Deliverable:	University of Hamburg (UHAM)		
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INSPIRE Overview

Process-based understanding of changes in commercial fish spatial distributions, and to disentangle the role of natural drivers and various anthropogenic impacts, is a challenging research topic with high relevance to resource management. The very recently started four-years BONUS INSPIRE project will fill in the most persistent gaps in knowledge of the spatial ecology of the major commercial fish and thereby support the effectiveness of the relevant policies and ecosystem-based management of the Baltic Sea. The project would serve as a „*framework axis project*" which other Baltic Sea research could be related to.

INSPIRE is designed to substantially advance our knowledge on the major commercial fish species – cod, herring, sprat and flounder, which represent key elements of the Baltic Sea ecosystems. The specific objectives of INSPIRE are to:

i. Quantify processes generating heterogeneity in spatial distributions of fish;
ii. Quantify and map potential hazards to the connectivity between identified key habitats, and assess the impact of anthropogenic and climatic environmental changes on habitat connectivity;
iii. Quantify the population dynamics and interactions of the fish species in a spatially explicit context;
iv. Develop spatially explicit advice for ecosystem-based fisheries management.

INSPIRE proposes pilot ecosystem integrated surveys to resolve the habitat requirements of different life-stages of fish species by combined use of traditional methods and application of modern advanced analysis techniques. The surveys are conducted in close collaboration with local fishermen.

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Executive Summary

INSPIRE's Work-package 2 contains statistical and process-based analyses of movements of the focal species at different temporal and spatial scales and in different life-stages. In Task 2.2 Migrations of adult individuals, net-migrations rates between adjacent sub-divisions will be estimated using existing tagging and acoustic survey data from the partner institutes. The estimates will be analysed in relation to subdivison based estimates of species density, predator abundance and competitor abundance. Traditional assumption of basic-scale density dependent emigration will be falsified. The resulting net migration estimates will be applied in the subdivision species forecasts of cod, herring and sprat distributions in WP4.

Deliverable 2.1 comprises a database on traditional tagging data. This data base is going to be used to estimate basic net migration rates of adult individuals, with the special focus to identify the contribution of adult migrations to observed redistribution patterns of the commercial fish species. Preliminary analyses indicate that cod in general do not perform long-distance migrations, but that only a small fraction (<10%) of the tagged population is conducting trans-basin migrations. This preliminary finding will form the working hypotheses for the manuscript in deliverable 2.4.

The database is completed (see Appendix below). Data are stored at UHAM, DTU-AQUA and UT.EMI and data access can be granted upon contact to christian.moellmann@uni-hamburg.de .

Introduction

INSPIRE is designed to substantially advance our knowledge on commercial fish species in the Baltic (cod, herring, sprat and flounder). These species form more than 95% of the commercial catches, and represent key elements in the functioning of the Baltic Sea ecosystem(s). INSPIRE will fill in critical gaps in knowledge that currently exist concerning (i) the mechanisms of changes in spatial distributions of different life-history stages of fish (due to various drivers such as climate, fishing and species interactions), (ii) the impact of such changes on the structure and function of the Baltic ecosystem(s), and (iii) the sensitivity and robustness of analytical fish stock assessent, particularly for flatfish. To accomplish these goals, INSPIRE will answer the following questions:

1. *What habitat (both pelagic and benthic) conditions characterize the spatial distributions of cod, herring, sprat and flounder?*

2. *To what extent do fishing and species interaction affect the local and basin-scale distribution of exploited stocks?*

3. *What drives spatial connectivity and migrations of different fish species/populations?*

4. *How does stock structure and separation of natural populations impact stock assessment outcomes?*

INSPIRE partners have long-standing expertise in designing/performing field surveys and carrying out research on spatio-temporal dynamics of the main commercial fish - cod, herring, sprat, and flatfishes - in the Baltic Sea. The partners also routinely apply quantitative models for stock assessment and ecosystem-based fisheries management. Furthermore, the INSPIRE partners have at hand the extensive data series necessary to realistically conduct such complex ecological analyses. Several partners have also strong expertise in investigating ecological processes in the Baltic

Sea by involving other trophic levels than fish as well as external and internal ecosystem drivers.
INSPIRE research is conducted in a matrix approach with four species specific case (cod, herring, sprat and flounder) and five research work-packages. The work packages deal with (i) habitat requirements and survival probability for different life stages, (ii) connectivity between habitat occupied in successive life stages, (iii) spatial scaling from local events to regional population dynamics, (iv) spatially explicit analytical stock assessments (including a comprehensive flatfish programme), and (v) ecosystem-based management and Marine Strategy Framework Directive indicators.

Moving beyond existing knowledge, INSPIRE will for the major Baltic fish species take the leap from homogeneous to heterogeneous population dynamics, by accounting for spatial heterogeneity in population models and ecosystem-based fisheries management. Spatial heterogeneity, defined as changes in the abundance of fish over space, which are not explainable by simple random (Poissonian) variability, can have different causes. The overall approach of INSPIRE is mechanistic in the sense that we aim to understand these causes and the underlying processes generating spatial heterogeneity, but also estimate its magnitude.

INSPIRE will generate new data and operational models that allow making projections on spatial distributions of Baltic key commercial fish species on different spatial and temporal scales, and their integration in analytical assessments and ecosystem-based fisheries management. Moreover, as the main providers of management advice on Baltic fish stocks, INSPIRE partners are also able to translate these model outputs into urgently needed advice on how best to move beyond spatially homogeneous approach of current fishery and ecosystem assessments, and adopt spatially explicit ecosystem-oriented management. The INSPIRE project is thus addressing major research objectives set forth by the revised Common Fisheries Policy, the Marine Strategy Directive (2008/56/EC), the EU Marine and Maritime Research Strategy, the HELCOM Baltic Sea Action Plan, and the BONUS research agenda.

The Scientific & Technological objectives of the INSPIRE project are:

1. To quantify processes generating heterogeneity in spatial distributions of cod, herring, sprat and flounder. This means to quantify habitat associations of the focal species at different life stages.
2. To quantify and map potential hazards to the connectivity between identified key habitats, and assess the impact of anthropogenic and climatic environmental changes on habitat connectivity.
3. To quantify the population dynamics and interactions of the focal species in a spatially explicit context.
4. To develop spatially explicit advice for ecosystem-based fisheries management of Baltic cod, herring, sprat and flounder, accounting for the spatial heterogeneity in fish distributions.

INSPIRE's Work-package 2 contains statistical and process-based analyses of movements of the focal species at different temporal and spatial scales and in different life-stages. Besides quantifying these movements, emphasis is put on the characterization of obstacles for the transport or movement between nursery and feeding habitats, between feeding and spawning habitat, and (closing the life cycle) between early life stages habitats and nursery grounds. This includes the assessment-relevant movements between ICES sub-divisions.

In Task 2.2 Migrations of adult individuals, net-migrations rates between adjacent sub-divisions will be estimated using existing tagging and acoustic survey data from the partner institutes. The estimates will be analysed in relation to sub-divison based estimates of species density, predator abundance and competitor abundance, Traditional assumption of basic-scale density dependent emigration will be falsified. The resulting net migration estimates will be applied in the sub-division species forecasts of cod, herring and sprat distributions.

Deliverable 2.1 comprises a database on traditional tagging data.This data base is going to be used to estimate basic net migration rates of adult individuals, with the special focus to identify the contribution of adult migrations to observed redistribution patterns of the commercial fish species.

i) Scientific Highlights

Data from 1236 cod recaptures from traditional tagging programmes and 602 records from data storage tags, comprising depth, temperature and salinity every 10 minutes while at large, have been collected in the INSPIRE tagging database.
For herring and sprat, acoustic data from the BITS acoustic survey have been compiled for 1974 to 2010 by quarter in order to estimate redistribution in spatially explicit population and management models.

ii) Progress

The database is completed.

iii) Deviations from the work-plan

There are no deviations from the original work-plan.

iv) Methods and results

In the following chapters we give an overview over the tagging data which are collected in the INSPIRE tagging database.

<u>Cod traditional tagging data</u>

Between 1974 and 1992 there were several tagging programmes in the Baltic. Tables 1 to 3 below show the recapture. Please note, that recapture rate represents >10 % of the actually tagged cod. Hence, to recapture the total of 1236 cod, more than 12 000 specimen had to be tagged.

Table 1: Finnish tagging programme

Year	Country	Subdivision	# Recaptures
1974	FIN	32	45
1975	FIN	29	119
1975	FIN	32	12
1976	FIN	29	89
1977	FIN	29	189
1978	FIN	29	161

1984	FIN	30	5
SUM	**FIN**		**620**

Table 2: Swedish tagging programme

Year	Country	Subdivision	# Recaptures
1982	SWE	25	2
1982	SWE	26	2
1982	SWE	27	3
1982	SWE	29	6
1982	SWE	30	53
1982	SWE	31	1
1983	SWE	24	1
1983	SWE	26	1
1983	SWE	27	3
1983	SWE	29	5
1983	SWE	30	95
1983	SWE	31	1
1983	SWE	32	1
SUM	**SWE**		**174**

Table 3: German tagging programme

Year	Country	Subdivision	# Recaptures
1988	GER	22	94
1989	GER	22	87
1989	GER	23	1
1989	GER	24	11
1989	GER	25	2
1989	GER	26	1
1990	GER	21	3
1990	GER	22	70
1990	GER	24	14
1990	GER	25	1
1991	GER	22	84
1991	GER	24	3
1992	GER	21	2
1992	GER	22	67
1992	GER	24	2
SUM	**GER**		**442**

Preliminary analyses with the traditional tagging data

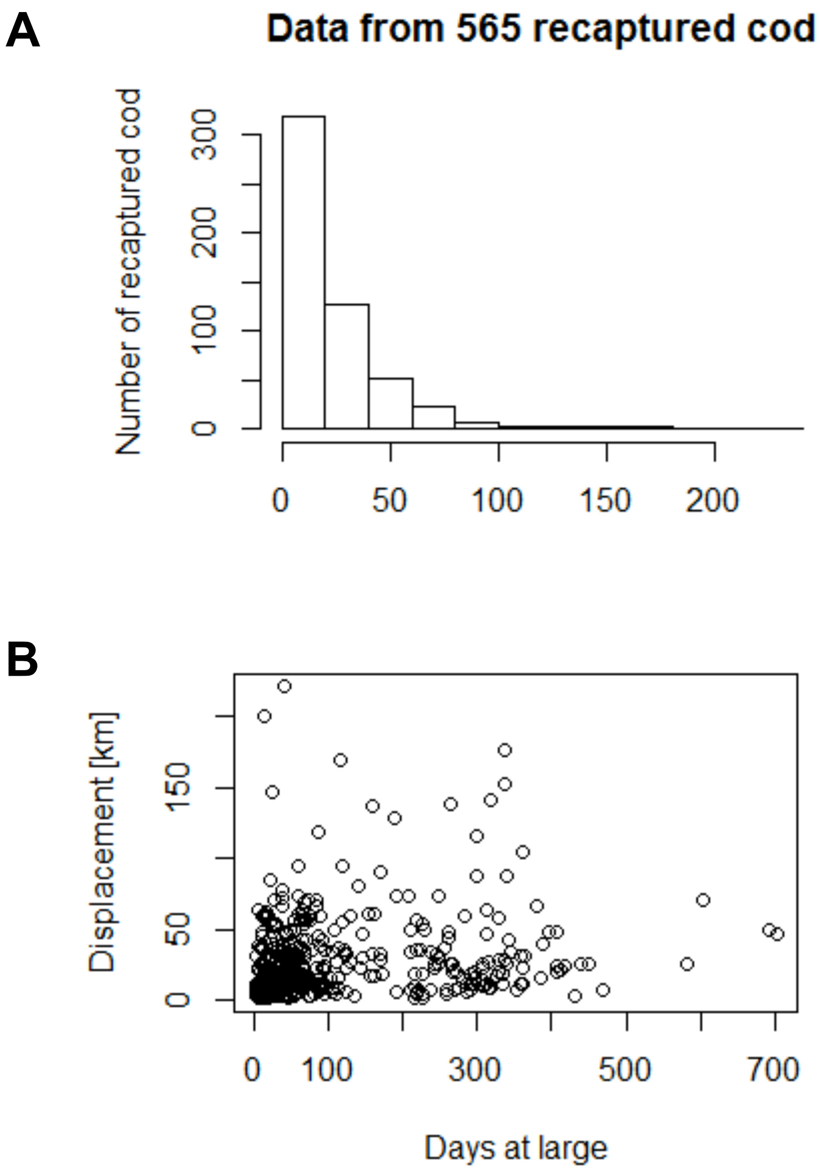

Figure 1: Net displacement data from a sub-set of 565 recapture (Panel A); Net displacement verus days at large (Panel B)

Preliminary analyses of the traditional tagging data has indicated that cod in general do not perform long-distance migrations, but that only a small fraction (<10%) of the tagged population is conducting trans-basin migrations (Fig. 1 A. Furthermore, the net displacement is independent of the time at large. There is hence no diffusion-like process at work. This preliminary finding will form the working hypotheses for the manuscript in deliverable 2.4.

Cod tagged with data storage tags

Between 2003 and 2008, DTU Aqua tagged 602 Balti cod with electronic data storage tags (Tables 4 & 5). Star-Oddi CTD tags were used, and each was programmed to record pressure, ambient temperature, and conductivity once every hour for a maximum recording period of 2 years. The tags converted the conductivity measurements into salinities automatically. After calibration with known salinities, the conductivity based tag measurements of salinity were accurate to ± 0.5 PSU. Temperature measurements after calibration were accurate to ± 0.1 °C, and pressure was measured accurate to ± 0.2 dbar.

The recapture rate was considerably higher than for the traditional tagging programmes, probably, because the project had been advertised in the media, and there was a reward of 100 Euros per tagged cod recapture (the reward was so high, because each DS tag costs about 500 Euros and is reusable).

Table 4: DST Tagging programmes

Program	Location	Date (start)	Longitude	Latitude	No. tags	No. returns::	Return rate:
2003a	Western Baltic	17.03.03			73	20	0.27
2003b	Eastern Baltic	28.04.03			62	30	0.48
2004a	Eastern Baltic	15.04.04			141	76	0.54
2005a	Eastern Baltic	02.05.05			167	84	0.50
2006a	Western Baltic	24.04.06			159	75	0.47
2007					80		0.00
2008					122	47	0.39
Total:					**602**	**285**	**0.47**

Table 5: DST Release positions

Description of stations:		Date (start)	Longitude	Latitude	Depth [m]	Bottom type
2003a:						
	1	17.03.03	12.5217	54.5422		sand
	2	18.03.03	12.3500	54.7577		sand
	3	19.03.03	12.0670	54.5725		sand
2003b:						
	1	28.04.03	15.1895	55.0457		sand with stones
	2	30.04.03	15.1637	55.0847		granite
2004a:						
	1	14.04.04	15.2083	55.0083	35-40	stone with corals
	2	14.04.04	15.2250	55.0250	32-36	stone
	3	14.04.04	15.2733	55.0100	58-62	clay with stones
	4	14.04.04	15.2333	54.9917	45-50	clay with stones
	5	15.04.04	15.2283	55.0708	70	clay with stones
	6	15.04.04	15.2167	55.0467	50-54	stone
	7	15.04.04	15.2250	55.0300	45-45	stone with corals
	8	15.04.04	15.1617	55.0750	20	stone
	9	15.04.04	15.1583	55.0542	20	stone

2005a:

1	02.05.05	15.1917	55.0167	25-30	stone
2	02/03.05.05	15.2333	54.9917	50	stonetop
3	02/03.05.05	15.2533	55.0000	60	stonetop
4	03.05.05	15.2167	55.0417	50-60	clay
5	03.05.05	15.1617	55.0750	25	granite

2006a:

1	24-04-2006	14.6750	55.1917	25-30	stone
2	24-04-2006	14.6083	55.1500	40-42	wreck
3	24-04-2006	14.6333	55.1000	25-30	stone
4	24-04-2006	14.6500	55.1367	32	stone

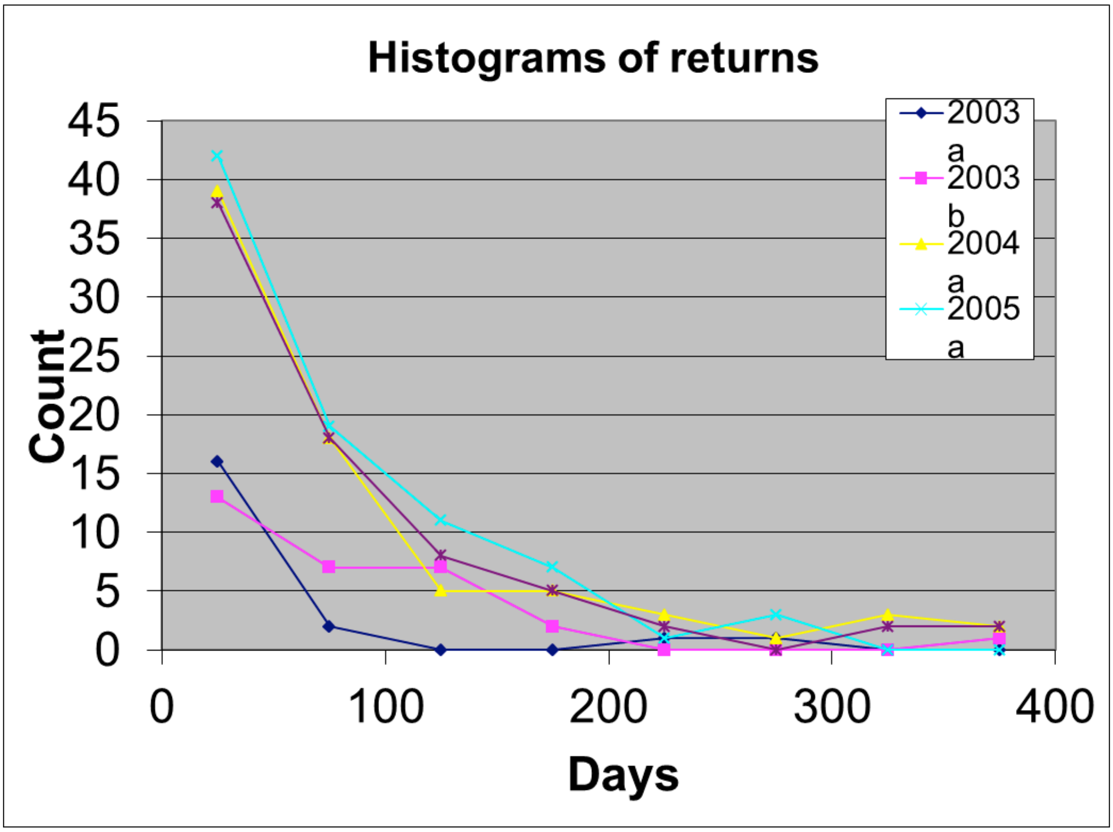

Figure 2: Histogram of returns from the Data Storage tag programme.

285 of the tagged cod were recapature after variable time at liberty (Figure 2). The data have been added to the INSPIRE tagging database.

<u>Herring and sprat</u>

The relative distributions of sprat and herring were estimated in two steps. First, for each quarter and species, we calculated the SD-specific distribution inside the area covered by SD 25, 26, 28. In a second step, we estimated the proportion of the stock outside of the area of SD 25, 26, 28, i.e. inside the area of SD 27, 29, 32. This two-step approach was chosen because distribution data from scientific surveys were mostly available only for the area of SD 25, 26, 28. The proportion of the stock

outside of this area (in SD 27, 29, 32) was mostly based on distribution of fisheries landings. The information from the two steps was then combined to obtain the relative quarterly proportions of the three species in SD 25, SD 26, SD 28, and in the area of SD 27, 29, 32 combined.
The distribution was calculated separately for young and adult fish. Adult fish approximately referred to the age-groups where most of the fish are mature. Young fish were considered represented by age-groups 0-1, and adult fish by age-groups 2 and older, and the numbers at age in survey data were combined accordingly. In landings, the data for 0-1 year olds were fragmentary; therefore the data for age-group 2 was included as well when calculating the distribution of young fish based on landings data.
The survey data by SDs were from the acoustic survey in the 4th quarter for sprat and herring and from the 2nd quarter acoustic survey for sprat. The quarterly landings at age in numbers in SD 25, 26, 28 in the years 1977-2003 were from the area-disaggregated multi-species database (ICES 1997). The quarterly total landings in numbers (SD 25-29, 32) in these years were from the input data of a combined multispecies assessment (MSVPA). From 2004 onwards, the SD –specific quarterly landings were extracted from the WGBFAS reports.

SPRAT:
The data from acoustic surveys in SD 25, 26, 28 were available for Q2 for 2001-2010. For the 4th quarter, the survey data for SD 25, 26, 28 were available for 1978-2010. The northern areas (SD 27, 29, 32) were covered by acoustic survey in the 4th quarter in the years 2003-2010.
Survey distribution was applied for quarters and years were acoustic data were available. The distribution of sprat in landings in SD 25, 26, 28 in the 2nd and 4th quarter was not substantially different from the distribution of sprat in surveys in the same quarters (Fig. 3, 4). The distribution of sprat landings showed quarter-specific patterns from the 1990s onwards (Fig. 5). Therefore, for this period, the distribution of landings was applied for these years and quarters where survey data were not available, instead of borrowing survey information from other quarters. For the period before the 1990s, the distribution of landings showed large variations and inconsistencies. Therefore, the average annual landings distribution was applied for the years and quarters, where survey data were not available. Details of the data applied to obtain stock distributions for each year and quarter are detailed in Tables 6 and 7.

Table 6. Data sources of the relative distribution of sprat inside the area covered by SD 25, 26, 28, by quarter.

Quarter	Years	Data
Q1	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2010	Landings Q1
Q2	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2000	Landings Q2
	2001-2010	Acoustics Q2
Q3	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2010	Landings Q3
Q4	1974-1976	Same as 1977
	1977	Landings (average of quarters)
	1978-2010	Acoustics Q4

Table 7. Proportion of sprat in the northern areas of the central Baltic Sea (in SD 27, 29, 32).

Quarter	Years	Data
Q1	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2010	Landings Q1
Q2	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2010	Landings Q2
Q3	1974-1976	Same as 1976
	1977-1989	Landings (average of quarters)
	1990-2010	Landings Q3
Q4	1974-1976	Same as 1977
	1977-1989	Landings (average of quarters)
	1990-2002	Landings Q4
	2003-2010	Acoustic Q4

*1989 is based on average for 1988 and 1990
*1993 is based on average of 1992 and 1994

HERRING:
For herring, survey data were available only for the 4th quarter, for the years 1978-2010. In the 4th quarter, some differences in the distribution of herring within the area of SD 25,26,28 in landings and in survey data were apparent, though less pronounced for adults compared to the young fish (Fig. 6). Among the different quarters, the distribution of landings in the 1st , 2nd and 4th quarter was relatively similar. In the 3rd quarter, a relatively larger proportion of landings were taken in SD 25, and a lower proportion in SD 28 (Fig. 7). However, comparison of the level of landings in SD 25 and SD 28 indicates that the landings in SD 25 have been comparable in all quarters, whereas the landings in SD 28 in the 3rd quarter have been much lower compared to the other quarters (Fig. 8). The relatively low proportion of SD 28 in herring landings in the 3rd quarter can thus be due to low fishing effort. Therefore, the distribution of herring in the 4th quarter survey was applied for all quarters for the years when survey data were available.
The proportion of the total central Baltic herring landings (SD 25-29, 32) inside the area of SD 25,26,28 was similar in the 1st, 2nd and 4th quarter, with a relatively higher proportion inside the area of SD 25,26,28 in the 3rd quarter (Fig. 9). This pattern was considered to potentially due to relatively low fishing in the northern areas in the 3rd quarter (Fig. 10). Consequently , quarter-specific distribution of landings was applied for the 1st, 2nd and 4th quarter, to obtain the proportion of the stock inside the area of SD 25,26,28 and a corresponding proportion outside of this area (in SD 27,29,32). For the 3rd quarter, the distribution was based on the average distribution of landings in the other quarters. Details of the information applied to estimate the relative distribution of herring by SD are given in Tables 8 and 9.

Table 8. Data sources of the relative distribution of herring inside the area covered by SD 25, 26, 28, by quarter.

Quarter	Years	Data
Q1	1974-1976	Same as 1977
	1977	Landings (average of quarters)
	1978-2010	Acoustics Q4
Q2	1974-1976	Same as 1977

	1977	Landings (average of quarters)
	1978-2010	Acoustics Q4
Q3	1974-1976	Same as 1977
	1977	Landings (average of quarters)
	1978-2010	Acoustics Q4
Q4	1974-1976	Same as 1977
	1977	Landings (average of quarters)
	1978-2010	Acoustics Q4

*1993 is based on average of 1992 and 1994

Table 9. Proportion of the herring in the northern areas of the central Baltic Sea (in SD 27, 29, 32).

Quarter	Years	Data
Q1	1974-1976	Same as 1977
	1977-2010	Landings Q1
Q2	1974-1976	Same as 1977
	1977-2010	Landings Q2
Q3	1974-1976	Same as 1977
	1977-2010	Landings (average of quarters)
Q4	1974-1976	Same as 1977
	1977-2002	Landings Q4
	2003-2010	Acoustic Q4

Resulting relative distributions

The resulting relative proportions of the three species in SD 25, 26, 28 and in the area of SD 27, 29, 32, by quarter, are shown in figures 11 and 12.

References

ICES. 1997. Report of the Study Group on Multispecies model implementation in the Baltic. ICES Document CM 1997/J: 2.

ICES. 2005. Report of the Study Group on multispecies assessment in the Baltic (SGMAB) ICES Document CM 2005/H: 06.

FIGURES

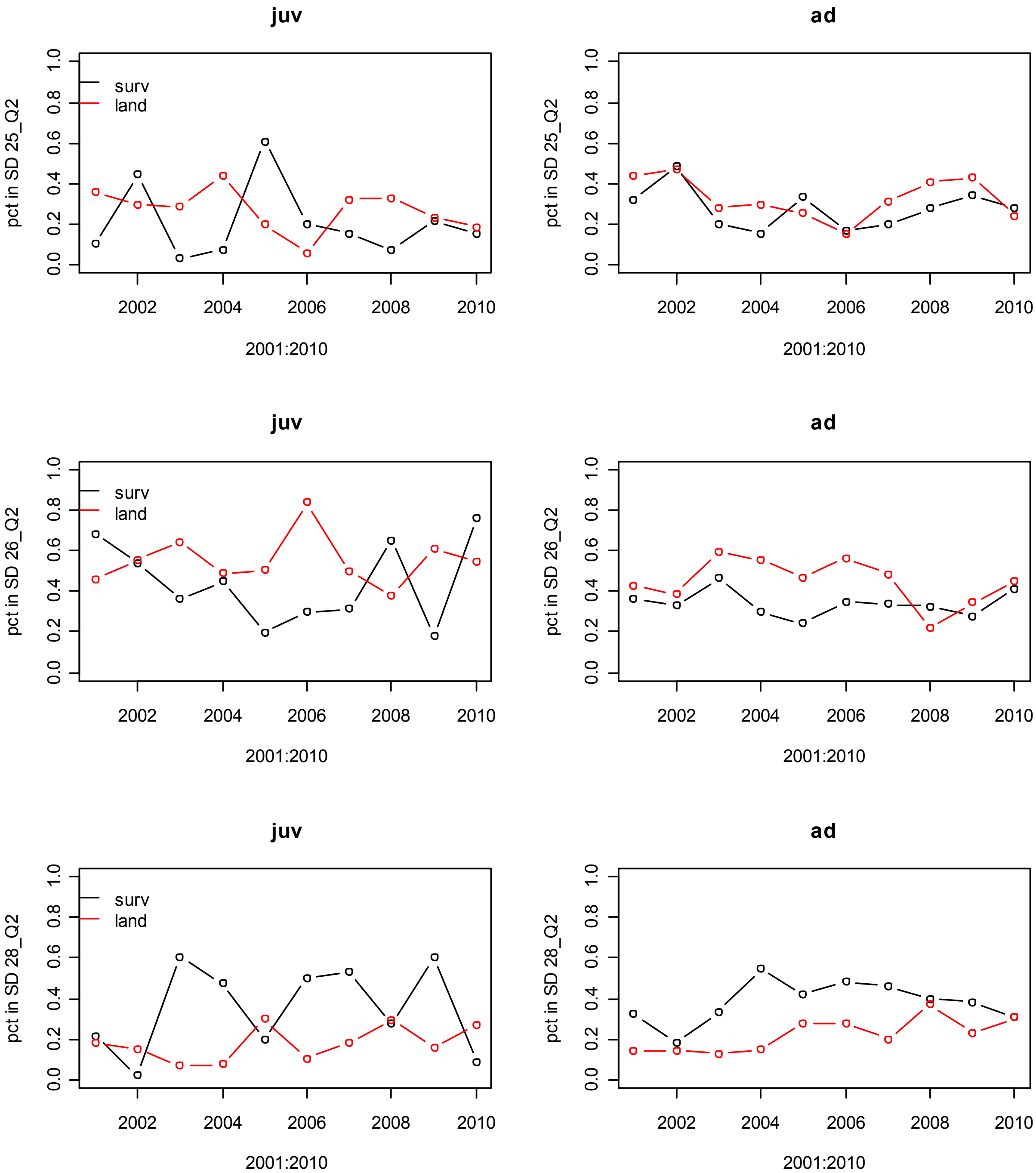

Figure 3. SPRAT: Distribution of sprat inside the area of SD 25, 26 and 28 in the acoustic survey and in the landings in the 2nd quarter, shown as a proportion of numbers in a given SD.

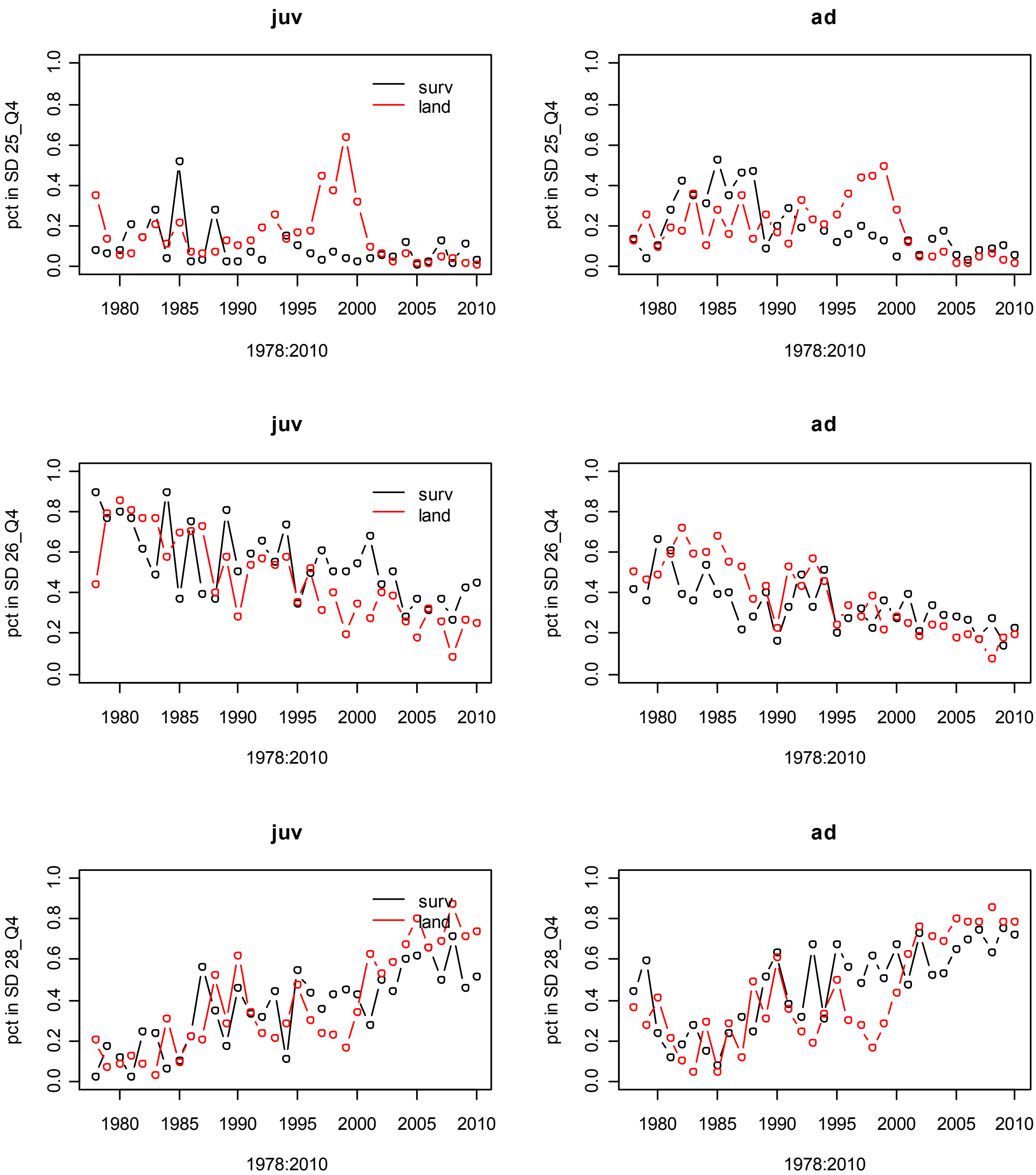

Figure 4. SPRAT: The distribution of sprat inside the area of SD 25,26,28 in the acoustic survey and in landings in the 4th quarter, shown as a proportion of numbers in a given SD.

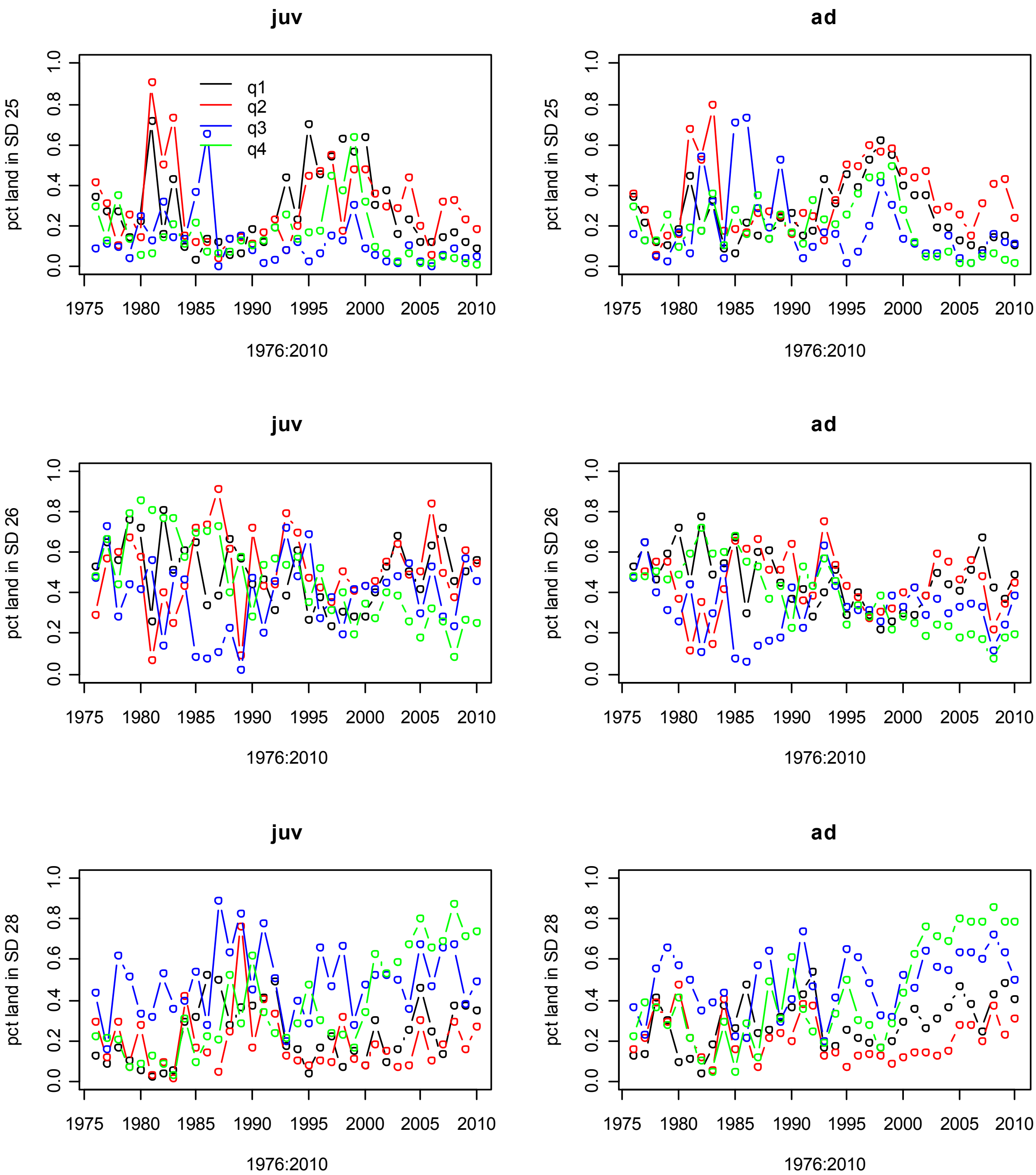

Figure 5. SPRAT: The distribution of sprat inside the area of SD 25,26,28 in landings, by quarter, shown as a proportion of numbers in a given SD.

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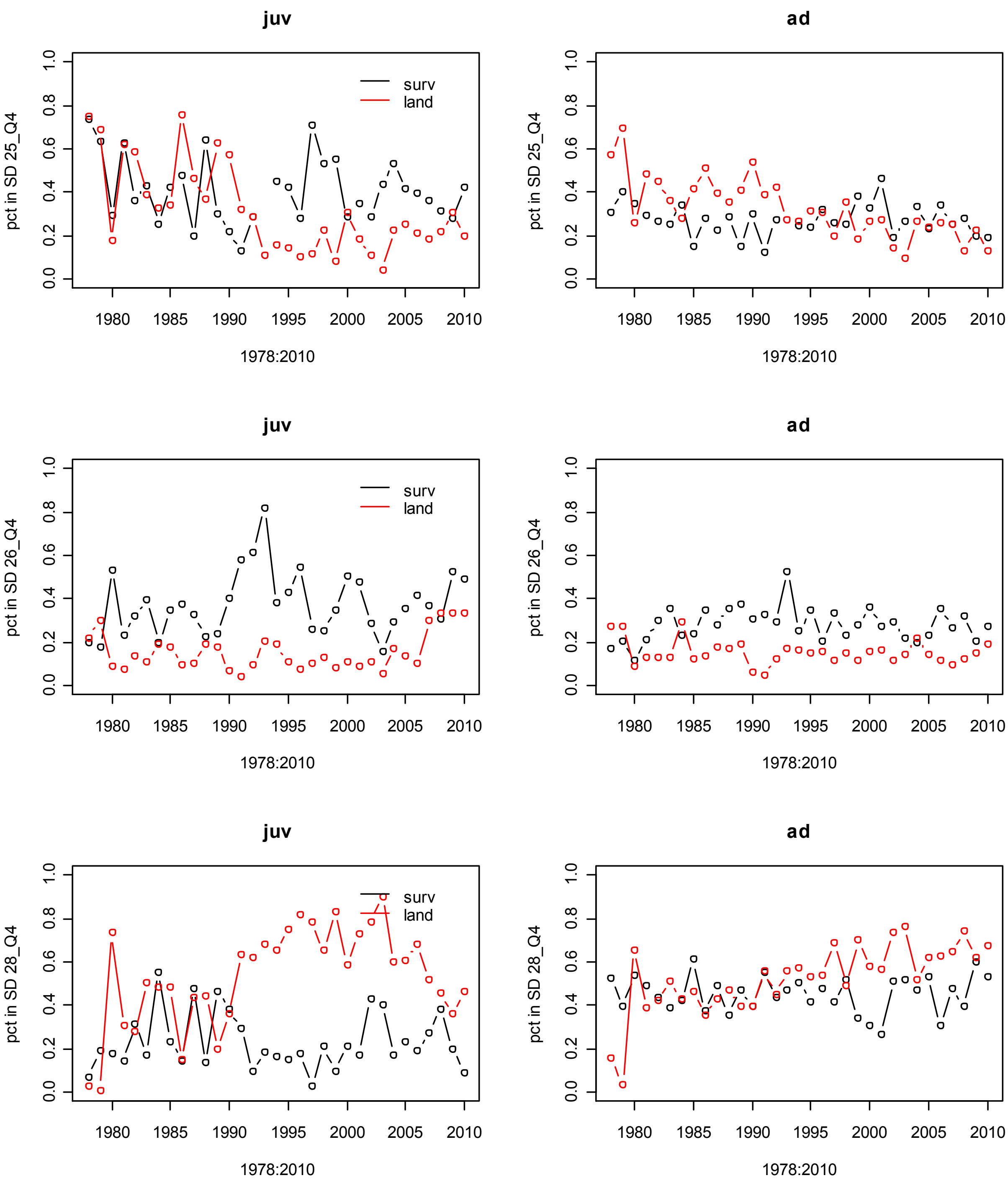

Figure 6. HERRING: The distribution of herring inside the area of SD 25,26,28 in the acoustic survey and in landings in the 4th quarter, shown as a proportion of numbers in a given SD.

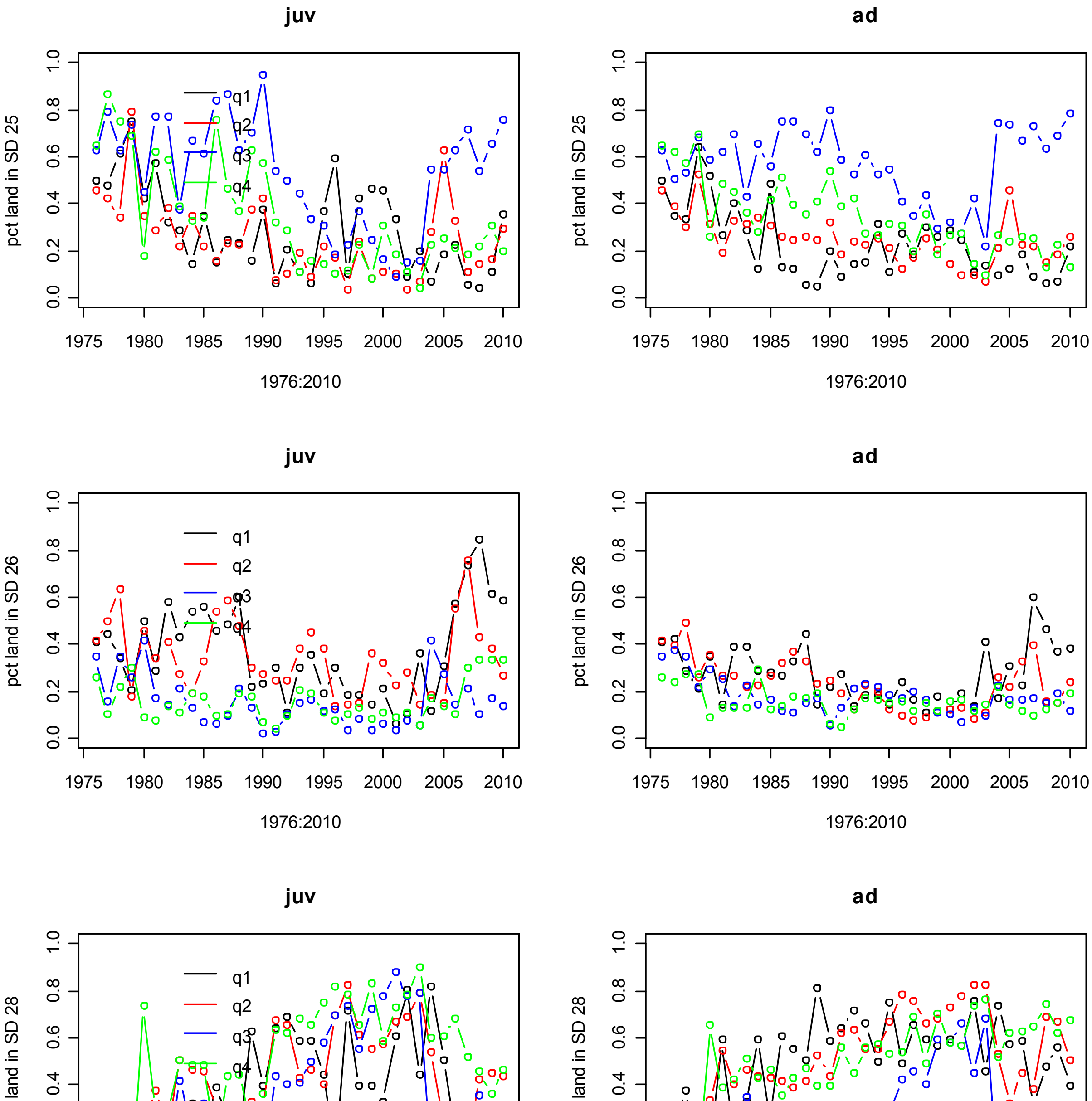

Figure 7. HERRING: The distribution of landings inside the area of SD 25,26,28, by quarter, shown as a proportion of numbers in a given SD.

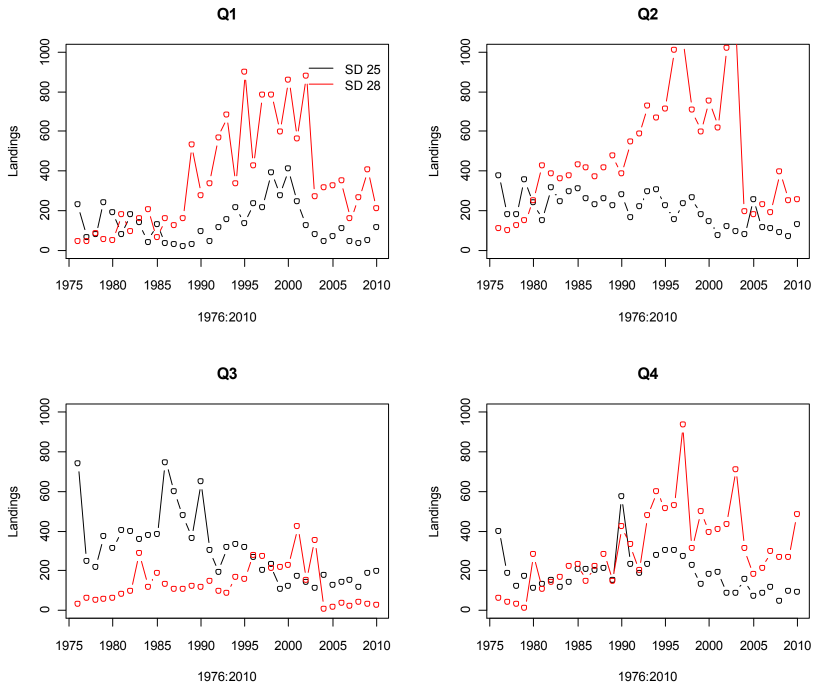

Figure 8. HERRING: Landings (in numbers) in SD 25 and SD 28, by quarter, for adult fish.

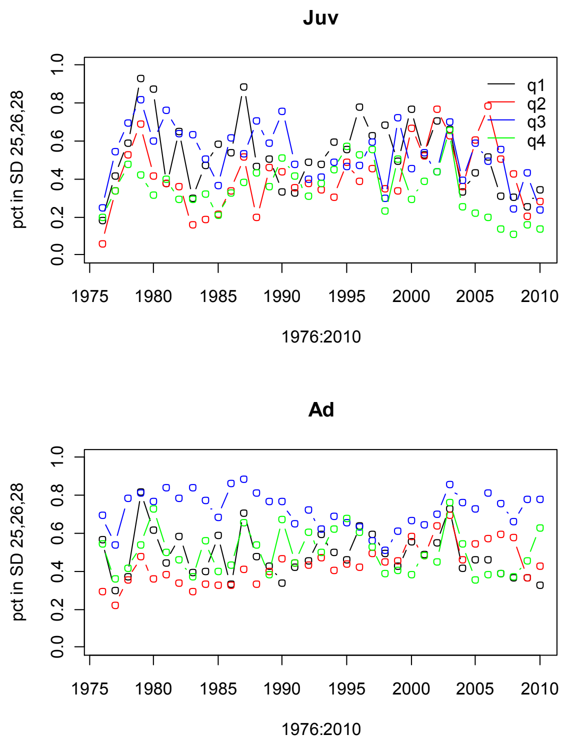

Figure 9. HERRING: Proportion of total central Baltic herring (SD 25-29,32) landings (in numbers) inside the area of SD 25,26,28, by quarters, for young and adult fish.

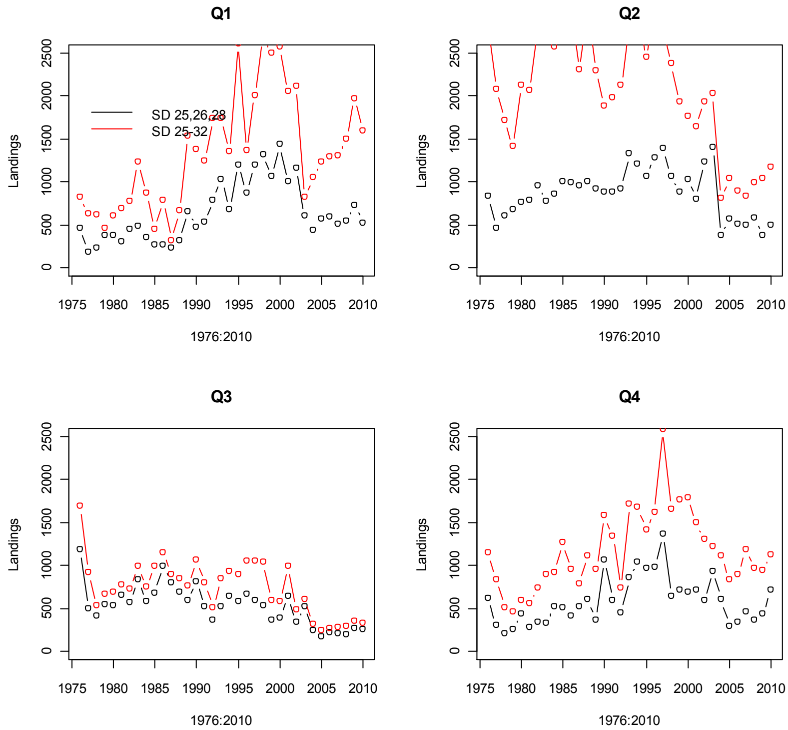

Figure 10. HERRING: Landings (in numbers) in the area of SD 25,26,28 compared to the landings in the total central Baltic (SD 25-29,32), by quarter, for adult fish.

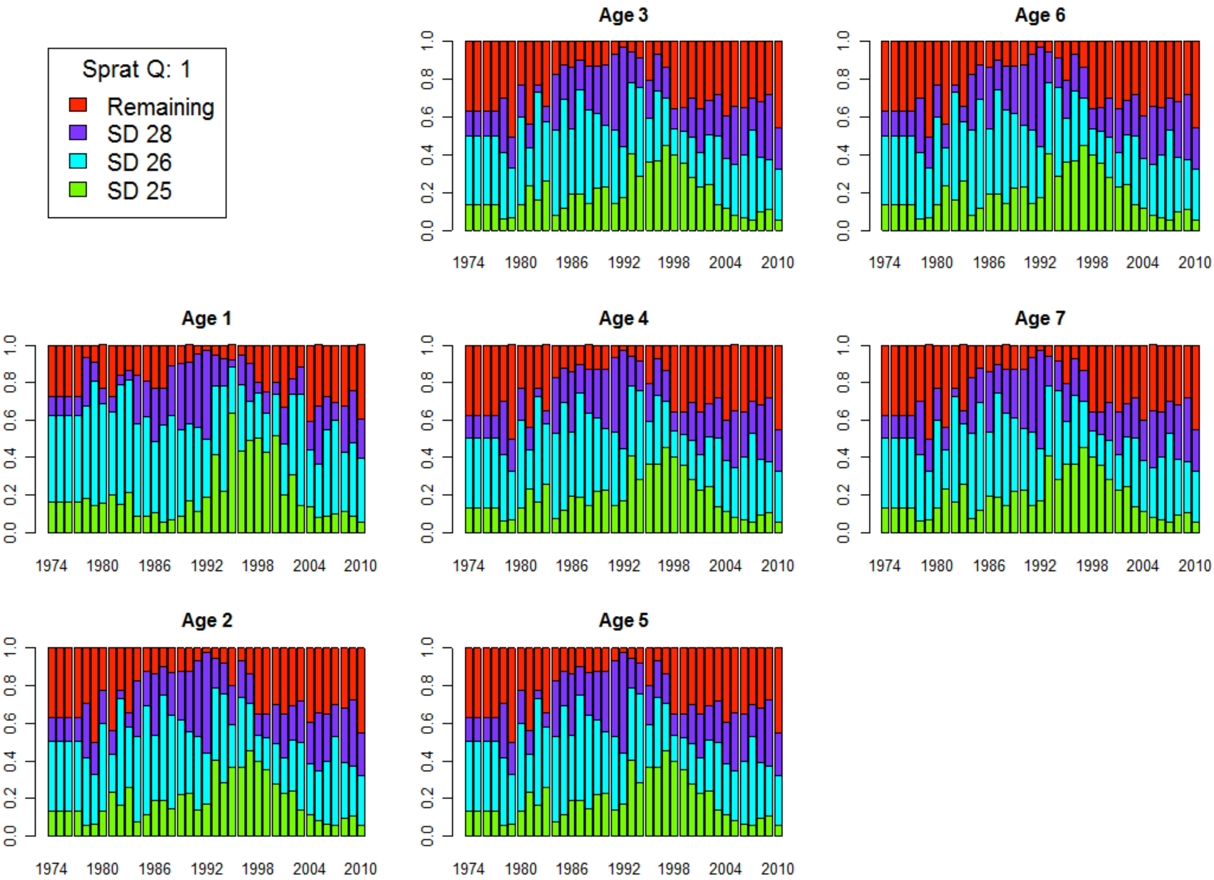

Figure 11a. Relative proportion of sprat in SD 25, 26, 28 and in the area of SD 27,29,32 in the 1st quarter.

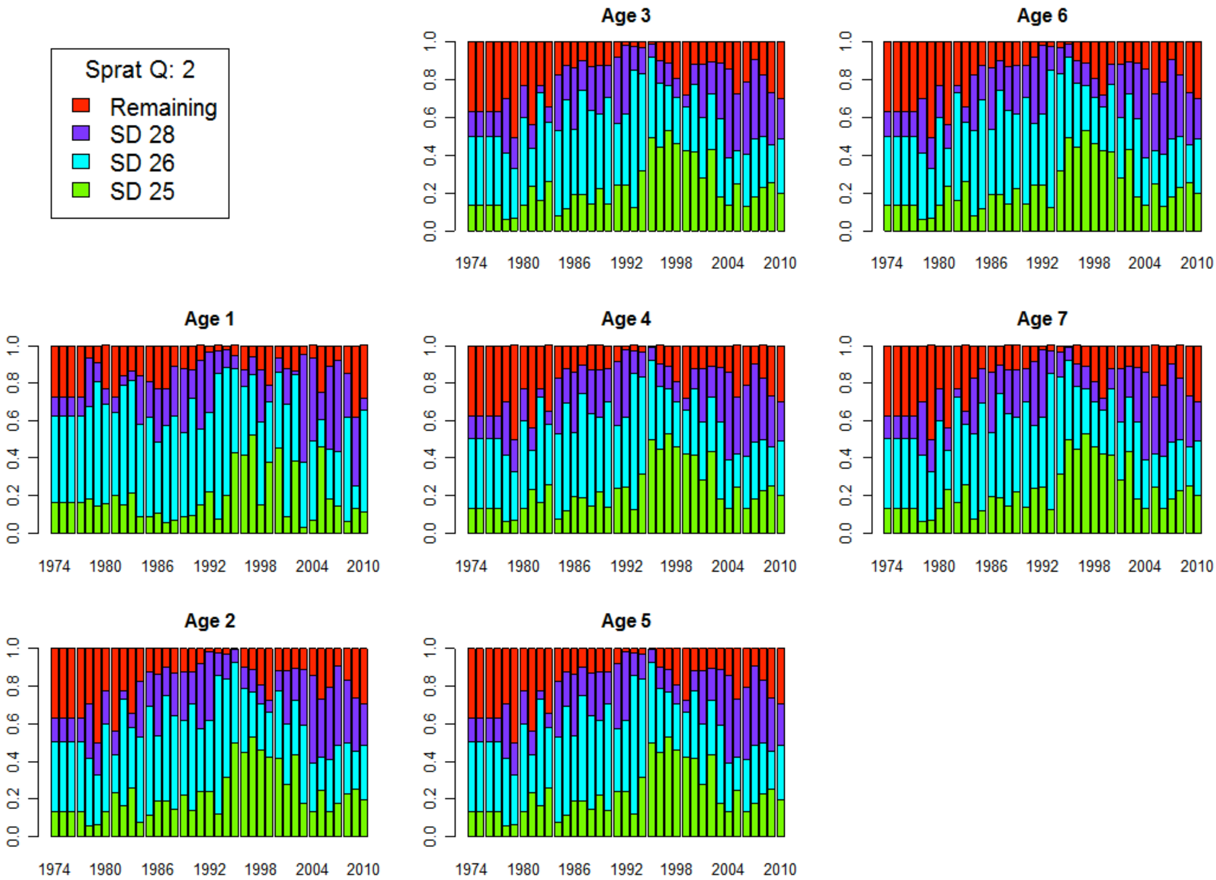

Figure 11b. Relative proportion of sprat in SD 25, 26, 28 and in the area of SD 27,29,32 in the 2nd quarter.

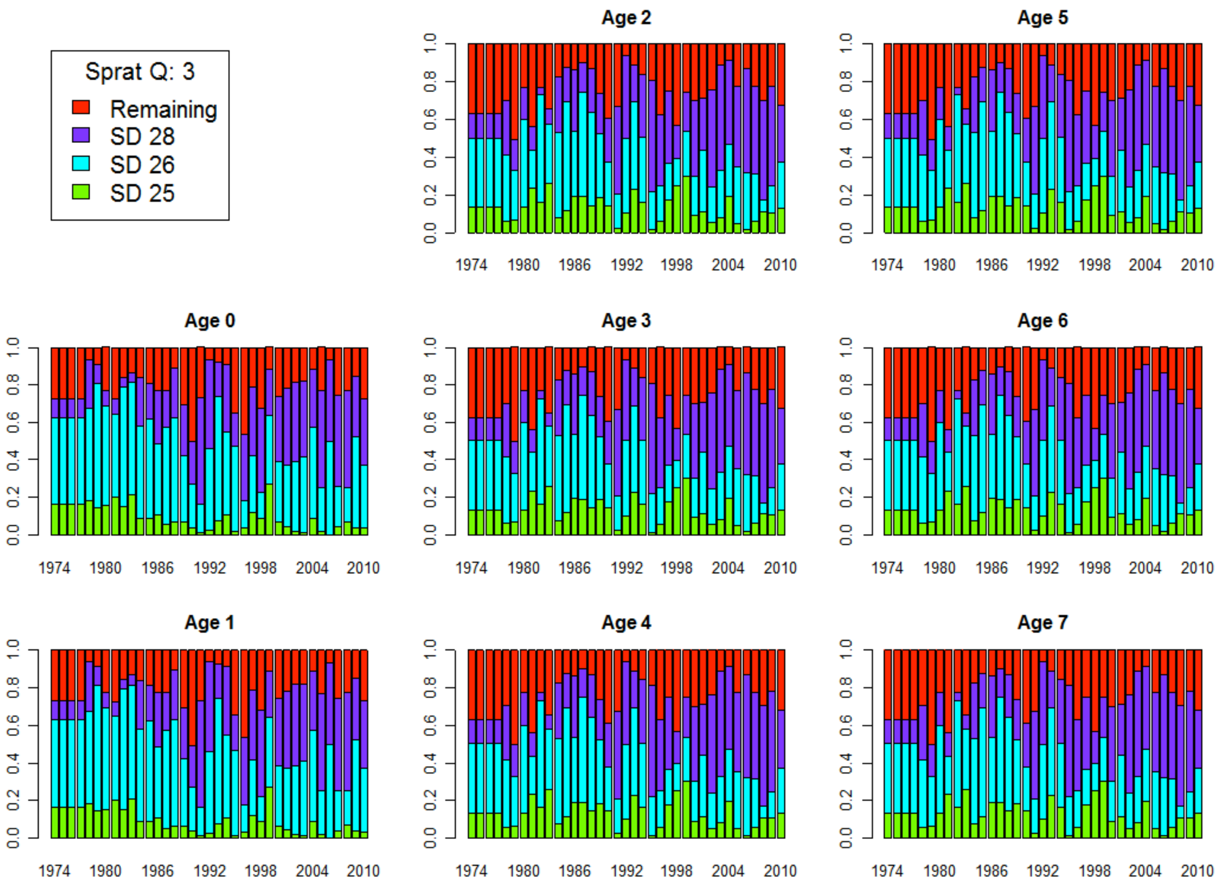

Figure 11c. Relative proportion of sprat in SD 25, 26, 28 and in the area of SD 27,29,32 in the 3rd quarter.

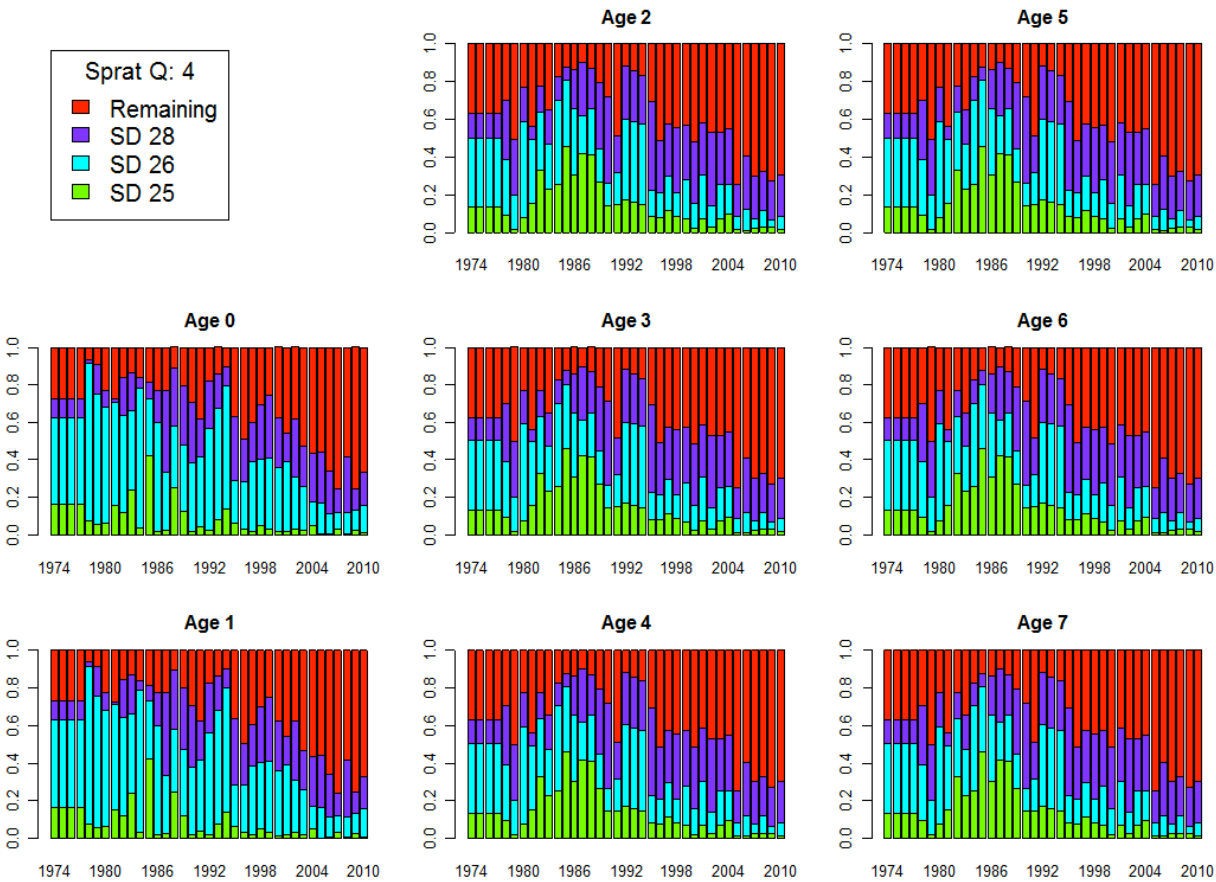

Figure 11d. Relative proportion of sprat in SD 25, 26, 28 and in the area of SD 27,29,32 in the 4th quarter.

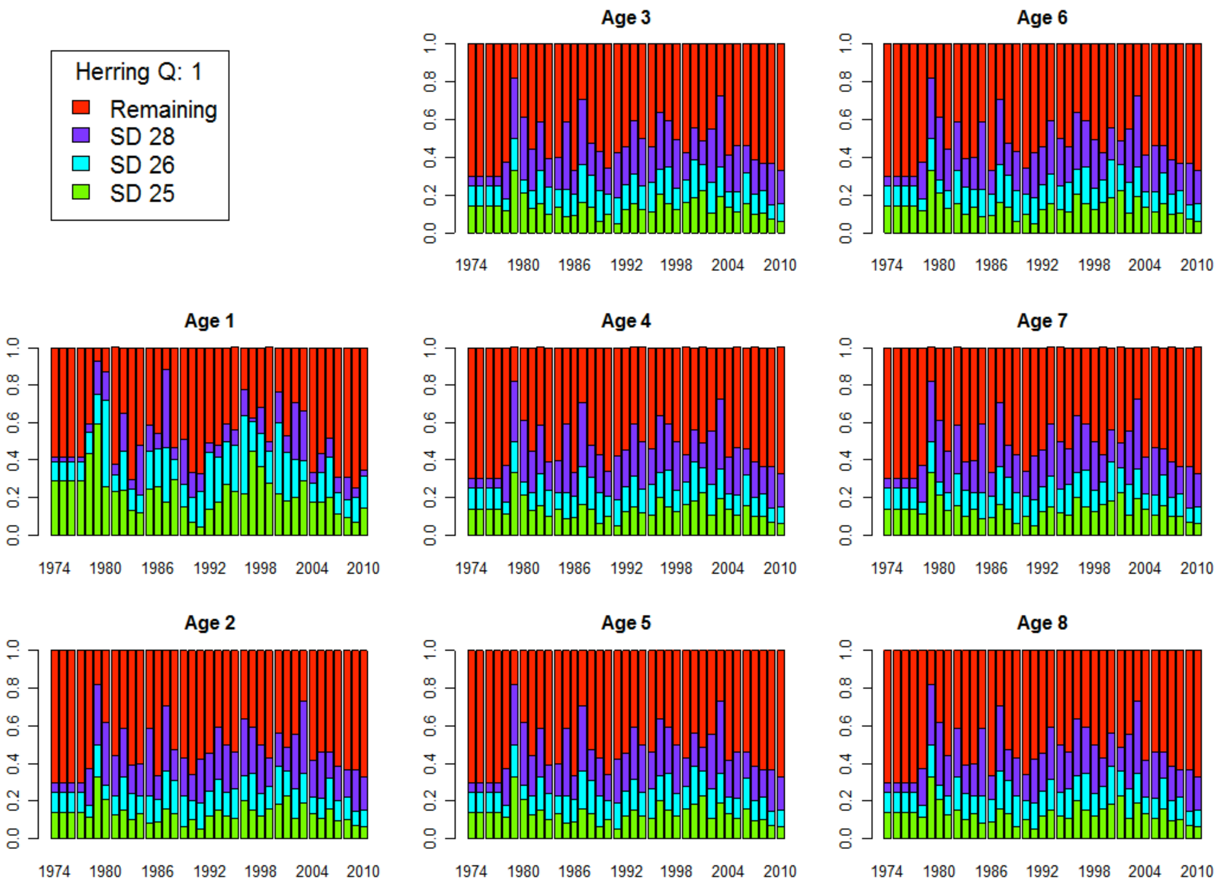

Figure 12a. Relative proportion of herring in SD 25, 26, 28 and in the area of SD 27,29,32 in the 1st quarter.

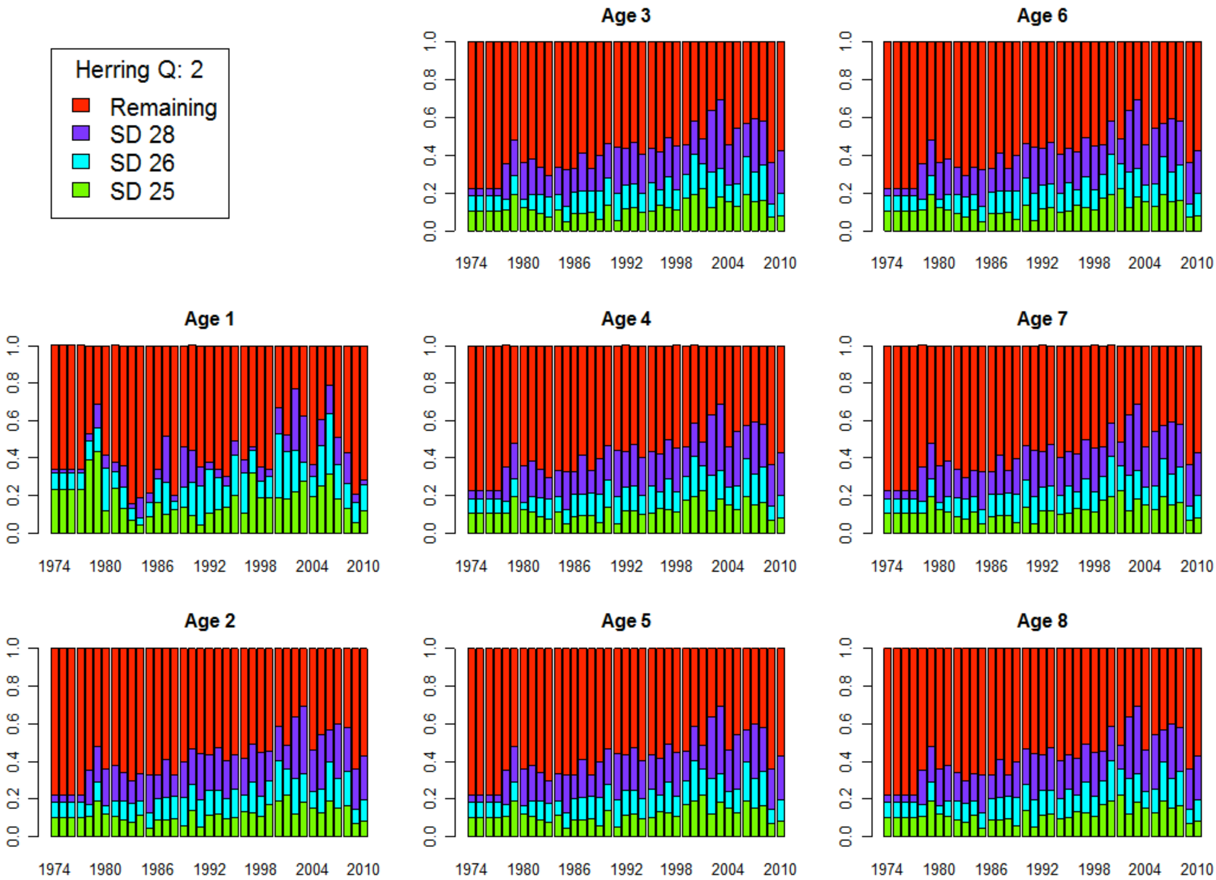

Figure 12b. Relative proportion of herring in SD 25, 26, 28 and in the area of SD 27,29,32 in the 2nd quarter.

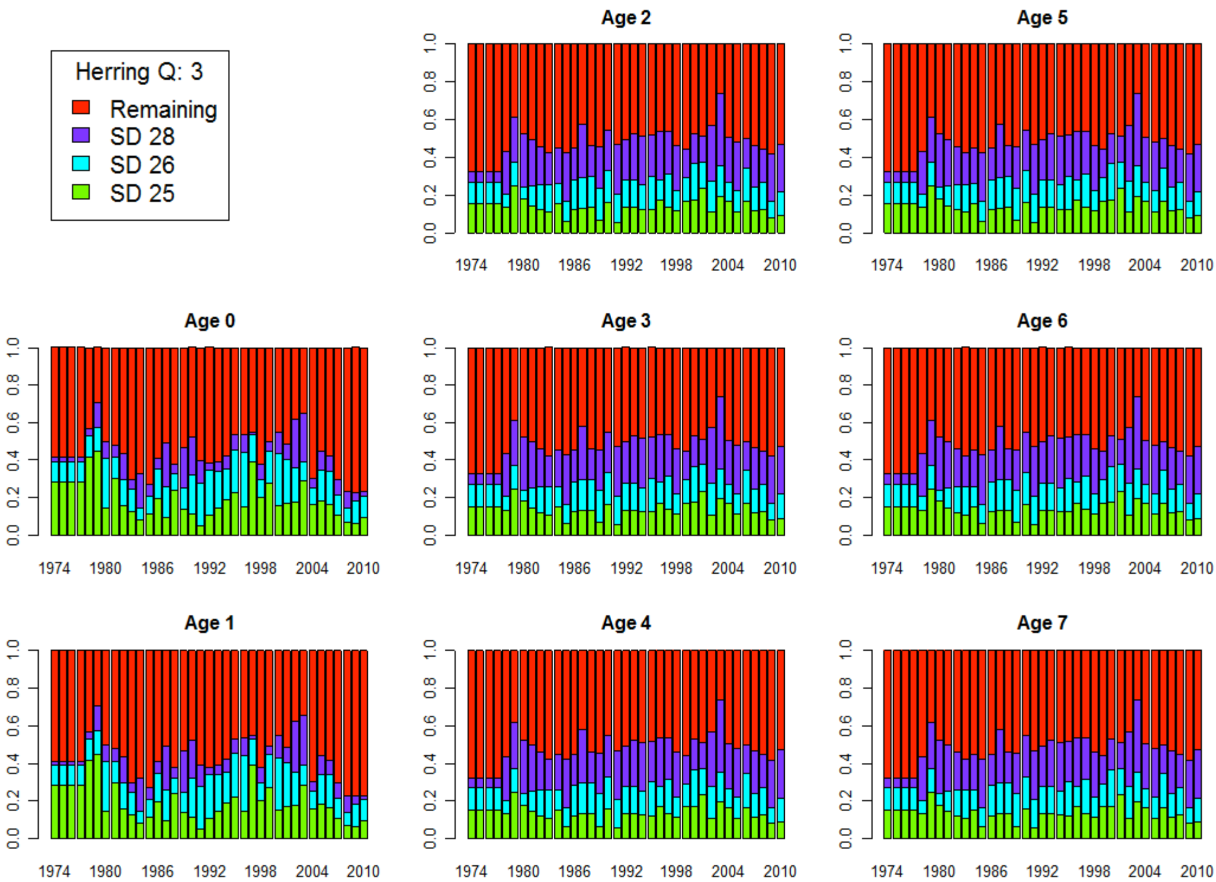

Figure 12c. Relative proportion of herring in SD 25, 26, 28 and in the area of SD 27,29,32 in the 3rd quarter.

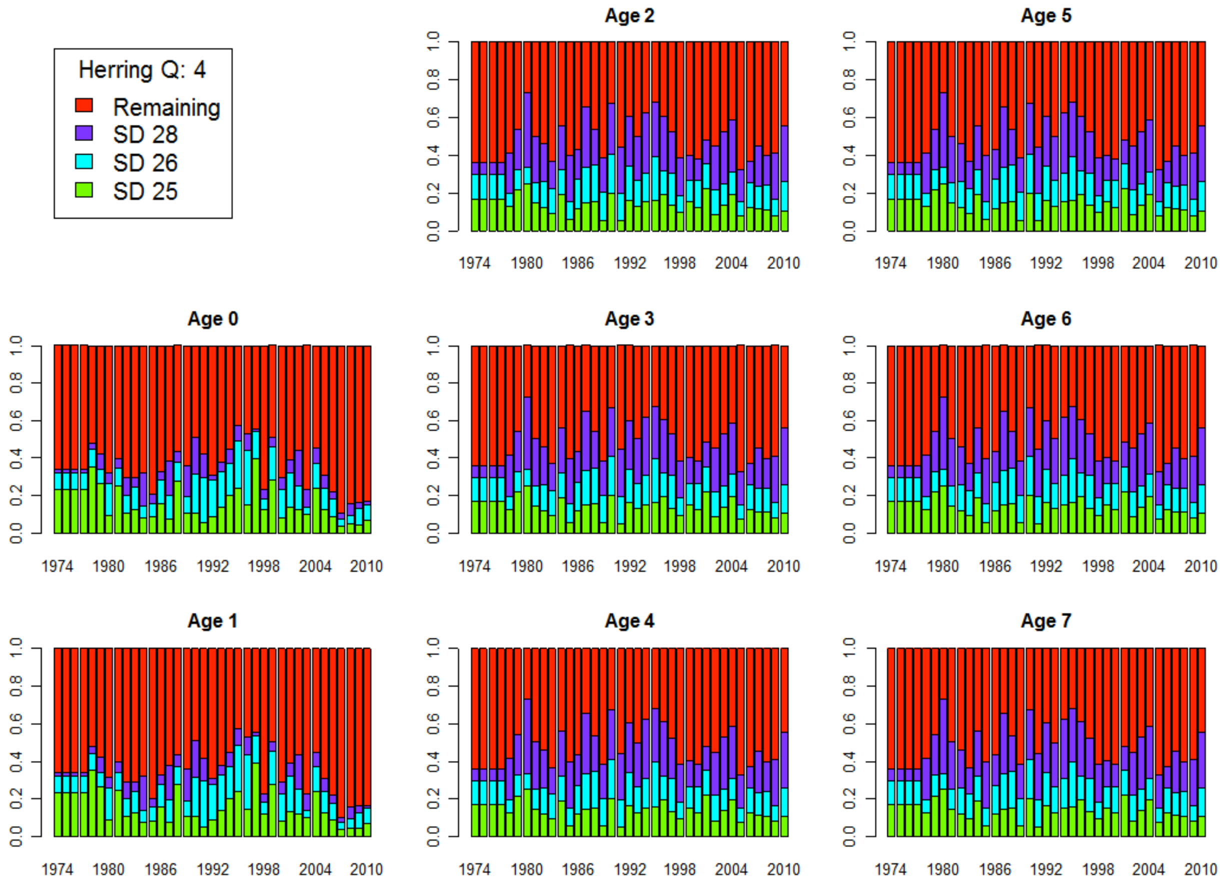

Figure 12d. Relative proportion of herring in SD 25, 26, 28 and in the area of SD 27,29,32 in the 4th quarter.

Appendix: BONUS metadatabase descriptors

No	Descriptor	Information
1	Title of dataset	Cod historical tagging data
2	General description of the dataset	The data include tagging experiments, both traditional and data storage tags (DST).
3	Keywords	Baltic, cod, tagging, migrations, data storage tags
4	Parameters in the dataset	Releasre recapture time and position; for DST temperature and pressure for individual cod every 10 mimnutes while at liberty.
5	Area covered	Whole Baltic Sea
6	Spatial resolution	Individual positions
7	Time span covered	1969-1985
8	Temporal resolution	Tagging data

9	Data quality	Computerized data from historical paper protocols
10	Date created	01-02-2015
11	Last update	01-02-2015
12	Availability	Project limited, upon request
13	Originator/Contact	Christian Möllmann, christian.moellmann@uni-hamburg.de
14	Location of dataset	UHAM, DTU AQUA, UT-EMI
15	Reference to sources other datasets	
16	BONUS Project	INSPIRE
17	WP	2