

# WKSPATIAL2 2016 REPORT

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## Report of the Workshop on Spatial Analyses for the Baltic Sea 2

8-10 November 2016

Riga, Latvia



**ICES**

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the Exploration of the Sea

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## Executive summary

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The ICES Workshop on Spatial Analyses for the Baltic Sea 2 (WKSPATIAL2) met in Riga, Latvia, 8-10 November 2016 (Chairs: Stefan Neuenfeldt, Denmark, and Michele Casini, Sweden), with 12 participants and 4 countries represented.

WKSPATIAL was held as second continuation of the Study Group on Spatial Analyses for the Baltic Sea (SGSPATIAL) that terminated its 3-year mandate in 2014. The broad aims of WKSPATIAL were to: 1) continue investigating the cod stomach contents from the EU tender with particular emphasis on the spatio-temporal changes, the relation to prey availability and environmental condition, and the link to cod growth/condition; 2) start investigating the relation between cod food intake and condition/growth, 3) continue investigating the spatial dynamics in quantitative and qualitative feeding of sprat and herring and identify their dietary overlap, and 4) investigate and identify possibilities for spatially-explicit multispecies models for fish species including the new stomach contents information.

Predator-prey overlap, juvenile cod growth and availability of benthic food were parameters suggested by WKSPATIAL2 to be included in future cannibalism models or multispecies models in which cannibalism is incorporated.

We calculated prey-type specific cod consumption rates and estimated trends in feeding levels for different lengths of cod, using the stomach database standardized in WKSPATIAL. Applying a simple bioenergetics growth model, we found that nowadays many small prespawning cod have feeding levels that imply severe growth inhibition that is then carried through life despite favourable feeding conditions for larger cod. While in 1975–1984, a 18 cm cod grew to 35 cm during 1 year, in 2005–2014 a 18 cm cod does almost not grow at all.

The cod stomach data standardized in WKSPATIAL were also used in Gadget multi-species assessment model. The model estimates fit well to the stomach data starting from late 1980s. The model detected a switch between the proportions of herring and sprat in the modelled diet of cod at the time of the regime shift in Baltic (late 1980s). Before the regime shift herring comprised a larger proportion in the cod diet than sprat did, while after the regime shift it became opposite. Spatially-explicit models will be built, being Gadget an area disaggregated platform.

Analyses of the relation between clupeid fish diet and prey availability showed that on average, the relatively richest food resource for herring and sprat, was observed in the Baltic Proper and the poorest in Gulf of Finland. The spatial dynamics in the taxonomic composition of herring and sprat stomachs broadly resembled that of the availability of prey. While the stomach fullness of sprat was relatively stable across the areas, that of herring was the highest in the eastern Gulf of Finland and the Irbe Strait area. Morisita dissimilarity index exhibited strong spatial variability and was generally the lowest in the eastern Gulf of Finland and often also in the Irbe Strait area.

## 1 Opening of the meeting

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The chairs Michele Casini (Sweden) and Stefan Neuenfeldt (Denmark) welcomed the participants (Annex 1). The chairs introduced the goals and focus of the meeting and the state of the different tasks to be conducted by the group.

The meeting has been given the following Terms of References (ToRs):

- Analyse the temporal and spatial variations in the stomach content of Baltic cod in relation to food availability and hydrological conditions;
- Analyse the relation between cod food intake and condition/growth;
- Investigate the spatial dynamics in quantitative and qualitative feeding of sprat and herring and identify their dietary overlap;
- Investigate and identify possibilities for spatially-explicit multispecies models for fish species including the new stomach contents information.

## **2 Adoption of the agenda**

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The chairs introduced the agenda which was shortly discussed, adjusted and finally adopted by the participants. However, a flexible agenda was adopted (Annex 2).

### 3 Introduction

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WKSPATIAL and WKSPATIAL2 were held as continuation of the Study Group on Spatial Analyses for the Baltic Sea (SGSPATIAL) that terminated its 3-year mandate in 2014 (ICES 2013a, 2013b, 2014).

Specifically, the focus of WKSPATIAL2 was to analyse the cod stomach content data collated and collected within the EU tender “Study on stomach content of fish support the assessment of good environmental status of marine foodwebs and the prediction of MSY after stock restoration” that run between 2012 and 2014. Moreover, in WKSPATIAL2 the temporal and spatial feeding habits of clupeid fish species and their diet overlap were characterized.

In June 2012, ICES has provided for the first time an example of multispecies advice for the Baltic Sea to the EU Commission. However, the models used for the multispecies advice were based on a very limited amount of cod stomach data, limiting their reliability. WKSPATIAL, analysing the newly compiled cod stomach data, is specifically intended to provide information on the spatio-temporal changes in cod predation on different food types (for ICES subdivision see Figure 3.1), its dependence to prey availability in the sea and hydrological conditions, the predator-prey ratios, and the factors that affect cod growth/condition. This information will improve the understanding of the Baltic Sea fish ecology and ecosystem functioning, and can be directly used to improve the current single-species (SAM, XSA) and multispecies (SMS, Gadget) assessment models, and therefore fisheries advice. The analyses of the stomach content data fulfilled the ToRs a) and b).

Another aim of WKSPATIAL was to analyse the features of the spatial and temporal feeding habits of pelagic fish and their diet overlap, and this was addressed by ToR c). Finally, WKSPATIAL identified possibilities for spatially-explicit multispecies models for fish species to include the new stomach contents information and this was addressed by ToR d).

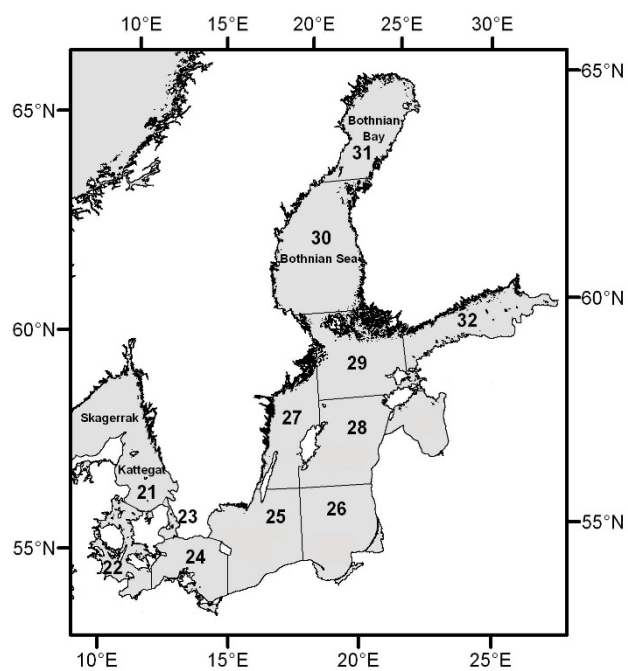


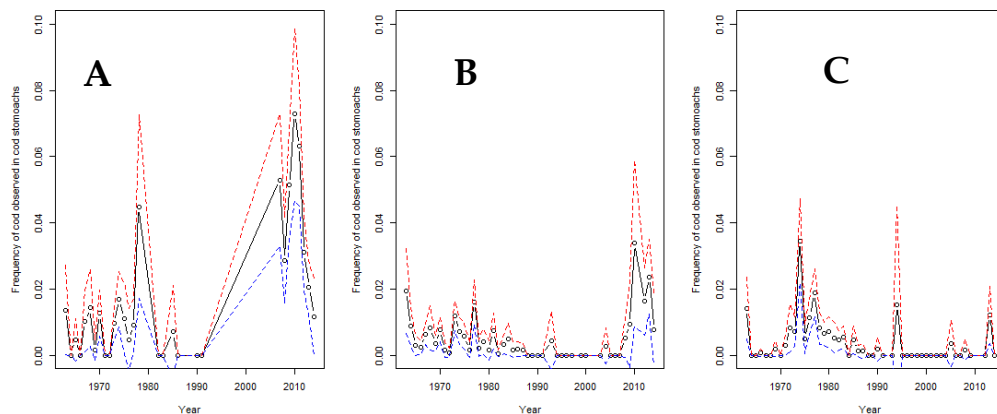
Figure 3.1. Map of the Baltic Sea with the ICES subdivisions (SDs).



## 4 Tor a) Analyse the temporal and spatial changes in the stomach content of Baltic cod in relation to food availability, hydrological conditions and cod body condition

### 4.1 Cannibalism of Eastern Baltic cod

As demonstrated in recent studies, juvenile mortality caused by cannibalism has increased (Köster *et al.*, 2016). This also is confirmed by the routine cod stomach sampling data analyses (Figure 4.1). Earlier studies identified that main factors affecting cannibalism frequency are related to recruitment or stock abundances (Neuenfeldt and Köster, 2000; Uzars and Plikshs, 2000). However, currently these factors cannot explain increased cannibalism alone as the large-scale ecosystem changes occurred in the Baltic leading changes in stock structure and biotic interactions (Eero *et al.*, 2014). This questions the perception on more complex nature of cannibalism. We suggest that recent cannibalism increase is related to key processes developed in the Baltic ecosystem. Therefore, the main aim is to reveal biologically argumentative pathways of direct and indirect effects of environmental and stock structure changes on cod cannibalism.



**Figure 4.1: Frequency of occurrence of cannibalism over time in cod stomach data in ICES Subdivision 25 (A), 26 (B) and 27 (C)**

The workshop based on present knowledge of key process and ecosystem changes in the Baltic, proposed flow chart allowing to investigate pathways of cannibalism dependencies (Figure 4.2).

The additional links to recruitment and adult cod abundance that required to be considered in cannibalism model are proposed:

1. Overlap of predator and prey (Neuenfeldt and Beyer, 2006; Horn, 1966). Due to extension of anoxic area recent decades (Carstensen *et al.*, 2014) the suitable habitat for cod decreased that assumes possible increase of juveniles and adult cod overlap in time and place and higher vulnerability to predation;
2. Juvenile cod growth. Decrease of cod growth suggests that smaller size cod has longer period to be vulnerable to predation of adult cod;
3. Changes in benthic food availability. Due to extension of anoxic area benthic invertebrates get less importance in food. Under such conditions the benthic fish (also juvenile cod) may have higher importance. Additionally, cod condition factor decrease (Casini *et al.*, 2016) may limit ability of cod to feed on pelagic fish due to higher energy costs. Swimming endurance of cod is markedly affected by fish condition, with starved fish swimming only 30% of the time (and distance) of fed fish (Martinez *et al.*, 2003).

WKSPATIAL2 suggests that due to Baltic hydrographic heterogeneity these pathways should be evaluated by principal basins, e.g. Bornholm, Gdańsk, and Gotland, because stock, environment and cannibalism interactions in each of them may differ.

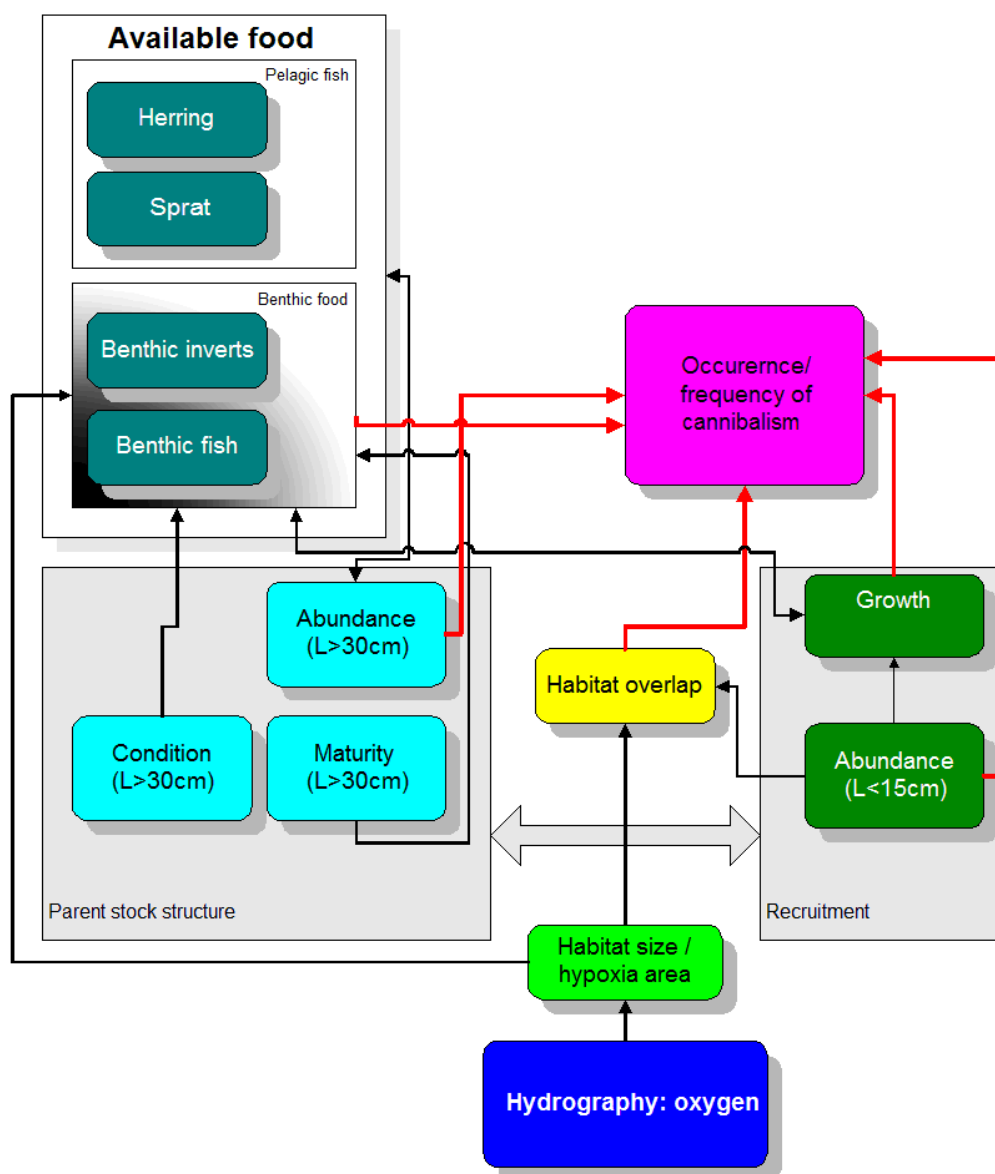


Figure 4.2. Theoretical flow-chart of cod cannibalism determining factors for Baltic cod. Red arrows indicate links for future detailed analyses.

#### 4.2 Extent of hypoxia and anoxia in the Baltic Sea, based on the annual SMHI report, updated and revised.

The Baltic Sea is suffering from a lack of oxygen. The oxygen deficiency is most wide spread in deep basins in the Baltic Proper, Gulf of Finland, and the Gulf of Riga. The limited inflows of high saline and oxygen rich water from the North Sea and the high freshwater input cause a strong stratification of the water column that prevents ventilation of the deep water. The strong stratification in combination with eutrophication and other factors forms the basis for the problematic oxygen conditions that are found in the Baltic Sea.

Anoxia is the condition when all oxygen is consumed by microbial processes and hydrogen sulphide ( $H_2S$ ) is formed, which is toxic for all higher marine life. Only bacteria

and fungi can survive in a water environment with total absence of oxygen. During anoxic conditions nutrients, such as phosphate and silicate, are released from the sediments to the water column, which, due to vertical mixing, can reach the surface layer and the photic zone. High concentrations of phosphate favour phytoplankton growth, especially cyanobacteria in the Baltic Sea during summer which can further enhance the oxygen depletion as the bloom sinks to the bottom and consume oxygen to decompose.

Oxygen depletion or hypoxia occurs when dissolved oxygen falls below the level needed to sustain most animal life. The concentration at which animals are affected varies broadly and in literature studies (Vaquer-Sunyer and Duarte, 2008) the threshold for hypoxia range from 0.2 ml/l to 2.8 ml/l. However, the sublethal concentration ranges from 0.06 ml/l to 7.1 ml/l. The mean and median for all experimental assessments was  $1.8 \pm 0.12$  ml/l and  $1.6$  ml/l  $\pm 0.15$  respectively. It has also been shown that Baltic cod eggs need at least 2 ml/l oxygen for successful development (MacKenzie *et al.*, 2000; Nissling, 1994; Plikshs *et al.*, 1993; U.S. EPA, 2003; U.S. EPA, 2000). In this analysis the limit of hypoxia is set to 2.0 ml/l.

Since 2011 SMHI (Hansson *et al.*, 2011) has published annual calculations on hypoxic and anoxic areas and affected volume of deep water in the Baltic Sea.

#### Data

The calculations are based on hydrographic data collected during the annual Baltic International Acoustic Survey (BIAS) complemented by data from national and regional monitoring programmes with contributions from most countries in the Baltic region.

Data from the BIAS cruises are well suited for concurrent oxygen surveys because of the vast spatial distribution of sampling occasions and since cruises are performed by different countries, almost all parts of the offshore Baltic Proper are monitored. The surveys are also performed during the autumn period (September/October) when the oxygen situation usually is most severe. Hence, this is an essential contribution of oxygen data, complementing the regular national and regional monitoring performed monthly at fixed stations.

#### Method

To process the dataset a few station profiles had to be filtered out: for example when data were missing in the deep water or when questionable data were found.

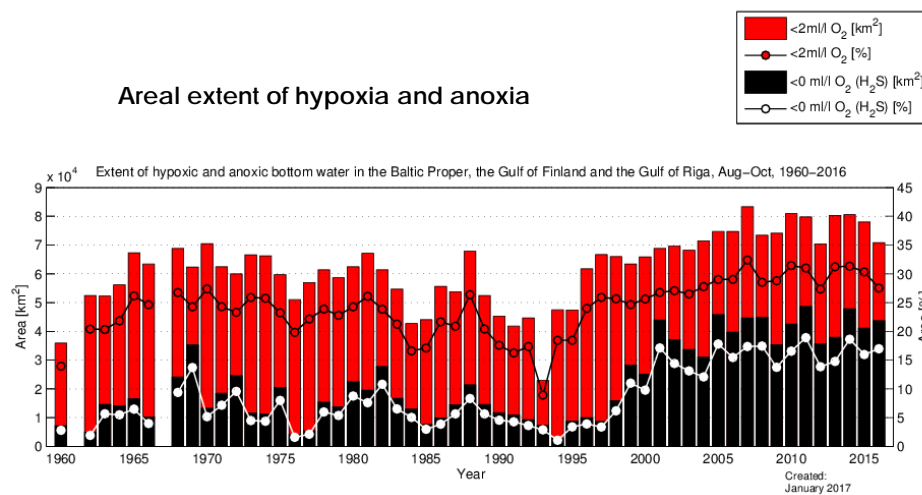
During autumn (August to October), each vertical profile including at least three data points, was examined for the occurrence of hypoxia ( $<2$  ml/l) and anoxia ( $<0$  ml/l). To find the depth of the onset of hypoxia and anoxia in each vertical profile, interpolation between discrete measurements in the profile was used. If hypoxia or anoxia was not found in the profile, the two deepest measurements in the profile were used to linearly extrapolate the oxygen concentration down towards the bottom. If two or more profiles were found at the same position an average profile was calculated for that position.

The depths of the onset of hypoxia and anoxia were gridded with linear interpolation (Delaunay triangulation) between sampling stations, producing a surface representing the depth at which hypoxic and anoxic conditions are found. The calculations do not account for the existence of oxygenated water below an anoxic layer. The surface has then been compared with bathymetry data, (Seifert, 2001) to exclude profiles where the hypoxic and anoxic depths were greater than the actual water depth. After filtering the results, the affected area and volume of hypoxia and anoxia have been calculated for

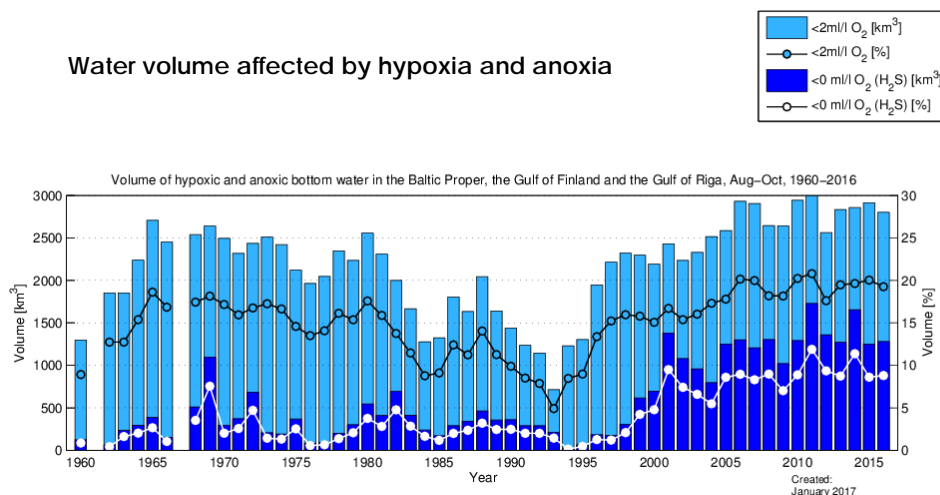
each year. Areal extent and volumes are presented in relation to the area and volume of the Baltic Proper, including the Gulf of Finland and the Gulf of Riga (Fonselius, 1995).

## Results

Extent and volume affected by hypoxia and anoxia between 1960 and 2016 are presented in Figures 4.3 and 4.4, respectively. The results have been used as a proxy for benthos availability within the GADGET model. Please add results in connection to this time-series.



**Figure 4.3.** Areal extent of anoxic and hypoxic conditions in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

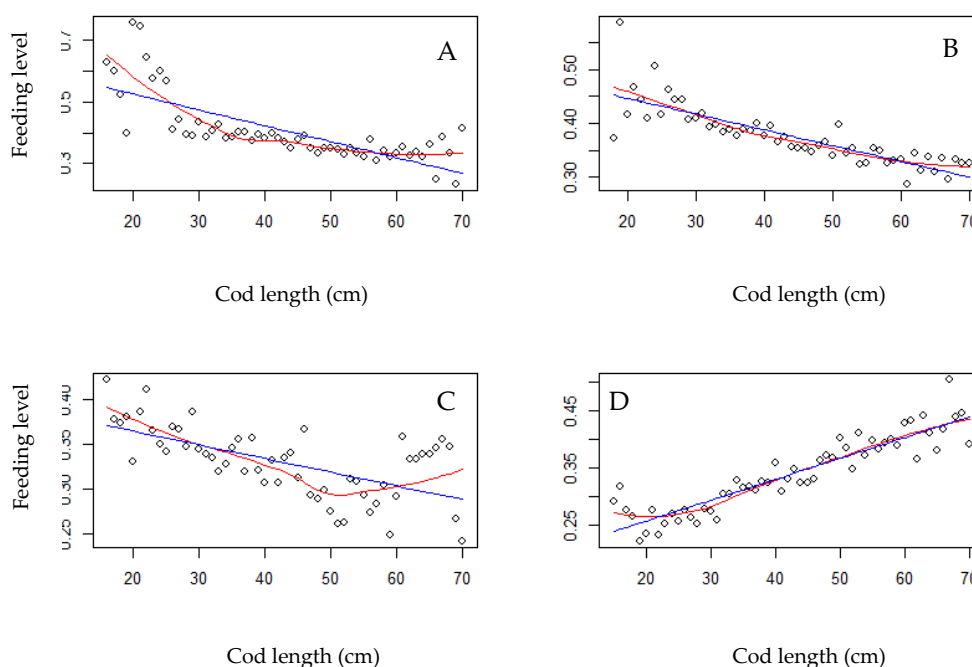


**Figure 4.4.** Volume of anoxic and hypoxic deep water in the Baltic Proper, Gulf of Finland and Gulf of Riga. Results from 1961 and 1967 have been removed due to lack of data from the deep basins.

## 5 Tor b) Analyse the relation between cod food intake and condition/growth

Simple density-dependence in predatory populations predicts that the *per capita* prey density limits predator average somatic growth. Most predators change their prey as they grow. Hence, density-dependence in an early life stage might create a growth deficit that is carried through life history. These processes are usually difficult to measure and their mechanisms difficult to understand *in situ*. We used five decades of stomach content data giving detailed insight into changes in diet composition and energy uptake of Atlantic cod in the Eastern Baltic Sea from 15 cm to 80 cm total body length during periods of inflow stagnation, decreased benthic productivity, and strongly varying population abundances of cod and Baltic sprat (*Sprattus sprattus* L.), the main fish prey for cod. As hypoxia progressed, the abundance of benthic food in the diet of small cod decreased. In parallel, cod initiated piscivory at an earlier stage of their lives (WKSPATIAL, 2016).

We calculated prey-type specific cod consumption rates and estimated trends in feeding levels (Figure 5.1). Preceding the observed drop in Baltic inflow frequency, large cod had the lowest feeding levels, but the negative trend in feeding levels during life history has been reversed. While the feeding level of large cod remained more or less constant, the feeding levels of small cod (15 cm–40 cm total length) decreased continuously during the time-series, simultaneously to the oxygen depletion of the deeper water.



**Figure 5.1** Feeding level (observed daily consumption relative to maximal daily consumption) of cod over cod length for 4 different periods: A 1975–1984, B 1985–1994, C 1995–2004, D 2005–2014.

Applying a simple bioenergetics growth model, we found that nowadays many small pre-spawning cod have feeding levels that imply severe growth inhibition that is then carried through life despite favourable feeding conditions for larger cod. While in

1975–1984 a 18 cm cod grew to 35 cm during 1 year, at the same time increasing its bodyweight from 50 g to 500 g, in 2005–2014 a 18 cm cod does almost not grow at all (Figure 5.2).

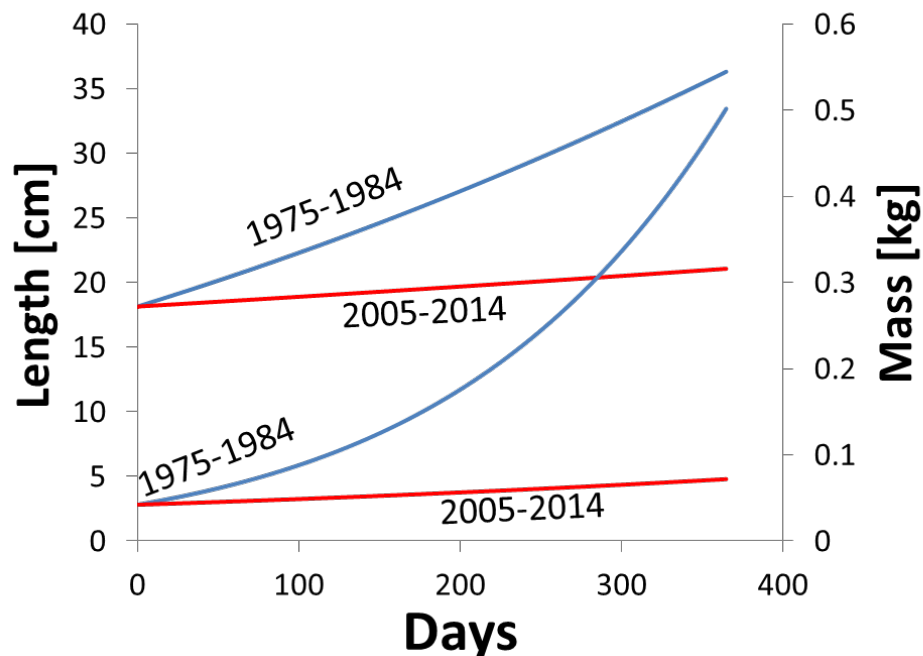


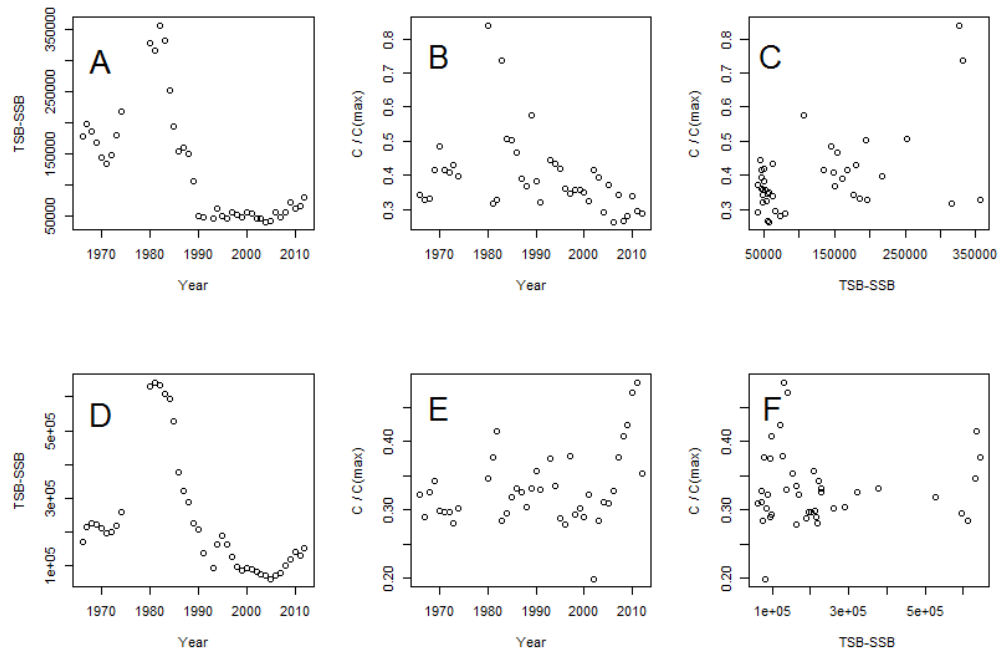
Figure 5.2 Cod growth in length and mass based on a bioenergetic model using observed stomach content data for the period 1975–1984 (blue) and 2005–2014 (red).

The decrease in cod growth is often described as result of density-dependence (Svedäng and Hornborg, 2016). The question is then: what exactly is density-dependence? When during life history is it limiting growth? And finally, assuming as supported by the data that density-dependence limits growth of relatively small and young cod, how is the growth deficit transported through life history?

When it comes to feeding, the limiting factor is the per predator capita numbers of available and accessible prey specimen. This factor depends both on predator density and prey density. While predator (cod) density can be regulated by fisheries management, the density of prey especially for small cod (benthos) depends on environmental forcing outside the short-term manageability by any environmental policy.

As a starting point, feeding levels of small (15–40 cm) and large (>40 cm) cod were put in relation to cod biomass (Figure 5.3). Neither biomass of non-spawners appears related to feeding level of non-spawner (figure 5.3C), nor shows feeding level of spawners a relation to spawning-stock biomass (Figure 5.3F). The absence of a straightforward relationship (as e.g. in Lorenzen and Engberg, 2001) in combination with the actually observed decreases in growth implies that the processes below are more complicated, and most probably related to prey densities.

These prey densities vary over time, and hence manipulating the predator (cod) density might, independent of whether small or large or both are protected, not necessarily generate the desired conservation effect.



**Figure 5.3: Direct density-dependence in feeding level. A** Non-spawner (TSB-SSB) biomass over time for cod 15–40 cm, **B** feeding level for cod 15–40 cm, **C** Biomass vs. feeding level for cod 15–40 cm. **D-F** the same for cod >40 cm.

## 6 Tor c) Investigate the spatial dynamics in quantitative and qualitative feeding of sprat and herring and identify their dietary overlap

Feeding habits of herring and sprat and their diet similarity was investigated in the northeastern Baltic Sea in the five transects (12 trawls) during one survey in July 2015. The study was carried out within the EU BONUS INSPIRE project (<http://www.bonus-inspire.org/>).

### Material and methods

Herring and sprat were collected from 30-minute hauls by pelagic commercial trawl (mesh size 10 mm) during the daytime in July 2015. In total, 12 trawls were performed in 5 transect locations studied (Figure 6.1 and Table 6.1). From each haul, up to 10 herring and 10 sprat individuals per 0.5 cm length group were collected for further analysis. In total, stomachs of 970 sprat and 556 herring were inspected. Fish were stored immediately after catch in 4% formaldehyde solution. Zooplankton samples were obtained from each trawling station by vertical tows of Juday net (mouth surface area 0.1 m<sup>2</sup>, mesh size 90 µm) from bottom to surface. The collected sample was stored in 4% formaldehyde solution.

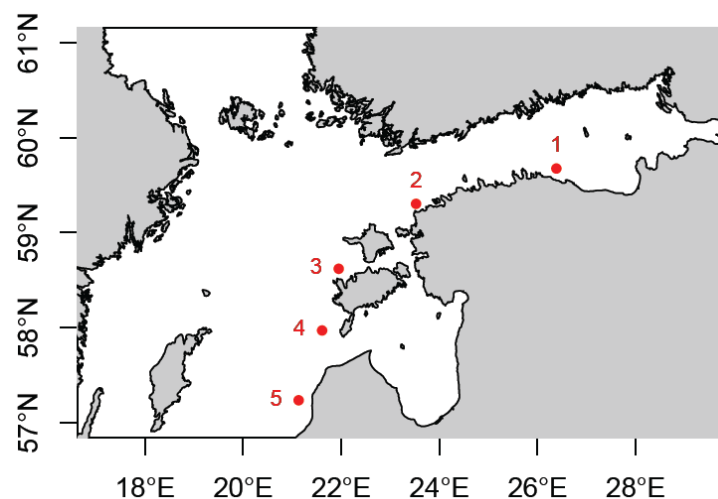


Figure 6.1. Map with locations of transects of the clupeid feeding survey in July 2015. For sampling details, see Table 6.1.



Table 6.1. Information on sampling stations and zooplankton sampling.

Location number	Location name	Survey date	Trawl no.	Trawl coordinates		Station depth	Zooplankton sampled (m)
1	Eastern Gulf of Finland	12.07.2015	1	59°44′	26°29,2′	64	60-0
1	Eastern Gulf of Finland	12.07.2015	2	59°37′	26°17′	38	38-0
2	Western Gulf of Finland	13.07.2015	3	59°18,4′	23°41′	50	50-0
2	Western Gulf of Finland	13.07.2015	4	59°18′	23°22′	50	50-0
3	Saaremaa island	14.07.2015	5	58°41,3′	21°49,6′	50	50-0
3	Saaremaa island	14.07.2015	6	58°35,4′	22°07,8′	37	37-0
3	Saaremaa island	14.07.2015	7	58°34,9′	21°53,5′	40	40-0
4	West of Irbe Strait	14.07.2015	8	58°03,3′	21°48,2′	34	30-0
4	West of Irbe Strait	15.07.2015	9	57°59,3′	21°32,6′	50	48-0
4	West of Irbe Strait	15.07.2015	10	57°52,2′	21°29,2′	60	55-0
5	Ventspils	15.07.2015	11	57°14,5′	21°06,4′	60	47-0
5	Ventspils	15.07.2015	12	57°13,9′	21°09,6′	40	35-0

The total length and weight of fish, and the wet weight of whole stomach content were measured. Stomach content analyses were performed according to Melnitchuk (1980). Larger prey items (*Gammaridae*, fish larvae, fish) were weighted to a precision of 0.001 g and counted separately. The remaining part (mesozooplankton) was diluted in water and subsample was counted in the Bogorov chamber under binocular microscope like an ordinary plankton sample.

Zooplankton samples were analysed according to the guidelines outlined by HELCOM COMBINE (<http://www.helcom.fi/action-areas/monitoring-and-assessment/manuals-and-guidelines/combine-manual>). In the current study, zooplankton biomass was expressed as mg/m<sup>3</sup>.

Based on the availability of fish in the samples, sprat and herring were divided into the following groups: small sprat (<10 cm), large sprat (>10 cm), small herring (<12 cm) and large herring (>12 cm).

Feeding intensity was measured as stomach fullness ( $I_{SF}$ ), calculated for each individual, and the percentage of empty stomachs per trawl and fish group. Stomach fullness was calculated as  $I_{SF} = 100M_F/M$ , where  $M_F$  is the total stomach content wet mass, and  $M$  the fish wet mass in grammes. The dietary patterns of fish were described by the relative proportion ( $I$ ) of the main prey taxa in the stomachs.  $I$  was calculated for each prey item only over positive cases (excluding zero proportions):  $I = 100S_i/S$ , where  $S_i$  is the mass of a given zooplankton taxa and  $S$  is the total stomach content mass.

Potential competition for food between herring and sprat was evaluated as dietary overlap using the Morisita dissimilarity index:  $C_H = 1 - 2 \sum p_{ij}p_{ik} / (\lambda_j + \lambda_k) \sum p_{ij} \sum p_{ik}$ , where  $\lambda_i = \sum p_{ij}(p_{ij} - 1) / \sum p_{ij} \sum (p_{ij} - 1)$ .  $C_H$  is the Morisita similarity index between fish  $j$  and  $k$ , and  $p_{ij}$  and  $p_{ik}$  are the proportion resource  $i$  of the total resources used by two species ( $i = 1, 2, 3, \dots, n$ ).

#### 6.1.1.1.1 Initial results

1. An average, the relatively richest food resource for herring and sprat, was observed in the Baltic Proper (transects 3–5) and the poorest in transects 1 and 2 (Gulf of Finland, Figure 6.2).
  1. Spatial dynamics in the taxonomic composition of herring and sprat stomachs broadly resembled that of the availability of prey. The copepod *Eurytemora affinis* strongly dominated in fish stomachs in the eastern Gulf of Finland while in the Baltic Proper, *Temora longicornis* played the most important role in fish diet together with *Acartia* spp. (Figure 6.2)
  2. While the stomach fullness of sprat was relatively stable across the 5 transects, that of herring was the highest in the eastern Gulf of Finland and the Irbe Strait area (Figure 6.3).
  3. The proportion of empty stomachs was far the lowest on transect 4 (Irbe Strait area). Large herring seems to be generally starving (over 80% fish have empty stomachs, except transect 4) while the percentage of empty stomachs in case of small sprat is usually below 20% (Figure 6.4).
  4. Morisita dissimilarity index exhibited strong spatial variability and was generally the lowest in the eastern Gulf of Finland and often also in the Irbe Strait area. The diet similarity appeared to be the highest between large sprat and large herring, large sprat and small herring, and small and large herring (0.25–0.26). The least similar diet was observed for small and large sprat (0.37).

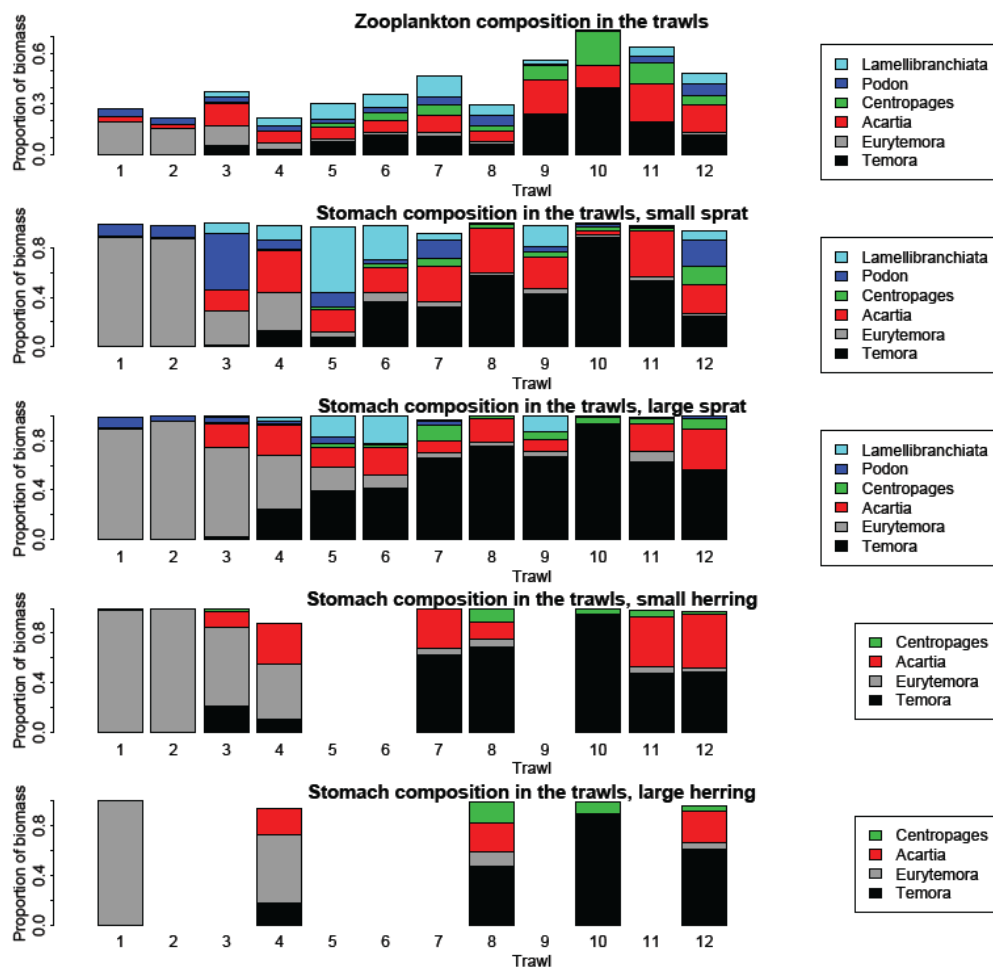


Figure 6.2. Proportion of biomass of the main clupeid prey in zooplankton community (uppermost panel) and in sprat and herring stomachs by trawls.

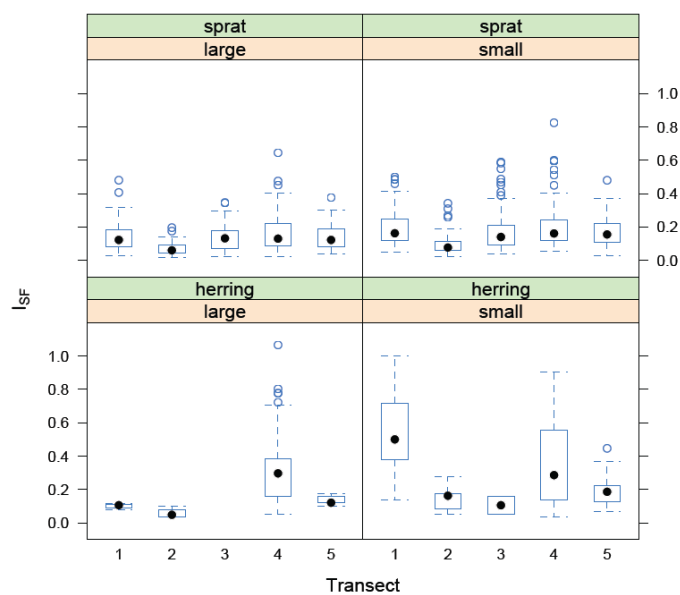


Figure 6.3. Stomach fullness index of small and large herring and sprat by five transect locations.

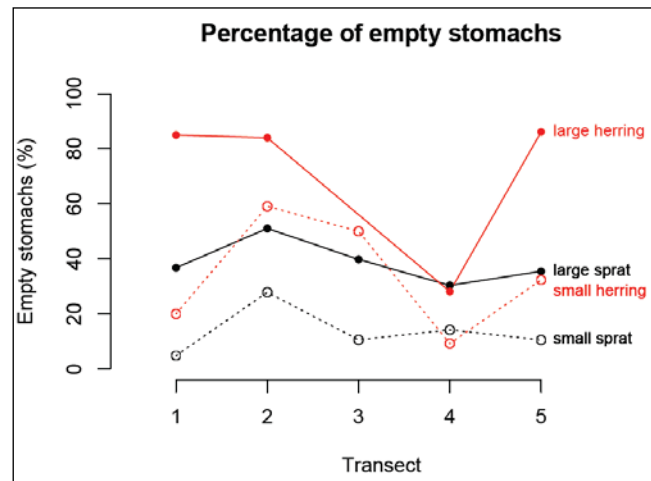


Figure 6.4. Percentage of empty stomachs of small and large herring and sprat at five transect locations

## 7 Tor d) Investigate and identify possibilities for spatially-explicit multi-species models for fish species including the new stomach contents information

Globally applicable Area Disaggregated General Ecosystem Toolbox (Gadget) may be a candidate platform for spatially-explicit multispecies model. It is very flexible and allows including various components of ecosystem: interactions between species, impact of environmental variables, impact of fisheries, etc. Having initial parameter values, Gadget run a forward projection model, compare estimates to observation and calculates likelihood scores depending on how well the fit was, then re-adjust parameter values and re-run the model until optimum parameter values are found which produce the best fit of the model to the most of components (Begley, 2005).

We built a multispecies model in Gadget which comprises of 3 species: cod (eastern Baltic stock), herring (central Baltic) and sprat. Model runs for 1974–2013, with a quarter step size and uses whole Baltic Sea (ICES SD 25-32) as a single area.

All three species grow according to von Bertalanffy growth function. Parameters in the model are fixed to estimates of single-species models with only natural mortalities ( $M$ ) of the clupeids being estimated to be downscaled to account for contribution from cod predation. For herring the entire vector of  $M$  is reduced of 20% with the exception of age 0, while for sprat the vector of  $M$  was reduced by 12–18% compare to the vector used in the single species model. Selected groups of parameters have been estimated in different runs of the multispecies model with the only purpose to verify that single species estimates still hold in the multispecies implementation.

The predator–prey interaction represented in our cod-herring-sprat model is regulated by two main aspects, the consumption and the prey size selection. Different consumption rates have been proposed for cod using data from different areas and applying empirical models based on different assumptions. Bogstad and Mehl (1990) investigated the impact of alternative gastric evacuation models for cod in a multispecies framework (MULTSPEC) and showed how different models and assumptions could result in largely different estimates of prey consumed.

After comparison of the gastric evacuation models performance using the cod stomach data from the Baltic: we selected the model proposed by Jones (1978) – which derived from empirical studies on cod in the North Sea – to estimate the daily evacuation rate ( $R$ ) of cod:

$$R = 0.16 * (L / 40)^{1.4} * S^{0.46} * 24 \quad (1)$$

where:

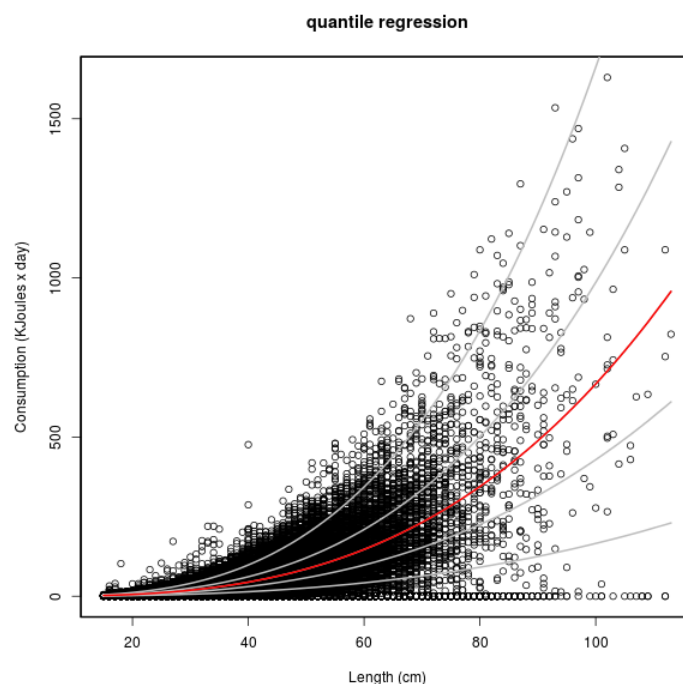
<  $L$  > is the cod length <  $S$  > is the stomach weight

Consumption in Gadget are described by few functions, among which are maximum consumption, feeding level of predator, which reflect the proportion of available food being consumed, and availability of prey, which is a function if prey biomass and selection by predator (based on length of predator and prey).

The model for the maximum consumption ( $M$ ) implemented in Gadget is

$$M(L) = m_0 * dt * e(m_1 * T - m_2 * T^3) * L^{m_3} \quad (2)$$

which was simplified assuming no effect of temperature ( $m_1 = m_2 = 0$ ). The parameters  $m_0$  and  $m_3$  were estimated using the consumption rates calculated from the Jones's gastric evacuation model. The parameters  $m_0$  and  $m_3$  were calculated based on quantile regression (Figure 7.1). Although the maximum consumption regulates the maximum amount of prey that cod is able to eat in a certain time interval (expressed in KJoules) we decided to select the 0.5 quantile rather than a higher quantile as the estimates appear more in line with daily consumption estimates from a number of experimental and fieldwork (Jobling 1988; Uzars, pers. comm.). Very little is known about other parameters of the consumption such as the “half-feeding” value which was fixed to 0 and the other food component which was fixed to  $1e10$ . The issue will certainly require further work at both the level of data and on the implementation of consumption in Gadget. The estimation of the maximum consumption parameters, assuming no effect of temperature resulted in  $m_0 = 2.4e-02$  and  $m_3 = 2.96$ .

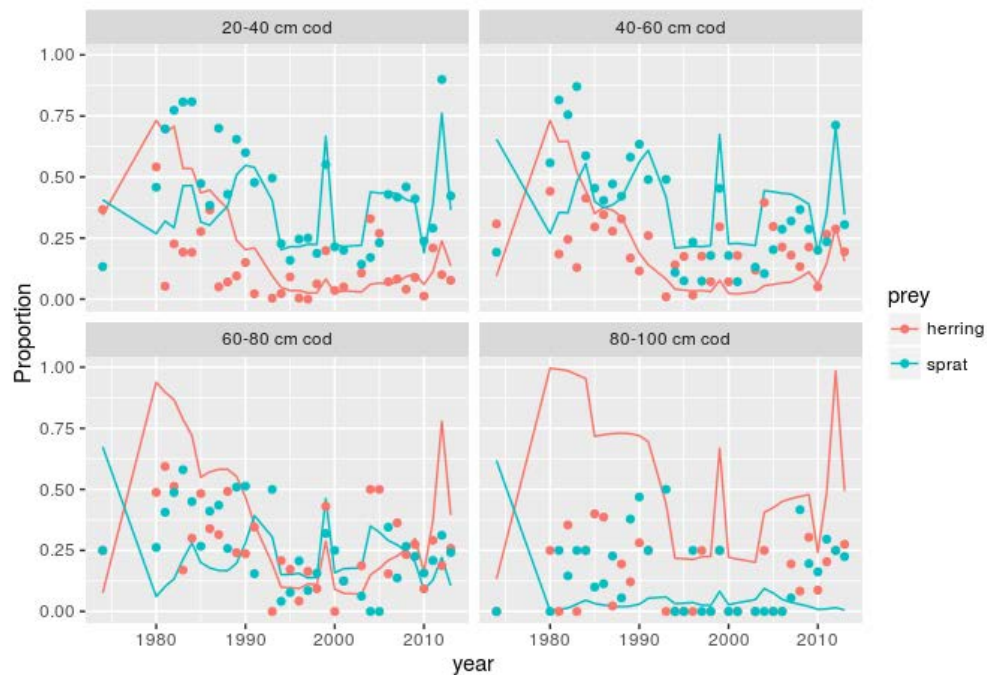


**Figure 7.1.** Cod consumption in relation to cod size as estimated from the Jones' gastric evacuation model. The grey lines represent the 0.05, 0.25, 0.75, 0.95 quantiles and the red line the 0.5 quantile used to implement cod consumption.

Cod diet composition is informed in the model by the cod stomach data. The ratio of the presence of herring and sprat in the stomachs is calculated for four cod length groups 20–40 cm, 40–60 cm, 60–80 cm, 80–100 cm by 1 cm length aggregation of the preys. In practice, the model compares the observed and modelled ratio of stomachs with sprat and herring of different length in different size classes of cod (Figure 7.2).

Our model estimates fit well to the stomach data starting from late 1980s, however it does not fit to the data concerning the largest cod size class (80–100 cm). This may be explained by the lower sample size of cod of this size class. An interesting result is a switch between the proportions of herring and sprat in the modelled diet of cod at the time of the regime shift in Baltic (late 1980s). Before the regime shift herring comprised a larger proportion in the cod diet than sprat did, while after the regime shift it became opposite. This switch happens at the beginning of time-series (early 1980s) in the observations from the stomach data, though.

As described above, our multispecies model is a single area model. However, Gadget, being an area disaggregated platform, allows the user to build spatially-explicit models. Users then need to define areas for model and provide model with the input data files of sufficient spatial resolution. Gadget simulates migration processes to describe movement of the stocks between the defined areas. Tagging data or prior knowledge of migration patterns of fish are beneficial in order to have good migration estimates. In multi-area multispecies model Gadget can account for spatial overlap between the predator and prey stocks, since the consumption will happen only in areas where both prey and predator are present in a time-step for which estimation is done.



**Figure 7.2.** Observed proportions of prey in the cod stomachs (dots) and estimated proportions of prey in the cod diet (lines).

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## Annex 1. List of Participants

### Workshop on Spatial Analyses for the Baltic Sea 2 8–10 November 2016

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## Annex 2. Agenda

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### Workshop on Spatial Analyses for the Baltic Sea 2 (WKSPATIAL2)

BIOR, Riga, 08.-10. November 2016

#### Tuesday 8 November

9-10 ToR a): update on the cannibalism work (Stefan, Maris et al)

10-13 Initiate work with the cannibalism data, discussing concepts, making an analysis plan to estimate assessment independent estimates of cod cannibalism rates in different areas, application of hydrography data asf.

13-14 lunch

14-15 Plenary: Update on the status of the WKSPATIAL papers– plan further writing work for the workshop, make the plots nice and so further.

15-16 Tor c) – Presentation by Henn and Riina. Discussion in the group how we proceed with this ToR

16-17 ToR b) Analyse the relation between food intake and growth (we can estimate time-trends in von Bertalanffy k, WGBFAS will love us), planning of the work during the workshop.

17-18 Start work in subgroups

#### Wednesday 9 November

9-10 or 11 ToR d) Maybe Valerio could present the status on Gadget, and we could, if necessary, discuss usage of the stomach data? Furthermore, I have a proposal for a model, but there are some things going on I really do not understand and I would like to get the input from the group.

Rest of the day: work in subgroups

#### Thursday, Nov. 10:

9-10 Plenary, update on the subgroup work

10-13 Work in subgroups

13-14 Lunch

14-16 Report writing

16-17 Plenary: wrap-up, future of the workshop, closing the meeting.