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Report of the Workshop on Spatial Analyses for the Baltic Sea (WKSPATIAL)

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Executive summary

The ICES Workshop on Spatial Analyses for the Baltic Sea (WKSPATIAL) met in Rome, Italy, 3–6 November 2015 (Chairs: Michele Casini, Sweden, and Stefan Neuenfeldt, Denmark), with 15 participants and 6 countries represented.

WKSPATIAL was held as 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 spatio-temporal relation between zooplankton and pelagic fish stomach content in the Gulf of Riga, and 3) continue investigating the small-scale properties of fish spatial distribution, as pelagic fish schools characteristics (size, density, distance, etc.). Aims n°1 and 2 were fulfilled, whereas aim n°3 could not be realized because of the lack of expertize in the group attending the Workshop.

The report contains an introductory chapter about the relevance of the WKSPATIAL for an increased ecological understanding of the fish and ecosystem dynamics, as well as for fisheries management and ecosystem-based management. The report continues with three chapters addressing the ToRs.

The prey composition in the cod stomachs and the relative contribution in weight of the different prey items were analysed in two periods, before and after 1987. The contribution of the benthic *Saduria entomon* to the stomach content was markedly lower in 1987–2014 than in the previous period. Such decrease was compensated by an increased contribution of sprat in the diet of small cod (< 45 cm) and of herring in the diet of intermediate size cod (45–60 cm). Cannibalism was also more relevant in 1987–2014 than before. Spatially, the contribution in weight of *Mysis mixta* in the cod diet (cod < 20 cm) was higher in SD28 than in SDs 25–26. The contribution of *S. entomon* in the cod diet (cod size 40 cm) was the highest in SD28, where instead the contribution of sprat in the diet was the lowest. The occurrence of herring in the stomachs was sensibly more relevant in SD25 (cod size 30–50 cm). The total consumption by size of the Eastern Baltic cod was also estimated. Cod of 15–40 cm total length showed a decreasing trend in total consumption and energy intake starting in the mid-1980s, coincident with a decrease in the ratio benthic/pelagic food. Cod > 40 cm did not show a clear decrease in total consumption and energy intake.

Analyses in the Gotland basin showed that cannibalism of Baltic cod is not an invariant behavioural feature, but is rather opportunistic as revealed by 1) the very small number of observed cases of cannibalism; 2) the relation between the cannibalism magnitude and the spatial overlap between juvenile and adult cod, and the juvenile abundance.

The predator–prey body size ratio was analysed using the cod stomach dataset. Large cod consumes larger prey items (herring and other cod) than smaller cod, but they still also prey on smaller items, such as isopod *S. entomon.* Thus, the size span of prey eaten by large cod is wider than that of small cod. No clear differences were observed in the size distribution of prey found in cod stomachs between the different SDs.

Spatio-temporal analyses made at the level of ICES statistic rectangle suggest that benthic hypoxia affects cod feeding, especially the juvenile life stages. An overall shift from feeding on benthic prey to feeding on pelagic species is seen with increasing

areas of hypoxia. This is coincident with a lower condition of juvenile cod. For large cod, there is a significant negative relationship between hypoxia and cod condition at a SD level. Thus, hypoxia seems to decrease cod feeding on benthic prey, which is manifested in lower cod condition.

Stomach contents of herring and three-spined from the Gulf of Riga were analysed. Spatial patterns of the prevalence of empty stomachs indicate that herring has better feeding conditions in the middle and the northeastern part of the gulf, while sticklebacks in the southernmost coastal area, in the plumes of Daugava River. A spatial heterogeneity associated with stomach fullness was also found, with generally lower values in the northwestern part (in the gulf entrance area) and higher values towards the eastern part.

A pan-Baltic database on zooplankton data were presented, along with ongoing work on compilation of *S. entomon* time-series at the whole Baltic scale, which can be critical to better understand the spatio-temporal variations in the feeding conditions and growth of pelagic and demersal fish.

WKSPATIAL expects to continue its work with a new workshop in 2017.

1 Opening of the meeting

The chairs Michele Casini (Sweden) and Stefan Neuenfeldt (Denmark) welcomed the meeting 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 changes in the stomach content of Baltic cod in relation to food availability, hydrological conditions and cod body condition;
- Analyse the long-time changes of the prey size and species composition in the Baltic cod stomachs in different areas of the Baltic Sea;
- Analyse the small-scale spatial distribution of pelagic fish;
- Investigate and identify scales of spatial dynamics of mesozooplankton to prepare integration with pelagic fish distributions for analyses of species interactions.

2 Adoption of the agenda

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

WKSPATIAL was 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 WKSPATIAL 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. In Figure 1 is shown the map of the Baltic Sea devided in the ICES Subdivisions (SDs) for reference to the text of the report.

In June 2012, ICES 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, by analysing the newly compiled cod stomach data, specifically intends to provide information on the spatio-temporal changes in cod predation on different food types, 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 (ex. SMS, Gadget) assessment models, and therefore fisheries advice. The analyses of the stomach content data fulfilled the ToRs a) and b).

The second aim of WKSPATIAL was to analyse the features of the spatial distribution of pelagic schooling fish species, along with the spatio-temporal distribution of their planktonic prey. This aim was not fulfilled due to the lack of expertize at the meeting. Therefore, ToR c) could not be addressed.

The third aim of WKSPATIAL was to investigate and identify scales of spatial dynamics of mesozooplankton to prepare integration with pelagic fish distributions for analyses of species interactions. These analyses fullfilled ToR d).

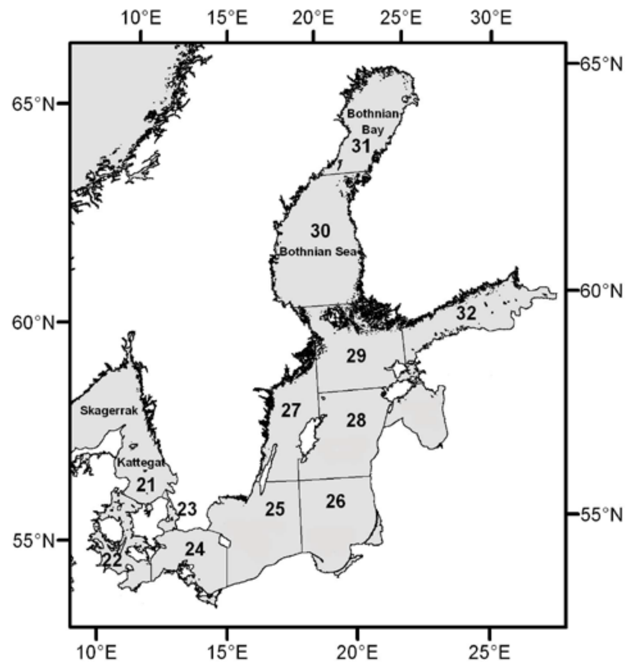

Figure 1. Map of the Baltic Sea with the ICES Subdivisions (SDs).

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 Contribution of different prey species to the cod stomach weight in relation to cod size

We want to characterize the prey composition in the cod stomachs and the relative contribution in weight of the different prey items. This represents a first step to understand the contribution of different ecosystem components (i.e. pelagic vs. benthic) to the energy uptake of cod in the Baltic and associated spatio-temporal changes.

We calculated the contribution in weight (proportion) of the following preys i.e. *Sprattus sprattus*, *Clupea harengus*, *Gadus morhua*, *Saduria entomon*, *Mysis mixta*, *Platichthys flesus* and "other preys", as observed in the cod stomachs in relation to the length of cod. The stomachs have been analysed separately for two periods (1963–1986 and 1987–2014) and for the different subdivisions (SD25: Bornholm Basin, SD26: Gdańsk Basin, SD28: Gotland Basin).

The overall analysis shows that *Mysis mixta* represents the main prey item in weight for small cod (< 20 cm). The contribution of *Saduria entomon* has a rapid increase in the diet of small cod until 30 cm, to decrease progressively for larger fish. In addition, the importance of sprat has a rapid increase until 45–50 cm when it represents approx. 40% in weight of the cod diet. Herring is progressively more important in the diet of cod with a pick at approx. 60–70 cm. Larger cod above 70 cm show an increasing preference for flounder. Similarly, cannibalism becomes more relevant to cod > 70 cm (Figure 2).

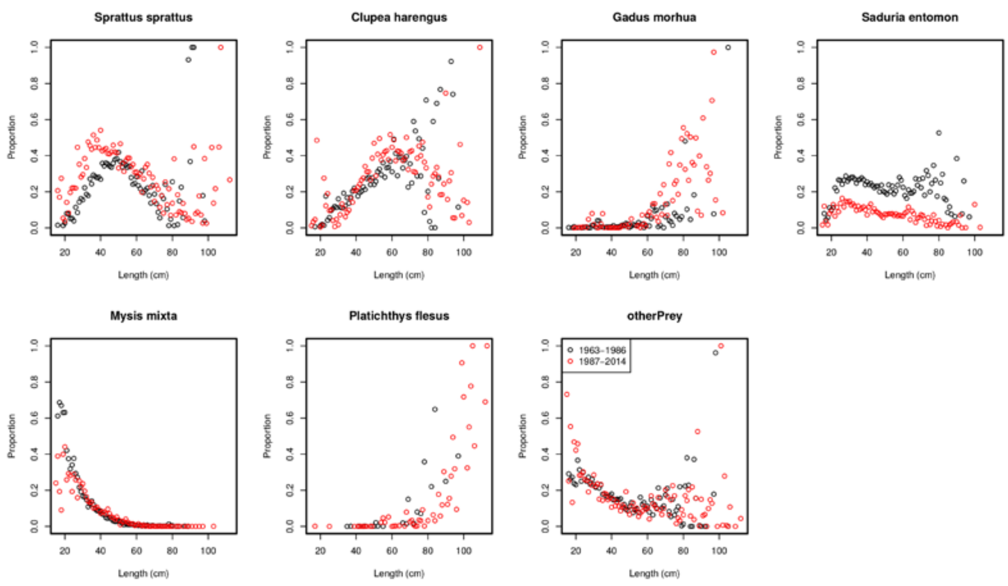

Figure 2. Proportional contribution in weight of different prey items in the cod stomachs in relation to cod size, separately for the period before (1963–1986) and after (1987–2014) the regime shift in the Baltic.

The analysis separated for the two periods show similar general patterns, but also important differences. In particular, the contribution of *Saduria entomon* to the stomach content is markedly lower in the 1987–2014 than in the previous period. Such decrease appears mostly compensated by an increased contribution of sprat in the diet of smaller cod (< 50 cm) and of herring in the diet of intermediate size cod (50–60 cm). Moreover, cannibalism appears more relevant in 1987–2014 than before (Figure 2.

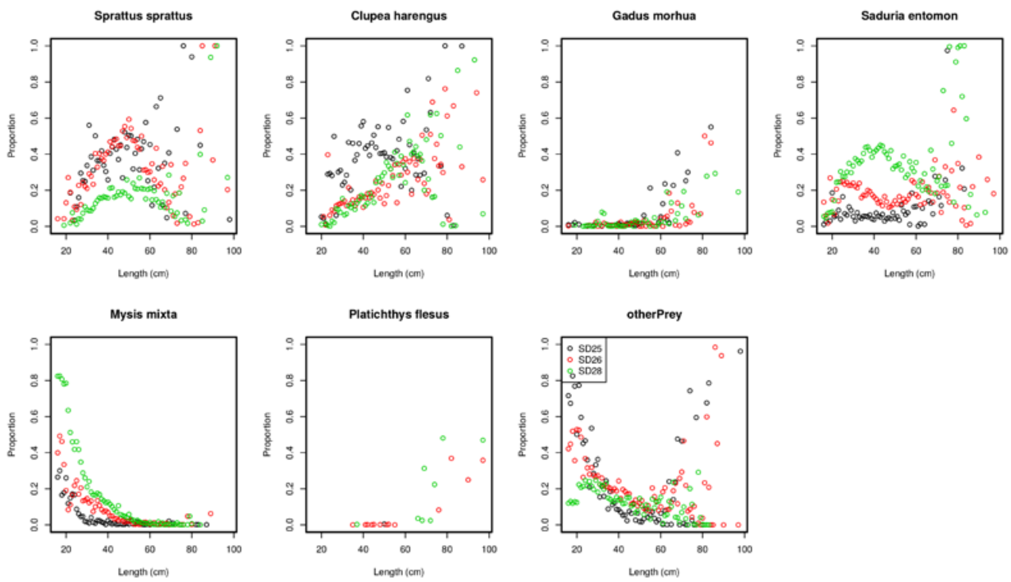

Figure 3. Proportional contribution in weight of different prey items in the cod stomachs in relation to cod size, separately for the ICES Subdivisions 25, 26, 28 over the period 1963–2014.

Comparison of the stomach contents among different ICES SDs shows a contribution of *Saduria entomon* in the cod diet up to > 40% of the stomach content in weight for cod of 40 cm in SD28, reduced to 15–20% in SD26 and < 10% in SD25. On the contrary, the contribution of sprat is higher in SDs25-26 (> 50% at 50 cm) than in SD28 (approx. 20%). The occurrence of herring in the stomachs is comparable in SD26-28 and sensibly more relevant in SD25. The contribution of *Mysis mixta* is higher in SD28 (approx. 80% for cod < 20 cm) than in SD26 (40%) and SD25 (25%). Cannibalism appears more pronounced and its relevance anticipated in the cod ontogeny in SD26 (Figure 3).

4.2 Cod consumption and energy intake

The next step was to estimate total consumption by size of the Eastern Baltic cod. The observed stomach contents were roughly separated in the two groups (i) fish and (ii) benthic invertebrates. For each group, the mass of consumed wet weight was estimated per individual stomach, as well as the energy that has been consumed, and then averaged for each 1-cm TL group (Figure 4).

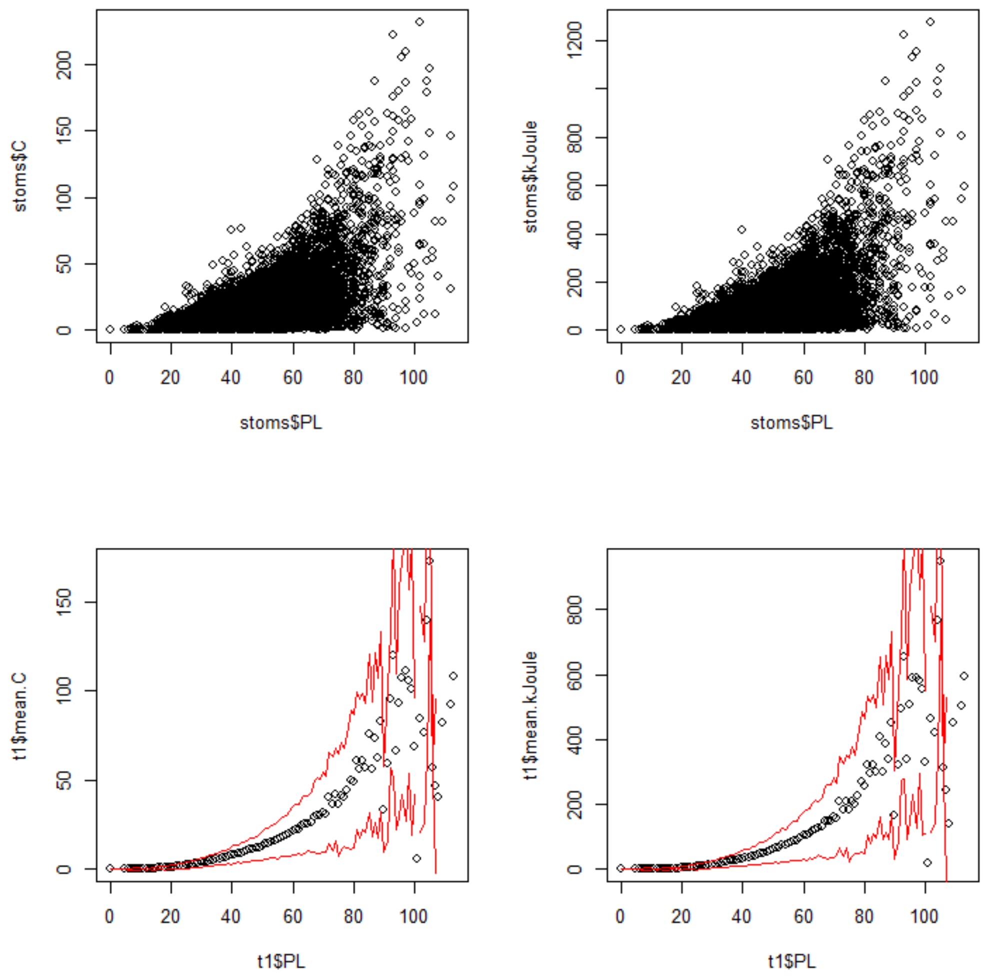

Figure 4. Wet mass and energy consumed for the individual stomachs (top left and right) and averages with one standard deviation (lower left and right)

Several exploratory analyses have been conducted in order to identify if there is a trend over time in total consumption, and if yes, for which length groups this trend may be considered consistent. The most general signal was visible, when cod < 40 cm were compared to cod > 40 cm.

Cod from 15–40 cm total length showed a decreasing trend in total consumption and energy intake starting in the mid-1980s, whereas cod > 40 cm did not show this tendency (Figure 5).

Focusing on cod 15–40 cm, the ratio between benthic and pelagic food decreased simultaneously (Figure 6).

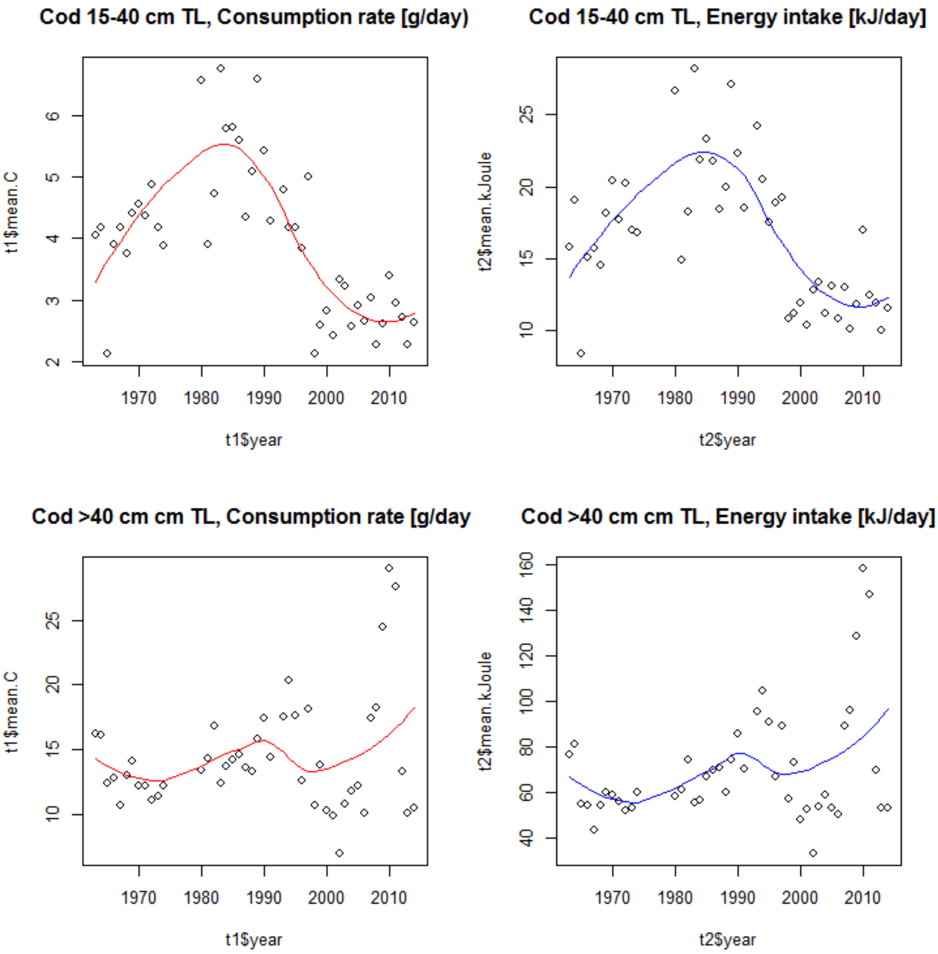

Figure 5. Consumption and energy intake for cod 15–40 cm, and > 40 cm total length over time.

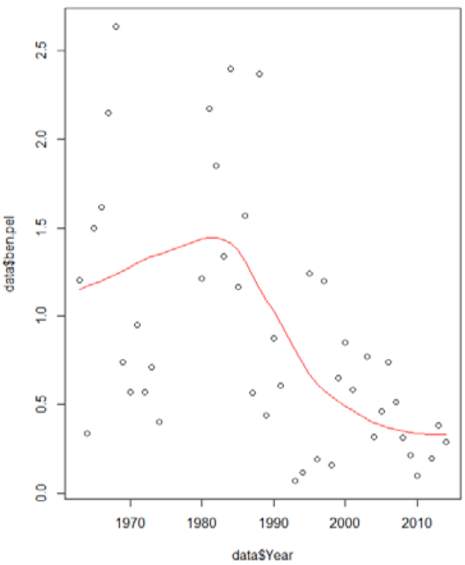

Figure 6. Ratio between consumed benthic and pelagic food for cod 15-40 cm total length over time.

The data need to be analysed in detail, however, some preliminary conclusions are:

- The onset of the inflow stagnation period in 1983 is reflected in the consumption, and condition of cod < 40 cm.
- Most probably, the absence of sufficient benthic food forces relatively small cod to forage on sprat with relatively low success.
- The development continued to date. Aggravated by decreasing sprat abundance in the central area of the cod distribution (additional decrease in the mid-1990's)
- Cod > 40 cm can compensate by feeding on herring, small cod, and benthic fish.

However, we also note that also the condition (Fulton's $K = W/L^3$) of large cod (> 40 cm) has decreased markedly since the mid-1990's, and this decrease has started at the same time (if not earlier) than the smaller cod. Therefore, further analyses on energy intake should be made in order to explain the decrease in cod condition.

4.3 Cannibalism of Baltic cod in Gotland Basin: preliminary analyses of possible causes

Available information on cod cannibalism in the Baltic Sea indicates two main dependencies:

Cod cannibalism is related to spawners abundance (Neuenfeldt and Köster, 2000);

Cod cannibalism is related to juvenile cod abundance (Uzars and Plikshs, 2000).

From a Multispecies virtual population analysis (MSVPA) perspective cod cannibalism can contribute significantly to recruitment success. Multispecies modelling predicted that about 32–60% of the 0-group in the second half of year, and about 13–31% of the 1-group cod, were consumed by conspecifics (Neuenfeldt and Köster, 2000). Consumption rate was higher in the years of high spawning-stock biomass and high recruitment abundance, i.e. during the end of 1979 and first half of 1980. Since then the stock size and consumption rates have significantly decreased: 14–25% of age group 0 and less than 10% of age group 1. It can be concluded that cannibalism is determined by spawning stock abundance. MSVPA runs reveal that consumed age group 1 significantly correlated with spawning stock abundance ($R^2 = 0.94$).

Other analyses of field observation show significant correlation between cannibalism rate and juvenile fish abundance (Uzars and Plikshs, 2000). This can be interpreted as higher recruit abundance leads to expansion of its distribution area and thus higher possible overlap with adult cod.

However, it is still not clear how important is cannibalism in relation to recruitment and stock dynamic and what is the magnitude of its influence on year-class strength. Based on previous findings, the hypothesis that Eastern Baltic cod cannibalism is related to spatial overlap between juvenile and adult cod was tested.

Data and methods

Stomach data: 1963–2013 from January–April.

Area: Gotland Deep (SDs 26 north and 28).

Horizontal overlap between adult and juvenile cod was calculated from Latvian demersal fish surveys 1979–2013 carried out in the Gdańsk basin and the Gotland basin in the first half of the year.

Coefficients (*Ro*) of horizontal overlap between juvenile cod (< 20 cm) and adult cod (> 20 cm) were calculated as Marishita's index (Morisita, 1959) modified by Horn (1966):

$$Ro = \frac{2\sum_{i=1}^{n}(P_{ij} * P_{ik})}{\sum_{i=1}^{n} P_{ij}^{\,2} + \sum_{i=1}^{n} P_{ik}^{\,2}}$$

where:

Ro- overlap index.

n – number of depth strata. Depth strata used: 20–39; 40–59; 60–79 and 80–100 m

P*ij* – number of cod > 20 cm (predator)

P*ik* – number of cod < 20 cm (prey)

The frequency of cannibalism is calculated as follows:

$$C_{FR} = \sum_{i=1}^{m} N_c /(N_t - N_e) * 100$$

where:

CFR- cannibalism frequency

m – sub-basins

Nc – number of stomachs with cod as prey

Nt – total number of stomachs

Ne – number of empty stomachs

Preliminary results

The cod stomach content database from 1963–2011 (first half of the year) revealed that cod as a prey was recorded in 182 cod stomachs (228 fish) out of the 51 574 stomach analysed. The spatial location of cannibalism was associated with certain locations on the slopes of the Basins (Figure 7). Cod prey in cod stomachs was mainly represented by cod < 20 cm, although the size distribution of the preys was different for the first and second half of the year (Figure 8).

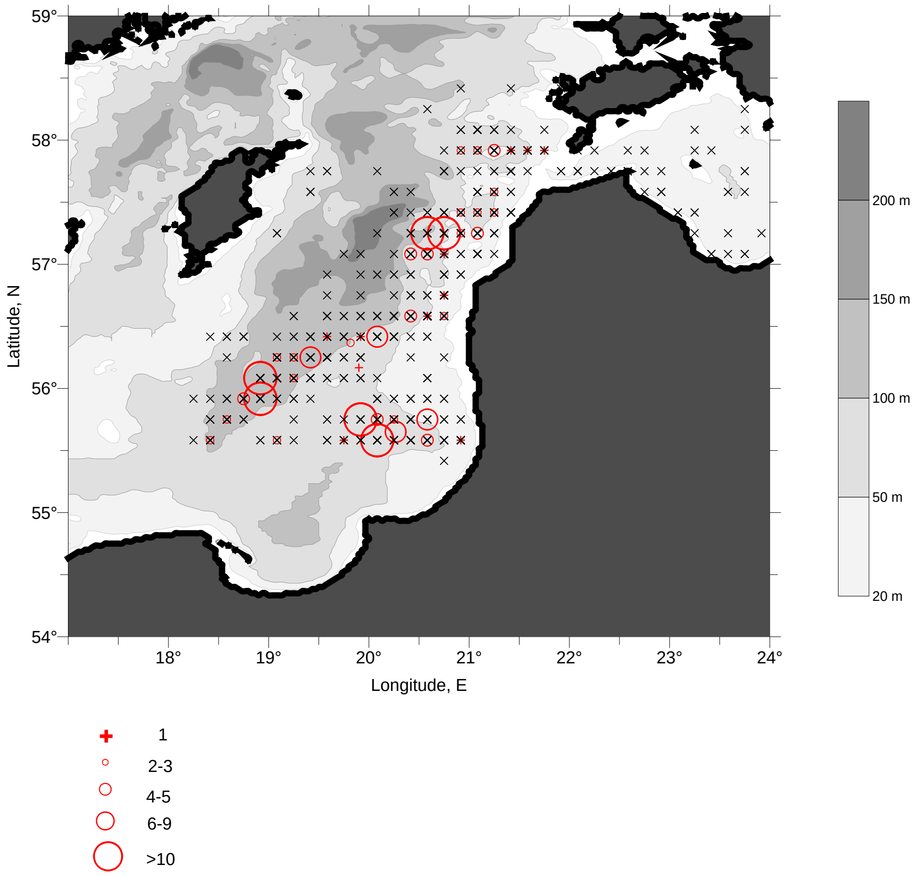

Figure 7. Locations of observed cod cannibalism (in numbers) from cod stomach sampling during 1963–2013. Black crosses indicate the sampling locations where cod was not observed in cod stomachs.

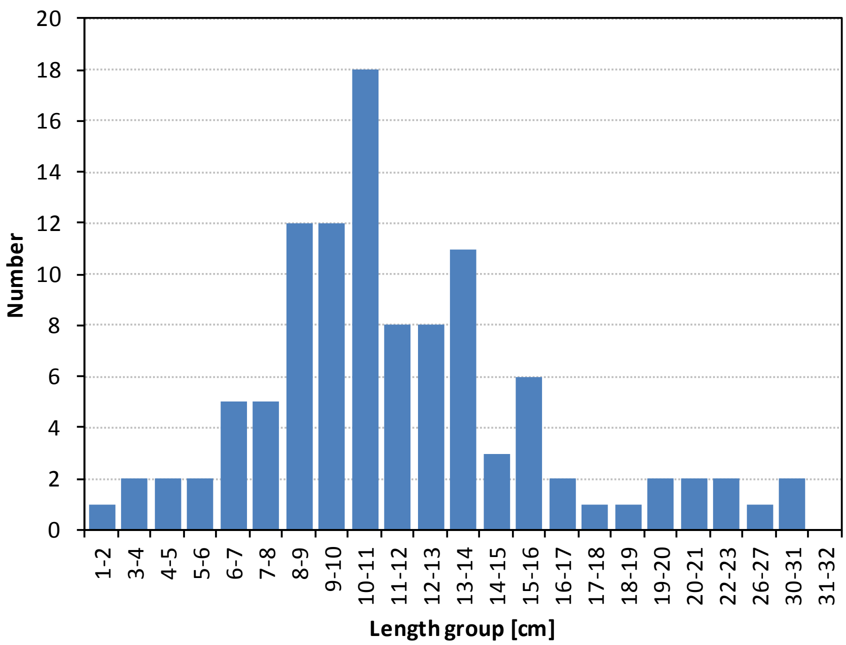

Figure 8. Size distribution of consumed cod in 1st quarter of the year.

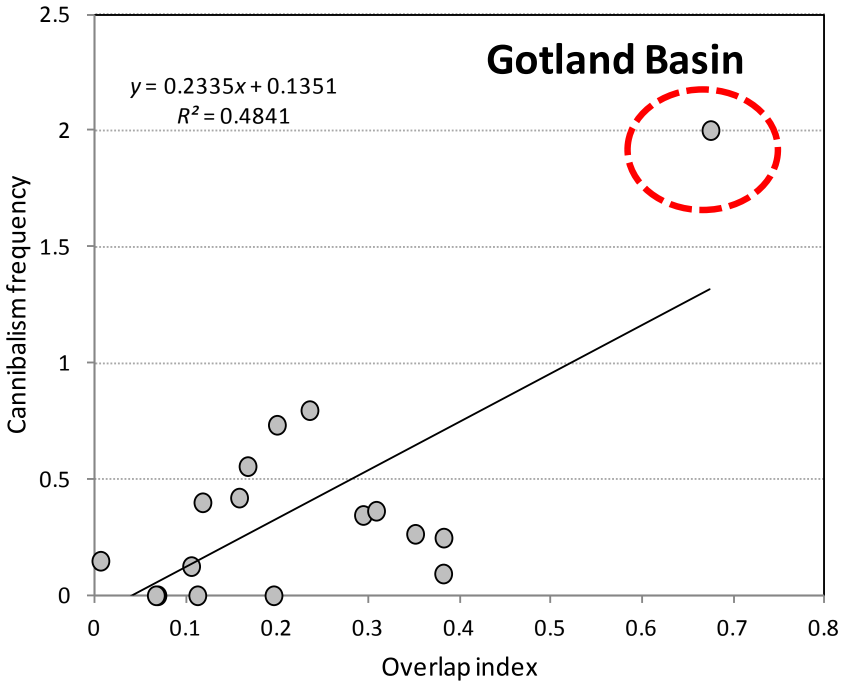

Figure 9. Relation between cannibalism frequency and overlap index of juvenile cod and adult cod in 1st quarter in Gotland basin.

Regression between the frequency of cannibalism and spatial overlap index for whole period 1973–2013 was statistically not significant, p=0.121, df=29, F=2.6, R^2=0.05. However, for the earlier period (1972–1990) the relationship was significant p=0.003, df=15, F=12.3. The significant relation was however mostly driven by the outstanding value in 1977 that represents the extremely abundant 1976 year class (Figure 9).

One of the reasons of the different relations in different periods could be the sampling intensity. After 1990 no more than 250 cod stomachs were collected, compared to the 500–1500 stomachs collected before this date.

Conclusions

Preliminary analyses of cod cannibalism in the Gotland basin (one of three main basins of cod distribution in the Baltic Sea) indicate that cannibalism depends on juvenile abundance and overlap between juveniles and adult cod. Similar analyses are necessary from other Baltic Basins e.g. Gdańsk and Bornholm, especially because cod distribution is recently concentrated in these more southern areas.

Analyses in Gotland basin reveal that cannibalism of Baltic cod is not an invariant behavioural feature, but is rather opportunistic because of:

1) Small number of observed cannibalism cases: 182 stomachs (and 228 fish totally in these stomachs) out of 51 574 stomachs analysed;

2) Indications that cannibalism magnitude has a relation with the spatial overlap between juvenile and adult cod, and with juvenile abundance;

3) No dome-shaped stock–recruitment relation for Baltic cod as predicted by Ricker (Smith and Reay, 1991).

Cod stomach sampling after 1992 in the Eastern Baltic basins might be inadequate in order to evaluate the incidence of cannibalism. Further analyses require update survey information (research trawl catches) by size or age groups. Similar cannibalism analyses should be conducted also with data from the second half of the year.

4.4 Cod diet and condition in relation to hypoxic areas

During SGSPATIAL 2014, analyses investigating the relationship between the areas extent of anoxic bottoms and the diet and condition of cod were initiated. These preliminary analyses indicated that benthic anoxia might affect cod feeding, by decreasing the feeding on both zoobenthos and pelagic fish, thus lowering the overall food intake. During WKSPATIAL 2015, a larger dataset was compiled for more in-depth analyses of the relationships between oxygen conditions and cod feeding and condition.

For these analyses, existing data on cod diet and condition in ICES SDs 24-28 were compiled. The data were from Denmark, Poland, Latvia, and Sweden from 2007 to 2013, quarter 4. For each cod in the dataset, the weight fractions of different prey groups were calculated, as well as the Fulton condition factor (weight/length^3). The analyses were made at an ICES statistical rectangle resolution. The areal extent of hypoxic areas (< 2 ml/l) was interpolated from field measurements in quarter 4 for each rectangle and year, according to the method described below. In the 2014 analyses we used areal extent of anoxic areas, but in these new analyses we used hypoxic areas instead. We hypothesize that hypoxia decreases the availability of zoobenthic prey in the Baltic Sea, and will push the predators to search for food in the pelagic zone. Increasing extent of hypoxic areas will:

- decrease the fraction of zoobenthos, and increase the share of mysids and pelagic fish in the diet;
- increase the proportion of fish with empty stomachs;
- decrease the mean condition of cod.

Distribution of hypoxic areas

The oxygen data used to calculate the areal extent of hypoxia was mainly retrieved from ICES (ICES Dataset on Ocean Hydrography). Approximately 4500 depth profiles (between 300 and 800 each year) were used to calculate the oxygen level in the area of interest, covering SDs 25-28, using the interpolation software DIVA (Troupin *et al.,* 2012). Horizontal gridded fields were calculated for every 10 meters between 50 and 250 meters depth. The resolution of the grid output was set to 0.1x0.1 degrees and the area for each grid cell was approximately calculated as mean (lon)*lat giving a grid area between 61 and 72 km^2. For each grid point, the deepest available value in the grid layers, i.e. the grid cell at the bottom, was noted. All grid cells within each ICES rectangle with an oxygen concentration < 2 ml/l were summed to give an approximation of the total hypoxic area within the rectangle. These calculations were made for data from all years combined (2007–2013) and for each year separately.

The Diva software takes data scattered in time and space and calculates a field based on "best fit" trying to minimize the cost function. Signal to noise ratio and correlation length (given in degrees) are given as input and for this purpose we use fixed values of these constants at all depths. The signal to noise ratio and correlation length were set to 1.0 and 0.7, respectively. For more information about the Diva software, see http://modb.oce.ulg.ac.be/mediawiki/index.php/DIVA.

Cod diet and condition in relation to hypoxia

For the analyses of cod condition and diet in relation to the extent of hypoxic areas, information from a total of 85 rectangles and years was available. In the analyses, cod was divided into two size classes, 15–35 cm and > 35 cm. A total of 1507 and 1549 individuals, respectively, had both condition and diet information. Regression analyses between hypoxia and cod condition, frequency of empty stomachs and weight fractions of different prey groups displayed a number of significant relationships (Table 1). For juvenile cod (15–35 cm), there was a negative relationship between hypoxic areas and cod condition and zoobenthos except *Saduria*, and a positive relationship with the frequency of empty stomachs and the fraction of mysids in the diet. For adult cod (> 35 cm) there was a positive relationship with the frequency of empty stomachs and with mysids, and a negative relationship with the fraction of demersal fish.

These analyses suggest that benthic hypoxia affects cod feeding, especially the juvenile life stages. An overall shift from feeding on benthic prey to feeding on pelagic species is seen with increasing areas of hypoxia. This corresponded to a lower condition of juvenile cod. For large cod, the relationship is negative but non-significant at the rectangle level, but at an SD level there is a significant negative relationship between hypoxia and cod condition (p=0.01). Thus, hypoxia seems to decrease the availability of benthic prey, which is manifested in a lower condition of cod.

Table 1. Linear regressions between hypoxia and cod condition, frequency of empty stomachs and weight fractions of different prey groups.

		Pred_condition	Empty	Saduria	Other_benthos	Mysidacea	Pelagic_fish	Demersal_fish
15-35 cm	r2	0.114	0.113	0.001	0.132	0.113	0.043	0.041
	slope	Neg	Pos	Pos	Neg	Pos	Pos	Neg
	p	**0.002**	**0.002**	0.738	**0.001**	**0.002**	0.066	0.070
>35 cm	r2	0.011	0.081	0.014	0.012	0.067	0.003	0.065
	slope	Neg	Pos	Neg	Neg	Pos	Pos	Neg
	p	0.339	**0.008**	0.288	0.323	**0.017**	0.604	**0.019**

When summarizing the prey of juvenile and adult cod divided into different groups based on their condition (< 0.8, 0.8–1.0, > 1.0) some patterns are apparent (Figure 10). For both size groups, there is a clear relationship between the frequency of empty stomachs and condition. For juvenile cod, *Saduria* increases in the diet with cod condition, while mysids decrease. For adult cod, all benthos prey decrease while fish prey increase with increasing condition.

In all, the analyses support the hypotheses posed, suggesting a clear effect of hypoxia on the feeding of cod, with an increase in pelagic feeding and an overall lower feeding success with hypoxia, potentially leading to a lower body condition.

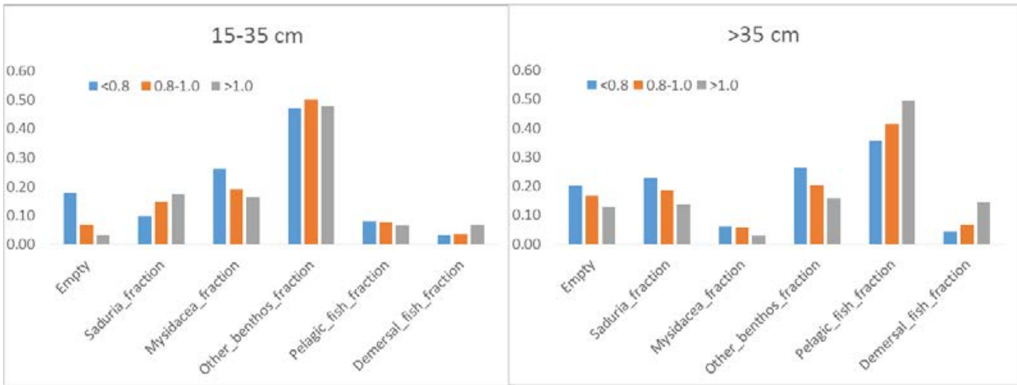

Figure 10. Frequency of empty stomachs and weight fractions of different prey groups for juvenile and adult cod divided into condition classes (< 0.8, 0.8-1.0, > 1.0).

4.5 Compilation and analyses of *Saduria entomon* data

Abundance and distribution data for *Saduria* are being compiled as part of the BONUS BIO-C3 project and aggregated indices in time and space will be used for WKSPATIAL analyses. The data are being compiled from various data sources around the Baltic. Much benthic data are already available in the Helcom monitoring database now held at ICES. A second large database for benthos is the one held and maintained at The Leibniz Institute for Baltic Sea Research, Warnemünde (IOW) (Gogina and Zettler, 2010). This database is based on data from many sources around the Baltic. Checking of this database showed that it contains some but not all Helcom monitoring data.

Work prior to and during the meeting has included contact with IOW and ICES regarding extraction of the *Saduria entomon* data from these databases, and inclusion of additional sampling related information (e.g. depths, sampling gear used, sampling region). Additional work will include incorporation of all Helcom monitoring data in the IOW database to increase time-space coverage. The data preparation work is therefore still ongoing so only some preliminary results are available. These nevertheless show that there is a large material available when aggregated across all years, areas and depth in the Baltic Sea for analysing spatial and temporal distributions and potentially also for abundances. Some examples of temporal (interannual and seasonal) and spatial (depth) distribution of the number of samples (sampling effort) are shown in Figures 11, 12, and 13.

The preparation of the database will continue in the coming weeks and months.

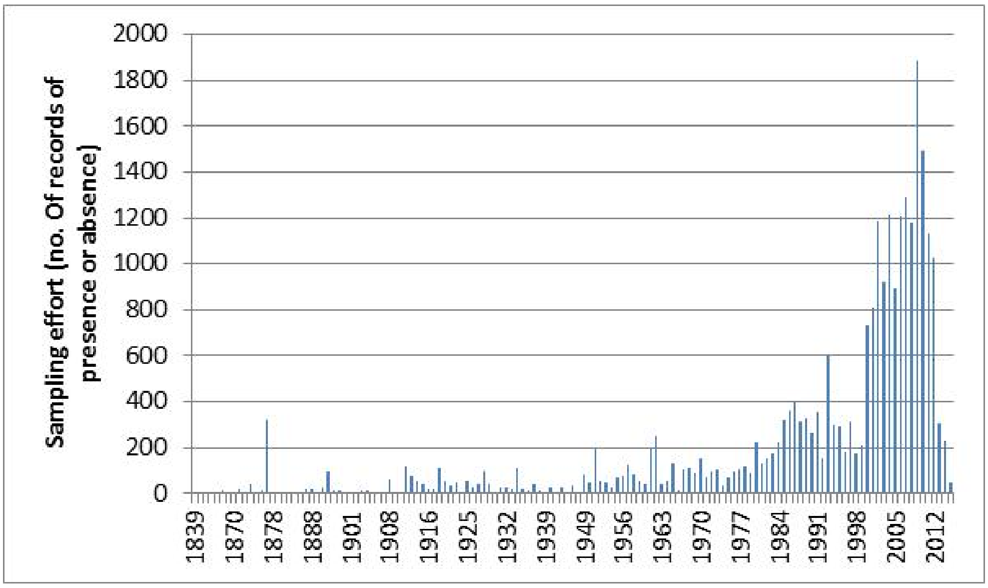

Figure 11. Number of sampling events for *Saduria entomon* in the Baltic Sea, based on observations in the IOW benthic database (Gogina and Zettler, 2010).

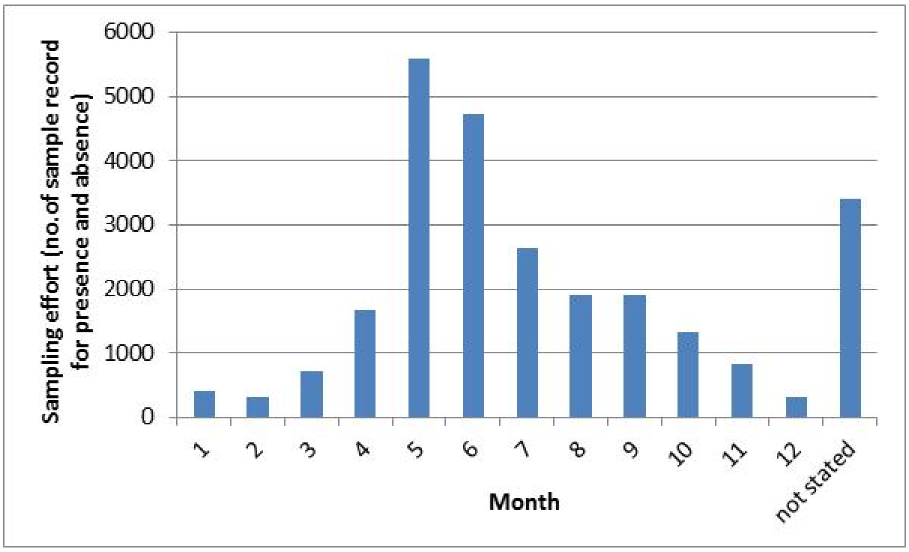

Figure 12. Seasonal distribution of benthic sampling effort for presence and absence of *Saduria entomon* in the Baltic Sea since 1850, based on database of Gogina and Zettler (2010).

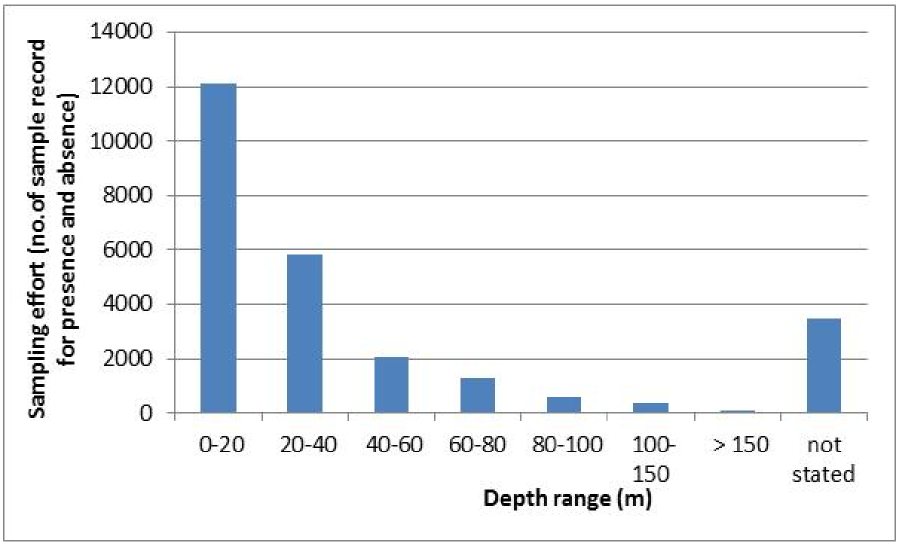

Figure 13. Depth distribution of sampling effort for presence and absence of *Saduria entomon* in the Baltic Sea since 1850, based on the database of Gogina and Zettler (2010).

5 Tor b) Analyse the long-time changes of the prey size and species composition in the Baltic cod stomachs in different areas of the Baltic Sea

To cover this ToR we explored the predator–prey body size ratio in the cod stomach dataset in different SDs.

Predator–prey body size ratios have been studied in several marine systems (Barnes *et al*., 2009, Scharf *et al.,* 2000). These studies suggest that body size distribution can play an important role in defining predator–prey linkages and their strength. Consequently, the assumption of optimum predator–prey mass ratio is also widely used for calculating prey preference functions in ecological models (e.g. Blanchard *et al.,* 2011, Watson *et al.,* 2014). The maximum predator–prey size ratio is limited by organism morphology, and is most often a species-specific feature (Scharf *et al.,* 2000), while the mean prey size eaten by a predator, for example, can be greatly affected by prey availability.

In WKSPATIAL, the predator–prey length (mm) ratio of Baltic cod and their prey were explored using the cod stomach database. These data cover the years 1963–2014 and ICES SDs 24-29 and 32. In total 51 932 samples were available that contained length (mm) information for cod (i.e. the predator) and the respective stomach content (i.e. cod prey length). Data availability was highest for The SDs 25, 26, and 28.

The relationship between cod body length and the length of its main prey items in the stomachs (*Clupea harengus, Sprattus sprattus, Saduria entomon, Mysis mixta, Platichthys flesus* and *Gadus morhua*) in different SDs is shown in Figure 14. First, a clear succession is observed in the species composition of prey items eaten following changes in cod length. *M. mixta* and *S. entomon,* together with smaller sized sprat, were found in the stomachs of small cod (< 300 mm). Herring, on the other hand, is a common prey item eaten by cod larger than 300 mm. Furthermore, the data indicates that larger cod might prefer larger herring and sprat than smaller cod, as the minimum size of these prey items increases slightly with cod size. The maximum size of herring eaten increased with cod body size until no larger herring are available as prey (i.e. for cod < 400 mm). Relatedly, the data also indicates that cannibalism is the only feeding mechanisms that can result in cod catching prey items larger than 300 mm in size. In general, the maximum predator–prey body size ratio for cod and its prey was around 2 in the dataset studied. This value is comparable to the findings by Scharf *et al.* (2000). Despite large cod consumes larger prey items than smaller cod, they still also prey on smaller items, such as isopod *S. entomon.* Thus, the size span of prey eaten by large cod is wider than that of small cod. Some overlap in size is observed between the different prey items eaten by cod (e.g. *S. entomon* and sprat, or sprat and herring).

No clear differences are observed in the size distribution of prey found in cod stomachs between the different SDs, with the exception that in SD 28 cod eaten (i.e. cannibalism) is smaller than in the SDs 25 and 26. However, this may be a result of fewer large cod being analysed in SD 28.

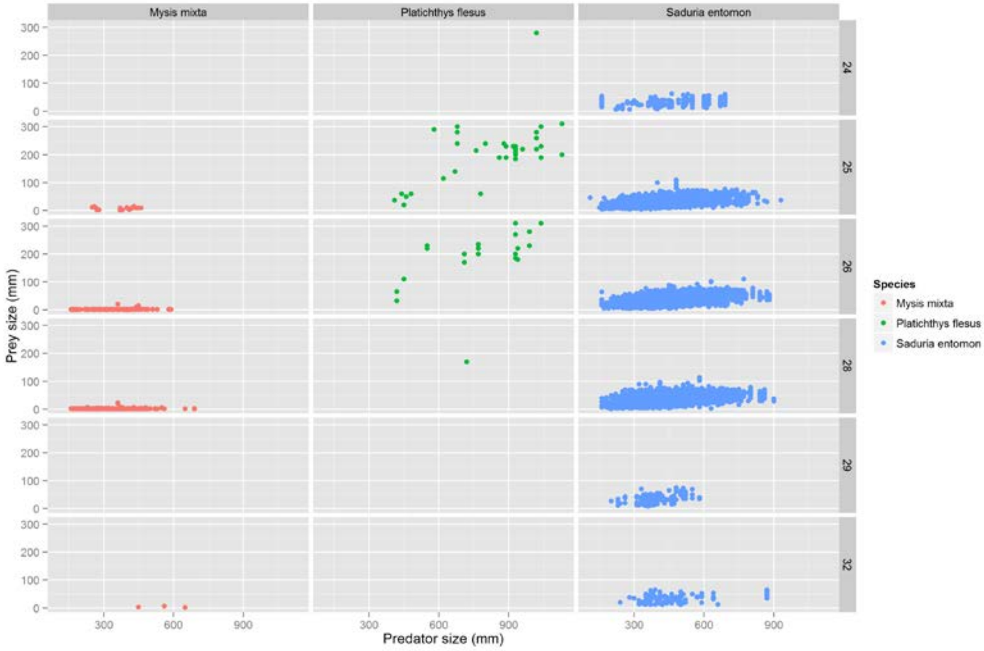

Figure 14. Predator–prey size (length) ratio between cod and its main prey across ICES Subdivisions 24–29 and 32 in 1963–2014.

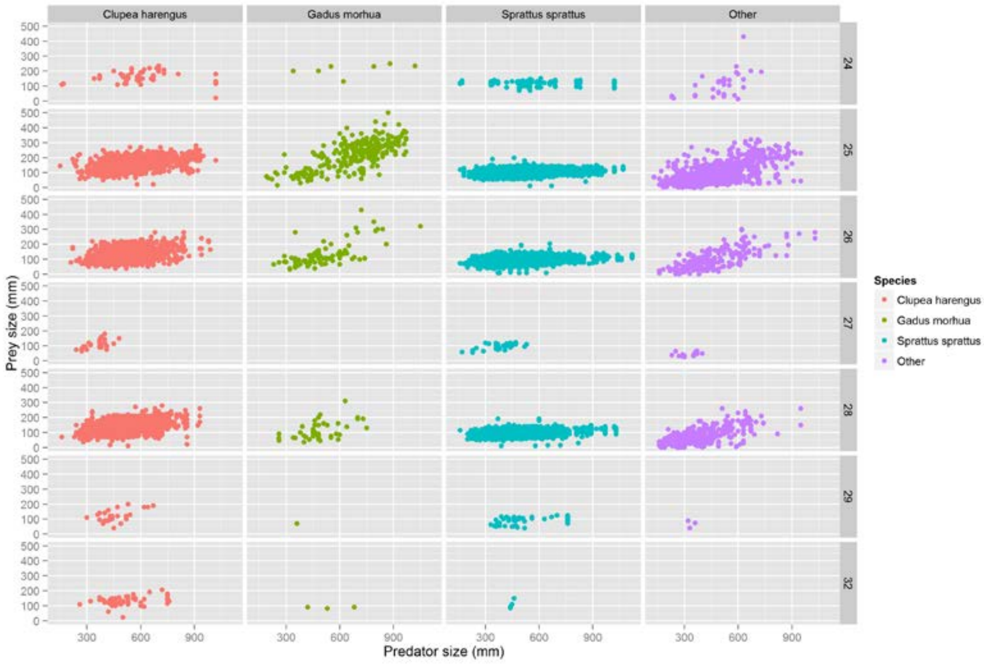

Figure 14 (cont.)

6 Tor d) Investigate and identify scales of spatial dynamics of mesozooplankton to prepare integration with pelagic fish distributions for analyses of species interactions

6.1 Spatio-temporal variability of the Baltic Sea mesozooplankton

The primary goal of the Baltic Sea mesozooplankton study initiative and data compilation effort is to assemble a pan-Baltic collection of raw zooplankton time-series data in an effort to look at all-Baltic patterns and ecosystem dynamics at multiple spatial and cross-disciplinary scales. As for now, the dataset contains original raw data from 9 providers sampled during 1957–2013 (http://kodu.ut.ee/~riina82/policy.html):

- Finland (2): Marine Research Centre, Finnish Environment Institute and Archipelago Research Institute;
- Estonia (1): Estonian Marine Institute, University of Tartu;
- Latvia (2): Institute of Food Safety, Animal Health and Environment, and Latvian Institute of Aquatic Ecology;
- Lithuania (1): Open Access Centre for Marine Research, Klaipeda University;
- Russia (1): Atlantic Research Institute of Marine Fisheries and Oceanography;
- Poland (1): National Marine Fisheries Research Institute;
- Sweden (1) Swedish Meteorological and Hydrological Institute.

The data have been harmonized for the structural organization of data and species taxonomy (including syntax and typing errors), yielding a coherent dataset of ca 23 000 zooplankton samplings representing nearly 15 000 vertical profiles (Figure 15). The network has a very strong and clear data policy stating that data belongs to data providers and not to the dataset manager.

There are several very clear benefits of such pan-Baltic network, that motivated both the effort of compilation, as well as original data providers to join: i) it has a potential to attract the people with skills and ideas, given that much of the time-consuming data harmonizations has already been done; ii) provides better chances of being co-authors in more papers and studies for the data providers; iii) and thereby increases the data usage, which on the other side also helps to sustain the long-term monitoring. When compiled together, the data with higher frequency and spatial coverage allow answering more general ecological questions.

Among the general questions of high priority is the quantification of the spatio-temporal variability of zooplankton abundance and biomass. Knowing the prominent scales of variability helps to determine the most optimal sampling frequency for the long-term environmental surveys. As a pilot study, we have carried out a preliminary analysis to compare the spatial and temporal scales at which the variability of samples is the largest. Analysis includes the abundances of key zooplankton groups: small and large cladocerans and small and large copepods, and data from small lagoons (Pärnu Bay, Vistula, and Curonian Lagoons), Gulf of Riga, and open Baltic Sea. Patterns of spatio-temporal variability will be studied in all the zooplankton groups, and in all water bodies listed.

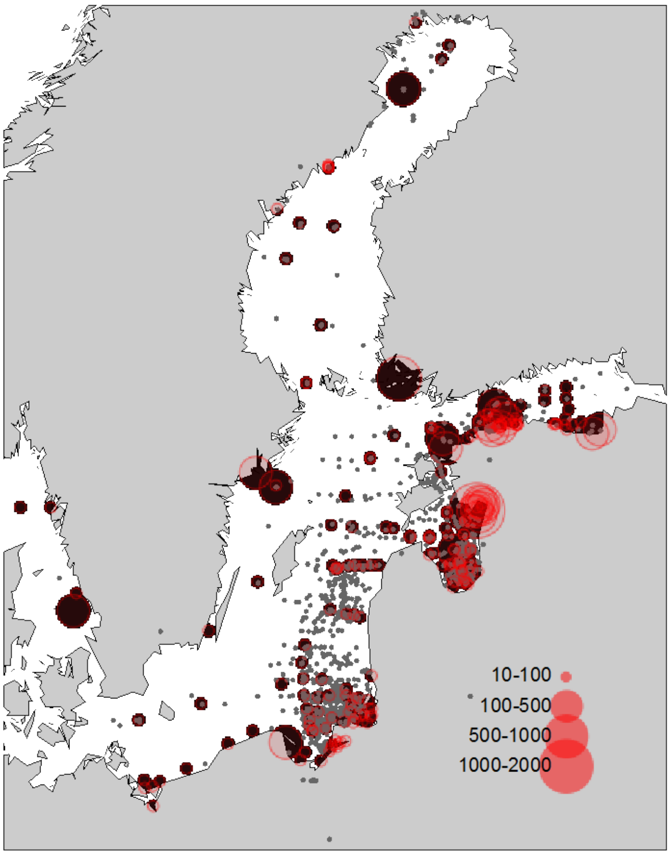

Figure 15. Spatial origin of data in the Baltic Sea zooplankton database

6.2 Pelagic fish feeding in the Gulf of Riga

Stomach contents of fish were collected during hydroacoustic surveys designed to estimate the size of commercially important pelagic fish stocks in the Gulf of Riga. In total, 264 trawl hauls were conducted (Table 2) using a pelagic commercial trawl in 30 min hauls. Sampling was performed during the second half of July every year between 1999 and 2014. The hauling speed was ca. 3 knots, the length of hauls around 2 km. Hauls were targeted at depths (generally at 20 m and deeper) where most of the fish biomass was observed using hydroacoustic devices. Stomachs of 20 randomly sampled individuals per species were stored for the analysis of diet in a 4% formaldehyde solution.

Stomach content analyses were performed according to Melnitchuk (1980). The total stomach content and larger prey types, e.g. mysids, amphipods, and *Cercopagis pengoi*, were weighed to a precision of 0.001 g. In total, 8696 adult and 3116 juvenile herrings, and 4483 three-spined sticklebacks were collected and analysed (Table 2).

The following parameters were calculated:

i. Percentage of empty stomachs;

ii. Feeding intensity: stomach fullness as percent of body mass: $I_{SF} = 100M_F M^{-1}$, where M_F is the total stomach content in g wet mass and M is the fish wet mass in g;

iii. Percent frequency of occurrence: $F = 100n_iN^{-1}$, where n_i is the number of fish with food category i in their stomachs and N is the total number of fish.

Table 2. Number of trawls and fish collected for stomach content analysis in the Gulf of Riga between 1999 and 2014.

YEAR	TRAWLS	THREE-SPINED STICKLEBACK	ADULT HERRING	JUVENILE HERRING
1999	12	246	289	0
2000	12	262	270	84
2001	12	222	334	54
2002	14	100	323	694
2003	18	385	541	304
2004	15	247	448	70
2005	16	319	390	226
2006	17	372	463	241
2007	15	328	700	452
2008	18	363	673	50
2009	19	152	742	51
2010	18	405	807	61
2011	20	516	666	491
2012	19	113	703	2 002
2013	18	113	657	0
2014	21	340	690	136
Total	264	4 483	8 696	3 116

The analysis performed so far indicate that:

1. Juvenile herring exhibits the lowest share of empty stomachs (long-term mean around 10%) while that of the three-spined stickleback and adult herring is substantially (2-3 times) higher (Figure 16). Spatial patterns of the prevalence of empty stomachs indicate that herring has better feeding conditions in the middle and the northeastern part of the gulf, while sticklebacks in the southernmost coastal area, in the plumes of Daugava River (Figure 17).

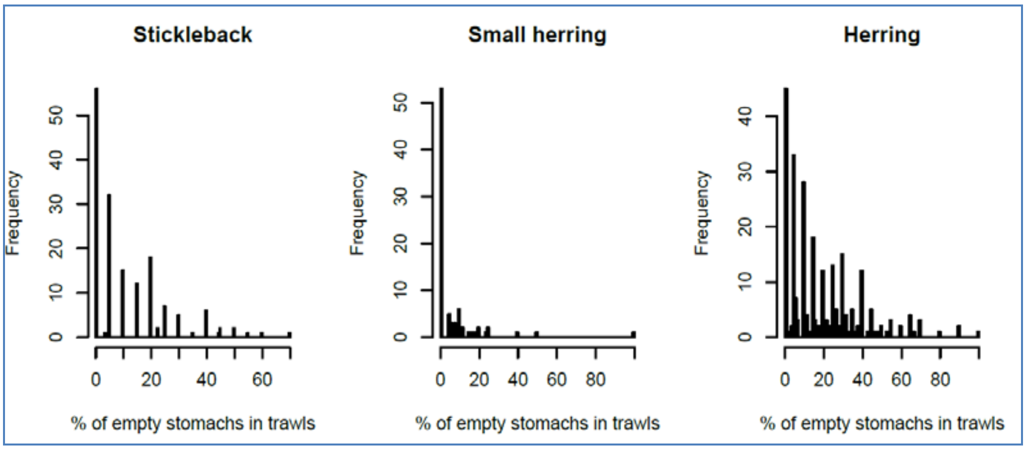

Figure 16. Frequency of empty stomachs of three-spined stickleback, juvenile herring and adult herring in trawls in the Gulf of Riga in summer 1999–2014.

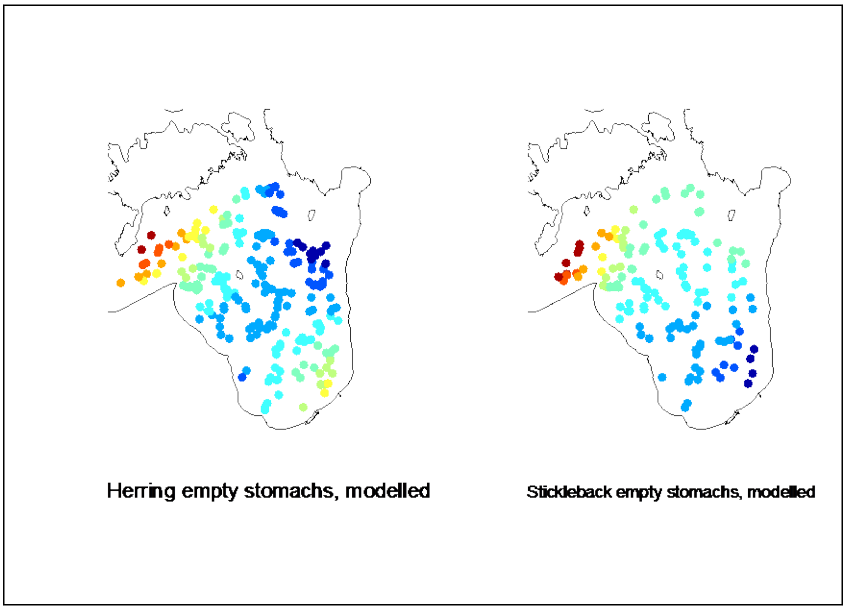

Figure 17. Spatial pattern of the frequency of empty stomachs. Blue means the low and red high percentage of empty stomachs.

2. Feeding activity, expressed as stomach fullness (I_{SF}) is the lowest for the adult herring (around 0.4) and the highest for the three-spined stickleback (around 1.5). There is also spatial heterogeneity associated with stomach fullness with generally lower values in the northwestern part (in the gulf entrance area) and higher values towards the eastern part characterized by lower hydrodynamic activity, more pronounced seasonal thermocline and generally higher temperatures (Figure 18).

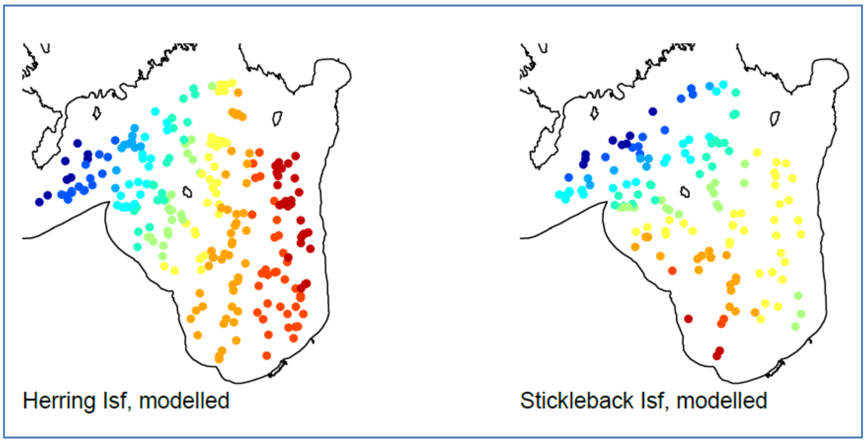

Figure 18. Modelled spatial distribution of the stomach fullness index (I_{SF}) of adult herring (left panel) and three-spined stickleback in the Gulf of Riga during 1999–2014. Blue denotes low and red high I_{SF} values.

3. Five zooplankton taxa clearly dominate in the diet of the three fish groups studied. These are: copepods *Eurytemora affinis* and *Acartia* spp., and cladocerans *Bosmina* spp, *Cercopagis pengoi*, and Podon/Pleopis complex consisting of *Podon* spp. and *Pleopis polyphemoides*. While four prey items dominate in the diet of herring, in most of the years only one species - *Bosmina* spp.– contributes most to the diet of the three-spined stickleback (Figures 19 and 20). While stomachs of adult herring and sticklebacks mostly contain one prey taxa at the time, juvenile herring contained on average two zooplankton taxa at the time.

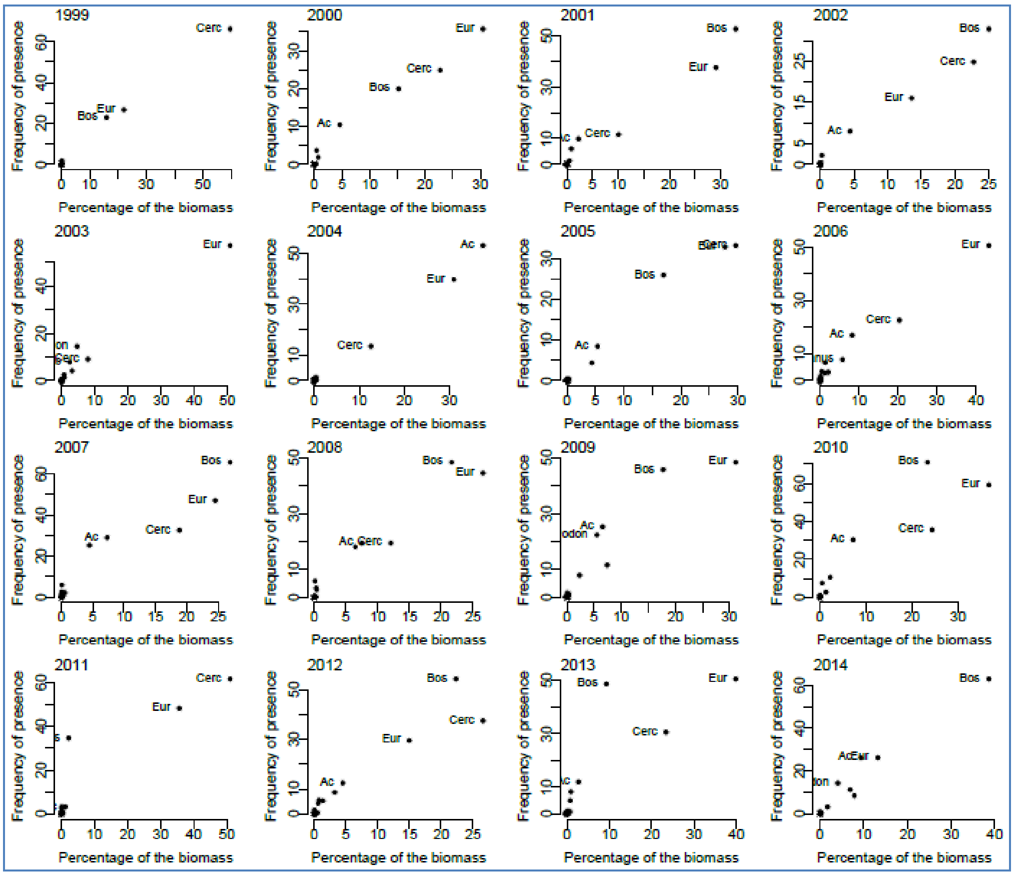

Figure 19. Percent frequency of presence (F) and stomach fullness index (ISF) of different prey items in the diet of adult herring in the Gulf of Riga by years (1999–2014). Legend for abbreviations: Eur. – *Eurytemora affinis*, Ac. – *Acartia* spp., Bos. – *Bosmina* spp., Cerc. – *Cercopagis pengoi*, Podon/Pleopis – *Podon* spp. and *Pleopis polyphemoides*.

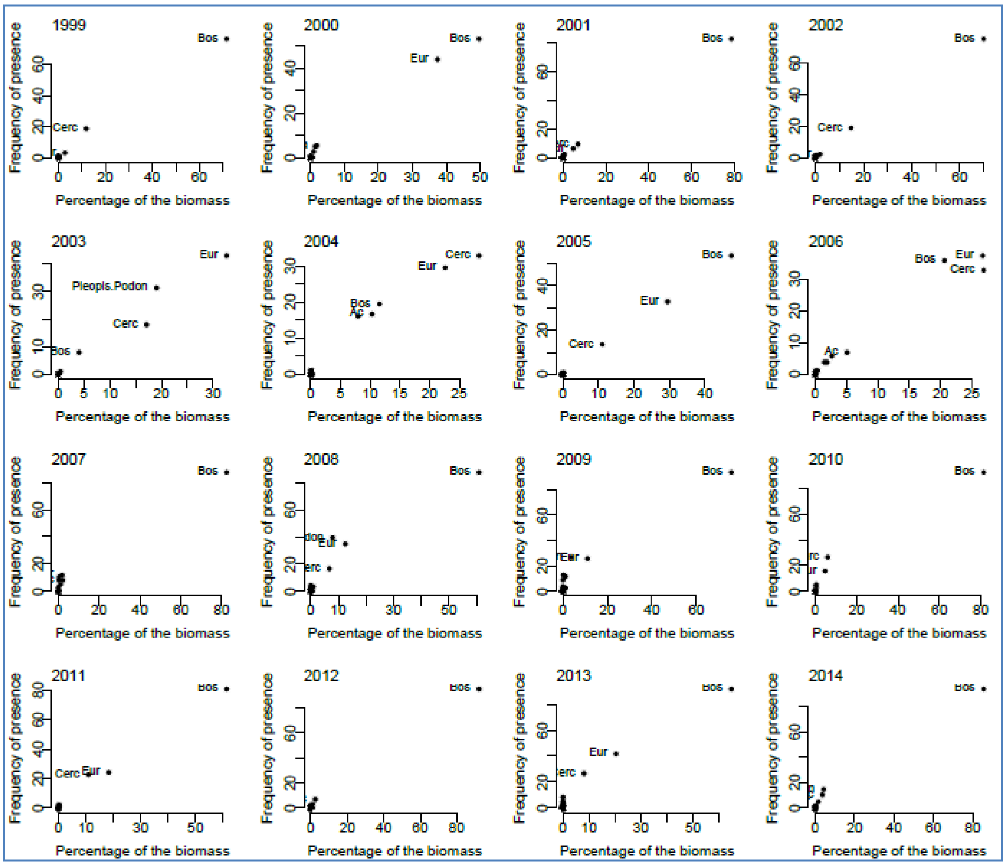

Figure 20. Percent frequency of presence (F) and stomach fullness index (I_{SF}) of different prey items in the diet of three-spined stickleback in the Gulf of Riga by years (1999–2014).

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Annex 2: Agenda

ICES WKSPATIAL 3–6 November 2015

Botanic Garden, Rome, Italy

Lunch 12:30-13:30

Tuesday 3 November (09.00–17.30)

Morning

1. Welcome and practical information (Michele, Stefan and Valerio)
2. Round table
3. Introduction to the meeting, ToRs and adoption of the agenda (Michele and Stefan)
4. Updates on the stomach content database (Stefan, Alessandro)
5. Presentations of the status of the analyses started last year (with ideas how to continue during the meeting):
   - Temporal changes in the frequency of occurrence of prey types/species (or generally, in cod diet) and empty stomachs, in view of hydrographic conditions, in different SDs and seasons (1964-2014 data) (Valerio). **ToRs a and b.**
   - Temporal comparison between cod stomach contents and prey availability, in view of hydrographic conditions, in different SDs and seasons (1964–2014 data) (Stefan/Michele). **ToRs a.**
   - a) Frequency occurrence of prey types (and cod condition) against anoxic conditions, and b) Comparison of food composition between cod with high/low condition (2007–2014 data, longer period if possible) (Ulf). **ToR a.**
   - Temporal changes in prey size (and species) composition per size classes of cod, in different SDs and seasons (1964-2014 data). (Susa/Meri). **ToR b**.
6. Presentations of new studies;
   - Cannibalism of Baltic cod: preliminary analyses of possible causes (Maris). **ToR a.**
   - Saduria as food for cod (Brian). **ToR a and b.**
   - Pan-Baltic zooplankton database and results (Riina). **ToR d.**
   - Pelagic fish feeding ecology (Henn). **ToR d.**

Afternoon

7. Duties and setup of the report (Michele and Stefan)
8. Preparation of the data needed for the analyses.
9. Work in subgroups, addressing the ToRs

Wednesday 4 November (9.00–17.30)

Morning

1. Work in subgroups, addressing the ToRs

2. Presentations and discussion of the results

Afternoon

3. Work in subgroups, addressing ToRs
4. Presentations and discussion of the results

Thursday 5 November (9.00–17.30)

Morning

1. Work in subgroups, addressing the ToRs
2. Presentations and discussion of the results

Afternoon

3. Work in subgroups, addressing ToRs
4. Presentations and discussion of the results

Friday 6 November (9.00–16.00)

1. Work in subgroups, addressing the ToRs
2. Presentations and discussion of the results
3. Report writing
4. How to move on next year
5. Others