ICES WKBEBCA REPORT 2017

SCICOM STEERING GROUP ON ECOSYSTEM PROCESSES AND DYNAMICS

ICES CM 2017/SSGEPD:19

REF. ACOM, SCICOM

Report of the Workshop on Biological Input to Eastern Baltic Cod Assessment (WKBEBCA)

1–2 March 2017

Gothenburg, Sweden

ICES CIEM
International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2017. Report of the Workshop on Biological Input to Eastern Baltic Cod Assessment (WKBEBCA), 1–2 March 2017, Gothenburg, Sweden. ICES CM 2017/SSGEPD:19. 40 pp.

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Executive summary

The ICES Workshop on Biological input to Eastern Baltic cod Assessment (WKBEBCA) met in Gothenburg, Sweden, 1–2 March 2017 (Chairs: Margit Eero, Denmark, and Michele Casini, Sweden) with 26 participants and 7 countries represented.

Assessing the status of the Eastern Baltic cod stock and providing management advice are presently challenged by a number of changes in cod biology and the ecological conditions affecting cod. The overall aim of WKBEBCA was to summarize the work ongoing in the Institutes of the ICES member states on the most important biological input parameters for stock assessment, i.e. growth, mortality and reproductive potential of Eastern Baltic cod. In particular, the objectives were to present and discuss new information, ongoing work and other available knowledge on changes in these three biological processes.

The report contains an introductory chapter about the current issues with providing an analytical stock assessment for the Eastern Baltic cod, and the relevance of WKBEBCA in this context, i.e. to follow up on the ongoing investigations that allow quantifying and explaining the recent changes in the key biological variables for stock assessment. The report continues with short abstracts from presentations given at the Workshop and final chapters summarizing the main outcomes of the Workshop concerning growth, natural mortality and reproductive capacity.

About growth in length, there was an overall agreement that growth has not increased since the 1990s, however different opinions and contradicting evidences were presented concerning whether growth in length has declined or remained stable. For small cod (<35cm) growth has presumably declined from the 1990s to late 2000s due to increased hypoxia, subsequent reduction in benthic prey species availability and overall reduction in food intake. In the period from 2000s onwards, growth can be hypothesised to have reduced due to smaller size at maturation and possibly due to reduced condition. However, size at age estimated from otolith daily increments was similar in 2001, 2004 and 2013. For larger cod (>35 cm), there is no firm evidence for growth changes since 1990s. It can be hypothesised that increased hypoxic areas, reduced condition and increased parasite load in this period have reduced growth in length, however, such links have not been documented to date.

About mortality, different factors have been identified that could have increased natural mortality in different sizes of cod: increased cannibalism for small cod (<15 cm); critically low feeding level, reduced size at first maturation and increased seal predation for middle size cod (15–35 cm); low condition and continued effects of seal predation and reduced size at maturation for intermediate-large cod (35–55 cm); and continued effects of low condition and additionally increased parasite infestation for large cod (>55 cm).

Concerning reproductive potential, preliminary results suggest that fish in low conditions have lower fecundity.

1 WKBEBCA Terms of Reference

a) Present and discuss new information, ongoing work and other available knowledge on changes in eastern Baltic cod growth over time, independent of traditional age readings (incl. growth estimates from historical tagging data, bioenergetic modelling, and other relevant methods and data analyses);

b) Present and discuss new information, ongoing work and other available knowledge on changes in eastern Baltic cod natural mortality over time. This includes quantification of changes in individual components of natural mortality, i.e. due to factors like cannibalism, low condition, parasites, seal predation etc.;

c) Present and discuss new information, ongoing work and other available knowledge on changes in eastern Baltic reproductive capacity over time (incl. changes in maturity, fecundity, skipped spawning, shift in spawning time, quality of reproductive output, etc.).

2 Introduction

A number of changes in Eastern Baltic cod biology have been observed, which include reduced nutritional condition of fish, maturation at a smaller size and increased parasite infestation. Also, relative abundance of larger individuals in the population has sharply declined since 2012. This could be due to low growth and/or high mortality, which has not been possible to disentangle due to lack of reliable age information on cod to determine growth.

Lack of reliable age readings and presumably non-constant natural mortality are the main reasons for present lack of analytical stock assessment for EB cod. Attempt are being made to re-establish quantitative stock assessment based on length information. However, such approaches still require information on growth of the fish and natural mortality is an important input parameter for stock assessment models. Thus, biological understanding of processes potentially affecting changes in growth and natural mortality is required to elucidate the likely direction of change in these variables and possibly quantify the likely magnitude of change. Additionally, given the large biological changes observed in the stock, effects on reproductive capacity could be hypothesised, which is important to consider in the context of future stock development and management advice.

The aim of WKBEBCA was to assemble and synthesise the present knowledge regarding possible changes in growth, natural mortality and reproductive capacity of EB cod. Number of presentations were given addressing these topics, including both summarizing the result from recent publications and presenting new analyses. The findings were then discussed in sub-groups and main points from these discussions are summarized in the synthesis chapter of this report. Additionally, short reports were given by participants on ongoing activities where results can be expected to be available in near future.

Change	Description	Drivers	References
Declined condition	Condition declined since 1990s in all areas, in all size groups, relatively more for larger cod	Suggested drivers include: hypoxia (via different mechanisms), food availability, parasites, selective fishing	Eero *et al.* 2012; Casini *et al.* 2016; Horbowy *et al.* 2016; Svedäng and Hornborg 2014
Reduced size at maturation	Size at first maturation declined both in male and female, by ca 20cm since the 1990s. Maturation happens in very narrow cm range.	Unknown	Köster *et al.* 2017; Tomkiewicz J. unpubl.
Increased parasite infestation	Increasing intensity and prevalence of the parasitic infection since 1980s	Increased seal abundance	Buchmann and Kania, 2012; Nadolna and Podolska, 2014; Horbowy *et al.* 2016
Reduced number of large individuals	Number of >45 cm cod reduced to lowest level since 2000s	Either reduced growth in length or high mortality, or a combination of both	Eero *et al.* 2015; ICES 2016

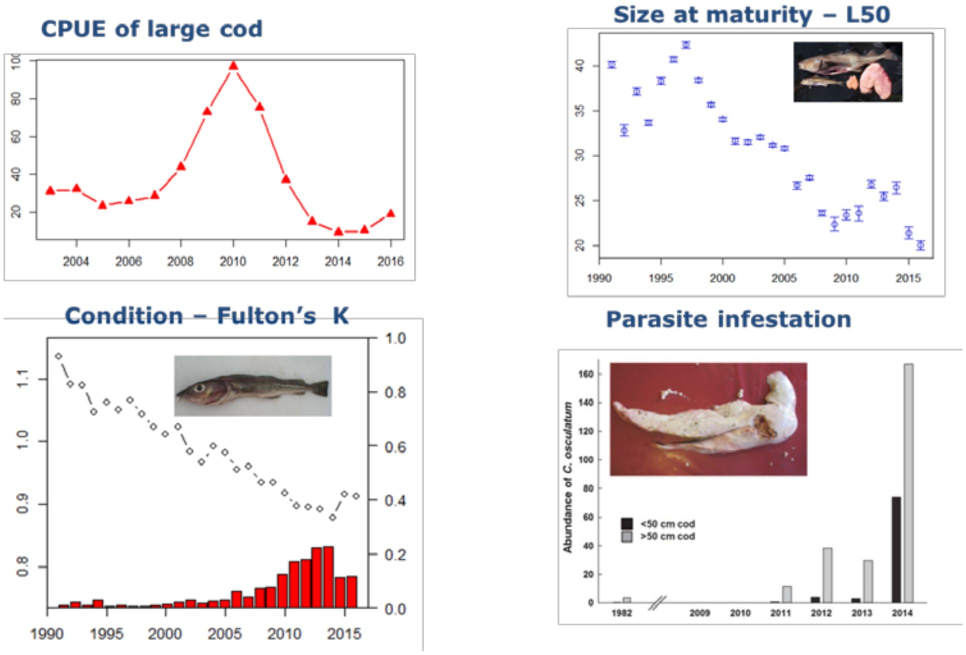


Figure A. Changes in a) cpue of large cod (>45cm in length) from BITS survey, ii) size at first maturation for females and males combined, from BITS Q1 survey; iii) mean Fulton's K condition factors for 40–60cm cod from BITS Q1 survey; the red bars showing the proportion of cod at condition below 0.8, and iv) parasite infestation (Eero *et al.* 2015).

3 Summaries of presentations on growth, natural mortality and reproductive capacity

Hypoxic areas, density dependence and food limitation drive the body condition of a heavily exploited marine fish predator

Casini M[1], Käll F[1], Hansson M[2], Plikshs M[3], Baranova T[3], Karlsson O[4], Lundstrom K[5], Neuenfeldt S[6], Gårdmark G[5]. and Hjelm, J[1]

[1]SLU Aqua, Department of Aquatic Resources, Lysekil, Sweden; [2]Swedish Meteorological and Hydrological Institute, Gothenburg, Sweden; [3]Fish Resources Research Department, Institute of Food Safety, Animal Health and Environment, Riga, Latvia; [4]Swedish Museum of Natural History, Stockholm, Sweden; [5]Department of Aquatic Resources, SLU Aqua, Department of Aquatic Resources, Öregrund, Sweden; [6]National Institute of Aquatic Resources, Technical University of Denmark, Charlottenlund, Denmark.

Investigating the factors regulating fish condition is crucial in ecology and the management of exploited fish populations. The body condition of cod (*Gadus morhua*) in the Baltic Sea has dramatically decreased during the past two decades, with large implications for the fishery relying on this resource. Here, we characterized the changes in the Baltic cod condition during the past 40 year. Moreover, we statistically investigated the potential drivers of the Baltic cod condition during the past 40 years using newly compiled fishery-independent biological data and hydrological observations.

The results showed that cod condition increased between mid-1970s to early 1990s, followed by a drop until the late 2010s. After that the condition stabilized at low levels. The same pattern was observed for all the ICES Subdivisions and all the length classes investigated (Figure 1).

The statistical analyses evidenced a combination of different factors operating before and after the ecological regime shift that occurred in the Baltic Sea in the early 1990s. The changes in cod condition related to feeding opportunities, driven either by density-dependence or food limitation, along the whole period investigated and to the fivefold increase in the extent of hypoxic areas in the most recent 20 years. Hypoxic areas can act on cod condition through different mechanisms related directly to species physiology, or indirectly to behaviour and trophic interactions. Our analyses found statistical evidence for an effect of the hypoxia-induced habitat compression on cod condition possibly operating via crowding and density-dependent processes. These results furnish novel insights into the population dynamics of Baltic Sea cod that can aid the management of this currently threatened population.

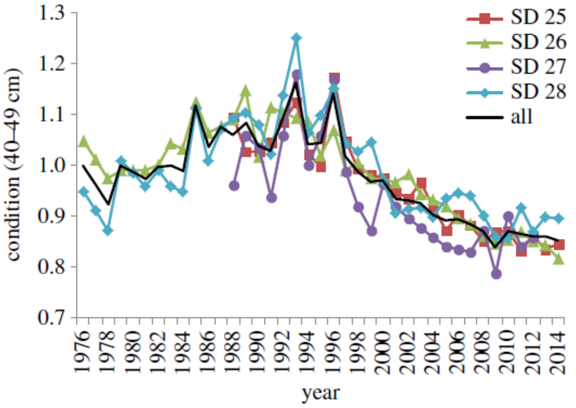


Figure 1. Temporal developments of mean cod condition in the different Subdivisions (SDs) of the Central Baltic Sea for cod 40–49 cm. The black thick line is the average between the SDs. From Casini *et al.* 2016.

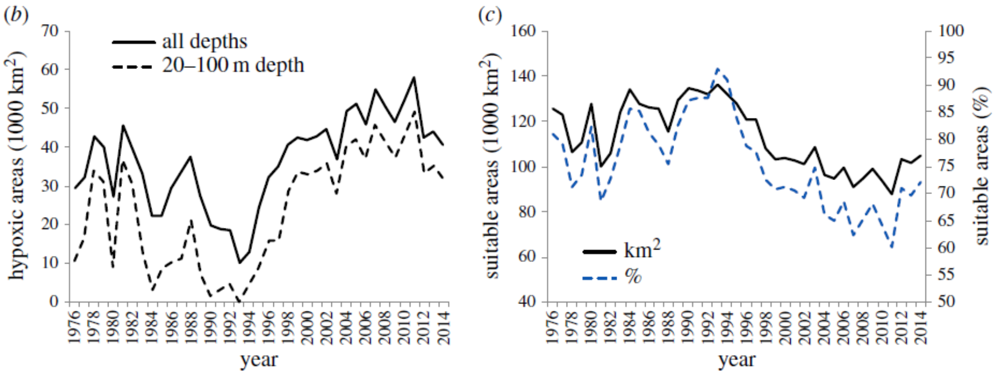


Figure 2. (b) time-series of total hypoxic areas (all depths), and hypoxic areas between 20–100m depth, the latter used as predictors to explain cod condition in the GAMs; c) time-series of suitable areas for cod (> 1 ml/l oxygen concentration) between 20–100m depth, in absolute values and in percentage. The time-series refer to the Central Baltic Sea (SDs 25–28). From Casini *et al.* 2016.

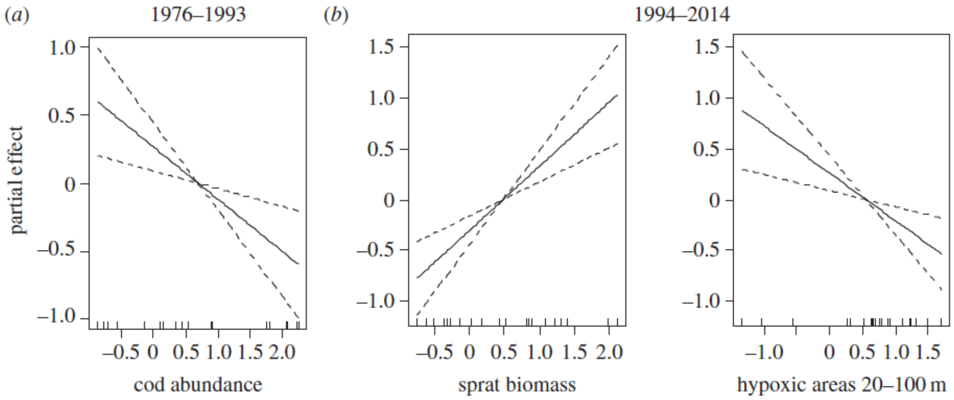


Figure 3. Results of the GAM (final model) for the two separated time periods (1976–1993 and 1994–2014). The partial effects of each predictor on cod condition are shown. From Casini *et al.* 2016.

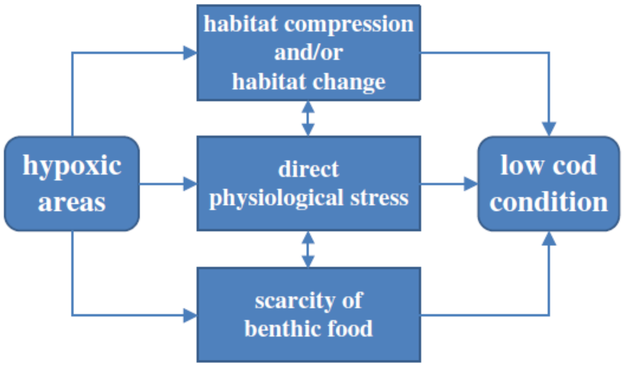


Figure 4. Schematic representation of the mechanisms potentially explaining the negative relationship between hypoxic areas and cod condition. From Casini *et al.* 2016.

Cod feeding level based on stomach content data

Stefan Neuenfeldt, DTU Aqua

Understanding the relation between feeding and growth potential is crucial in population ecology and management of exploited fish populations. Massive environmental changes, including stagnation of oxygen content in the bottom water, decreased benthic productivity and strongly varying population abundances of cod and Baltic sprat (*Sprattus sprattus L.*), the main fish prey for cod and also an exploited fish population, have been shown empirically to drive the body condition of Atlantic cod (*Gadus morhua L.*) in the Baltic Sea during the past 40 years. Subsequently, five decades of stomach content data allowed detailed insight into simultaneous changes in diet composition and energy uptake of the cod. As the abundance of benthic food in the diet decreased, cod initiated piscivory at an earlier stage of their lives. We calculated prey-specific consumption rates and estimated trends in feeding level, a predictor for growth potential. Preceding the observed ecological regime shift that occurred in the Baltic Sea in the early 1990s, large cod had the lowest feeding levels compared to smaller ones. However, afterwards the negative trend in feeding levels during life-history successively reversed. While larger cod can compensate for the lack of benthic food in their diet by increasing predation on larger forage fish and cannibalism, smaller cod are not big enough for this compensatory behaviour. In consequence, many small pre-spawning cod have presently feeding levels that imply severe growth limitation or even starvation.

Growth of juvenile EB cod from back-calculation of otolith measurements

Karin Hüssy, DTU Aqua

Objective: To test whether growth of young Baltic cod has changed since the early 2000s and whether growth and condition of the fish are related.

Background: In otoliths of young Baltic cod, daily growth increments in the otoliths may be used for inferring age. The width of these increments is strongly temperature-dependent, forming specific bell-shaped patterns with increasing increment widths during spring and early summer and decreasing widths in fall. These features are interrupted by zones where increments become so narrow that they are not discernible under a microscope. These zones correspond to the time of the year when the cod are experiencing the coldest temperatures.

Sample selection: Cod < 40 cm were selected randomly from the Danish Baltic International Trawl Survey (BITS) from the first quarter of the years 2001 (n = 59), 2004 (n = 71) and 2013 (n = 133) in ICES SD 25. Fish length and weight were recorded, Fulton's K calculated and otoliths extracted.

Back-calculation: On the sectioned otoliths, winter zones without daily increments were identified and their distance to the core measured. Since otolith size and fish size are linearly related, these measurements can be used to back-calculated the size of the cod at previous ages, using traditional procedures.

Growth patterns: Growth patterns were analyzed using Linear Mixed Effects Models with year as fixed effect and individuals as random effects (Figure 1). While the intercepts of the growth curves of 2001 and 2004 did not differ statistically from each other, they were both lower than the intercept of the growth curve for 2013. Differences in intercept may be attributable to either differences in growth during the early life stages, or due to differences in spawning time, which affects the width of the otolith until the first winter. The slopes of the regression, corresponding to overall growth over the years, did not differ between the years. Growth in cod < 40 cm has thus apparently not changed over the years 2001–2013.

Condition and growth: In order to test the relationship between growth and condition, a relative measure of growth in the form of residuals from the relationship between growth and age of the fish was first calculated for each year. Positive residuals are indicative of faster than average growth, while negative residuals are the result of slower growth. These residual growth values were then regressed on the Fulton's *K* of the fish at catch. Residual growth was linearly related with Fulton's *K* of the fish (Figure 2) without any significant difference between years (ANCOVA, df = 4 and 145, $p < 0.05$, $r^2 = 0.02$). Even though the regressions were statistically significant, the variability explained is limited (only 2%).

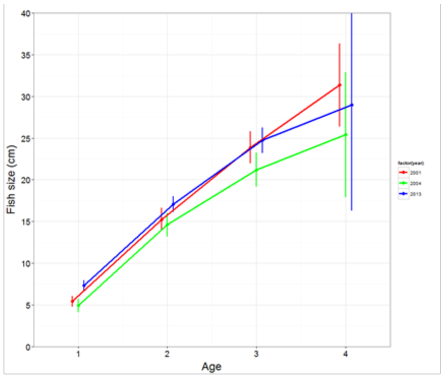


Figure 1 Growth patterns of Baltic cod, back-calculated from otolith measurements. Data shown are means ± confidence intervals, with x-values dodged for improved visibility of the growth curves. Years: 2001 (red), 2004 (green) and 2013 (blue).

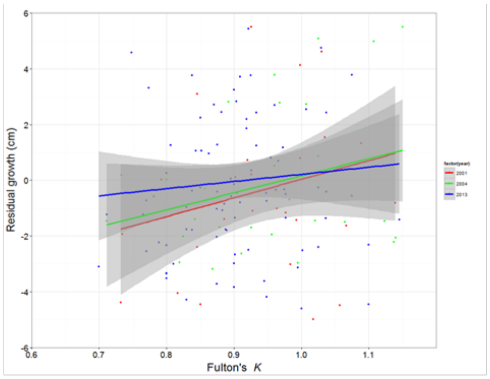


Figure 2 Relationship between residual growth and Fulton's K for Baltic cod. Positive residuals correspond to faster than average growth, negative values to slower growth.

Growth and maturity of eastern Baltic cod as illustrated by ICES subdivision 26 of the Baltic Sea

V.M. Amosova, A.I. Karpushevskaya, I.V. Karpushevskiy (AtlantNIRO, Russia)

The results of our research confirmed the trends of early maturation of the eastern cod stock, which began after 2005 and are continuing the present time. Hepatosomatic indices of all cod size groups decreased by 2013 in comparison with the beginning of the 2000s. This fact is proved by our analysis of cod energy level dynamics while studying the liver fat - the proportion of fat content in chemical composition (Figure 1).

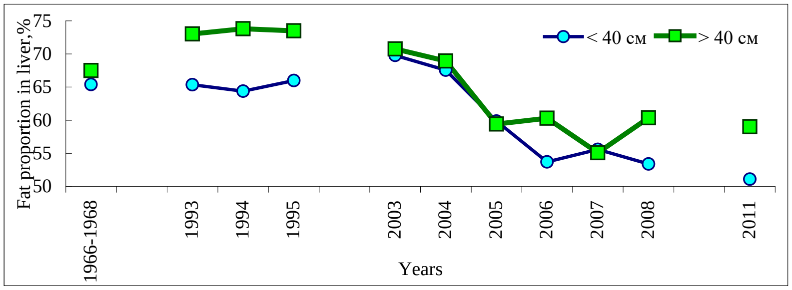


Figure 1. Fat content proportion in liver of different cod size groups according to the chemical analysis (data provided by Perova L.I. and M.L. Vinokur, technological direction of AtlantNIRO: Reports on research work "Investigation of food and biological value of commercial and non-commercial fishes of the Atlantic Ocean and the Baltic Sea based on the catches obtained during the periods of 1993–1995 and 2003–2011"; 1966–1968 - Pechatina V.I., 1972, Perova L.I. and Kovalyova, 1995; Perova, 1998).

Growth of any organism, including fish, is closely linked to food supply. Taking into account the reduction of liver energy supplies of all cod size groups after 2005, reflecting the deterioration of this species physiological state as well as increasing of the sprat fed state degree while decreasing of its feeding rate by crustaceans, it can be assumed that availability and abundance of *Saduria entomon* and *Mysis myxta* is an important biotic factor in the ration of cod. Despite the highest sprat biomass in the mid 90s, *Mysida* and

Saduria were in 2 times more observed in the stomachs of cod < 40 cm before 2005 (figure 2).

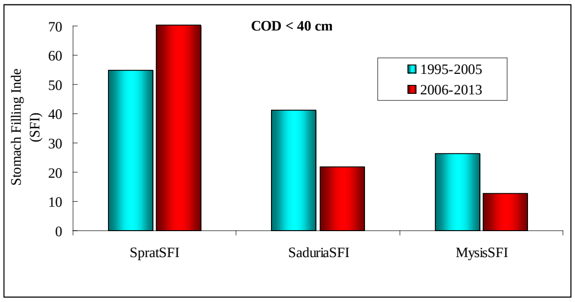


Figure 2. Cod Stomach Filing Index (SFI) by preys in SD 26.

The main fish growth driver is vitamin B1 content which is responsible for metabolism. According to the data obtained by researchers from AtlantNIRO [Chernyshova O.Yu., Perova L.I, 1998] one of the causes of thiamine deficiency is the presence, in the cod's ration of fish that contains significant amount of thiaminase enzyme. It was found that thiaminase activity of sprat and herring does not depend on the season and is almost stable for these fish species. However, its content in sprat is nearly 5,5 times more than in herring. In recent period, the main cod prey item is sprat. Sprat' thiaminase collapses thiamin synthesized by cod's digestive tract microflora, as well as it collapses thiamin coming with food – all this explains vitamin B1 deficiency.

Against the background of these changes, we analyzed maturation of cod by length. In the period from the beginning of the 2000s, 100% of females matured at the length of 45 cm, males - at 40 cm. Currently, 100% of females mature at a length of 35 cm, males – at 30 cm. The length of the 50% maturing of males and females has decreased by an average of 5 cm (females up to 30 cm, males up to 21 cm); (ICES CM 2016/F:665).

Linking length and weight of the fish to growth rate

Lars O. Mortensen, DTU Aqua

The current study investigated a possible link between length, weight and growth rate of fish. A combination of length and weight expresses condition of fish. The hypothesis was that if condition and growth rate are connected, one could use changes in condition to predict respective changes in growth rate, in situations like EB cod, where length at weight data are available, but growth rate is hard to determine due to unreliable age information. However a key challenge is that condition and growth are temporally displaced, with condition being a state variable while growth is a transition variable. Thus, condition could affect growth or growth could condition. To investigate this, data on age, length and weight on individual cod were used for EB cod (derived from BITS survey). For comparison, similar data were derived for the North Sea cod, Norway costal cod and Southern Coast of Saint Lawrence cod.

Initially, annual mean length and weight at age were calculated for all populations. Subsequently, growth in length and weight was estimated by calculating the inter-annual change in mean length and weight at age from one year to the next. As age readings after

2006 in the Baltic are unreliable, growth information for the Baltic was only used for before 2006. Mean annual condition of the cod was estimated by using the slope coefficient of a linear regression of the relationship between log(Length) and log(Weight).

Effect of growth on condition was analyzed using a t-test, comparing growth in the period prior to higher than average condition with growth in the period prior to lower than average condition. Similarly, effects of condition on growth were analyzed using a t-test, comparing growth in the period after higher than average condition with growth in the period after lower than average condition. This was done both for EB cod for the period before 2006 and for the other cod populations. Comparisons were done for small (<50 cm) and large individuals (>50cm).

Only very few comparisons showed a significant difference in growth in periods prior and after high and low conditions. Thus, these analyses did not indicate changes in growth as a result of changes in condition. However, as comparisons were done using population averages, nuances and details could have been overlooked, thus the current result does not exclude a change in growth in the EB cod along with the declining condition.

Future analysis to circumvent the challenges of averages and other issues include constraining intercepts in the condition estimates, estimating condition of large and small individuals separately and modelling conditions effect on growth and subsequently using raw data to estimate growth in high and low condition regimes.

Compared to Other stocks

Baltic

Overall	Length High: 1.18 Low: 1.23	Weight High: 1.73 Low: 1.94
Small	Length High: 1.25 Low: 1.32	Weight High: 2.09 Low: 2.38
Large	Length High: 1.09 Low: 1.11	Weight High: 1.30 Low: 1.32

NSIBTS

Overall	Length High: 1.38 Low: 1.28	Weight High: 3.61 Low: 2.45
Small	Length High: 1.72 Low: 1.54	Weight High:6.71 Low: 4.08
Large	Length High: 1.14 Low: 1.12	Weight High:1.47 Low: 1.48

Coastal Norway

Overall	Length High: 1.21 Low: 1.19	Weight High: 2.09 Low: 1.82
Small	Length High: 1.43 Low: 1.38	Weight High: 3.44 Low: 2.85
Large	Length High: 1.11 Low: 1.10	Weight High: 1.41 Low: 1.31

S. Gulf St. L

Overall	Length High: 1.15 Low: 1.17	Weight High: 1.58 Low: 1.76
Small	Length High: 1.20 Low: 1.24	Weight High: 1.82 Low: 2.10
Large	Length High: 1.05 Low: 1.06	Weight High: 1.19 Low: 1.21

Figure 1. Comparison of growth (in length at in weight) in periods prior to higher than average conditions to growth in periods prior to lower than average conditions, for four cod stocks. Red indicate non-significance, yellow show p<0.1 and green show p<0.05.

Compared to Other stocks

Baltic

Overall	Length High: 1.24 Low: 1.20	Weight High: 1.99 Low: 1.81
Small	Length High: 1.32 Low: 1.28	Weight High: 2.40 Low: 2.19
Large	Length High: 1.14 Low: 1.09	Weight High: 1.46 Low: 1.28

NSIBTS

Overall	Length High: 1.29 Low: 1.30	Weight High: 2.52 Low: 2.79
Small	Length High: 1.52 Low: 1.61	Weight High: 4.03 Low: 5.03
Large	Length High: 1.12 Low: 1.12	Weight High: 1.46 Low: 1.48

Coastal Norway

Overall	Length High: 1.20 Low: 1.20	Weight High: 2.01 Low: 1.92
Small	Length High: 1.39 Low: 1.42	Weight High: 3.18 Low: 3.13
Large	Length High: 1.11 Low: 1.09	Weight High: 1.42 Low: 1.31

S. Gulf St. L

Overall	Length High: 1.15 Low: 1.67	Weight High: 1.67 Low: 1.69
Small	Length High: 1.21 Low: 1.23	Weight High: 1.96 Low: 1.98
Large	Length High: 1.04 Low: 1.06	Weight High: 1.16 Low: 1.24

Figure 2. Comparison of growth (in length and in weight) in periods after higher than average conditions to growth in periods after lower than average conditions, for the four cod stocks. Red indicate non-significance, yellow show p<0.1 and green show p<0.05.

Using alternative biological information in stock assessment: condition-corrected natural mortality of Eastern Baltic cod

Michele Casin[1]i, Margit Eero[2], Sofia Carlshamre[1] and Johan Lövgren[1]

[1]SLU Aqua, Department of Aquatic Resources, Lysekil, Sweden; [2]DTU Aqua, Copenhagen, Denmark

The inclusion of biological and ecological aspects in the assessment of fish population status is one of the bases for an ecosystem-based fisheries management. During the past two decades the Eastern Baltic cod has experienced a drastic reduction in body condition, and likely also in growth, that may have affected its survival. We used results from published experimental literature linking cod condition to starvation and mortality, to estimate the annual proportion of cod close to the lethal condition level in the Eastern Baltic cod stock. Thereafter we applied these results to adjust the natural mortality (M) assumed in the analytical stock assessment model. The results in terms of Spawning Stock Biomass (SSB), Fishing mortality (F) and Recruitment (R) in the final year from the stock assessment using M values adjusted for low condition were up to 40% different compared with the assessment assuming a constant M=0.2. These estimates could be used in combination with other estimations of additional mortality (such as seal predation and parasite infection) to adjust the natural mortalities used in analytical stock assessment.

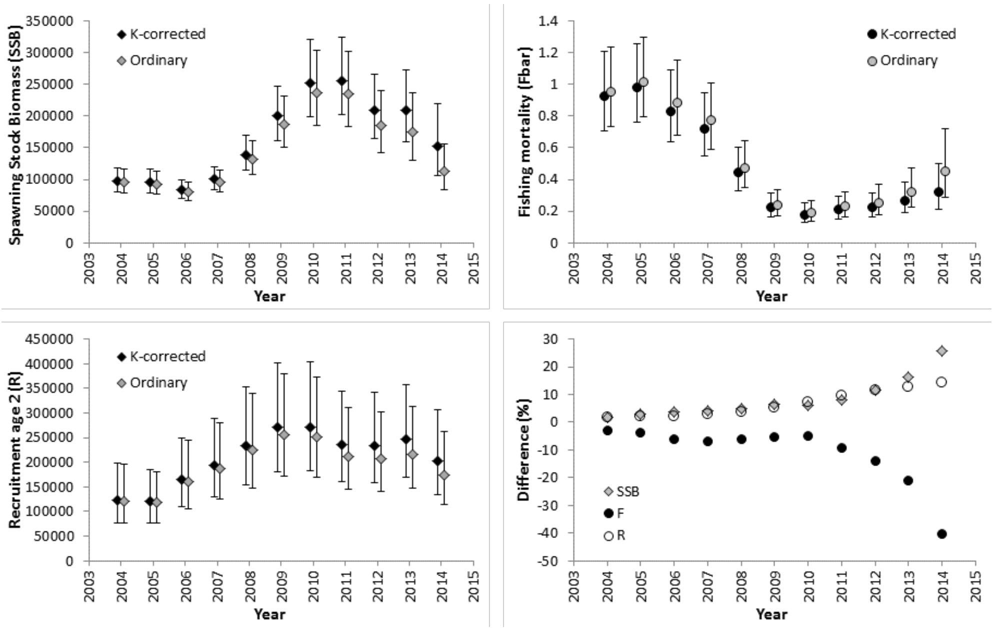


Figure 1. Comparisons of Spawning Stock Biomass (SSB), Fishing mortality (F) and Recruitment (R) by year for the SAM runs with constant natural mortality of 0.2 and the SAM runs with K-corrected natural mortalities. The symbols represent the final year estimate of 11 runs where we excluded step-by-step one year at a time back to 2004 (i.e. they represent the final year of 11 retrospective runs ending from 2004 to 2014). The relative differences in SSB, F and R using SAM runs with constant natural mortality of 0.2 and the SAM runs with K-corrected natural mortalities are also shown. Bars show 95% confidence intervals. From Casini *et al.* 2016.

Mortality due to seal predation

Karl Lundström, SLU Aqua

Abundance of seals in the southern Baltic Sea

The populations of harbour seals and grey seals in the Baltic Sea have recovered from very low numbers. Grey seal is the most abundant species and approximately 30 000 animals have been counted during the last years accounting for around 70% of the total population size. The highest concentration of grey seals is in the northern Baltic Proper (Figure 1). Harbour seals occur as a distinct population in the Kalmar Sound and in the south-western Baltic (Figure 1). The Kalmar Sound population has varied between 800 and 1000 animals during the last years, representing around 60% of the total number.

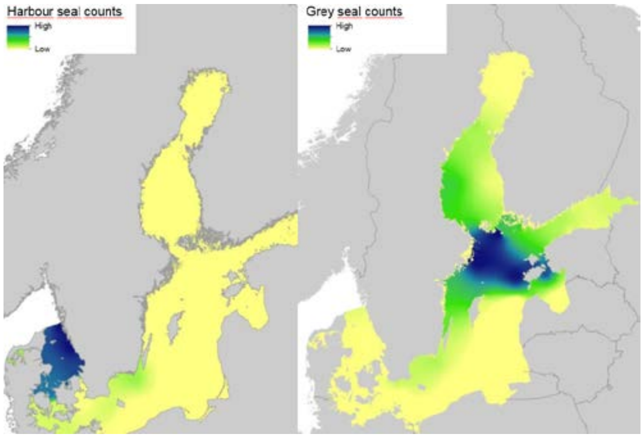


Figure 1. Distribution of harbour seals and grey seals in the HELCOM area based on average number of counted seals during the moulting period 2011–2016. Maps modified from HELCOM 2016 Maps for marine mammals 5-1-Rev.1.

Spatial dynamics of seals

Information about the spatio-temporal distribution of both harbour seals and grey seals and their overlap with the eastern Baltic cod stock is limited. Especially grey seals can migrate long distances, with individual variation between seals foraging more locally in a few feeding areas to long-range foragers altering between several feeding areas in different basins of the Baltic Sea, several 100 km apart. Figure 2 shows GPS positions of tagged grey seals. Even though the GPS tracks do not show the population-wide distribution and are biased towards the areas in which the seals were caught, they provide an overview of areas used by the tagged seals.

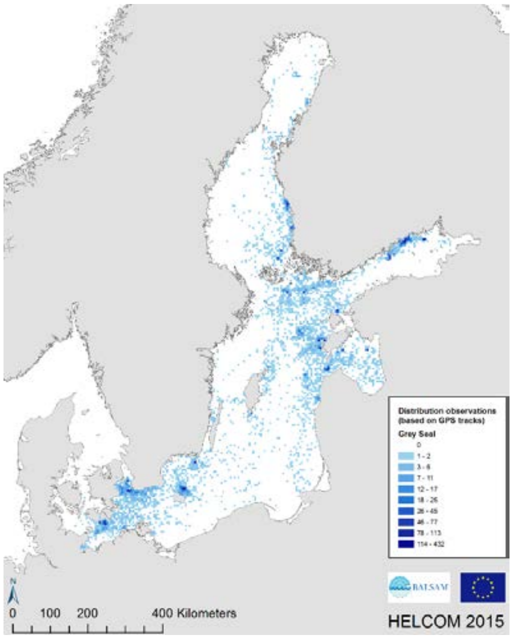


Figure 2. Density (number of locations per 5 x 5 km) of grey seals in the Baltic Sea based on satellite telemetry. Map from HELCOM, supported by the BALSAM project.

Diet of seals in the southern Baltic Sea

Diet data from harbour seals in the southern Baltic Sea is lacking. Previous grey seal diet data is mainly available from the central and northern Baltic Sea (ICES SD27, 29–32). Recent analyses of faceal scats from grey seals on Christiansø, north of Bornholm, clearly indicate that cod is a key prey species for grey seals in the southern Baltic Sea, occurring in between 85–100% of the examined samples (Kroner 2016; Pittman Botnen 2014). This is further supported by preliminary results from a study off Gotland where cod was found in 30% of the samples, constituting 25% of the diet by weight (SLU unpublished data). Based on otoliths in the diet samples, grey seals seem to prefer cod larger than 25 cm (Figure 3).

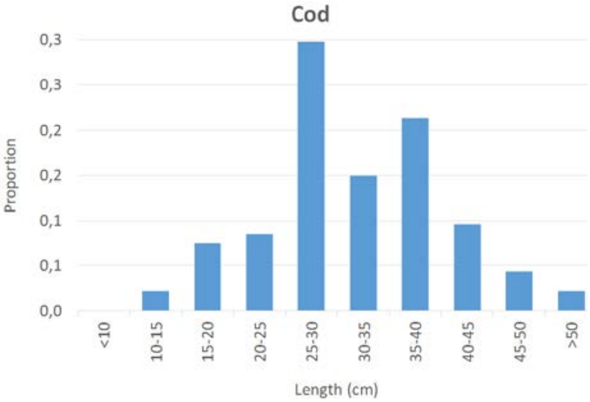


Figure 3. Length distribution of cod in the estimated diet of grey seals off Gotland (SLU unpublished data).

Together with SLU and the Natural History Museum of Denmark, DTU Aqua is running a project to improve the knowledge about the feeding habits of grey seals in the southern Baltic Sea. Faceal scats are collected from all major haul outs in the area and the collected samples will be analysed morphologically as well as with DNA barcoding.

Has natural mortality of cod increased? - some supporting observations and analyses

Jan Horbowy, MIR, Poland

Presentation was based on two recently published papers: one on dynamics of cod infection with nematodes that are present in the liver of fish (Horbowy *et al.*, 2016) and the other one on the effects of varying natural mortality on the assessment of eastern Baltic cod (Horbowy, 2016).

In the first paper the data on cod infection with parasites present in the liver, covering south of Baltic in 2011–2014, were analysed using GLMs. The analyses revealed that both prevalence and intensity of infection were increasing with length of fish (which was expected) but next peaked up and declined for bigger cod (Figure 1). Following the model of des Clers (1989) and Horbowy and Podolska (2001) the intensity of infection should increase due to accumulation of parasites during the host life. At least part of the discrepancy between the Horbowy and Podolska (2001) model (red line in the figure) and the model fitted basing on observations may be related to increasing mortality of older and heavily infected cod.

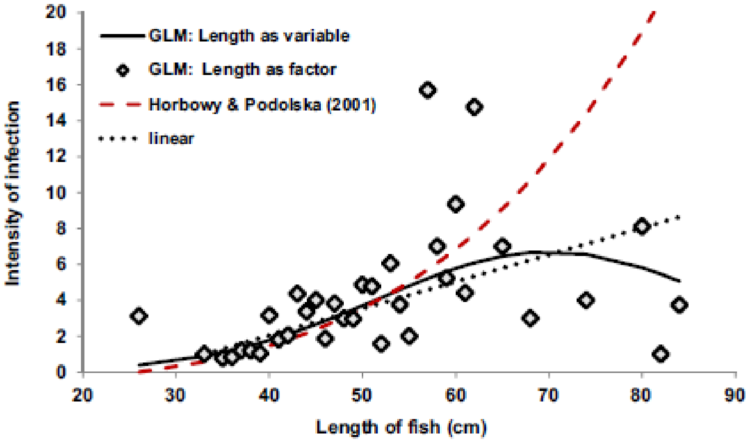


Figure 1. The dependence of the intensity of infection with *Anisakis* sp. on the length of cod as estimated by the GLM with length as a factor (diamonds) and as a variable (solid line). Also shown for comparison are Horbowy and Podolska's (2001) model of the intensity of infection (broken line) and the linear regression model (dotted line), both fitted to the increasing part (up to 50 cm) of the GLM estimates with the length of the host as a factor.

In the research by Horbowy (2016) on the effects of varying natural mortality on the assessment of eastern Baltic cod, the cod assessment was performed with two models: age-structured CAGEAN (Deriso *et al.*, 1995) and difference stock-production model (Horbowy, 1992). In both models two options for natural mortality dynamics were implemented, i.e., the natural mortality was constant by years or it was allowed to change after the 2007. In CAGEAN model the M was related to cod weight by hyperbolical function, M(y) = 0.2 + slope/w(y) , and in production model it was increasing with time by constant vales M (y) = 0.2 + (y-2007)*ΔM , where w is weight, y is year, and slope and ΔM are parameters estimated within the models. Implementation of varying natural mortality to the models markedly improved their poor performance with constant M: retrospective analyses showed much more consistent estimates of biomass and fishing mortality and distribution of catch residuals did not show blocks of positive and negative values as in case of constant M models (Figure 2). In addition, increasing M option in the production model reproduced observed in survey decline of biomass after 2011, not observed with constant M approach. The estimates of natural mortality (mean M by age weighted by biomass of age group) are quite consistent between both models and show increase of M from 0.3–0.4 in 2007 to 0.6–0.7 in 2013 (Figure 3).

Analyses presented in both papers suggest that natural mortality of cod underwent marked changes in recent years, showing generally increasing trend.

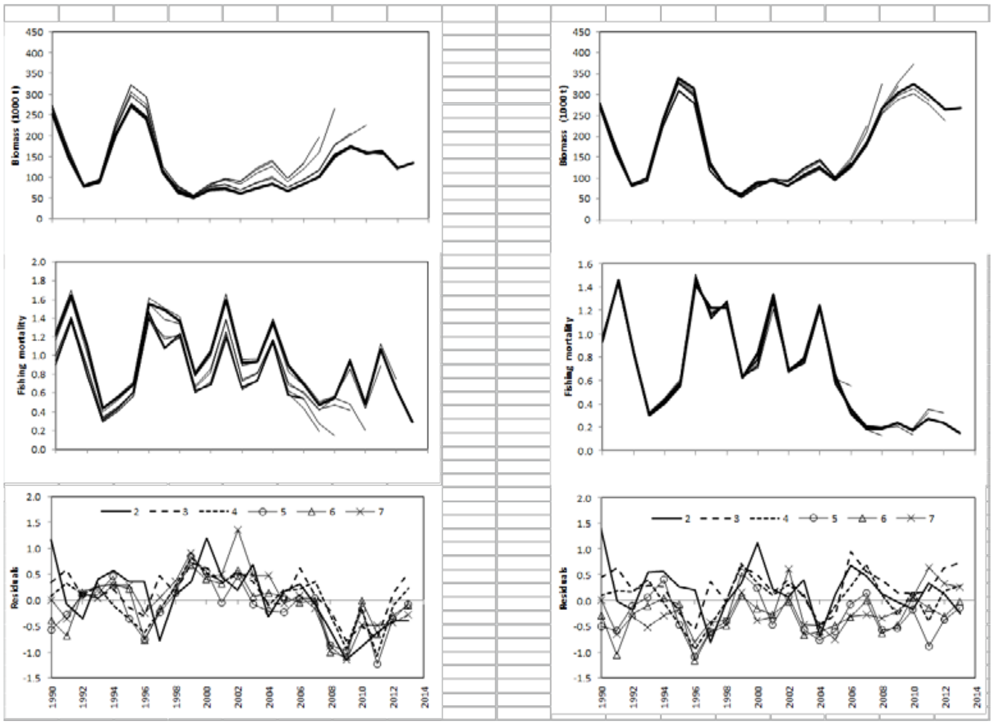


Figure 2. Retrospective estimates of biomass and fishing mortality and distribution of catch residuals from CAGEAN assessment of cod for constant natural mortality (left panel) and weight dependent (declining with weight) M (right panel).

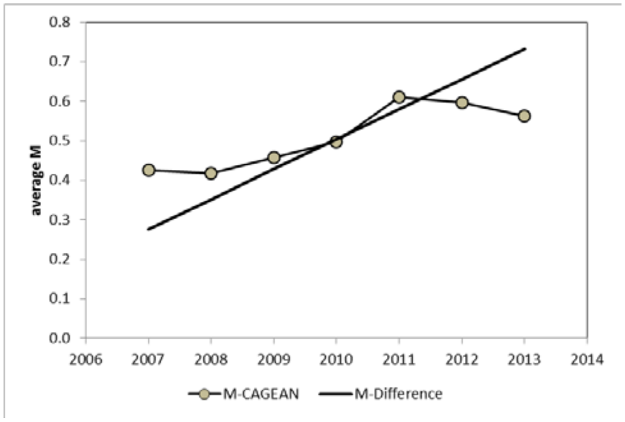


Figure 3. Comparison of the natural mortality estimates from the CAGEAN and production (difference) models. The M in difference model is interpreted as mean M by age weighted by biomass of age group, so mean M from CAGEAN model is similarly calculated.

Spatial distribution of seal-associated liver worm (*Contraceum osculatum*) in cod

Jane Behrens[1], Kurt Buchmann[2], Bastian Huwer[1]

[1] DTU Aqua, [2] KU-SUND

Concurrent with the increase in the number of grey seals in the Baltic, infestation rate with the seal-associated liver worm *Contraceum osculatum* in cod livers has increased in fish caught in some areas of the Eastern Baltic, in particular in the waters adjacent to Christiansø, where a seal haul-out exists. Yet, the extent to which infestation rates have increased also in other areas remains unclear. With the purpose of getting an overview of the spatial distribution of *C. osculatum* in cod livers, DTU Aqua has in Q4 2016 collected cod livers from cod caught in the North Sea, Skagerrak, northern and southern Kattegat, the Sound, the waters adjacent Christiansø and two area east and northeast of Bornholm. To enable comparison between areas, and since infestation rate correlates positively with fish length, only livers from cod between 35 and 50cm have been collected. In collaboration with Copenhagen University, livers from four areas have so far been analysed (Table 1), showing an increasing trend from east to west in both prevalence (percentage of cod infected) and intensity (number of worms per infected liver) of *C. osculatum*. Table 1.

Area (number of livers)	Length (cm)	Fulton K	Prevalence (%)	Intensity (no. of worms)
Southern Kattegat	38 ± 4	1.1 ± 0.1	64	3 ± 4
The Sound	40 ± 4	1.1 ± 0.1	62	1 ± 1
Christiansø	38 ± 3	0.9 ± 0.1	100	29 ± 23
East of Bornholm	38 ± 3	0.8 ± 0.1	100	45 ± 29

Analysis of the four remaining areas (North Sea, Skagerrak, northern Kattegat and the area northeast of Bornholm) will reveal if the initial trend from east to west in both prevalence and intensity of *C. osculatum* (Table 1) can be supported. Ultimately, prevalence and infestation will be correlated with the distribution and number of grey seals throughout the area wherefrom livers have been collected.

Changes in maturation and resource allocation of Baltic cod

Tomkiewicz J., Støttrup J.G., Jacobsen C., Huwer B., Eero M., Köster F.W.

During the two recent decades, Eastern Baltic cod population dynamics has changed with significant alterations in vital rates and life history parameters. In a recent review (Köster *et al.*, 2016), we analysed time trends in cod maturation pattern, condition and nutritional status. Here, we evidenced that size at sexual maturation in Eastern Baltic cod has decreased over the last 20 years. Figure 1 shows length at sexual maturity (L50) of female and male cod, respectively. While it is common that male fishes reach sexual maturation earlier in life than females, the trend towards maturation at smaller size is extraordinary. For females L50 has changed from around 43 cm to 24 cm and for males from around 35 to 19 cm over a 20 year period. Reduced L50 correlates with reduced condition and increased parasitism. Earlier maturation is commonly associated with shorter life span, which matches a significant decrease in proportion of males at increasing size (Figure 2).

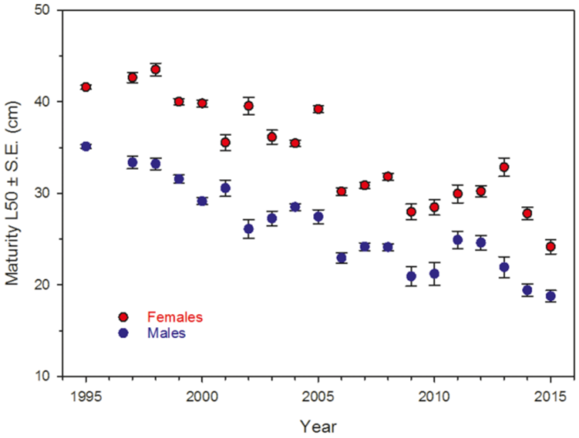


Figure 1. Mean length at 50% sexual maturity of female and male Eastern Baltic cod in Subdivision 25 during 1995–2015 (Baltic International Trawl survey, Danish data); error bars indicate standard error (published in Köster *et al.* 2016).

The prominent reduction in size at sexual maturation was validated as part of the Bonus Bio-C3 project. Here, 314 specimens of cod sampled in ICES Sub-division 25 in 2015 for histological determination of maturity stage, including 189 females and 122 males. The histological maturity classification confirmed the macroscopic staging on board the research vessel and the observed maturation at small size.

In addition to the deterioration of the condition e.g. Fultons K. (Eero *et al.*, 2015; Casini *et al.* 2016), the lipid composition of the diet of Baltic cod shows limitations in essential fatty acids, i.e. DHA, EPA, ARA (Tomkiewicz *et al.* 2009; Røjbek *et al.* 2012, 2014a,b). Low maternal condition has been shown to impact not only the quantity but also the quality of spawning products and viability of offspring in other cod stocks. This is likely also the case for Eastern Baltic cod, whose diet is dominated by sprat and herring and few benthic species such as *Saduria entomon*. In recent studies, low arachidonic acid (ARA) levels were observed in cod livers and in whole fish of sprat and herring, while high levels pertained to *Saduria* (Røjbek *et al.*, 2012, 2014a). Thus, changes in prey availability and quality for cod, specifically shortage of benthic prey (Eero *et al.*, 2015), may impact cod reproductive success via offspring survival (Røjbek *et al.* 2014b). Likewise, limitation of ARA in the food supply of cod may be associated with a delay in spawning resulting in the protracted spawning time of the stock (Tomkiewicz *et al.* 2009; Røjbek *et al.*, 2012).

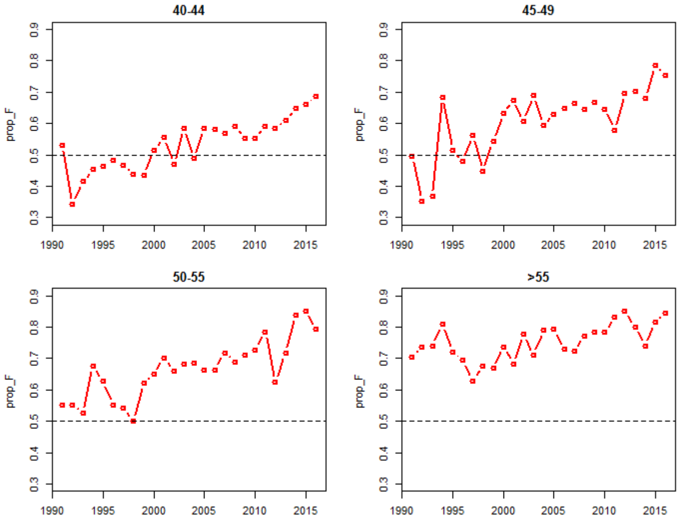


Figure 2. Changes in sex ratio (proportion of females shown in y-axis), for different size groups of cod based on Q1 BITS data from DATRAS database.

Maturation cycle in Eastern Baltic cod

Jens-Peter Herrmann and Richard Klinger

In total 19341 data on individual cod from the Bornholm Basin collected on 32 cruises from 2002 to 2015 were analyzed with respect to: 1) establish a mean maturity cycle for both sex; 2) look at differences in relative maturity distributions between years (in August, at peak spawning times over the last 15 years); and 3) describe differences in weight at length.

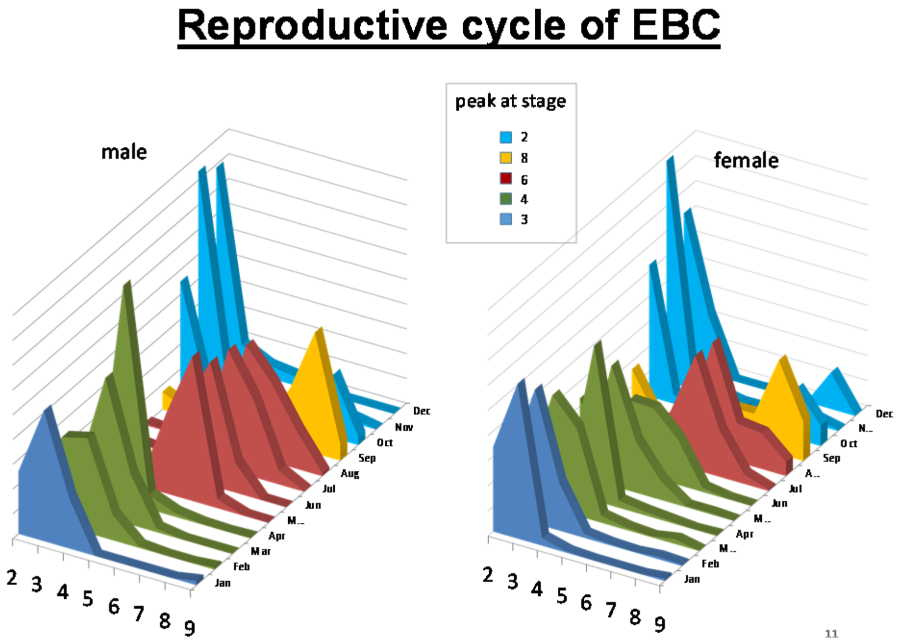


Figure 1. Mean Reproductive cycle of male and female cod from the Bornholm Basin (2002 to 2015). For each month the relative distribution of maturity stages is presented; the peak of maturity stage is indicated by colour.

Males and females show differences in the mean reproductive cycle (Figure 1) as males develop earlier than females. Males also have a prolonged time staying at active spawning (majority at maturity stage 6) from May to August in comparison to females (majority at maturity stage 6) from July to August.

The relative distribution of maturity stages from 2002 to 2015 in August of each year is presented in Figure 2. In most of the years the majority of cod showed maturity stage 6 indicating active spawning. However in the years 2002, 2003 and 2015 the majority of cod had already finished spawning. These two periods of shifted spawning to earlier time in the year may be driven by the two strong inflow events in 2003 and 2014, but the reasons seem to be unclear.

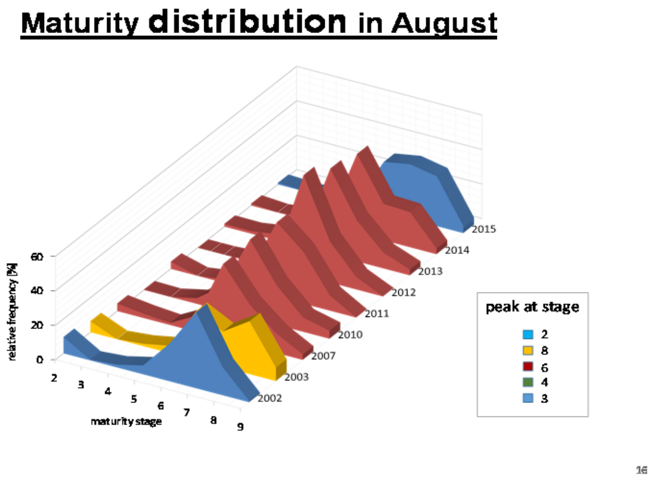


Figure 2. Relative maturity distribution of cod from the Bornholm Basin in August (2002 to 2015). For each year the relative distribution of maturity stages is presented; the peak of maturity stage is indicated by colour.

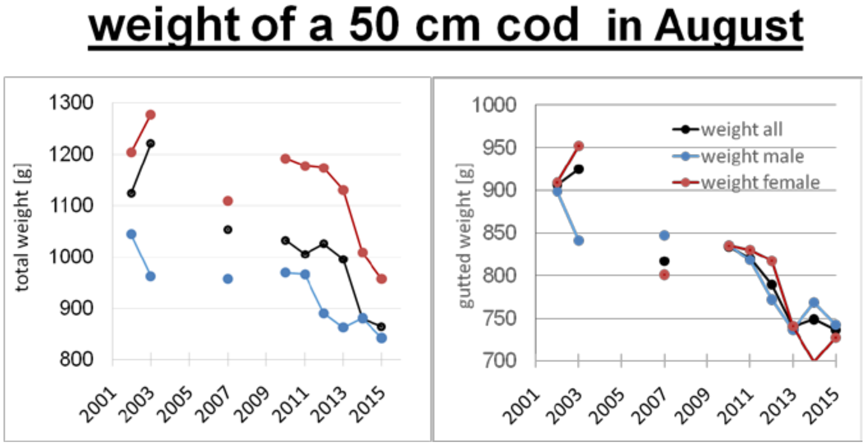


Figure 3. Development of the weight of a 50cm cod calculated from the length weight relationship of each year for the period 2002 to 2015. Data are given for male, female and both sex together for total weight (left) and gutted weight (right).

The total weight as well as the gutted weight has substantially decreased by approximately 20% in the period from 2002 to 2015. The mechanism responsible for the lower weight of a cod at a given size is not clear. However from a bioenergetics point of view there is evidence that cod either must be food limited in quantity or quality or the energy expenditure has increased may be by the increase in infection with parasites.

Long-term changes of annual reproduction cycles of Eastern Baltic cod

Maris Plikshs[1], Tatjana Baranova[1] &Christian Möllmann[2]

[1]Institute of Food Safety, Animal Health and Environment „BIOR”, Riga, Latvia

[2]Institute for Hydrobiology and Fisheries Science, University of Hamburg, Germany

Based on long-term data from research surveys carried out by BIOR and its predecessor institutes, the cod maturity was analyzed in the Gotland Basin. Although the Gotland basin importance in cod reproduction in recent decades is questioned, in the southern part of the basin depending from hydrological situation quite frequently the spawning may occur (Köster *et al.* 2016).

Sexual maturity of cod was determined by visual inspection of the gonads using 6 grade scale developed by Kiselevich in 1923 (Pravdin, 1966). All fishes according to maturity stages were aggregated into 3 group: 1) immature/resting (stages I and II); 2) ripening (stages III-IV); and 3) spawning (stages (V and VI). Annual distribution of these groups in recent decade shows:

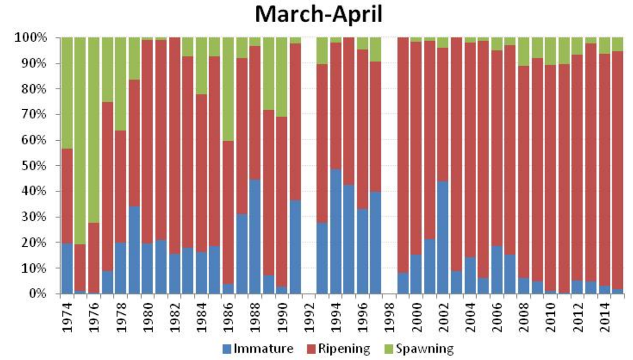
1) an increase of ripening fish in the first quarter but decrease of spawning fish. This suggest that spawning timing change from spring towards the summer/autumn months.
2) an increase of spawning (up to 20%) and ripening fish while immature fish share decrease in 4th quarter (Figure 1).

This analyses suggest that until 1990 the spawning time of cod in the Gotland Basin occurred mainly in the early or late spring. During 1990s the spawning peck timing mainly was in summer. Such change is confirmed by ichthyoplankton analyses (Wieland *et al.* 2000). However, in recent decade from gonad visual inspection it is not possible to determine spawning peak timing. Almost through the whole year the fishes are in all maturity development stages and spawning of population extends from early spring till late autumn. The mechanisms determining such change is not clear but obviously are related to present hydrological regime and stock abundance changes.

Additionally, maturation schedules of cod since year 2000 shifted towards smaller size. It may be associated with strong decrease of population size in Gotland basin and Baltic after late 1980s. Trend is similar for both sexes (Figure 2). Since 2005 the male L50 at maturity is below 25cm but for female – below 35 cm that is lowest during 1975–2016. Similar tendencies are shown for collapsing population of Atlantic cod near Labrador and Newfoundland (Olsen *et al.* 2005).

Conclusions:

1) Estimation of maturity ogives of cod for recent 30 years from research surveys based on visual detection of maturity stages is problematic due to changes in spawning timing;
2) Estimation of spawning stock size since 2005 should account for shift of maturation of smaller fishes e.g. 20–30cm.



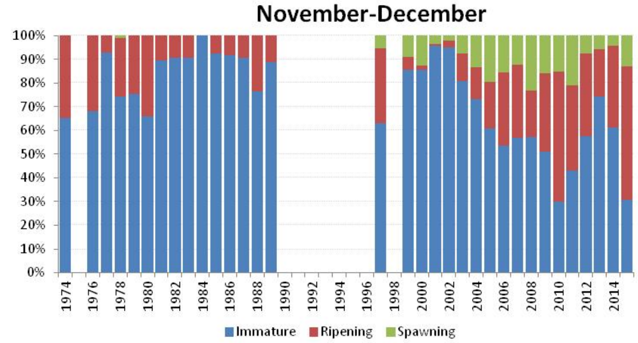


Figure 1. Percentage of immature, ripening and spawning cod (>30cm) in the Gotland Basin during 1st and 4th quarter BITS surveys.

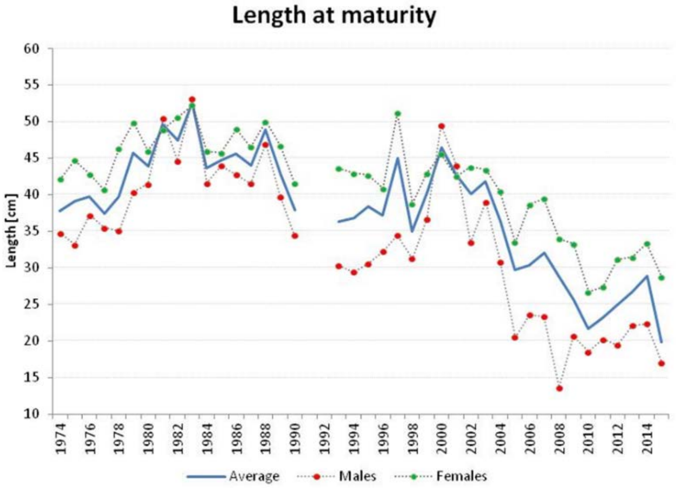


Figure 2. Length at first maturity (L50) of cod in the Gotland Basin.

Application of the auto-diametric method to study the Baltic cod's fecundity and influence of condition

Mion M.[1], Thorsen A.[2], Casini M.[1]

[1]**SLU Aqua, Department of Aquatic Resources, Lysekil, Sweden;** [2]**IMR, Institute of Marine Research, Bergen, Norway**

An increasing number of studies have shown that SSB fails to accurately account for stock specific features that can produce different number of recruits at the same spawning biomass level, such as length composition and condition (Marshall *et al.,* 2006). In particular condition (used as a proxy for total energy reserves) has been shown to have a significant effect on individual fecundity (Kjesbu *et al.,* 1998), rates of atresia (Kjesbu *et al.,* 1991) and egg quality (Marteinsdottir and Steinarsson 1998). Consequently when a stock is dominated by small individuals with a decrease in condition, as in the case of the Baltic cod stock, this leads to an overestimation of the reproductive potential.

In this study we applied and validated the auto-diametric fecundity method, as described by Thorsen and Kjesbu (2001), to 114 ovary samples belonging to SD 24 and 25 for the years 2015 and 2016. As a results, to be able to estimate potential fecundity from mean oocyte diameter and ovary weight we calculate a calibration curve between the mean oocyte diameter from image analysis and the oocyte density from the manual counting.

In addition, to investigate the relationship between potential fecundity and possible predictors (body size, gonadosomatic index, Fulton's condition factor and hepatosomatic index), a series of generalized linear models were used (Table 1).

Body size, specifically length more than weight (74% against 69% respectively) was the best predictor of fecundity in terms of proportion of explained variance. The addition of condition and hepatosomatic index to the fecundity/length relationship increased the explained variance respectively of 5% and 6%. Therefore the predicted potential fecundity, mirroring the reproductive potential, for the same length class, will be lower if the condition or hepatosomatic index (lipid content) are low.

Table 1. GLMs results. β_0 is the intercept while, β_1 is length, weight or gutted weight (depending on the model) coefficient. β_2 is the Fulton's K, GSI or HSI (depending on the model) and β_3 is HSI. *p* and *df* are the *p-value and* the degrees of freedom, respectively. AIC is the Akaike's information criterion and PEV is the proportion of explained variation.

Model	β_0	$p_{\beta0}$	β_1	$p_{\beta1}$	β_2	$p_{\beta2}$	β_3	$p_{\beta3}$	df	PEV	AIC
PF~L	9.71	<0.001	0.10	<0.001					112	0.74	3090.4
PF~W	12.20	<0.001	0.00	<0.001					112	0.69	3110.9
PF~W_{gutted}	12.12	<0.001	0.00	<0.001					112	0.71	3103.1
PF~LT+K	8.39	<0.001	0.10	<0.001	1.74	<0.001			111	0.79	3067.1
PF~LT+GSI	9.76	<0.001	0.10	<0.001	-0.01	ns			111	0.74	3092.1
PF~LT+HSI	9.53	<0.001	0.09	<0.001	0.09	<0.001			111	0.80	3065.0
PF ~ LT + K + HSI	8.46	<0.001	0.09	<0.001	1.41	<0.001	0.08	<0.001	110	0.83	3047.1

Thinner females – fewer eggs? Temporal trends in Eastern Baltic cod fecundity (2005–2016)

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Currently there is the question whether the strong decline in Eastern Baltic cod condition during the last decade has led to lower fecundity. As part of GEOMAR's annual multidisciplinary Baltic cruises, cod single fish data and frozen gonad samples are available from spring 2005–2016 from Bornholm Basin (ICES SD25); (Figure 1). To exploit this resource to assess fecundity over time, the established auto-diametric method on formalin preserved samples was adapted to frozen gonad samples. Method validation tests showed that results between the two methods were comparable.

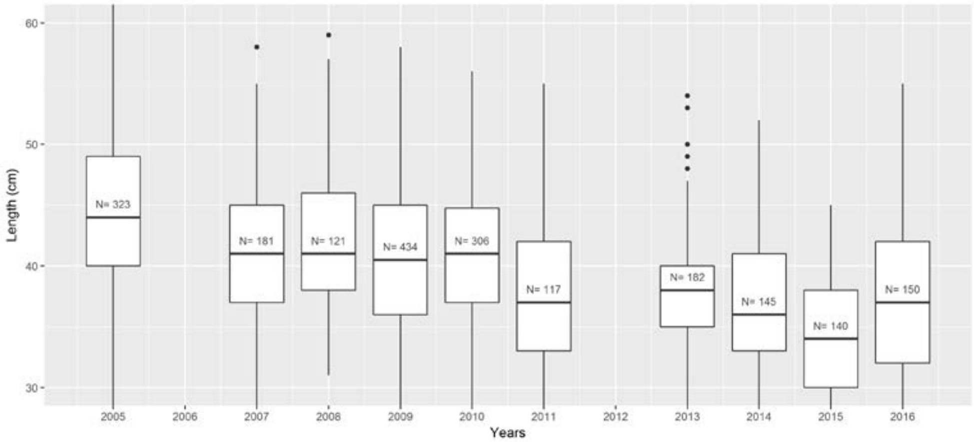
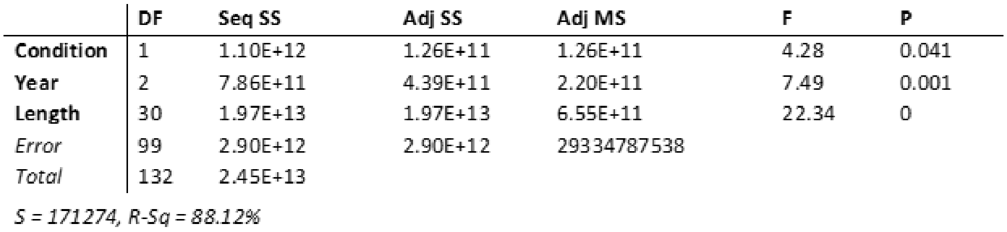


Figure 1. Overview of available frozen cod gonad samples 2005–2016 from SD25. The length refers to female stage 4 from which gonads were sampled.

As a first step, we assessed the potential fecundity of fish of different sizes and in different condition in the years 2005, 2009 and 2016. Preliminary analysis based on this initial dataset indicated that besides the (expected) strong positive correlation of fecundity with fish size, fecundity was also marginally significantly correlated with fish condition, and differed significantly between years (Table 1).

Table 1. General linear model (ANCOVA) of potential fecundity, using adjusted SS for tests



	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	1	1.10E+12	1.26E+11	1.26E+11	4.28	0.041
Year	2	7.86E+11	4.39E+11	2.20E+11	7.49	0.001
Length	30	1.97E+13	1.97E+13	6.55E+11	22.34	0
Error	99	2.90E+12	2.90E+12	29334787538		
Total	132	2.45E+13				

S = 171274, R-Sq = 88.12%

As next step, we will strongly increase the number of analyzed samples, both within the years analyzed to date, and by adding fish spanning the maximum possible span in body size and condition from additional years, with results expected by mid-April 2017. We will then repeat the statistical analysis in a more formal way using this complete dataset. This will include the assessment of possible interaction terms in the model, and the assessment of the possible role of environmental factors, such as surface water temperature or inflow events, in explaining inter-annual variation. Fecundity data from this study will provide valuable long-term information for better management strategies of this important species.

Calculating growth of Baltic cod from mark-recapture data: experience gained from tagging of western Baltic cod.

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Growth of western Baltic cod estimated using mark-recapture data was presented to offer comparison with the current eastern Baltic cod tagging project (TABACOD) and to highlight potential issues which may also arise through TABACOD. Data from two German cod tagging projects in the western Baltic Sea were available for analysis. Three main issues relevant to TABACOD were encountered with these datasets:

1) Only 0.7% of cod tagged through one of the western Baltic cod tagging projects have so far been recaptured, resulting in a relatively low sample size. A higher recapture rate (17%) has been achieved for the other tagging project, although this is likely due to the fact that the majority of cod were recaptured in cod pots maintained by staff involved in the tagging project, and which were located at the same reef where they were released. When relying on commercial and recreational fishers to supply recaptures, large num-

bers of cod must be tagged to ensure a large enough sample size is available despite potentially very low recapture rates.

2) Short-term recaptures introduce both an increase in the amount of variability caused by measurement error and a downward bias in estimates of growth. To reduce the potential for downward bias, 50 days was suggested as the minimum time at liberty required for measurable growth to occur. However for this growth analysis, a very conservative minimum of 180 days at liberty was selected to exclude the majority of variation related to short times at liberty.

3) Some recaptured cod were frozen before measurements could be taken. Freezing causes noticeable shrinkage of fish, so including these recaptures in analysis would bias growth estimates downwards. A correction factor relating length of live fish to length of defrosted fish must be developed to account for this shrinkage effect.

Growth of western Baltic cod was estimated using the GROTAG maximum likelihood method (Francis, 1988), a re-parameterisation of the von Bertalanffy growth function (VBGF) for estimating growth from length increment data. Inclusion of additional parameters describing individual variability, seasonality of growth, measurement error and the probability of outliers significantly improved the model fit, even when fish at liberty for less than 180 days were excluded from analysis. This suggests that these factors influence the growth rates of Baltic cod as estimated from tagging data, and so should be considered when conducting growth analysis. The model estimated the average growth rate per length, for example predicting a growth rate of 12.2cm/year for a 45cm western Baltic cod. The VBGF parameter estimates derived from this model were L_∞=164cm, k=0.11.

Why we will need in silico experiments about the past to understand the future of Eastern Baltic Cod

Maria E. Pierce *et al.*, Thuenen Institute for Baltic Sea Fisheries

The option of using simulation models (as opposed to prognostic or statistical models) to conduct in silico experiments, where these would either be unfeasible in the field or would pertain to a state of the ecosystem which no longer exists, was presented. The current model is formalised in the domain specific language ML-Rules and includes a working model of basic cod bioenergetics and rudimentary behaviour. Although this type of models takes a long time to develop, over time, results could deliver valuable input to stock assessment in terms auf biological data such as growth dependent on abiotic factors but also in many other aspect such as behaviour, predator-prey interaction and the impact of abiotic conditions on stock dynamics.

Exploration of length-at-age data of eastern Baltic cod*

Valerio Bartolino and Nataliia Kulatska, Swedish University of Agricultural Sciences (SLU)

*This work was provided after the WKBEBCA meeting and was thus not presented and discussed at the meeting.

This preliminary analysis aims to investigate potential changes in the individual growth of eastern Baltic cod.

Data on individual length and age of cod collected during the Baltic International Trawl Survey (BITS) between 1991 and 2015 were downloaded from the ICES DATRAS database (datras.ices.dk). Additionally, we looked at individual data collected during bottom trawl surveys in the Baltic Sea carried out in the years 1988–1990 by the former Swedish Board of Fisheries (currently the Swedish University of Agricultural Sciences, Department of Aquatic Resources) and the former Baltic Fisheries Research institute (BaltNIIRH; currently the Latvian Institute of Food Safety, Animal Health and Environment). The dataset is dominated by samples collected during quarter 1 and 4 when the BITS survey is carried on. The analysis presented is restricted to the ICES subdivision 25. Visualization of the length distribution by age from Q4 (Figure 1) shows rapid increase in the length at age during the end of the 1980s followed by a steady decrease from the early 1990s to present. The decrease appears more pronounced in the older ages but the sample size sensibly decrease for ages >6. Differently, Q1 data show no decrease in the length at age for the age1-3, and some decrease is visible only from age4. The von Bertalanffy growth model (with and without the t0 parameter) was fit to data from every year separately.

$$lt = L\mathrm{inf}(1 - e^{-K(t-t0)})$$

The data from different seasons were pooled before fitting and the age adjusted considering the actual time spent up to the time of the sampling, i.e. a fish aged 2 in February was assigned an age of 2.125 while a fish age 3 in November was assigned the age of 2.875.

No clear temporal trend was found for the K and Linf parameters, but this could be partly explained by the dependency of the growth parameters. Once the von Bertalanffy model was fit for every year, it was used to predict the mean length for each age group. Annual predictions of mean length-at-age (Figure 2) showed a clear decrease in time with minor differences if the parameter t0 was estimated or assumed equal to 0. A steady decrease of length is modelled for the younger fish. In the older fish, length fluctuates with no trend during the 1990s until mid-2000s and a real drop is estimated only in the last period from 2010-onward.

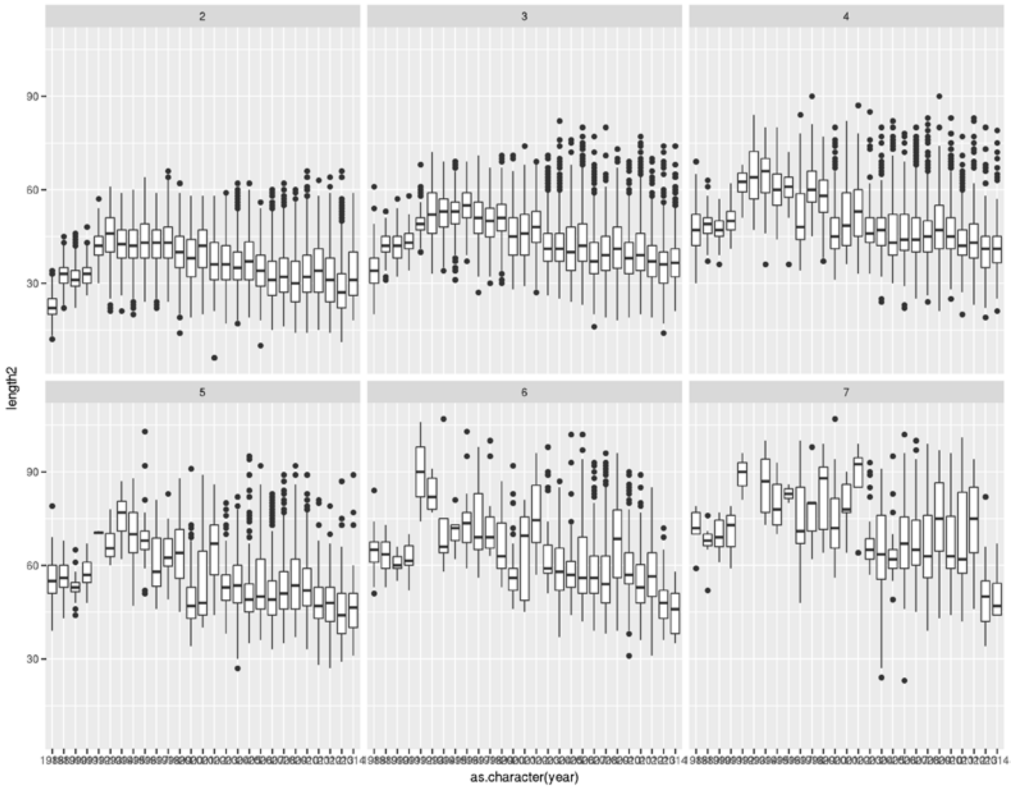


Figure 1. Time-series of the distribution of lengths for the ages 2–7 from individual fish measurements. Each boxplot represents the median, and lower and upper hinges the 25th and 75th percentiles.

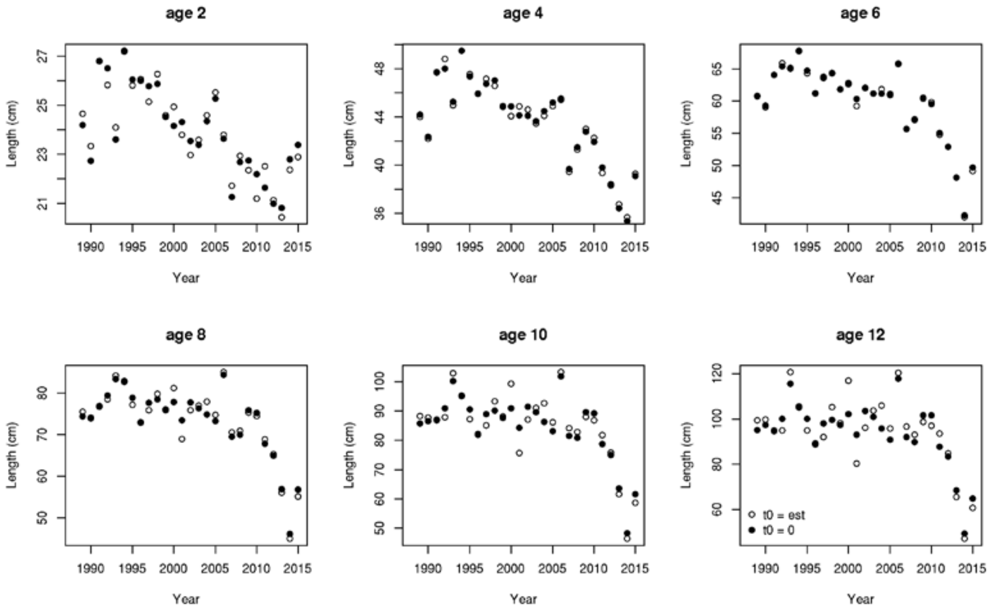
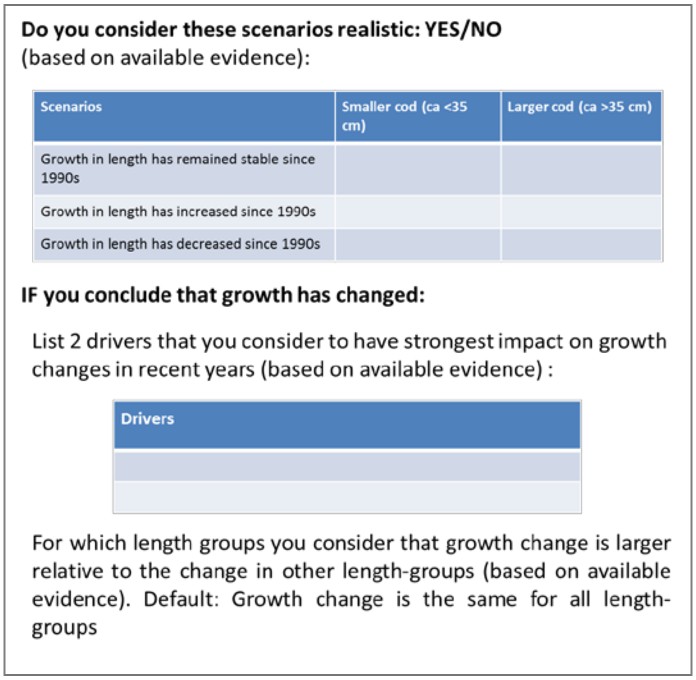


Figure 2. Time-series of estimated mean length for different age classes from the von Bertalanffy model fitted on individual years.

4 Synthesis of workshop findings and discussions

4.1 Potential changes in growth in length

Potential changes in growth in length of Eastern Baltic cod were discussed in sub-groups and summed up at the plenary, based on the information presented at the meeting, and other expertise of the participants. The groups we asked to discuss along the following questions:



Do you consider these scenarios realistic: YES/NO
(based on available evidence):

Scenarios	Smaller cod (ca <35 cm)	Larger cod (ca >35 cm)
Growth in length has remained stable since 1990s		
Growth in length has increased since 1990s		
Growth in length has decreased since 1990s		

IF you conclude that growth has changed:

List 2 drivers that you consider to have strongest impact on growth changes in recent years (based on available evidence) :

Drivers

For which length groups you consider that growth change is larger relative to the change in other length-groups (based on available evidence). Default: Growth change is the same for all length-groups

The direct and circumstantial evidences brought up by the group, that may or may not have affected growth of EB cod in length are summarised in Figure 4.1. There was an overall agreement that growth has not increased since the 1990s, however different opinions and contradicting evidences were present concerning whether growth in length has likely declined or remained stable for different size groups.

For smaller cod (<35 cm in length), most direct evidence available was from counts of daily increments on otoliths that did not suggest a change in mean length at age between 2001, 2005 and 2013 (Hüssy K; unpubl). In the period from around 2000 onwards, stomach data suggest stable consumption rate for 15–40cm cod, which does not indicate a change in growth. However, consumption rate and energy intake for cod at this size range has declined in the period from 1990s to 2000s and remained stable at low levels afterwards. Besides food availability, one of the major factors affecting condition, and potentially also growth, is considered to be hypoxia potentially affecting the fish through different mechanisms (direct physiological stress, reduction of benthic food and increase of density dependence). The extent of hypoxic areas has increased from mid 1990s to 2010 and has levelled off afterwards (Casini *et al.* 2016). Thus, if food intake and hypoxia have reduced growth, this has likely happened already in the 1990s, with possibly a continued decline until the late 2000s, along with the trend in hypoxia. Condition has continuously declined from the late 1990s up to recent years, which can be hypothesized to have reduced growth in length as well, however, such a relationship between condition and growth has not been clearly demonstrated. A major biological change that has occurred since the 2000s was a reduced size at first maturation that is expected to slow growth due to energy allocation for reproduction. In conclusion, growth is likely reduced from the 1990s due to increased hypoxia and reduced food intake. In the period from 2000s onwards, smaller size at maturation and possibly reduced body condition may have contributed to reducing the growth further. As the magnitudes of changes in growth for different reasons are not clear, it remains unknown how much the growth likely has changed in specific periods.

For larger cod (ca >35 cm), direct measurements of growth are not available, as daily increments are not possible to count for larger cod, and the traditional age reading is considered problematic especially in later years. Compared to smaller cod, consumption rate and energy intake for > 40 cm cod are not showing clear trends since the 1970s. On the other hand, developments in body condition and hypoxia are probably influencing the larger cod similarly to the small ones, with an increased hypoxia from the mid-1990s to 2010 and a parallel decline in condition in the same time frame. An additional factor affecting growth of larger cod may be increased parasite infestation, though the effect of EB cod parasites on growth is unknown. In conclusion, although there is no direct evidence for growth changes of larger cod since 1990s, it can be hypothesised that increased hypoxic areas, reduced condition and increased parasite load in this period have reduced growth in length, however, such links have not been documented to date.

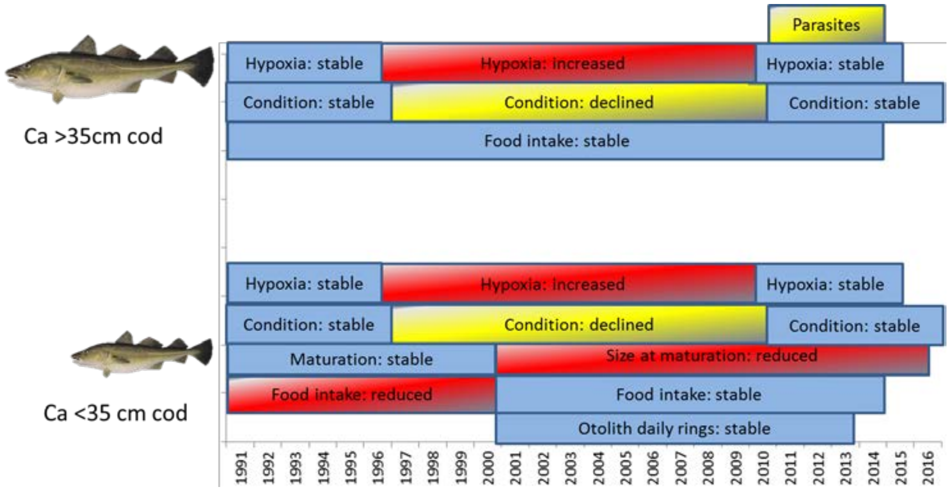
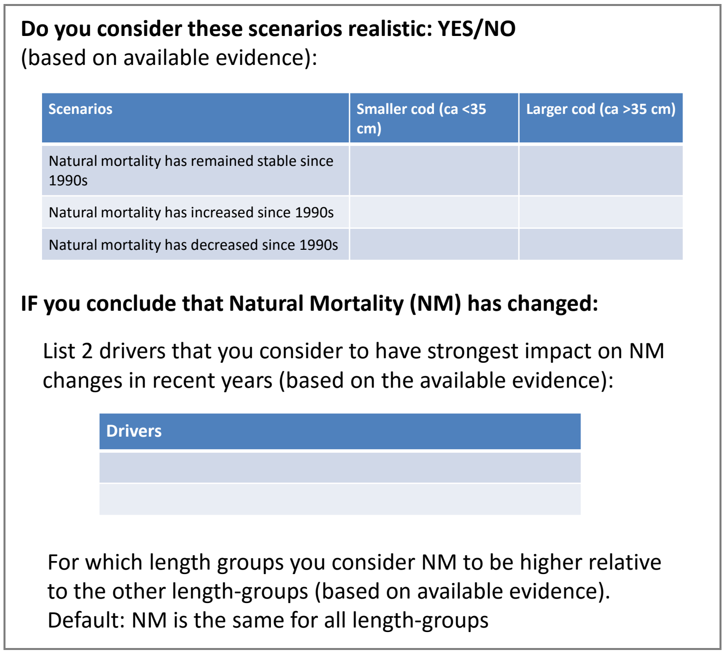


Figure 4.1. Schematic illustration of changes over time potentially influencing growth in length of EB cod. Blue colours indicate stable values, thus no effect on growth in the marked time period; red colours suggest a trend towards reduction in cod growth in the marked time period; while yellow colours indicate a trend in the particular variable that may have reduced growth in a given time period, though the effect is not clearly documented.

4.2 Potential changes in natural mortality

Discussions on potential changes in natural mortality followed a similar setup as for growth. The topic was discussed in sub-groups following similar set of questions as for growth:



Do you consider these scenarios realistic: YES/NO
(based on available evidence):

Scenarios	Smaller cod (ca <35 cm)	Larger cod (ca >35 cm)
Natural mortality has remained stable since 1990s		
Natural mortality has increased since 1990s		
Natural mortality has decreased since 1990s		

IF you conclude that Natural Mortality (NM) has changed:

List 2 drivers that you consider to have strongest impact on NM changes in recent years (based on the available evidence):

Drivers

For which length groups you consider NM to be higher relative to the other length-groups (based on available evidence).
Default: NM is the same for all length-groups

The changes in cod biology and in the ecosystem that possibly may have resulted in increased natural mortality since the 1990s are summarized in Figure 4.2. For the smallest cod (ca <15 cm), no other indications for increased natural mortality could be identified than possibly increased cannibalism, especially in years when adult cod stock has been estimated to have increased (late 2000s). However, the intensity of cannibalism remains to be verified by stomach data.

For ca 15–35 cm cod, a number of changes were identified that likely have increased natural mortality. Stomach data suggests critically low feeding level for this size-group of cod in the period from 2000s, that probably has increased mortality compared to the 1990s (Neuenfeldt unpubl.). Further, size at first maturation has been gradually reduced to lower lengths since 2000s that is expected to cause increased mortality. Also, increasing number of seals in later years is likely exhibiting an increased predation mortality on cod.

For larger cod (ca 35–50 cm), the effects of increased seal predation and also increased mortality due to maturation at a small size likely remain, given that the change towards maturing at a smaller size causes increased mortality throughout the life-span of the fish, not only immediately after first spawning. Further, there seems to be increased mortality of males relative to females at smaller sizes than before. Proportion of males in the stock at 40–50cm length has been 50–60% until mid-2000s and declined to 25–30% in 2015. Only about 20% of 50–55cm cod is currently males. Additionally, the proportion of cod at critically low condition has increased in this size-group that can explain increased mortality by approximately M=0.1 a year since the second half of 2000s (Casini *et al.* 2016). For largest cod (ca >55cm), low condition and small size at maturation likely continue to cause increased mortality in 2000s, while seal predation for this size group is likely reduced. Also, sex ratio seems to be stabilised for these larger cod (although only few fish in the data), indicating that the relatively higher mortality of males already takes place at smaller sizes. A factor that is suggested to have increased natural mortality in this size-group is parasite infestation (Horbowy *et al.* 2016).

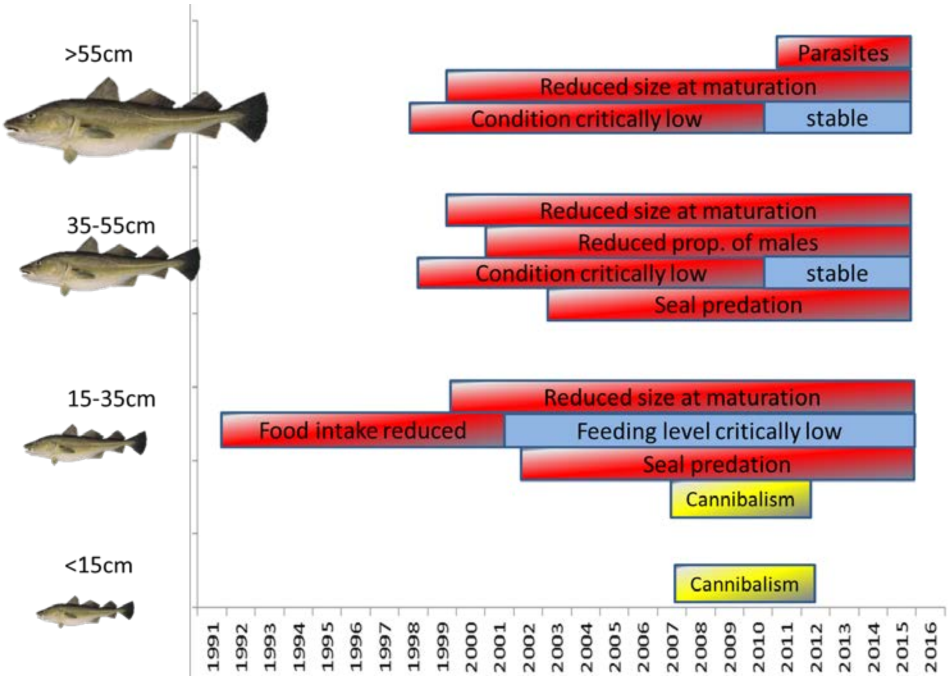


Figure 4.2. Schematic illustration of changes over time probably influencing natural mortality of EB cod, roughly by size-groups. Red colours indicate a trend within the marked time period in respective variable that is suggested to have increased natural mortality; while yellow colours indicate a trend in respective variable that possibly increased natural mortality, though the effect is unclear. Blue colour indicates stable level in the depicted time period.

4.3 Potential changes in reproductive capacity

One of the key questions in relation to reproductive capacity is whether or not the reproductive potential of the stock has been reduced given the poor condition of the fish, small size at maturation, and a population consisting mainly of smaller individuals. New analyses are ongoing on the relation between potential fecundity and condition for the Baltic cod, the preliminary results showing that fish in low conditions have lower fecundity, as observed in other cod stocks. It could also be hypothesized that a fraction of the stock would skip spawning, if in poor condition, however such development has not been documented for Eastern Baltic cod for later years. Studies on this aspects are recommended in future.

It has been documented that larger females produce larger eggs, which have a higher survival probability due to differences in egg buoyancy (Hinrichsen *et al.* 2016). Thus, it could be expected that the eggs of the current spawning stock consisting of small individuals have reduced survival probability compared to the previous situation with on average larger spawners. However, recruitment of cod in the Baltic Sea depends on a number of other factors and complex interactions (Köster *et al.* 2017), which makes it difficult to conclude on the relative effect of a spawning stock structure on realized recruitment. Developments in recruitment are suggested to be continuously monitored at all life stages.

In relation to reproductive capacity, one of the main questions that was discussed at the workshop was whether the reduced size at first maturation should be taken into account when calculating the index of spawning stock biomass for the purpose of management advice. Currently, the survey biomass indices used for providing management advice, as a proxy for trends in SSB, represent relative trends in cod biomass at or above 30cm in length, thus not accounting for changes in size at maturation. It was pointed out that the most appropriate way of addressing maturation in these calculations would very much depend on the intended use of the results. Caution should be taken in interpreting the developments in spawner biomass, when accounting for the trend towards earlier maturation that would increase the relative spawning stock biomass index in later year compared to earlier period. In this case, the relatively higher spawning stock biomass in later years is not necessarily a health sign, as reduced size at maturation is generally considered a negative development and has in some cases been associated with stock collapse (e.g. Olsen *et al*. 2005).

It was concluded that, in case of the present approach where only 5 years of survey data are used to provide advice, accounting for changes in size at maturation is of a lesser issue, as large changes have taken place at a longer time scale. However, when the analytical assessment is restored, appropriate interpretation of the changes in spawning stock size due to changes in maturation is important to keep in mind.

Another question that was discussed was related to defining stock-recruitment relationship in present situation, whether there are substantial changes affecting such relationship especially in later years. S-R relationships are presently not used in the context of management advice, but will become actual when the analytical assessment will be re-established. The discussion remained inconclusive in this aspect. A number of studies have attempted incorporating other variables in S-R relationship, also for EB cod, however such relations are often not stable over time and seldom used in the management context. On the other hand, if spawning stock alone is not reflecting developments in recruitment, as it is often the case, ignoring the other impacting drivers may be problematic as well.

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Annex 2: Agenda

Agenda

Workshop on Biological Input to Eastern Baltic Cod Assessment (WKBEBCA)

Date: 1-2 March, 2017

Place: Swedish Agency for Marine and Water Management (HaV), Gullbergs Strandgata 15,Gothenburg

1 March, START 10:00		
Welcome	Welcome, practical info	Michele Casini
Introduction to the meeting	Progress and issues with stock assessment of EB cod; expected outcome of the WK; key biological changes in the stock	Margit Eero /Michele Casini
Changes in growth:	Changes in growth based on food intake estimated from stomach data	Stefan Neuenfeldt
	Comparison of growth rates from counting otolith daily rings in different time periods	Karin Hüssy
	Is there a link between condition an growth, how does it look for other stocks	Lars O. Mortensen
	Growth, conditional natural mortality and maturity ogives of cod in SD 26	Victoria Amosova
	Changes in maturation and resource allocation	Jonna Tomkiewicz
	Parasites as a factor affecting fish growth	Jane Behrens
Group- work	Synthesis of knowledge/evidence: Trends/magnitude of change in growth rate, for smaller and larger cod	All
LUNCH: 13.00-14.00		
Sum up on growth	Discuss and sum up the outcome of sub-group work	All
Changes in natural mortality	Mortality due to low condition	Michele Casini
	Mortality due to seal predation	Karl Lundström
	Mortality due to parasites/Extent of parasite infestation	Jan Horbowy/Uwe Krumme
Group -work	Synthesis of knowledge/evidence: Trends/magnitude of change in natural	All

	mortality that can be explained by different drivers, for smaller and larger cod	
Sum up on mortality:	Discuss and sum up the outcome of sub-group work	All
2 March, START 9:00		
Reproductive capacity:	Temporal trends in fecundity (2004-2016)	Serra Örey
	Fecundity and atresia	Monica Mion
	Long-term changes of annual reproduction cycles	Maris Plikshs
Discussion:	Synthesis of knowledge: i) How to define spawning stock in present situation? ii) What should be taken into account in S-R relationships in present situation?	All
LUNCH: 12.00-13.00		
Ongoing work with quantifying growth, mortality, reproductive capacity:	Status of new taggings, and microchemistry method development (TABACOD project)	Karin Hüssy
	Overview and status of activities with historical tagging data?	Michele Casini
	Experience with calculating growth from taggings , based on WB cod	Kate McQueen
	Individual-based model of EB cod physiology, behaviour and ecology	Maria Pierce
	Other short information on ongoing work	All
END: 15.00		