International Council for
the Exploration of the Sea

C. M. 1998/CC:15
Population Biology

DEVELOPMENT OF JUVENILE BALTIC COD DESCRIBED WITH MERISTIC, MORPHOMETRIC AND SAGITTA OTOLITH PARAMETERS

by

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ABSTRACT

In connection with the EU funded project AIR2 94 1226 investigations were carried out concerning the recruitment processes of the eastern Baltic cod. In our institute analyses of the otolith microstructure of juvenile cod were carried out as a part of this project.
At different stations juvenile cod was caught in the Bornholm Basin and as a reference area in the Arkona Sea, too.
Pelagic (total length between2 and 4 cm) as well as cod within and after the settling process was sampled and analysed.
Beside the fish parameters the parameters of the Sagitta otoliths were measured. Then with a time consuming procedure the Sagitta otolith were prepared for making a counting of the daily increments possible.
In the period 1994 - 1996 323 individuals and their otolith were investigated and included in these analyses.
It could be shown that

- after 45 days average the juvenile cod starts with the secondary accessory growth centres (AGC)
- the different hydrographical conditions in the Arkona Sea and Bornholm Basin does not influence the fish and otolith parameters significantly and
- the growth of the juvenile cod is less in the winter than in the summer.

The back-calculated birthdays of the juvenile cod agree very well with the results of the spawning time investigations.
For the analyses single and multiple regressions were calculated and compared using statistical software. For special problems own tools were developed.
The results were discussed and compared with result from other authors which used different data and methods.

Key words: Baltic cod, juveniles, otolith microstructure, growth

I. Introduction

The decrease of the eastern Baltic Sea cod stock was the reason why investigations concerning the mechanism of the recruitment processes came into the foreground. Within the framework of the EU financed project AIR2 94 1226 „CORE" the different stages of the development of a cod year-class were investigated in the eastern Baltic Sea (ICES Sub-divisions 25 - 32) to find the main factors that influenced the year-class strength fundamentally.
One field of these investigations was concerned with the analyses of the microstructure of the otolith from juvenile cod.
The daily deposition of growth increments of fish otoliths was described for the first time by Panella (1971). Since these investigations have been done, studies to the otolith microstructure occupied a growing status in the fishbiological science and the daily growth increments of the otoliths were accepted in the meantime as general characteristic of the teleostiers. Microstructure investigations are a useful tool for age and growth studies at larval and juvenile fishes and made the fish population parameters more reliable. Beside permitting age determination, otolith microstructure can provide other information about fish biology and ecology. Biological and physical environmental changes are reflected in time sequences at otoliths. Studies concerning this can help on the enlightenment of the individual life-history of a fish.
Otolith-microstructure has been used for stock discrimination (Moksness and Fossum 1991), for validation of ageing (Steffensen 1980), for taxonomic purposes (Brothers 1984, Linkowski 1990) as well as for the determination of temporal terms in the early life-story of fish, e.g. the duration of the larval stage, the change from pelagic to demersal life and migration behaviour. (Radtke 1984, Karakiri 1990). Summaries of the used methods are given in Secor, Dean and Laban (1991) as well as in Stevenson and Campana (1992). Secor, Dean and Campana (1995) summarised the current status and the present development of the investigations.
The fundamental proof of the daily periodicity of the increment formation in the Sagitta and Lapillus otoliths of cod (Gadus morhua) result from the investigations of Dale (1984), Bergstad (1984), Radtke (1989) and Campana and Hurley (1989). Most of the studies were concentrated on cod larval stages. The microstructure of otoliths from juvenile cod was investigated by Steffensen (1980), Linkowski and Kowalewska-Pahlke (1993) as well as by Mosegaard et al.(1995).
The investigated material was sampled in the Arkona Sea and in the Bornholm Basin between 1993 and 1996. The first results using only a part of the material were published in Böttcher & Oeberst (1996). The main emphasis was the description of the relations between the fish and the otolith parameters. Further it was examined whether the settlings process of the juvenile cod produced clear defined marks in the otolith structure,or not.
Since now all available otoliths from 1993 to 1996 were analysed further analyses of the data were carried out with the following main points:

- In many cases the determination of daily increments within the otolith centre beginning with the hatching check was not possible. In opposite to that the secondary increments, that start with the accessory growth centre (AGC), were in most cases clearly countable. From our investigations followed that the period between the hatching check and the AGC seems to be relatively constant. An estimate of the mean period makes an ageing possible if the otolith structures were uncertain in the otolith centre.

- Investigations according to the influence of the factors year, area and month on the relationships between the fish and Sagitta otolith parameters. If it can be assumed that the variability of these relationships is very little depending on the outer parameters for the juvenile cod these relationships can be used for the interpretation of outliers in the ageing of cod in combination with the well determined growth function. For a better interpretation of the results from the juvenile cod fish and Sagitta otolith data from individuals sampled in annual surveys with age 0 and 1 were analysed.

- The estimation of the birthdays of the juvenile cod were carried out using the otolith microstructure and the comparison of these results with other investigations of our institute. In investigations concerning the development of sex products and the spawning seasons of cod it could be shown that cod in the western Baltic Sea (SD22) spawned considerably earlier than cod in the Arkona Sea (SD24) and the Bornholm Sea (SD25). It was to check whether the spawning seasons agree well with the estimated birthdays, or not.

- Investigations concerning the growth of juvenile cod were carried out.

These investigations were linked into the international CORE project financed by the EU. Our investigations were extended over the target area of the project, the eastern Baltic Sea (SD25 - 32). Also included were the Arkona Sea (SD24) to get comparable values for both stock units as used in the ICES.
The goal of this paper is the presentation of the used methods and the discussion of the results in the context of results from other methods of investigations.

II. Material and Methods

II. 1 Areas of the investigations

The microstructure of Sagitta otoliths from juveniles with a total length from 2-18 cm was investigated. The material was sampled during 6 surveys in the Arkona- and Bornholm Sea (Figure 1) performed by R/V „Solea" in September and October covering the years 1993 - 1996. The individuals were caught in pelagic hauls (more than 15-20 m above the bottom) and in bottom or near-bottom hauls (3-6 m over the bottom). The fish were deep frozen on board. Further investigations were carried out after thawing in the lab.
81 otoliths of pelagic and 243 otoliths of demersal caught individuals were analysed. In the laboratory the meristic parameters of the fishes were determined and Sagitta of otoliths were taken after the dissecting of the fish. The stomachs of the juveniles were dissected and then they were fixed in a formalin - seawater - solution (4%). The analyses of the stomachs were carried out by Danish colleagues / partners. The results of the prey type analyses were used for the assignment of the individual pelagic or demersal life custom.
Table 1 summarises the number of juvenile cod depending on the prey type (sum of all years).
The microstructure investigations were carried out at the Sagitta otoliths. For the investigations a transverse section of otolith was used. The readings of the daily increments were carried out at the video monitor in case of clear structures and directly at the microscope if the structure was unclear.
For the image analyses a black/white CCD camera with a matrix of 572x768 pixels was used. In most cases it was worked with a magnification factor of 40 for the objective of the microscope. For the image processing the software Image Pro Plus from Cybernetics was used.

II. 2 Determination of the fish and otolith parameters

The parameters which were determined for each individual are shown in Table 2. Figure 2 shows a transverse section of a Sagitta otolith in combination with some notations. More detailed information about the preparation and the interpretation of the microstructure of the Sagitta otolith are described in Böttcher & Oeberst (1996).

The main problems of the preparation were to find the core area as well as the preparation of this area during the grinding process with high quality.
Since only the counting of the primary increments within the centre of the Sagitta otolith was possible at a proportion of about 20% of the analysed otolith an estimate of the mean number of primary increments was used if these otolith structures were unreadable. This mean value was estimated for the number of increments between the hatching check and the accessory growth centre (AGC). This mean value based on the analyses of the readable otoliths and additionally on otoliths, which were made available from Danish partners. These otoliths came from juvenile cod from breeding experiments, for which the accurate age after the hatching is known.

II. 3 Estimation of following data and statistical analyses

For the juvenile cod the number of days after the hatching check was then calculated with the following equation:

age in days after the hatching = mean number of primary increments
+ counted number of secondary increments

Furthermore single and multiple regressions were calculated to describe the relationships between the fish and Sagitta otolith parameters. For the comparison of different regression models concerning the best goodness-of-fit the correlation coefficients or the coefficient of determination and the residual variance were used. Additional analyses of the residuals were carried out.
Especially the influence of the factors year, area and month of the catch on the relationships between the fish and Sagitta otolith parameters was investigated using generalised linear models. For these calculations the software „Statgraphics" were used.
In an additional step the fish and Sagitta otolith parameters (total length, weight, Sagitta length and Sagitta width) from older cod were determined. From the trawl surveys carried out by our institute cods of the age groups 0 and 1 were used for this analyses. With statistical models it was controlled whether the regressions estimated for juvenile cod present stable relationships in the further development process, or not.
The estimations of the birth dates of the juvenile cod were realised by the date of catch and the age in days. Then the data calculated as described above were compared with the results of the investigations concerning the spawning seasons in the western and eastern Baltic Sea.
In a further step the parameters of the length distributions of the juvenile cod were estimated for the two spawning seasons. It was investigated if these length distributions can be described with the model of the normal distribution.
The data of the juvenile cod were used to estimate the growth function. After that it was proved if this growth relation can be extrapolated for older cod. For these investigations the length distributions of the age groups 0 and 1 from the November and February trawl surveys were used. These surveys made it possible to estimate the year-class indices of cod in the Sub-divisions 22 - 25 and the length distributions of the year-classes (Hinrichs et al. (1991), Müller & Frieß (1995, 1996), Schulz & Vaske (1980), Vaske & Schulz (1985)). The birth dates of the cod from the surveys were estimated starting from the different length intervals using the observed growth function. Then these calculated values were compared with the results of the spawning time investigations.

III. Results

III. 1. The mean number of primary otolith increments

The main problem of the preparation process was to find the core area within the transverse section as well as the preparation of this area during the grinding process with high quality.
At well prepared Sagitta otoliths the hatching check is the first clear defined mark.
The following 10 to 20 increments within the Sagitta otolith centre, which surround the hatching check are very thin and with little contrasts. Often these increments could not be determined clearly. For an other region of 5 to 15 increments close before the AGC the counting was difficult, caused by unclear substructures. In opposite to the central region the numbering of the secondary increments, which started behind the accessory growth centres (AGC), was possible without big problems in most cases.
In the first studies (Böttcher & Oeberst 1996) 18 otoliths could be prepared in such a quality that the number of increments between the hatching check and first secondary increments were readable with high accuracy. The number of these increments varied from 42 to 56. The mean value was 49.3. However, slight contrasts and resolution-limited visibility of the finest internal increments can have caused a bias.
For additional analyses of this problem Danish colleagues provided us 18 otoliths from juvenile cod with a known age in days after the hatching. The age was 48 days. The first AGC could be observed at all investigated individuals. The numbers of the secondary increments were situated between 5 and 7. The development of the AGC started between the 41^{th} and 43^{th} day after the hatching check. The mean value was 42 days. Using these data and the results of former analyses a mean value of 45 days can be assumed for the time interval from the hatching check until the beginning of the secondary increments. This value was used in the following analyses.

III. 2. The influence of the factors year, area and month of catch on the relationships between fish and Sagitta otolith parameters

Because data from different years, months and areas were available it was necessary to analyse the influence of these factors on the variability of the fish and Sagitta otolith parameters.
For these analyses the methods of the multiple linear regression and the GLM were used.
For the three relations
Weight = f(total length, year, area, month),
Sagitta length = f(total length, year, area, month) and
Sagitta width = f(Sagitta length, year, area, month)
the parameters of the generalised linear model are presented in Table 3. The first columns present the whole model. The regression parameters and the p-values are given. Then a reduced model with only one of the three factors year, month and area (with the lowest p-value) is shown.
In a third step the parameters for the relations without the three factors are presented. Although the p-values point out the significant influence of some factors the decrease of the coefficients of determination is very low. From these results follows, that the three factors year, month and area of catch explain only a very small part (about 1%) of the variability of the dependent variables.
Figure 3 presents the regression curve between the weight and the total length of all available data of the juvenile cod. Figure 4 shows the plot for the variables Sagitta length and total length and Figure 5 illustrates the relation between Sagitta width and Sagitta length for the juvenile cod. Within these figures additional data from the trawl surveys are included. A comparison of the relations is discussed later.

Using these results it is certain, that strong relationships exist between the somatic growth and the growth of the otolith. The influence of other factors directed to these relationships is very low. That is the reason why the relations between the somatic and otolith growth are not suited for the differentiation of the spawning seasons and the spawning areas.
This result is an essential precondition for the summary of data from different years. Because the number of analysed juveniles was low for the different years and investigated areas the summary of all data is useful and can help for a better understanding of the growth and settling process. In Appendix A the parameters and the plots of many different relations between the fish and Sagitta otolith parameters are presented.
Starting from the results additional data was analysed. From individuals with age 0 and 1 the parameters total length, weight, Sagitta length and Sagitta width were determined. These cods were caught within the trawl surveys of our institute in February and November. Because these data were outside of the data range of the juvenile cod it was possible to analyse if these new data produce significant changes in the regression parameters.
The analyses of these new data show, that the relations between the fish length and weight as well as the Sagitta parameters length and width are stable over a long time. These data are included in Figures 3 to 5 and are marked. The different relationships did not chang significantly.

III. 3. The estimations of the birthdays of the juvenile cod

In Bleil & Oeberst (1997) investigations concerning the spawning periods of cod in the western and eastern Baltic Sea are described. Using the results of the microstructure analyses it was possible to compare the estimated birthdays of the juvenile cod and the observation of the spawning seasons.
For these estimations of the birth dates the following equation was used:

Birth date = Catch date
- mean number of days for the development of the eggs (C1)
- mean number of day between the hatching check and the beginning of the secondary increments (C2)
- number of secondary increments (NDI)

Additionally the variable birthday was used. The birthday refers to the number of days between the first of January and the birth date in the same year. This variable was used to combine the data of the different years.
As described already before, the mean value of 45 days was used for C2.
For the variable C1 a constant value of 20 days was used. This value follows from the observed temperature regime in the Baltic Sea and the investigations from Thompson and Riley (1981). Their results agree with the investigations of Wieland et al. (1994) and with observations of natural spawned eggs from Baltic cod held in a marine hatchery (unofficial information from Bleil).
If under these circumstances it is considered, that the spawning periods of the ICES Sub-division 22 on one hand and the ICES Sub-divisions 24 & 25 on the other hand were very different this inaccuracy in the estimation of the birthdays can not lead to essential mistakes during the assignment of the spawning areas.
The results of the estimated birthdays are presented in the Figures 6 and 7. Figure 6 shows the plotted birthdays in relation to the total length for juvenile cod caught in ICES Sub-division 24. Figure 7 shows the same information for the juvenile cod caught in ICES Sub-division 25. For these figures the data of all years were summarised.

It seems to be that for the cod caught in SD 24 two spawning periods can be detected. The first spawning period starts at the beginning of March and finishes at the end of May. The second period reached from July to August.
For the cod caught in SD 25 three spawning periods could be detected. The first laid in the time period from January to February. The second and the third spawning periods agree well with the data from SD 24. These results, that are confused at the first view, go very well with the investigations considering the timing of the reproduction of cod from Bleil & Oeberst (1997).
Juveniles which were spawned between January and February were caught in SD 25 1995. In the same year a very low number of trawls was carried out in SD 24. Only 2 individuals could be caught for the microstructure analyses. That is the reason why this group of juvenile cod was not observed in SD 24. It is assumed that these juvenile cods were spawned in the Kattegat or Öresund.
Furthermore the impression emerges that the proportion of cod spawned in SD 22 is higher in SD 24 than in SD 25. Juvenile cod spawned in the summer was dominant in the Bornholm Basin. But cod with these birthdays were caught also in the Arkona Sea.
Because the analysed juvenile cods did not come from random surveys it is not possible to estimate the proportions of the juvenile cods which were spawned in the different areas, without a bias. If these proportion should be estimated another cruise design or other techniques would be necessary.
Independent of these remarks a first attempt has been done to analyse the length distributions from the two spawning seasons of the Baltic cod.
Figure 8 shows the frequency distributions of the total length for the different years. The length data were separated and marked concerning the two different spawning seasons. In one interval those juvenile individuals, which were spawned between the 150th and 240th day of the year (second spawning season - eastern spawning stock) were included. The other interval ranged from the 30th to the 150th day of the year (first spawning season - western spawning stock). These length frequencies are shown for the years 1993 to 1996.
As a first remark it must be pointed out, that the number of the analysed otoliths is too low to give secure results for the analyses of the length distributions. But it can be concluded from these data that the length distributions of a year class of cod has more than one peak. It can be suggested that two intervals can be separated. The first peak has a mean length of about 5 cm and a standard deviation of about 1 cm at the time of the investigations. These cods were caught normally with the pelagic trawl. The total length raged from about 2 cm to 8 cm. These juvenile individuals were spawned within the second spawning season in the Arkona and Bornholm Sea. The results of the of the χ^2 goodness-of-fit test suggested, that the length distribution of these juvenile cods can be described with the normal distribution.
The interpretation of the larger juvenile individuals with more than 8 cm total length is not so easy. These cods were caught with the bottom or near bottom trawl. The settling process was finished. It may be that there exists more than one peak within the length distribution. This result can be caused by the occurrence of cod from the Kattegat and Öresund region or from the small differences between the spawning seasons of the Kieler Bucht and the Mecklenburger Bucht.
In all years the standard deviation of the length distribution is higher than at the fist peak. This result agrees with the observations from larval cod, that the deviation of hatching batches increases with the increasing age in days.
Table 4 presents the selection parameters (birthday start/end and month of catch) for the separation of the spawning seasons as well as the parameters of the length distributions number, mean length, standard deviation (std) and the p-values of the of the χ^2 goodness-of-fit and the Shapiro-Wilk's W statistic. If the p-values are lower than 0.05 the length frequencies are significantly different from the normal distribution using an error of first kind $\alpha = 0.05$. The

data of Table 4 show, that in many cases the hypothesis of the normal distribution can be accepted. In some years the number of data was too little for the tests.
In October the juvenile cod, which was spawned in the Arkona Sea / Bornholm Sea region was in the settling process. About 20 days later, that is the time of the November trawl survey of our institute (see later) the settling process of these individuals was nearly finished and most of them had a total length of more than 7 cm.
The juvenile cod spawned in SD 22 has a mean total length between 8 and 12 cm. In October the mean length ranged from 10 to 14 cm. About 20 days later in November the mean length ranged from 10 to 15 cm. From these result follows that the differences from 3 to 8 cm between the mean length of both spawning seasons are normal.
From these results it can be suggested, that

- for the description of the length distribution of the single spawning seasons of the Baltic Sea cod the normal distribution can be used and
- the juvenile individuals of both spawning seasons can be separated clearly by using the length distributions.

Because the data base is low for these additional investigations the conclusions must be proved with new data or other methods of analyses.

III. 4. Growth of the juvenile cod

A further emphasis of the investigations was the analyses of the growth of juvenile Baltic cod. Figure 9 presents the relationships between the age in days and the total length (TL) for different stages of the development of the juvenile cod. Stage 1 refers to the pelagic life phase, stage 2 describes the transition phase and stage 3 refers to the benthic life cycle. The parameters for the different regression analyses are presented in Table 5.
For the third stage two regressions were calculated. The first regression for the time interval was with an age from 125 to 265 days. For the second regression this interval was reduced and the age ranged only of 125 to 240 days. Because the total length of the juvenile cod in the time interval from the 240th to the 265th day (Kattegat/Öresund) were relatively small compared to the other intervals it seems to be reasonable to use the second regression for the further analyses.
In addition the relationship between the age, catch position (pelagic or benthic) and the prey type is shown. Also the parameters of the inverse regressions between the total length and the age for stage 3 are presented. These relations can be used for the estimation of the age from total length data.
The transition of the juvenile cod from pelagic life to the benthic stage means an essential change of the living conditions for the individuals.
The transition phase starts with an age of about 85 days after the hatching check or in mean 105 days after the spawning and it is finished in mean 20 days later. The total length of these individuals laid between 40 to 70 mm in this time. It seems to be that the transition stage is a process over a longer time interval where the stay at the bottom alternates with pelagic phases.
Although the juvenile cods with an age of more than 125 days were caught predominantly at the bottom, the benthic prey type was dominant only from an age of 145 days for the investigated fishes.
The used relationships between the total length and the age with 3 different stages seem to be a better description of the growth process than the former used non linear regression function for the whole time interval.
An other way was used to estimate the daily growth rate of the juvenile cod. Using the length data from the cruises in September and in October in mean 30 days later in combination with the estimated birthdays two regressions can be calculated in the form

total length = f(birthdays)

for both months and all years with the conditions: birthday $\in [50,240]$.

The results are presented in Figure 10. Table 6 shows the parameter of the linear regressions. The slopes of the linear regression it nearly the same. The shift between the intercepts of the regressions is about 2.1 cm. If a difference of 30 days as a mean value is used (surveys end of September and end of October) the mean growth rate was about 0.07 cm/day. This value agrees well with the estimated growth rate in Böttcher & Oeberst (1996).

III. 5. Extrapolation of the growth of juvenile cod

Because the time interval for the estimation of the growth relation was short an extrapolation of this function can produce biases.
This problem is fundamental because in November and the following February trawl surveys were carried out in the same areas to estimate year-class indices. A splitting of the youngest year-class into the two spawning seasons is necessary for an accurate estimation of the cod indices. In November a large part of the juvenile cod, which were spawned in the Arkona Sea or the Bornholm Basin has finished the settling process. Furthermore it can be assumed, that all juvenile cod has finished this process in the following February and they can be investigated by trawl surveys.
To answer the question whether the estimated growth function can be extrapolated or not the following way was used: The length distributions of the surveys and the estimated growth function were combined to estimate the birth dates of those individuals caught in the trawls. If the estimated birth dates agree well with the observed spawning seasons it can be concluded, that the growth function from the juvenile cod can be extrapolated. If the estimated birth dates do not agree an extrapolation of the growth function is not possible.
For this calculation the following equation was used:

birth date = catch date - 80 - 9 * total length

As an example the results of the cod year-class 1995 in the Arkona Sea are presented in Table 7. Among the length distributions of the age group 0 in November 1995 and age group 1 in February 1997 the estimated birthdays are included.
They show, that the observed relations between the age and the total length for stage 3 can be extrapolated until November. The calculated birthdays using the November survey agree well with the observed spawning seasons in the western and eastern Baltic Sea.
The length distribution of the age group 1 in February suggests that the growth of these cods was nearly zero from November to February. The estimated birthdays from the length distribution of the February survey support these results. The estimated spawning seasons do not agree with the observations in the fields. The difference of the estimated birthdays between the results from the November and February surveys were about two months. From these results follows, that the growth of the juvenile cod can be extrapolated only until the November. In winter the growth decreases.
This result could be observed for other year-classes of cod , too. That is the reason why for the analyses of the growth a seasonal component must be put into account if the used data come from different times of the year. As an additional example Figure 10 presents the mean total length of the cod year-class 1994 in the Arkona Sea and supports the seasonal components of growth.

IV. Discussion

IV. 1. Mean number of primary otolith increments

Since the preparation of the otolith centre with recognisable primary increments was only possible for about 20% of our otoliths so it was necessary to use an estimate (C2) for this period between the hatching and the AGC during the assessment of the age.
This low number of successful preparations of the whole otolith is comparable with the results of Linkowski & Kowalewska-Pahlke (1993). They prepared about 25% of the analysed otoliths with readable primary increments.
The used mean value of 45 increments for the primary increments was estimated from different investigations. The number of these increments varied between 42 and 56 within our observations. The mean value was 49.3. However, slight contrasts and resolution-limited visibility of the finest internal increments can have caused a bias. From the 18 cods with known age a mean value of 42 days was estimated for the primary increments. These individuals came from a hatchery experiment. For all these individuals the same hydrographical conditions influenced their development.
Bergstadt (1984) and Thorisson (1992) found a temporal correlation between the AGC and the metamorphosis of Atlantic cod and other species. For Atlantic cod they assessed, that the metamorphosis starts between the 35^{th} and 40^{th} day after the hatching.
In the Baltic Sea the hydrographical conditions have a higher variability and strong changes in the temperature and salinity can be observed between spring and summer. It seems to be secure, that these changes produce higher variability within the number of primary increments.
Following these observations a mean value of 45 day seems to be useable. The possible error of about ± 5 days can be ignored if it is considered, that the spawning seasons of cod take more than 90 days and the difference between the two spawning seasons in the Baltic Sea is very large.
From these results it can be concluded, that the AGC of the Baltic cod starts short after or within the metamorphosis.

IV. 2. The influence of the factors year, area and month of catch on the relationships between fish and Sagitta otolith parameters

The investigations concerning the relations between the fish and Sagitta otolith parameters show that the somatic and the otolith growth are highly correlated.
From these results it can be concluded, that the different temperature and salinity within the both investigated areas, the different years and the different months of spawning did not produce large variability in the regression analyses.
For further investigations it seems to be possible to combine data from different observation periods and different ICES sub-divisions of the Baltic Sea.
As a description of the actual status of the relationships between the investigated parameters the Appendix A is included in this paper.
The analyses of the variables total length, weight, Sagitta length and Sagitta width of cod with age 0 (November) and age 1 (February next year) support the very strong relationships between the somatic and otolith growth. It seems to be, that these relations are very stable over a long time interval independent of the changed hydrographical regimes (temperature and salinity) and from the changed prey types.
From these results it can be suggested that it seems to be possible to use these relations for a correction algorithm or a plausibility test for cod age readings.

IV. 3. The estimations of the birthdays of the juvenile cod

For the estimation of the birth dates a mean value (C1) for the time between the spawning and the hatch process must be used. It is known, that this development phase is depending on the temperature.
Thompson & Riley (1981) analysed the regression between the temperature and the duration of the egg development for North Sea cod in the laboratory using artificially fertilised eggs.
From the hydrographical routine observations of the Institute of the Baltic Sea in Rostock-Warnemünde it is known, that the water temperature in February varies between 2°C and 4°C at the bottom. In spring and summer the temperature increases in the more shallow water of ICES Sub-division 22. In the deeper areas of the Arkona Sea and the Bornholm Basin the water temperature does not increase as quick as in the shallower western Baltic Sea. Furthermore it must be pointed out that especially in the western Baltic Sea the hydrography is strongly influenced by separated inflow processes.
Using these information it can be concluded that the duration of the cod egg development varies between 17 and 27 days in the western Baltic Sea.
Wieland et al. (1994) found at artificially fertilised cod eggs from the central Bornholm Basin incubation periods between 27.5 days at 2°C water temperature and 13 days at 7°C and pointed out, that reduced oxygen levels did not significantly affect the time of hatching.
During investigations of Baltic cod broodstocks under natural conditions of the Kieler Bucht comparable time intervals were observed for the Baltic cod eggs (personal information M. Bleil).
If these eggs had high survival rates they needed in mean about 14 days at temperatures between 6 and 7 °C. Thes data have nearly the same level as the results from Thompson & Riley (1981) and Wieland et al. (1994).
Following these results a mean value of 20 days can be used for the time interval between the spawning and the hatching of cod larvae within the further investigations.
Because the variability of the both time intervals C1 and C2 is not too large it can be assumed, that the differences between the real birthday and the estimated birthday are less than 15 days in most cases.
The two periods of birthdays between March and August, estimated from the juvenile cod caught in SD 24 and 25, agree well with the observed spawning seasons of cod (Bleil & Oeberst 1997). Both groups of birthdays can be led back to the different spawning periods of ICES Sub-division 22 and ICES Sub-divisions 24 & 25.
The estimated birthdays between January and the middle of March let suppose, that these individuals were spawned in southern Kattegat or in Öresund. An other assignment to the observed birthdays is not possible.
Westernberg (1994) analysed the occurrence and drift of cod eggs in the Öresund. He estimated that about 10^{11} cod eggs were transported from the Öresund region in the Arkona Sea 1993 and 1994.
In these years juvenile cod with estimated birthdays between January and March could not be observed within the analysed juvenile cod. There are different possible reasons for this discrepancy. One reason may be, that the sampling strategy for the investigations of juvenile cod did not base on a survey design but the numbers of analysed juvenile cod in both years were relatively large (1993 72 otoliths, 1994 126 otoliths)
Another possible and more realistic reason can be, that the eggs float within water with a salinity between 18 to 20 psu in the Öresund. If this water drifts into the Arkona Sea it forms a layer at the ground caused by the higher density. Already a small decrease of the salinity caused by a mixing within the Arkona Sea produces a drop of the eggs onto the bottom. It can be supposed, that the mortality rates of these eggs increase rapidly and the number of surviving eggs is very low.

From the investigations of Nehring et al (1994, 1995, 1996) it is known, that small inflow events could be observed in the springs of the different years. Table 8 presents the time periods of the inflow events within the winter - spring periods 1993 - 1996. Beside these inflow events with different intensities periodic inflow pulses with alow intensity were detected at the Darßer Sill. As a particularity the event during the beginning of April 1995 can be looked at. The juvenile individuals spawned in January and February in the Kattegat / Öresund had an age between 85 and 95 days at this time. With this age the juvenile cod with a total length of about 4 cm is situated in the midwater and can be transported with a shift of the water masses over a long distance. From these results follows, that such inflow events can transport pelagic juveniles from the Kattegat / Öresund region into the Arkona Sea and Bornholm Basin in late spring with a high survival rate.
Within the Bornholm Basin the entered water body drops below the 60 m depth. According to Böttcher et al. (1998) the pelagic juvenile cod was observed within the water layer between 0 and 60 m. This layer of the water column is not directly correlated with the moving of the inflow event below 60 m. From these results follows, that the juvenile cod, which were transported with the inflow water into the Bornholm Sea, leave this water body and stay within the Bornholm Sea. A further drift of these individuals in eastern directions (Gdansk or Gotland Sea) is improbable.
Another possible drift of cod eggs spawned in the Arkona Sea or the Bornholm Basin into the ICES Sub-division 22 caused by water transport processes of the surface layer in the summer could not be analysed because juvenile cod from ICES Sub-division 22 was not available.

IV. 4. Growth of the juvenile cod

The latest investigations about the daily growth of the juvenile cod confirm the results from Böttcher & Oeberst (1996). Comparable results were achieved using two independent ways. These results agree investigations by Linkowski & Kowalewska-Pahlke (1993). They found growth rates of 0.73mm per day between the 95 – 110 day of life for Baltic cod caught during Polish young fish surveys. Later the growth rate decreased until 0.24 mm per day, at the age of 257 days. It was assumed, that these cod hatched between June and October.
From these results follows, that the transition stage of the juvenile cod produces a growth depression. It is supposed, that the energetic needs of the growing juvenile cod is higher than the possible intake by using the small zooplankton. Such depression phase were observed by Thorisson (1992) for cod larvae with length between 10 – 14 mm. At this time a change of the prey could be observed.
If the shift in direction of larger benthic prey organisms was successful, the growth rates reached again values as observed in the pelagic life stage. The variability of the growth increases after this successful change to the demersal life phase. An influence of the factors sub-division, year and month of catch directed to the growth were not found within the available data material.

The comparison between the estimated birthdays from the length distributions of the surveys (November age group 0 and February age group 1) proves, that the daily growth of juvenile cod estimated from the September/October data can be extrapolated only until December.
The estimated birthdays based on the February surveys distinguish from the observed spawning seasons of the Baltic cod. This result shows, that the growth of the juvenile cod decreases in the winter and increases again in the summer. Such seasonal components were already shown for adult cod by Borrmann & Berner (1985 a, b) and Berner & Borrmann (1985) using the results of tagging experiments.
Our investigations confirm, that seasonal components occur already at juvenile cod.
Linkowski & Kowalewska-Pahlke (1993) used the relation between the otolith age and the Sagitta otolith weight for the back-calculation of the hatch data for juvenile cod. They

calculated hatching period between June and October and pointed out, that this way is very rough. A possible reason may be, that seasonal components were not used. The analyses of our data show, that the relation beween the age in days and the otolith weight changed after the settling.

Following these results it can be concluded, that it is absolutely necessary to use periodic components within the assessment of the growth function to reduce errors of interpretations if comparisons between areas or years should be carried out.

Mosegaard et al. (1997) analysed the relations between cod size and measurements of the Sagitta otolith from cod with age between 1 and 3 years. They found, that the seasonal growth of the otolith is asymmetrical in different radial directions and pointed out, that a possible improvement of back-calculated length at age would require a better understanding of the seasonal asymmetry.

Our investigations show, that the growth of the settled juvenile cod is stable. The different spawning seasons do not influence the growth significantly.

From these results follows, that the differences between the length distributions of the juvenile cod spawned in the ICES SD 22 or in the ICES SD 24 & 25 do not change over a long time period.

The differences of about 5 cm between the mean length of the two spawning periods and the relative small standard deviations of about 1 cm are suited to separate these groups in data sets come from later investigations (surveys).

Wieland et al. (1996) analysed the temporal course of the cod egg densities in the Bornholm Sea. They used the model of normal distribution to describe these egg densities. Following this suggestion it can be concluded, that the length distributions of the juvenile cod can probably also be described by the model of the normal distribution.

Using this model of normal distributed length mathematical algorithms can be used to analyse exchange processes between the cod stocks of the Baltic Sea.

These algorithms split the length distributions of an age group in normal distributed components. These components can be classified in the different spawning seasons and the portions of these components can be used for interpretations of the exchange processes. First analyses show, that this way is suited to analyse the migrations between the western and eastern cod stocks.

Aknowledgment

We thank the Danish colleagues K. Hüssy and H. Mosegaard for the appropriation of otolith from juvenile cods with a known age and for the analyses of the stomach contents.
We thank also M. Bleil for the information about the duration of the development of cod eggs and P. Ernst for the leaving of the data from trawl surveys.

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Table 1: Separation of the number of the analysed juvenile cod otoliths concerning years and sub-divisions as well as for prey types

number of individuals	year			
Sub-division	1993	1994	1995	1996
24	39	18	2	25
25	33	91	94	22

prey type	number of individuals
pelagic	73
demersal	115
mixed	63
empty	27
not identificable	46

Table 2: Summary of the notations and accuracies of the measured parameters.

on the fish:		
notation	accuracy	parameter
SL	1 mm	standard length
TL	1 mm	total length
W	0.01 mg	whole weight
gW	0.01 mg	gutted weight
HA	1 mm	height over the analis
DE	1 mm	diameter of the eyes

on the Sagitta:		
notation	accuracy	parameter
SagLength	10 µm	Sagitta length
SagWidth	10 µm	Sagitta width
SagWeight	0.01 mg	Sagitta weight
PriIncrN	day	Number of primary increments
SecIncrN	day	Number of secondary increments (increments between the first accessory growth centre and the otolith edge)
NDI	day	number of daily increments after the hatching check (estimated primary increments + secondary increments)

Table 3: Regression parameters and coefficients of determination of the different GLM

ln(Weight) = f(ln(total length), year, sub_division, month)

	estimate	p-value	estimate	p-value	estimate	p-value
constant	-6.025	0.00	-5.237	0.00	-5.236	0.00
ln(total langth)	3.186	0.00	3.184	0.00	3.187	0.00
year	0.0169	0.04				
subdivision	-0.0386	0.01	-0.0334	0.03		
month	0.0152	0.33				
number	324		324		324	
coefficient of determination	**99.50**		**99.49**		**99.49**	

Sagitta length = f(√(total length),year, area, month) for SagLength>0

	estimate	p-value	estimate	p-value	estimate	p-value
constant	-4593.46	0.01	-6631.31	0.00	-3879.90	0.00
√(total length)	2720.24	0.00	2717.69	0.00	2712.68	0.00
year	-22.75	0.16				
subdivision	116.73	0.00	109.90	0.00		
month	-5.06	0.86				
number	323		323		323	
coefficient of determination	**98.72**		**98.71**		**98.64**	

Sagitta width = f(Sagitta length, year, sub-division, month) for SagWidth>0

	estimate	p-value	estimate	p-value	estimate	p-value
constant	-484.129	0.48	-41.322	0.66	159.811	0.00
SagLength	0.380	0.00	0.380	0.00	0.379	0.00
year	10.923	0.09				
subdivision	-28.473	0.01				
month	32.255	0.01	20.228	0.03		
number	323		323		323	
coefficient of determination	**98.63**		**98.59**		**98.57**	

Table 4: Parameters of the data selection and the length distribution (number of the otolith, mean length, standard deviation (std), p-values of the χ^2 goodness-of-fit and the Shapiro-Wilk's W statistic)

Year	Birthday start	Birthday end	Month	Number	Mean	std	χ^2 p-value	Shapiro p-value
1993	30	150	10	26	11.79	2.64	-	0.31
1993	150	240	10	35	4.71	0.89	0.98	0.98
1994	30	150	10	30	10.40	1.94	0.45	0.86
1994	150	240	10	57	5.07	0.85	0.25	0.06
1995	30	150	9	20	12.20	2.29	-	0.01
1995	30	150	10	13	14.24	2.44	-	0.05
1995	150	240	9	3	4.33	0.64	-	-
1995	150	240	10	22	5.16	1.67	-	0.12
1996	30	150	9	36	8.98	1.15	0.05	0.06
1996	150	240	9	6	3.85	2.30	-	-

Table 5: Parameters of the different linear regressions between the total length (TL) and the age in days for the described three stages of the growth
TL = intercept + slope * age
and the inverse regressions for the estimation of the birthdays from length data

range of age	intercept	slope	correlation coefficient	number
age ∈ (65,105]	-0.539	0.0666	0.782	68
age ∈ (105,125]	6.754	-0.0136	-0.101	36
age ∈ (125,265]	0.515	0.0629	0.806	155
age ∈ (125,240]	-1.665	0.078	0.839	143

age = intercept + slope * TL

range of age	intercept	slope	correlation coefficient	number
age ∈ (125,265]	70.745	10.315	0.806	155
age ∈ (125,240]	80.340	9.000	0.840	143

Table 6: Parameters of the linear regressions total length = f (birthday) for the different catch months with the conditions:
birthdays between the 50th and 240th day of the year

Month	Intercept	Slope	Number	Correlation coefficient
9	17.36	-0.0741	58	-0.88
10	19.49	-0.0747	174	-0.95

Table 7: Estimated birthdays based on the length distributions of surveys and the age-length relation of the third stage (Table 5)

area	Arkona Sea		Arkona Sea	
month	November		February	
age group	0		1	
mean catch day	01.12.1996		15.02.1997	
		estimated		estimated
Length in cm	Number	Birthdays	Number	Birthdays
6	5	20.07.1996	32	04.10.1996
8	281	02.07.1996	7	16.09.1996
10	1455	14.06.1996	69	29.08.1996
12	1885	27.05.1996	490	11.08.1996
14	1580	09.05.1996	830	24.07.1996
16	558	21.04.1996	999	06.07.1996
18	290	03.04.1996	1222	18.06.1996
20	39	16.03.1996	867	31.05.1996
22	9	27.02.1996	307	13.05.1996
24			127	25.04.1996
26			13	07.04.1996

Table 8: Times of inflow events with different intensities within the time period late winter - spring

Year	Time period
1993	December
1994	March
1995	beginnig of February
	beginnig of April
1996	middle of February to middle of March

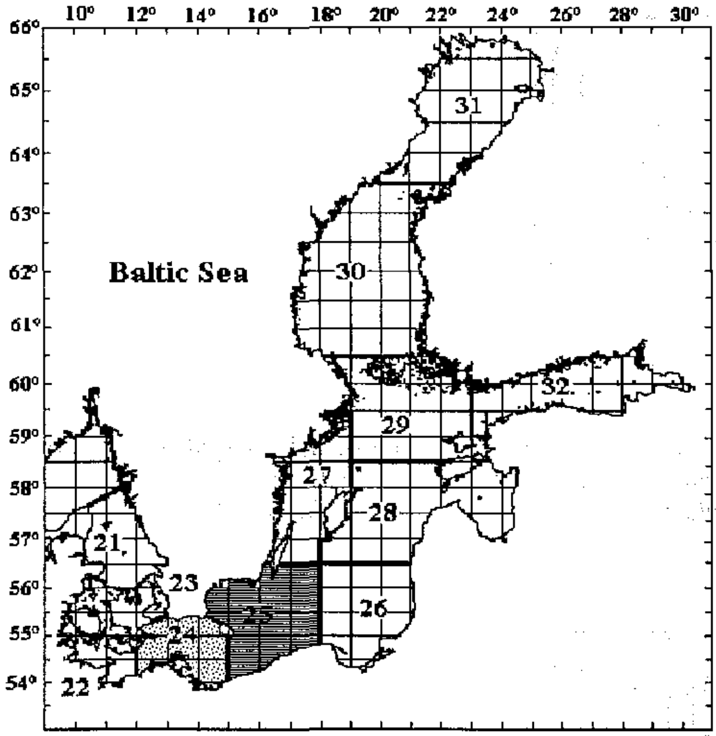


Figure 1: Baltic Sea with ICES sub-divisions and the areas of investigations

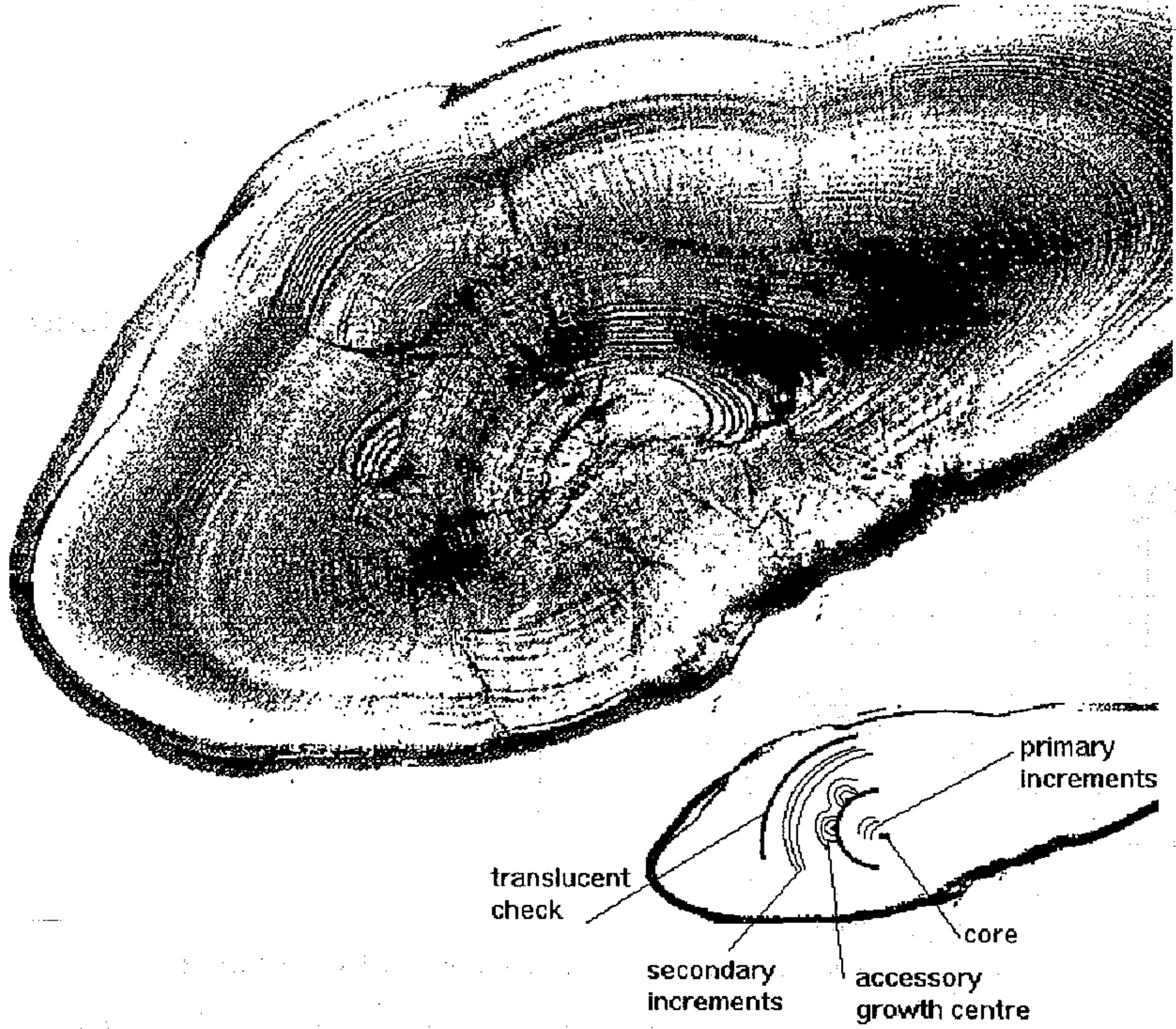


Figure 2: A transverse section of a Sagitta otolith in combination with some notations

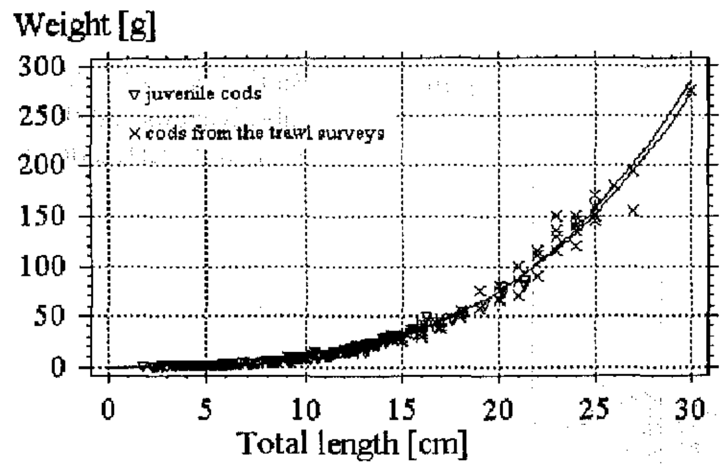


Figure 3: **Multiplicative regressions between total length (TL) and whole weight for all data**

juvenile cods: $Weight = ln(-5.236) * TL^{3.187}$; $R = 0.997$; $N = 324$

cods from the trawl surveys: $Weight = ln(-5.531) * TL^{3.288}$; $R = 0.992$; $N = 68$

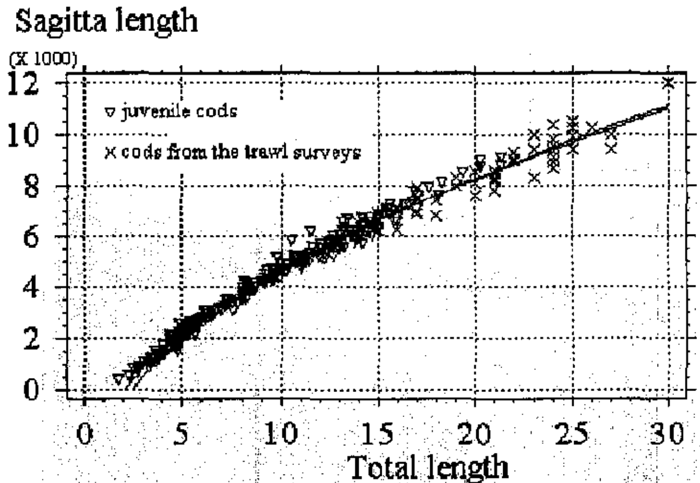


Figure 4: Square root x regressions between Sagitta length (SagLength) and total length (TL) for all data

juvenile cods: $SagLength = -3879.90 + 2712.68 * \sqrt{TL}$; $R = 0.99$; $N = 323$

cods from the trawl surveys: $SagLength = -4478.66 + 2851.88 * \sqrt{TL}$; $R = 0.98$; $N = 61$

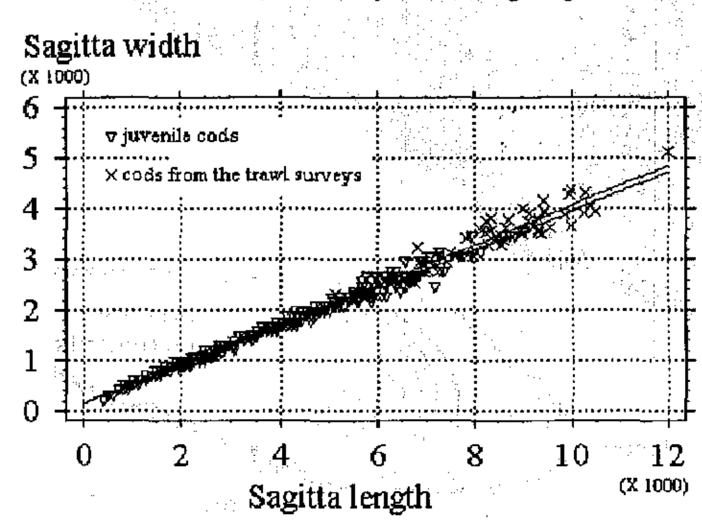


Figure 5: Linear regressions between Sagitta width (SagWidth) and Sagitta length (SagLength) for all data

juvenile cods: $SagWidth = 159.81 + 0.379 * SagLength$; $R = 0.99$; $N = 323$

cods from the trawl surveys: $SagWidth = 136.25 + 0.393 * SagLength$; $R = 0.95$; $N = 62$

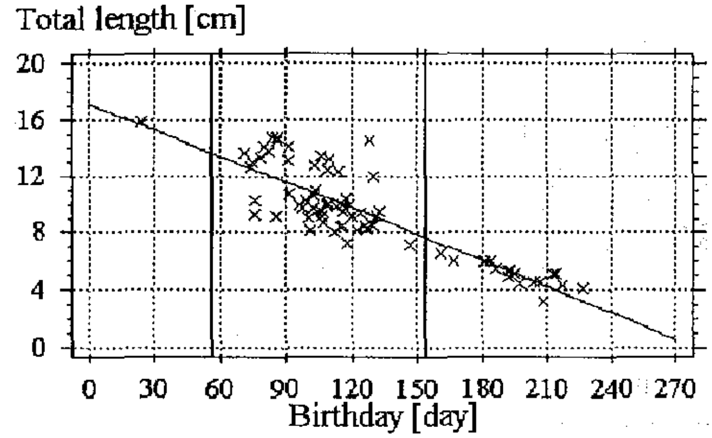


Figure 6: Distribution of the birthdays for juvenile cod caught in ICES Sub-division 24 (all data) with the marked spawning seasons

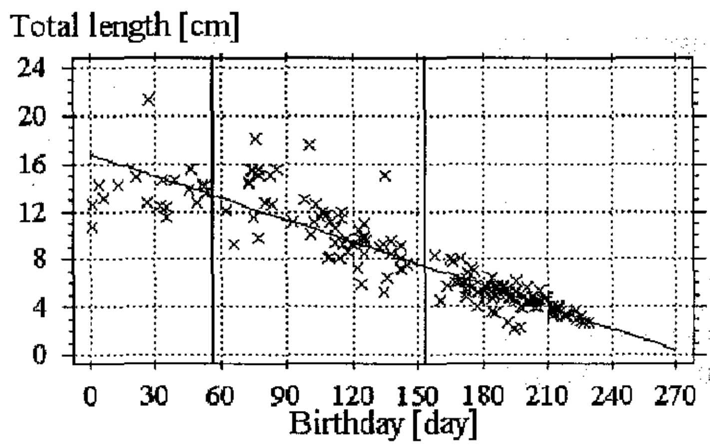


Figure 7: Distribution of the birthdays for juvenile cod caught in ICES Sub-division 25 (all data) with the marked spawning seasons

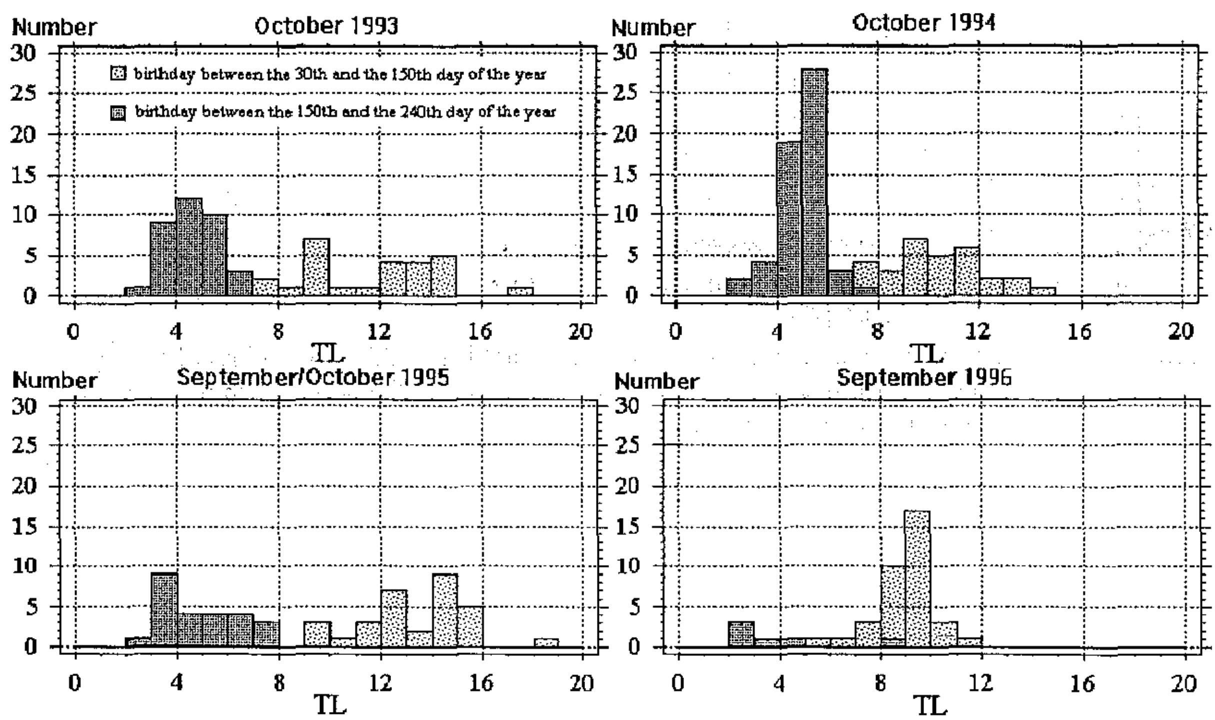


Figure 8: Length distributions of the juvenile cods in the different years separated for birthday intervals

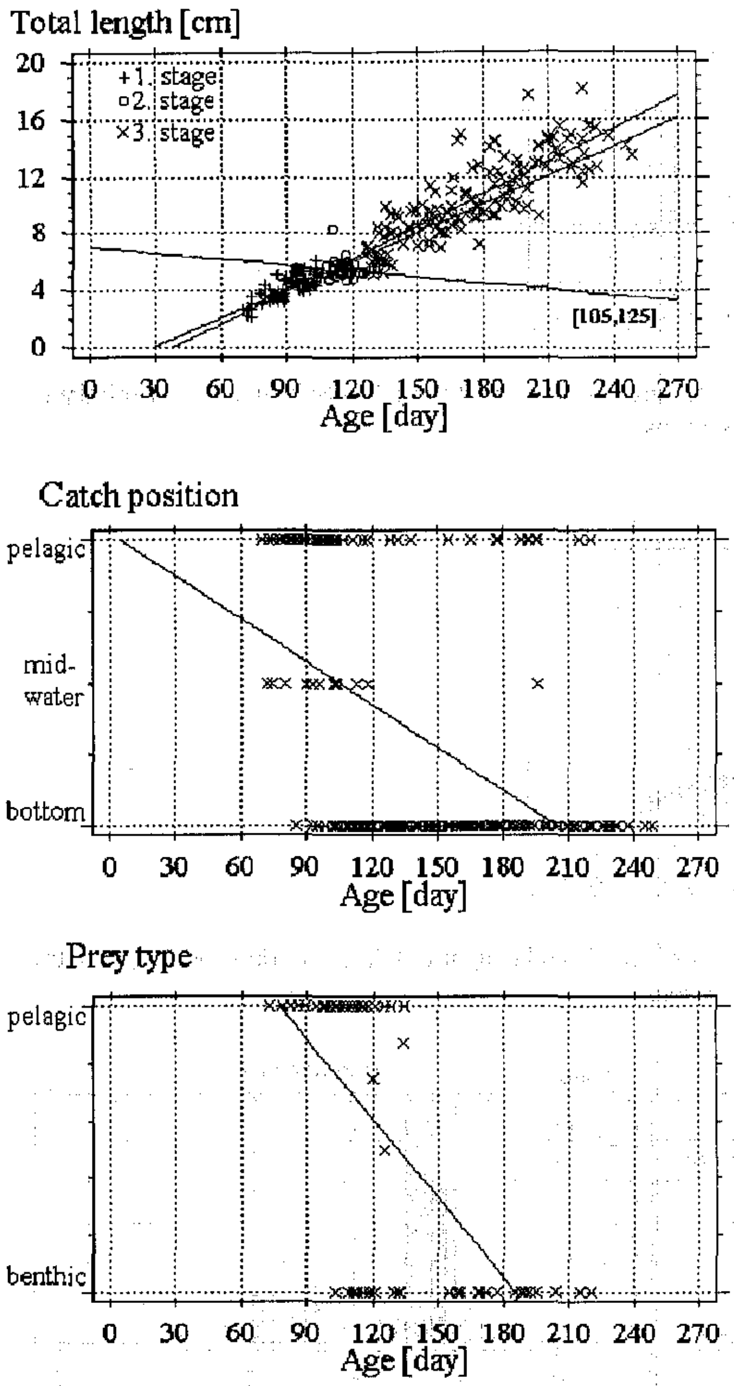


Figure 9: Linear regression between age in days and total length (TL) for different life stages (additionally the distribution of the catch position and the prey type in relation to the age) - (all available data)

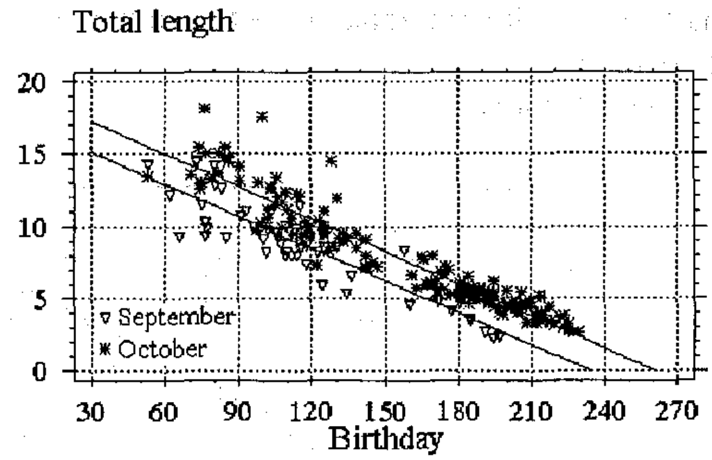


Figure 10: Relations between birthday and total length depending on the time of catch (September / October), spawned in the ICES SD 22,24 or 25
birthdays between the 50th and 240th day of the year

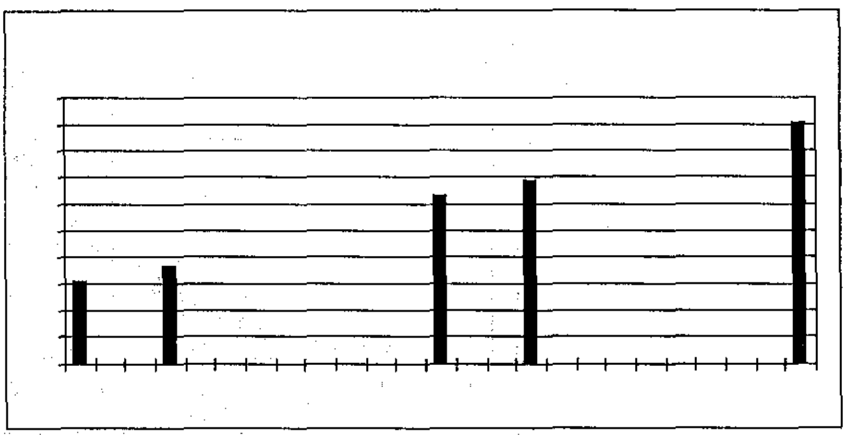
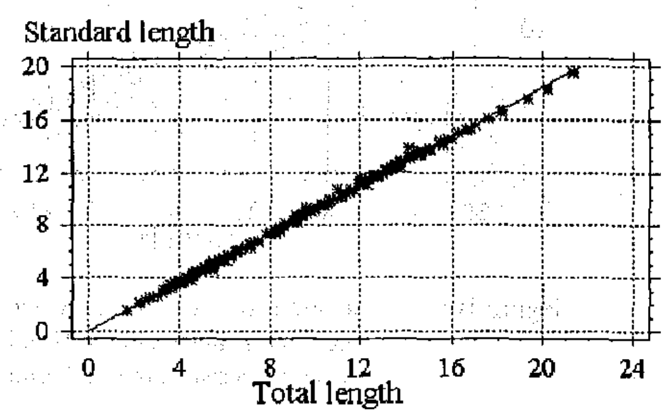
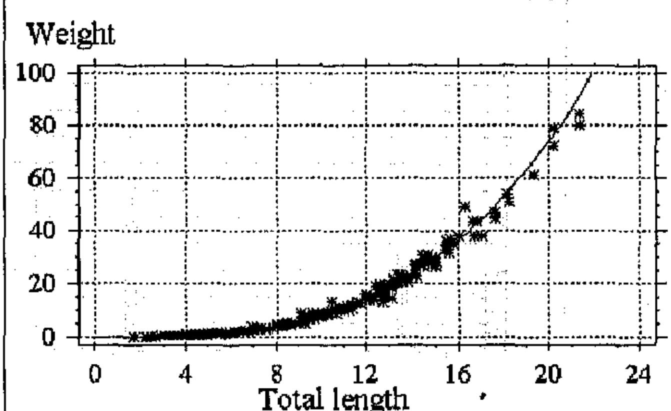
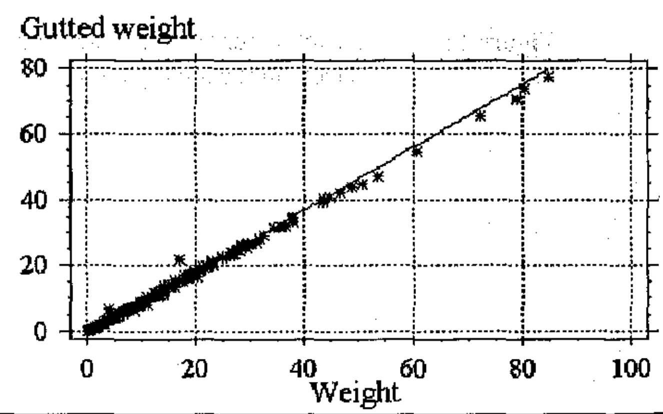
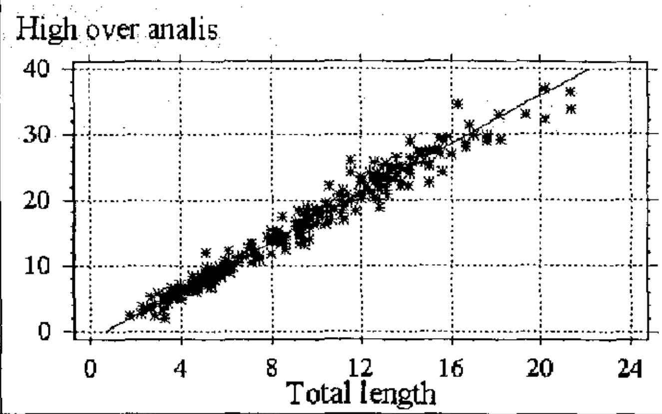


Figure 11: Development of the mean total length of the cod year-class 1994 in the Arkona Sea based on the survey data

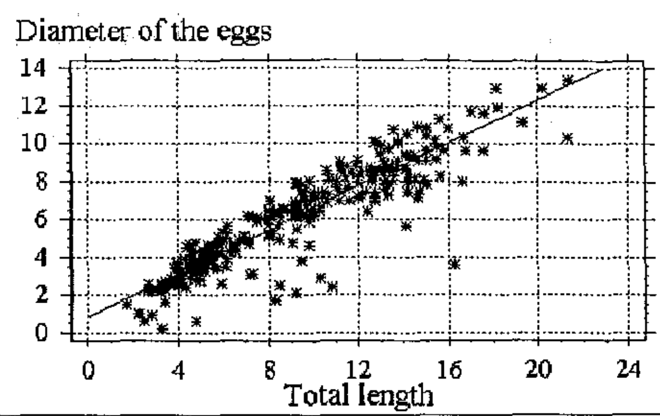
Appendix A: Parameters and plots of the different relations between the fish and Sagitta otolith parameters
a description of the actual status

dependent variable	standard length (SL)	
independent variable	total length (TL)	
selection parameter		
SL =	-0.0425+0.924*TL	
N	324	
r	0.999	
dependent variable	total length (TL)	
independent variable	standard length (SL)	
selection parameter		
TL =	0.0552+1.0882*SL	
N	324	
r	0.999	
dependent variable	weight (W)	
independent variable	total length (TL)	
selection parameter		
W =	ln(-5.236)*$TL^{3.187}$	
N	324	
r	0.997	
dependent variable	gutted weight (gW)	
independent variable	weight (W)	
selection parameter		
gW =	-0.125+0.901*W	
N	324	
r	0.999	

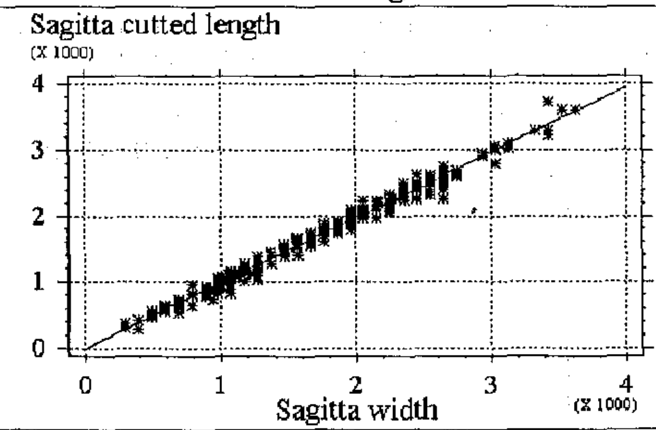
dependent variable	height over the analis (HA)
independent variable	total length (TL)
selection parameter	
HA =	-1.247+ 1.859 *TL
N	324
r	0.986



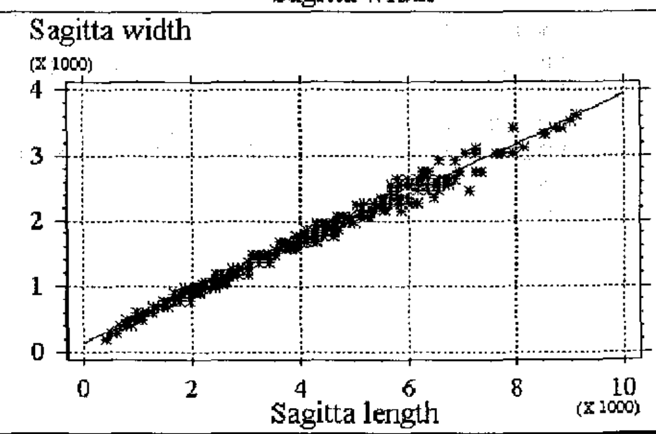
dependent variable	Diameter of the eys (DE)
independent variable	total length (TL)
selection parameter	
DE =	0.820+0.576*TL
N	323
r	0.915



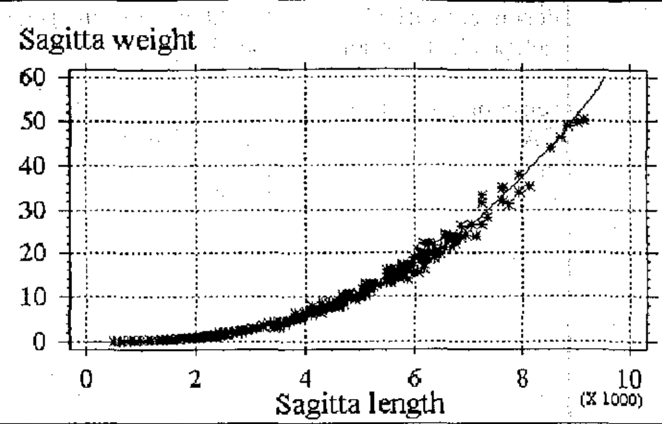
dependent variable	Sagitta cutted length (SagCutL)
independent variable	Sagitta width (SagWd)
selection parameter	SagCutLen > 0
regression	SagCutL=-1.485+0.987*SagWd
N	300
r	0.994



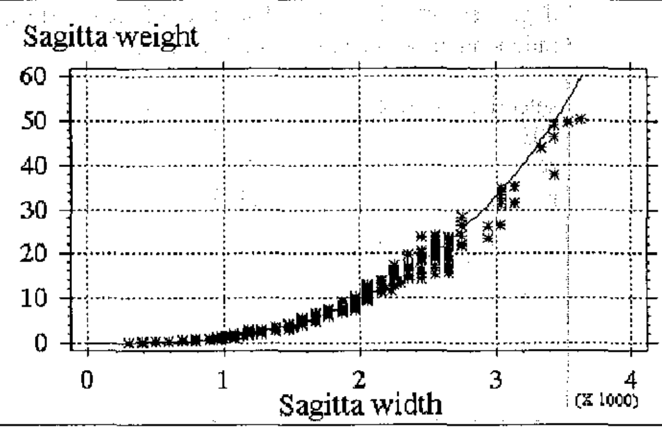
dependent variable	Sagitta width (SagWidth)
independent variable	Sagitta length (SagLength)
selection parameter	
SagWidth =	157.353+0.379*SagLength
N	324
r	0.993



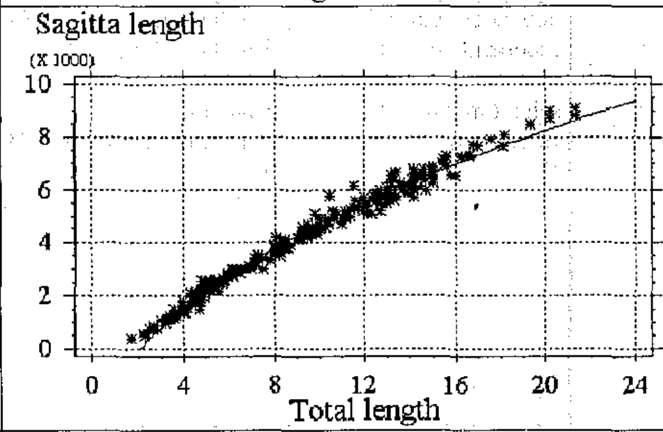
dependent variable	Sagitte weight (SagWeight)
independent variable	Sagitta length (SagLength)
selection parameter	SagWeight > 0
SagWeight =	ln(-20.444) * SagLength $^{2.678}$
N	322
r	0.995



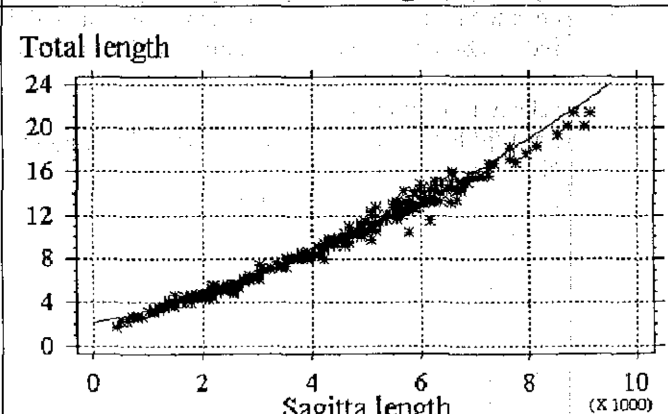
dependent variable	Sagitta weight (SagWeight)
independent variable	Sagitta Width (SagWidth)
selection parameter	SagWeight > 0
SagWeight =	ln(-20.900)*SagWidth $^{3.048}$
N	322
r	0.993



dependent variable	Sagitta length (SagLength)
independent variable	total length (TL)
selection parameter	SagLength > 0
SagLength =	-3879.9+2712.7*√TL
N	323
r	0.993



dependent variable	Total length (TL)
independent variable	Sagitta Length (SagLength)
selection parameter	SagLength > 0
SagLength =	(1.450+0.000364*SagLength)^2
N	323
r	0.993



dependent variable	Sagitta weight (SagWeight)
independent variable	Weight (W)
selection parameter	SagWeight>0
SagWeight =	1.764+0.684*W
N	322
r	0.975