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Herring (*Clupea harengus)* of the Central Baltic Sea and the Western Baltic Sea:

A discrimination approach using eye diameter-/ length ratios

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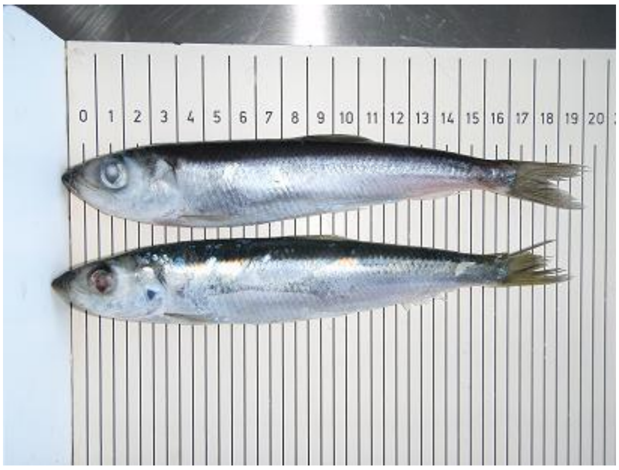


Abstract One of the major problems of stock assessment is to separate and quantify different stocks in mixing areas. Therefore, separation methods are needed. Several methods are described for different herring stocks, whereas most of them are associated with remarkable efforts. It could be observed that herring (*Clupea harengus)* caught in the Central Baltic Sea seems to have larger eyes relatively to its body length than herring caught in the Western Baltic Sea. The question raised by this observation is if the eye diameter in relation to the body length can serve as a separation attribute. From 2005 to 2008 the eye diameter and body length of herring was measured in different areas of the Baltic Sea during different seasons. The present study compares the relation between eye diameter and body length for herring of the Central Baltic Sea and the Western Baltic Sea. Significant differences are shown. The feasibility of eye diameter as a separation attribute is evaluated by discriminant analyses. Furthermore the proportion of Central Baltic herring within the transition zone of the Central Baltic and the Western Baltic Sea was estimated. The fraction of Central Baltic herring occurring in subdivision 24 lies between 7% and 13% depending on the year.

Introduction

The basis of fishery management is the knowledge of stock size and structure, the reproductivity of stocks and their movements. The currently accepted definition of a stock in fisheries science, is that of Begg *et al.* (1999), *"…[a "stock"] describes characteristics of semi-discrete groups of fish with some definable attributes which are of interest to fishery managers."*. Furthermore a stock can be seen as a reproduction unit separated from other individuals of the same species within its biological range. Several stocks of herring *(Clupea harengus)* are defined in the Baltic Sea. These stocks follow a migration cycle between their spawning and feeding grounds (Aro, 1989). Thereby it comes to a mixing of different stocks in certain areas and seasons. For a better understanding of the problem of mixing stocks a short overview of concrete migration patterns will be given both for Western Baltic and Central Baltic herring.

Also a short definition of Western Baltic Sea and Central Baltic Sea will be given: The Baltic Sea is divided into defined districts called subdivisions (SD). These range from 22- 32 (Fig. 1). Subdivisions 22-24 are defined as Western Baltic Sea,

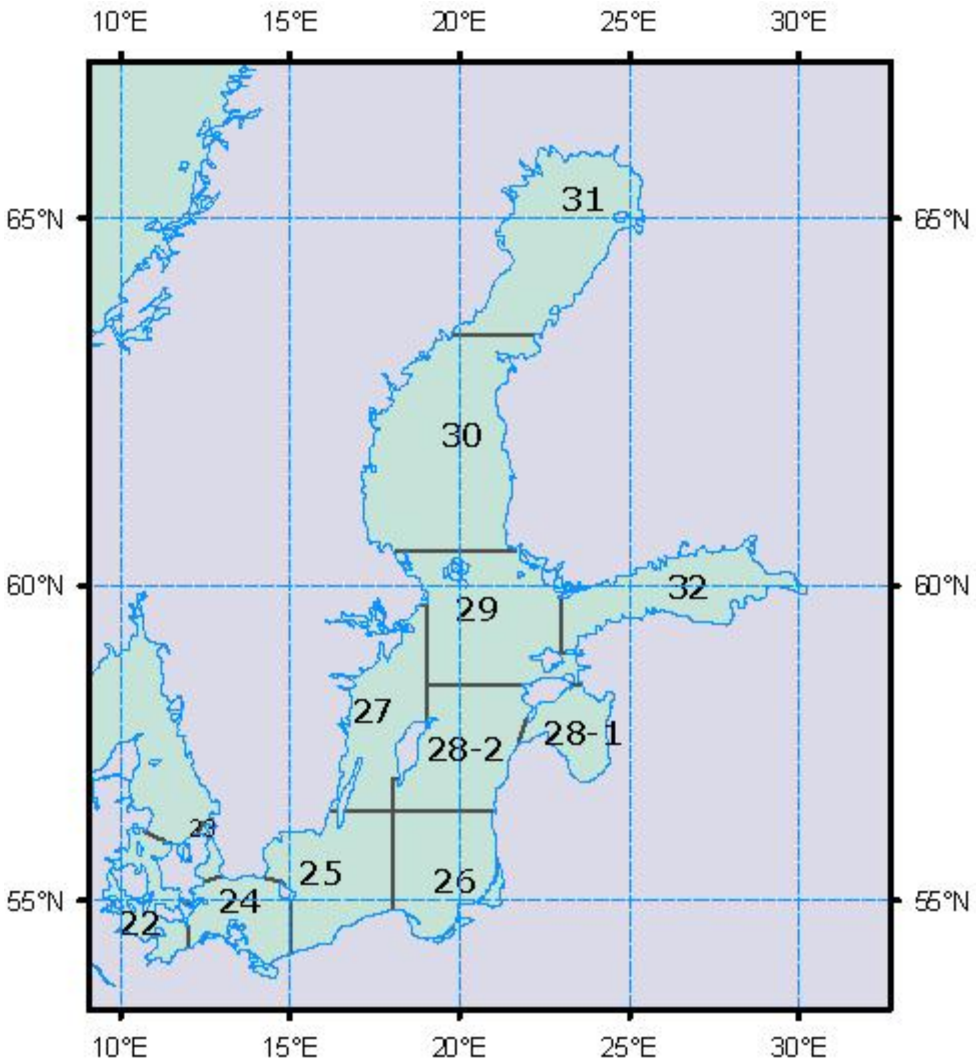


Fig. 1: ICES subdivisions of the Baltic Sea

subdivisions 25-27 as part of the Central Baltic Sea (subdivisions 25-27, 28.2, 29 and 32). The Western Baltic Sea is mainly occupied by Western Baltic Spring Spawning Herring (WBSS), also known as Rügen-herring because the main spawning area is considered to be the Greifswalder Bodden south of Rügen. After spawning during spring time, WBSS herring mainly migrates out of the Western Baltic Sea in quarter 2 of the year to feed in the Skagerrak area during summer time. Large concentrations of 2+WBSS herring can be found in the southern Kattegat and subdivision 23 during quarter 3 and 4 as they aggregate for overwintering (ICES, 2008). Some of the older herring, however, migrate to the south of Bornholm, to the Oder Bank off the coast of Poland

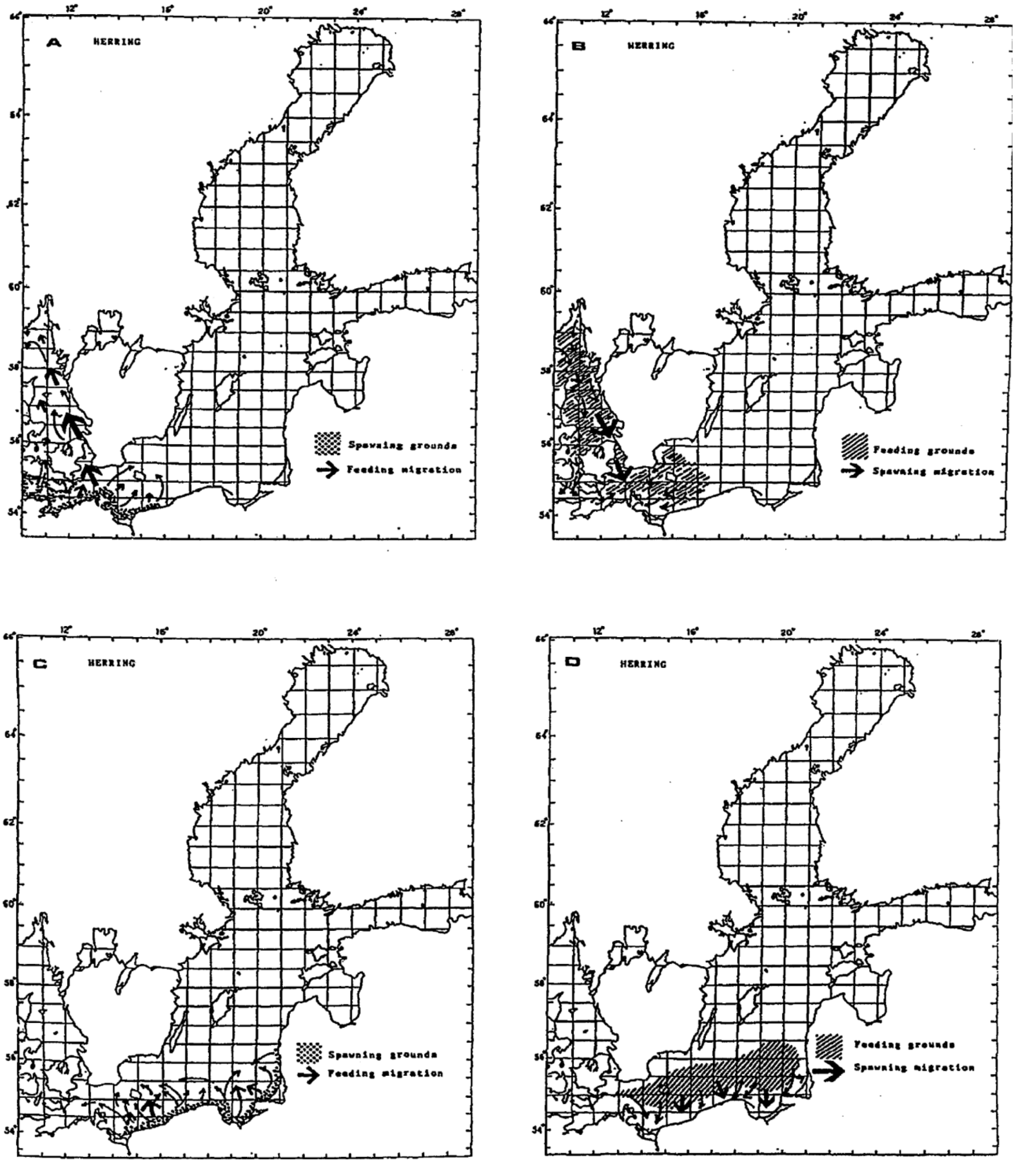


Fig. 2: The migration pattern of spring spawning herring in the Western Baltic Sea (A, B) and spring spawning coastal herring of the Central Baltic Sea (C,D). (A) Spawning grounds and feeding migration of the spring spawning herring of the Western Baltic Sea; (B) Feeding grounds and spawning migration of the spring spawning herring of the Western Baltic Sea; (C) Spawning grounds and feeding migration of the spring spawning coastal herring of the Central Baltic Sea; (D) Feeding grounds and spawning migration of the spring spawning coastal herring of the Central Baltic; (Figure by Aro, 1989)

and to the Hanö Bay open sea areas near the Swedish coast (Biester, 1979), where they feed and overwinter together with the specimens from other stocks (Aro, 1989). In quarter 1 of the following year all stocks return to their spawning grounds (Fig. 2 A, B).

Several stocks can be distinguished in the area of the Central Baltic Sea (subdivisions 25-27). One of these stocks is the spring-spawning coastal herring (Aro, 1989). The spring- spawning coastal herring has its spawning grounds in Pomorska Bay, Gdańsk Bay and Vistula Lagoon (Popiel, 1964). Spawning starts in March/ April. The main feeding grounds are around Bornholm and in the Gdansk Basin during July and December (Aro, 1989) (Fig. 2 C, D). The description of these migration patterns is to primarily show one thing: Both stocks have a potential mixing area: the region around Bornholm as feeding grounds and the area east of Rügen as spawning grounds. Therefore, in subdivision 24 we have the phenomenon of mixing stocks. This, again, leads to the question how stocks can be separated. Various approaches have been done:

Researchers have attempted to use many different techniques to distinguish among herring stocks, including: scale pattern analysis (Rowell, 1981), tagging studies (Hourston, 1982), morphometrics and meristics (Podolska *et al.*, 2006), microsatellite DNA (O'Connell *et al.*, 1998), and otolith microchemistry (Otis and Heintz, 2003). However, most techniques have proven to be unreliable at fine spatial scales. Also procedures based on size distributions were tested but often turned out to fail. The introduction of otolith microstructure analysis for herring in 1996- 1997 (Mosegaard and Popp-Madsen, 1996), however, enables a good separation between autumn, winter and spring spawners but not between stocks with similar spawning periods. Alternatively or in correspondence with otolith microstructure vertebral counts (VC) are used. Vertebral counts already served to distinguish between WBSS and North Sea autumn spawners (NSAS) (Gröger and Gröhsler, 2001). This method is quite sensitive to within-stock variation (e.g. between year classes) in mean VC (ICES, 2008) and like the otolith microstructure analysis not well usable for separating stocks with a similar spawning period (ICES, 2008). Molecular genetic approaches are rather promising. Significant variation has been found among spawning populations in Division IIIa and subdivisions 22-24, which indicates the presence of multiple distinct spring spawning populations or subpopulations (Ruzzante *et al.*, 2006). According to other sources, however, genetic approaches don't necessarily guarantee to be a reliable separation method (O'Connell *et al.*, 1998). A new method of stock identification was applied successfully to discriminate known herring stocks and reveal differences among putative stocks at relatively fine spatial scales (> 100 km) (Otis and Heintz, 2003). The method discriminates stocks using differences in the fatty acid composition of cardiac tissue. The investigation by Otis and Heintz (2003) refers to stocks of the Pacific herring (*Clupea pallasi*) along the Northern Gulf of Alaska. Other methods, like the analysis of enzymes (Heath and Walker, 1985) or the analysis of parasitic infections (Kühlmorgen- Hille, 1983), are just to be named here. In general the use and the discriminatory power of a method very much depends on the area in which the different stocks are living. In order to separate Central Baltic herring stocks from Western Baltic herring stocks morphometric characters as well as meristic characters (vertebrae counts, gill rakers) have been tested so far (Podolska *et al.*, 2006).

The use of eye diameter in relation to body length for Central Baltic and Western Baltic herring has not received much attention yet in technical literature. This seems to be the first approach in using eye diameter as a discriminating parameter for herring of the Central Baltic and the Western Baltic, which would be an effective method.

In order to investigate the usability of eye diameter as a discriminating parameter, this work follows two major questions:

1). Are there any differences at all between Central Baltic herring and Western Baltic herring in terms of their eye diameter and total body length?

2).Can we use eye diameter and body length as parameters for an accurate stock separation method within mixing areas?

Material and Methods

To investigate the possibility of the separation of herring stocks in the Baltic Sea using the eye- diameter/ length relation, samples were taken from subdivision 21- 29 within annual quarters 1, 2 and 4 between 2005 and 2008. The temporal and spatial coverage differed between years. The samples originate from hydroacoustic surveys of research vessel "Solea" in quarter 4, research vessel "Walther Herwig III" in quarter 2 as well as from commercial catches in subdivisions 22 and 24 in all three quarters. Only stations, where eye diameter in addition to body length, weight, etc. was taken, have been considered in this study. A detailed overview about the number of samples, origin of samples (subdivisions), period of sampling (quarters) and fishing method is shown in **Annex, Tab. 4**. Hydroacoustic survey samples derive from trawl net catches. Commercial samples comprise gillnet, trapnet and trawl net catches.

Eye diameter and *body length* were measured by the same group of people over the years. Eye diameter was measured in mm rounded without decimals using a sliding caliper, the total fish length was measured as 0.5 cm below. Statistical analyses were carried out by the statistical software R (R Development Core Team, 2008 R: A language and environment for statistical computing).

In order to answer the two tasks of the study, two major steps were done during this work:

1. Investigation and definition of pure stocks
2. Defining and testing a separation method for mixed stocks

1. Investigation and definition of pure stocks

The intention of defining pure stocks was to create a strong separation and find clear differences between stocks.

The characterization of herring stocks was done using samples from the second quarter only (**Tab. 1**), due to the following reasons:

- The investigated herring stocks are spring spawners and have different spawning areas. Therefore, they are assumed to be separated during spawning time, whereas in other seasons the possibility of mixing between herring stocks is assumed to be higher.
- Quarter 2 also comprises data of subdivisions 22- 29, whereas other seasons don't provide data for all these subdivisions.
- To eliminate possible seasonal variation

1.1 Investigation of potentially pure stocks in subdivisions 22- 29

This part of the work is composed of two different uses of the data:

The *raw data* were used for a general comparison and overview of eye diameter and body length values, but also for a standardization procedure. Afterwards the *mean values* of the eye diameter were calculated to run cluster analyses, to compare two subdivisions by the slope of their regression model and to fit different regression models.

1.1.1 Comparing raw data of subdivisions 22- 29

Various comparisons and approaches were made in order to show possible differences due to eye diameter/ body length ratio: First all subdivisions together were compared as an overview. Afterwards subdivision 24 together with subdivision 25 were compared. These 2 subdivisions are expected to be the main transition zone of the Western Baltic and the Central Baltic herring stocks. Additionally subdivisions 24 and 25 were compared only by considering maturity stage 6 – spawning (Heincke, 1898).

In this case (quarter 2) it means that only individuals which definitely belong to subdivision 24 or subdivision 25 are recorded because they spawn in these areas. Differences in eye diameter and body length were expected to be small between these 2 subdivisions. Assuming a spatial gradient in the eye diameter/ body length ratio the more subdivisions are away from each other, subdivisions 22 and 29 were finally compared.

Tab. 1: Overview of the number of samples in quarter 2; sorted by year, catch method and origin.

Quarter 2		commercial samples			hydroacoustic survey	
year	subdiv	gillnet	trapnet	trawl	trawl	total
2005	24	482	597	450	292	1821
	25				535	535
	26				193	193
	total	482	597	450	1020	2549
2006	22		60			60
	24	100	849	537	271	1757
	25				310	310
	26				138	138
	27				210	210
	total	100	909	537	929	2475
2007	22		58	151		209
	24	378	501	321	240	1440
	25				566	566
	27				248	248
	total	378	559	472	1054	2463
2008	25				1	1
	22		53	123		176
	24	173	407	364	394	1338
	25				519	519
	26				240	240
	27				252	252
	29				134	134
	total	173	460	487	1540	2660
05-08	total	1133	2525	1946	4543	10147

1.1.2 Standardization of the raw data

The intention was to obtain standardized values of the eye diameter for each subdivision being independent from body length. Therefore, regression lines had to be calculated for each subdivision. The coefficients of the regression models were used to standardize eye diameter, i.e. to calculate a theoretical eye-diameter at a length of 20cm, which is approx. the middle of the entire length-range and also based on a sufficient number of samples.

$\text{eye diameter}_{(\text{standard})} = \text{eye diameter}(x) + (\text{body length}_{(\text{standard})} - \text{body length}(x)) * \text{slope}(x)$ (**eq. 1**)

with *slope(x) = slope of the regression line for each subdivision.*

Finally, for each subdivision the frequency distributions of calculated values of the standardized eye diameter were compared.

1.1.3 Cluster analyses using mean values

Mean values of eye diameter were calculated for 1cm length classes (total length as cm below).

To minimize the influence of outliers, length 1cm classes with less than 4 specimen were exclueded. The final table is given in **Annex A Tab. 5**

Using the values of (**Tab. 5**) three different approaches were made to show differences between herring of the Central Baltic and the Western Baltic in terms of eye diameter and body length:

The first approach was a *cluster analysis* comprising subdivisions 22 to 29. The distance used to design a dissimilarity matrix was the *euklidean distance*, the linkage method used was both the *single linkage method* and the *ward method*. **(detailed description in Annex B)**.

1.1.4 Comparison of two regression slopes

An alternative approach was to calculate linear regression models (for mean eye diameter against body length) and to compare the regression slopes by a *two- sided-t- test*. The test statistic was calculated as follows:

$t = (b_1 - b_2) / s_{b1,b2}$ **(eq. 2).**

where b_1 and b_2 are the two slope coefficients and $s_{b1,b2}$ the pooled standard error of the slope (b) (The pooled standard error is the weighted sum of the single standard errors).

Subdivisions 24 and 25 representing most of the data were chosen to represent Western Baltic and Central Baltic, because these two areas are closest to each other. That would make it difficult to show significant differences due to eye diameter and body length. But in case of significant differences these would potentially be also valid for other subdivisions with a larger geographical distance.

1.1.5 Comparison of two different regression types

Two different regression models were fitted:

$f(x) = b_0 + b_1 * x$ *(linear model)* **(eq. 3)**

$f(x) = b_0 + b_1 * \log(x)$ *(logarithmic model)* **(eq. 4)**

Their parameters were tested for significance (t-test for each parameter) as well as the model itself was tested (F-test for variance). The regression analyses were restricted to subdivisions 24 and 25. Again, mean values of the eye diameter **(Annex A**, **Tab. 8)** were used to fit regression models. Some details concerning the regression analyses are given in **Annex B**, ***Regression models*** (**explanation 2**).

1.2 Definition of pure stocks within a mixing area

The area of this particular investigation was subdivision 24 considered as a mixing area between herring of the Central Baltic and the Western Baltic Sea. Herring of the Western Baltic grows faster than herring of the Central Baltic. Therefore, herring of the Central Baltic needs more time to reach the same body length or weight. The other way round, herring of the Central Baltic having the same age as herring of the Western Baltic must be of smaller size and weight, which is documented by ICES (International Council for the Exploration of the Sea) data, showing different mean- weight- at- age values for different subdivisions (ICES HAWG report 2006-2008; ICES WGBFAS report 2006-2008**)**. The idea behind was to create one group of Western Baltic herring scattering around the specific mean- weight- at- age value for the western region and a second group of Central Baltic herring scattering around the specific mean- weight- at- age value for the central part of the Baltic Sea. The "Herring Assessment Working Group for the Area South of 62° N" (HAWG) of ICES provides data for herring of division III a and subdivisions 22-24, the "Baltic Fisheries Assessment Working Group" (WGBFAS) of ICES provides data for subdivisions 25-29 and 32. Data were provided for years 2005 -2007. A total mean- weight- at- age value for subdivisions 22- 24 was used per age group (representing the Western Baltic). Similarly a total- mean- weight- at- age value for subdivisions 25-29, 32 was used per age group (representing the Central Baltic) (**Annex A,Tab. 6**).

Using those values, herring of subdivision 24 was splitted in two different ways:

First all herring with a specific weight higher than the mean- weight- at- age for subdivisions 22- 24 were considered to be Western Baltic herring. Herring with a specific weight lower than the mean- weight- at- age for subdivisions 25- 27, 32 was defined as Central Baltic herring. All herring inbetween remained undefined **(**Fig. **3)**.

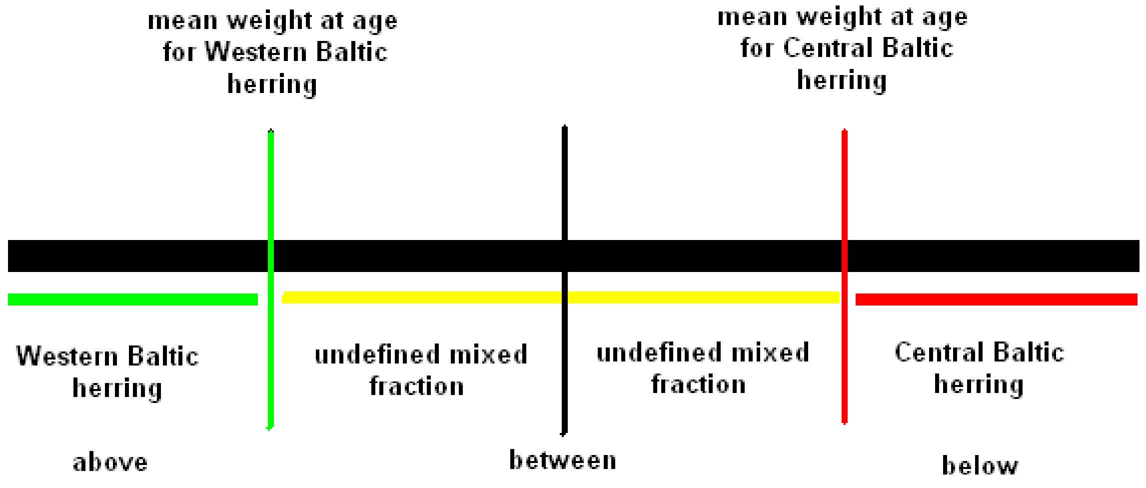


Fig. 3: Schematic representation of the separation procedure of herring stocks using the mean weight at age. Green vertical line = mean weight at age for subdivisions 22- 24. Red vertical line = mean weight at age for subdivisions 25- 29, 32. Black vertical line = mean of red and green vertical line.

Afterwards the undefined mixed fraction was splitted at half the distance between mean- weight- at- age values for Central Baltic and Western Baltic **(**Fig. **4)**.

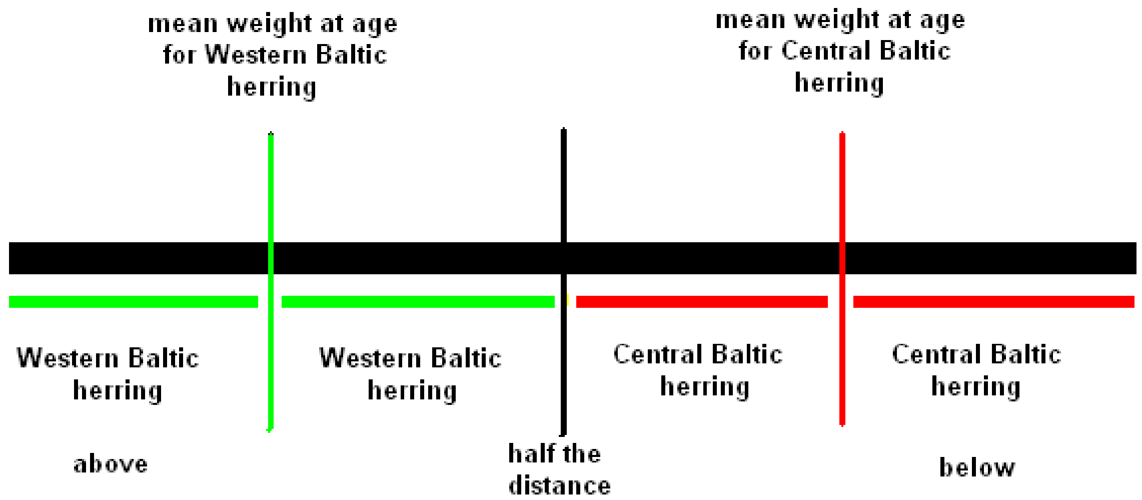


Fig. 4: Schematic representation of the separation procedure of herring stocks using the mean weight at age. Green vertical line = mean weight at age for subdivisions 22- 24. Red vertical line = mean weight at age for subdivisions 25- 29, 32. Black vertical line = mean of red and green vertical line.

A summary of the splitting procedures and the concrete values used for them are given in **Annex A**, **Tab. 7**. The resulting fractions (Western Baltic, Central Baltic herring) of these splitting procedures were now plotted with eye diameter against body length. This was done for each year and age group separately.

2. Defining and testing a separation method

The second aim of this work was to investigate the separation qualities of the eye diameter in relation to body length for Central Baltic herring and Western Baltic herring. First pure herring stocks had to be defined representing a fraction of Central Baltic and Western Baltic herring, respectively. After two pure stocks had been defined they were examined in terms of eye diameter and body length. Discriminant analyses were carried out to validate the eye diameter as a discriminant parameter.

Linear discriminant analyses were run on the basis of a jacknifed prediction. The basic idea behind the jacknife estimator lies in systematically recomputing the statistic estimate leaving out one observation at a time from the sample set. Discriminant functions were calculated:

$f(x)= u_0+u_1x_1+u_2x_2$ **(eq. 5)**

with $f(x)$ *: discriminant value*

u_o*: constant*

u_1,u_2*: discriminant coefficients*

x_1 *: body length and* x_2*: eye diameter*

the value for u_0 is specifically determined in R so that the critical discriminant value is standardized to 0. The critical discriminant value y* is used as discriminant rule for different groups

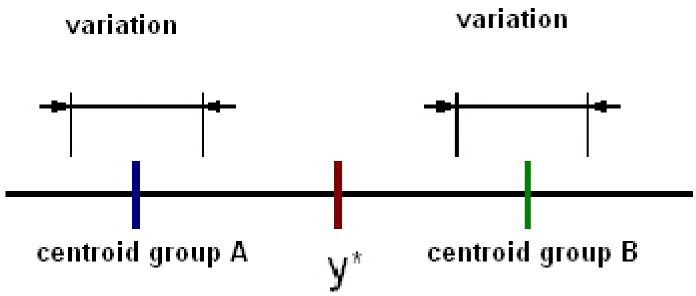


Fig. 5: Critical discriminant value y* splitting two groups; is set to 0 in R.

So in this case it is:

Western Baltic herring ≥ 0 , *Central Baltic herring* < 0

The goodness of fit for the discriminant function found was checked by comparing predicted values with original values due to their affiliation. The whole procedure was only run for age groups 1 and 2 which showed a clearer separation than other age groups and therefore served as examples.

Results

1.1.1 Comparing raw data of subdivisions 22- 29

In order to find any differences between the subdivisions of the Central Baltic and the Western Baltic concerning eye diameter, the following comparisons were made **(Fig. 6)**:

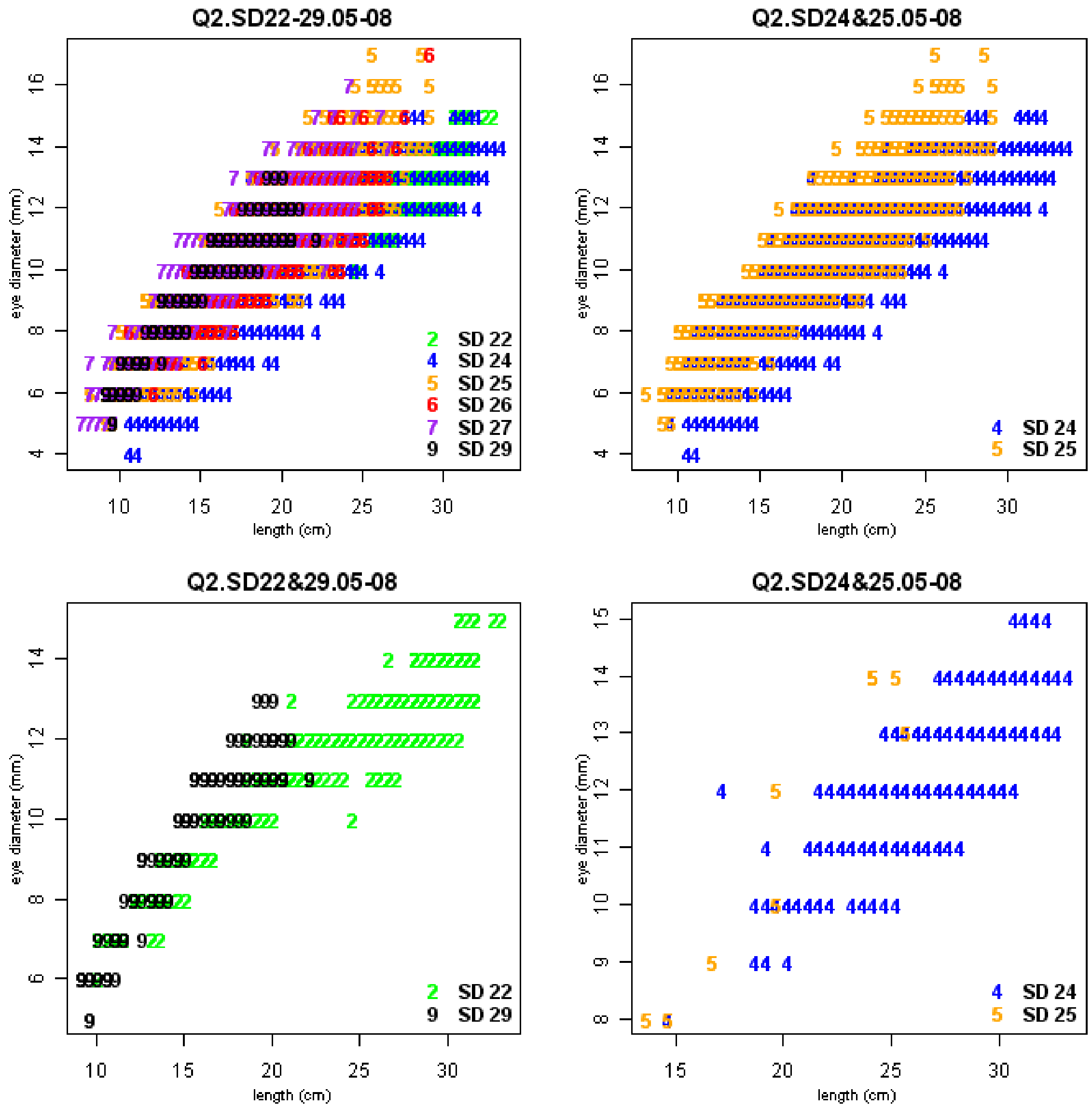


Fig. 6: Raw data of eye diameter and body length; 2005-2008 in quarter 2; each subdivision represented by a certain colour and number; bottom right: herring of subdivisions 24 and 25 with maturity 6 (spawning) only

As it seems there is a wide overlapping in the eye diameter-/ body length ratio between the subdivisions.

These data of subdivisions 22- 29 rather show a broad overlapping, no distinct clusters can be seen (**Fig.**

6, top left). Comparing only subdivisions 24 and 25 being closest together show slight differences in their marginal values of eye diameter and body length (**Fig. 6**, top right). These differences become larger the more subdivisions depart geographically (**Fig. 6**, bottom left). Therefore, a gradient between Western Baltic Sea and Central Baltic Sea can be observed in terms of the eye diameter-/ body length ratio (area of overlapping data decreases). Herring of subdivision 29 tends to have larger eyes in relation to its body length than herring of subdivision 22 (**Fig. 6**, bottom left).

Herring of subdivisions 24 and 25 in spawning condition (maturity grade 6) could not be compared due to their large difference in sample size (**Fig. 6**, bottom right, SD24=1316 specimen vs. SD25= 10 specimen).

1.1.2 Standardization of the raw data

The first step of the standardization procedure is represented by linear regression models (**Tab. 2**). The coefficients are highly significant. Only the estimated intercept of subdivision 29 wasn't significant, but still wasn't excluded to allow a comparison of all subdivisions.

Tab. 2: The linear regression models are summarized each by estimators of intercept, slope and the standard errors; t-values of a one- sample- t- test; probability of making a type 1 error on a level of significance of 0.001 (***).

SUBDIV	Coefficients	Estimate	Std.Error	t value	Pr(>|t|)
22	Intercept	391.984	0.25788	15.20	1.88e-12***
	slope	0.32460	0.01176	27.61	< 2e-16***
24	intercept	291.547	0.25706	11.34	2.05e-10***
	slope	0.34660	0.01142	30.34	< 2e-16***
25	intercept	215.081	0.20319	10.59	6.69e-09***
	slope	0.44428	0.01053	42.19	< 2e-16***
26	intercept	311.016	0.37643	8.262	5.78e-07***
	slope	0.39233	0.01967	19.946	3.28e-12***
27	intercept	208.397	0.28989	7.189	3.13e-06***
	slope	0.47480	0.01684	28.191	2.08e-14***
29	intercept	0.7753	0.6003	1.292	0.226
	slope	0.5629	0.0390	14.432	5.06e-08***

The second step of the standardization procedure is presented as frequency/ density distributions of the standardized eye diameter. These density distributions (**Fehler! Verweisquelle konnte nicht gefunden werden.**, top left) overlap. The density functions of subdivisions 24 and 29 differ most, but still show a wide range of overlapping values. Concerning only the means and standard deviations (**Fehler! Verweisquelle konnte nicht gefunden werden.**, bottom left) of these density functions, subdivision 24 and 29 don't intersect.

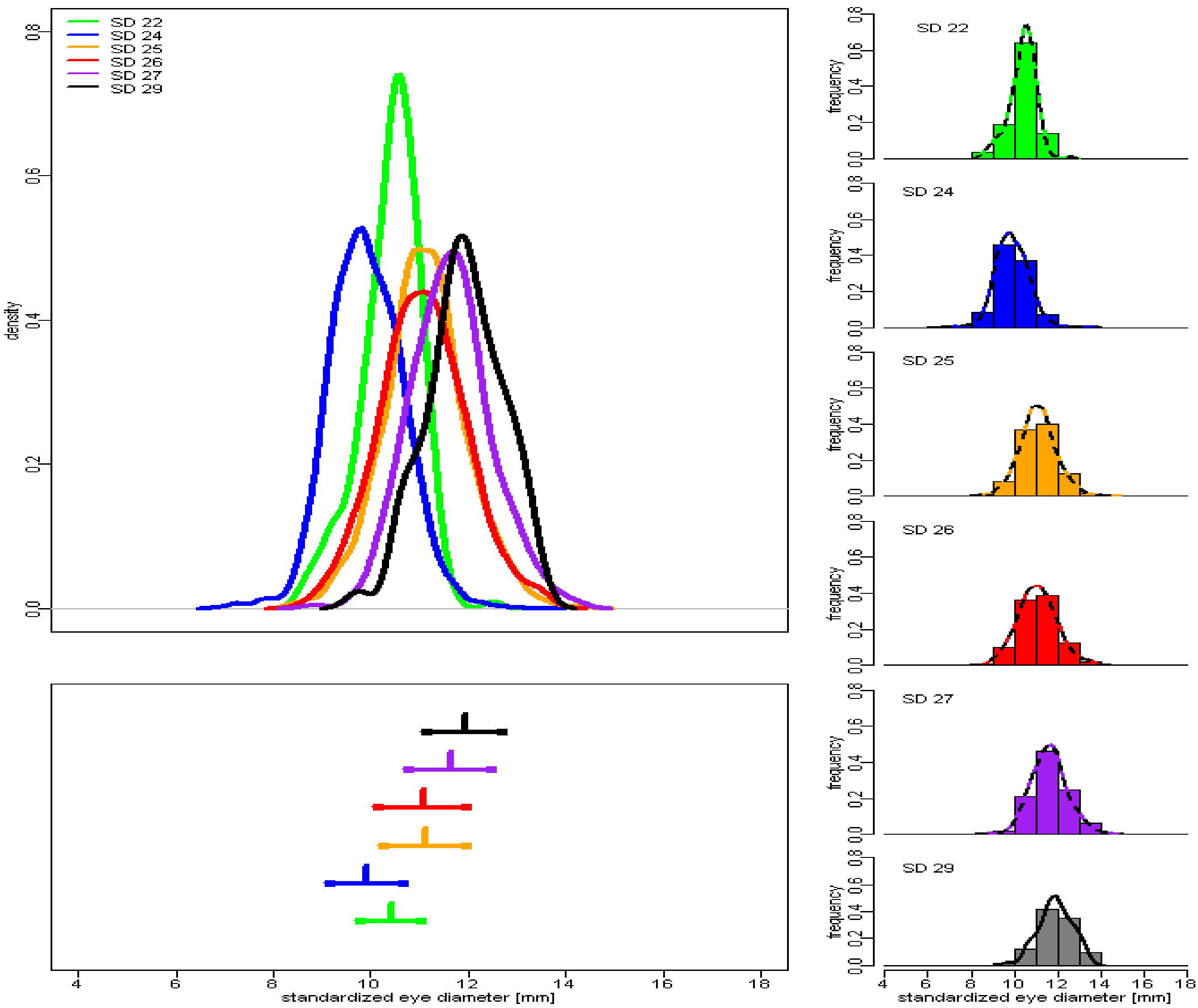
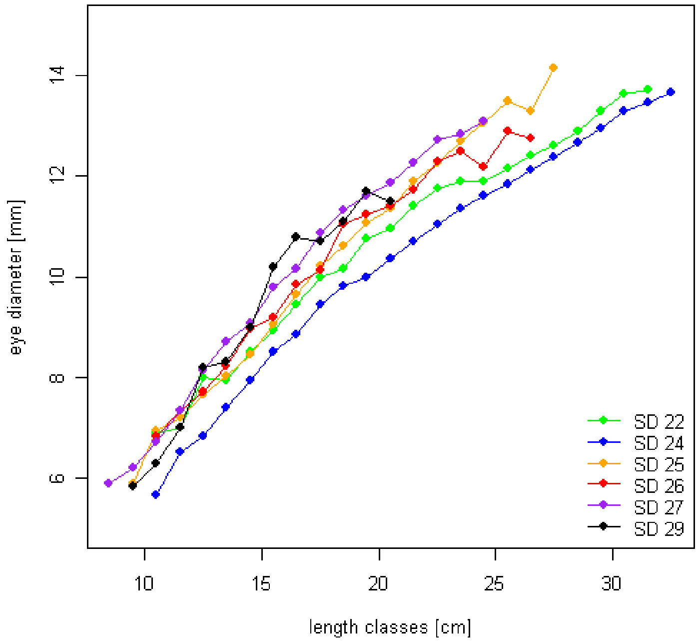


Fig. 7: Three different views of the standardized eye diameter distributions for each subdivision in quarter 2: Discrete frequency distributions of standardized eye diameter (right panel); density lines were added respectively; density lines extracted from right panel were put on top of each other (panel top left); these show continuous frequency distributions; vertical lines represent the means, horizontal lines show standard deviations of the density distributions (bottom left).

1.1.3 Cluster analyses using mean values

The mean eye diameters of each length class partially show a distinct constellation (**Fig. 8**, left). However, adding the standard deviations of these values still confirm the wide variety of original values of which the mean values consist. Mostly these standard deviations overlap (**Fig. 8**, right).



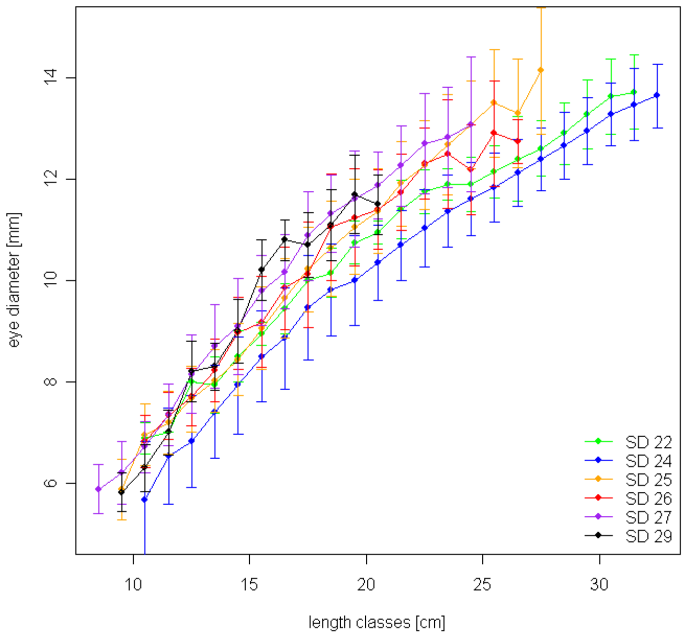


Fig. 8: Mean eye diameter - body length relationship for all subdivisions and all years in quarter 2. Left: Mean eye-diameter per 1cm length class; Right: Mean eye-diameter per 1cm length class including standard deviations.

The classification itself shows the following tendency:

Except of subdivision 22 all other subdivisions successively reach higher values of eye diameter per length class the more they are located in the eastern and northern part of the Central Baltic Sea. Subdivision 22 is more similar to subdivision 24 at upper length classes from about 25 cm on, whereas from 18 cm to 25 cm it proceeds between subdivision 24 and subdivision 25- 29. In smaller length classes it is more similar to subdivision 25- 29.

These results are confirmed by *cluster analyses* (**Fig. 9**) which represent distinct units of the Western Baltic (subdivisions 22 and 24) and the Central Baltic (subdivisions 25-29) with the Central Baltic consisting of two minor clusters. Depending on the linkage method subdivision 22 is linked with subdivision 24 or linked with subdivisions 25 and 26

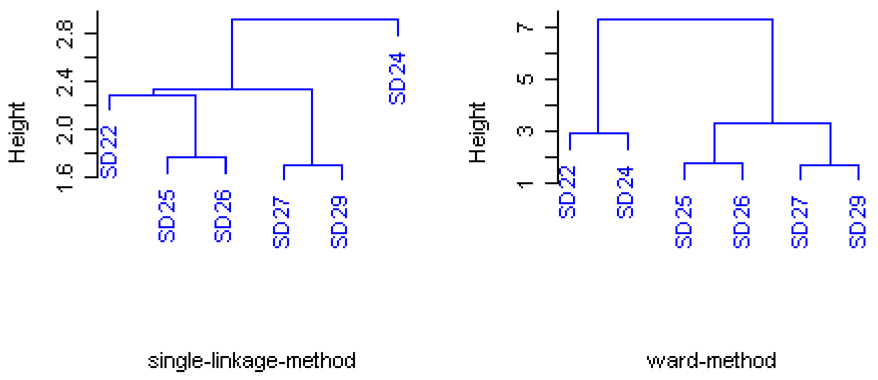


Fig. 9: Cluster analyses of mean eye diameter comprising subdivisions 22- 29 in quarter 2. Two different cluster analyses; quarter 2; all subdivisions; all years; the ordinate of these dendrograms show the height which is the distance between merging clusters at the successive stages.

Details of the cluster analyses are given in **(Annex B,** *Cluster analyses* **(explanation 1)**.

1.1.4 Comparison of two regression slopes

The difference of mean eye diameter at a certain body length class between subdivision 24 and subdivision 25 according to their regression slopes was highly significant (p-value = 2.305553e-07).

1.1.5 Comparison of two different regression types

The linear regression models reach correlation coefficients of 0,99 for subdivision 25 and 0,97 for subdivision 24, which means that data of eye diameter and body length can almost totally be explained by these models. A different measure to qualify the models was used for the logarithmic regressions: The achieved convergence tolerance. This measure represents the range in which the estimated parameters can vary. Thus, the smaller this range is the more accurate these models are. For subdivision 24 it was 5,257e-07, for subdivision 25 it was 1,369e- 07. Both kinds of regression models reach, therefore, a high agreement with the mean data. Comparing the residual sum of square of both models shows that the logarithmic regression has a better fit for SD24 (residual sum of square: 0,08284) than the linear regression (0,3634). For subdivision 25 the linear regression has a slightly lower residual sum of square (0,2514) than the logarithmic regression (0,2623).

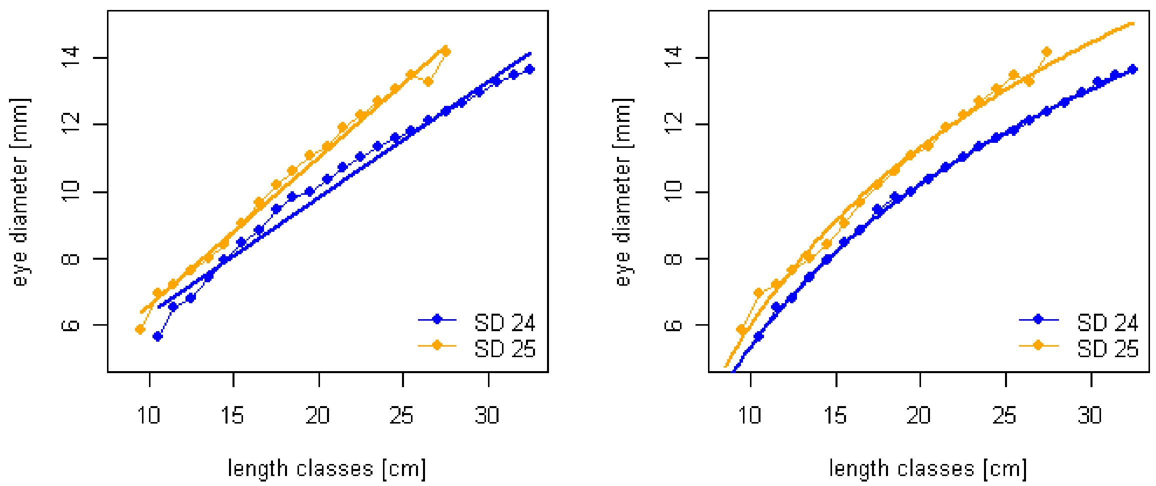


Fig. 10: Comparison of two different regression models fitted to the correlation of eye diameter and length classes; left: linear regression models; right: logarithmic regression models.

1.2 Definition of pure stocks within a mixing area

Using the separation rules in **Annex A,** Fehler! Verweisquelle konnte nicht gefunden werden.**,** the fraction of Central Baltic herring in subdivision 24 varies between years from 0,4 % (2007) to 2,6% (2006) **(Annex A, Fehler! Verweisquelle konnte nicht gefunden werden.)** for separation method 1 (distinguishing between Central Baltic herring, an undefined fraction and Western Baltic herring)

(Fig. 11). Separation method 2, which splits the undefined fraction into Central Baltic herring and Western Baltic herring, increases the proportions of Central and Western Baltic herring **(Fig. 12)**. Thus the resulting fractions of Central Baltic and Western Baltic herring are of greater uncertainty. In the second case the number of Central Baltic herring ranges from a minimum of 7% (2007) to a maximum of 13,8 % (2005) **(Annex A, Fehler! Verweisquelle konnte nicht gefunden werden.)**. However, not only variation in the fraction of Central Baltic herring appears between the years 2005- 2007, but also between age groups within the years:

Concerning to **Fig. 12** the fraction of Central Baltic herring is high for age groups 1 and 3 in year 2005, for age groups 1 and 2 in year 2006 and finally for age groups 4 and 5 in year 2007.

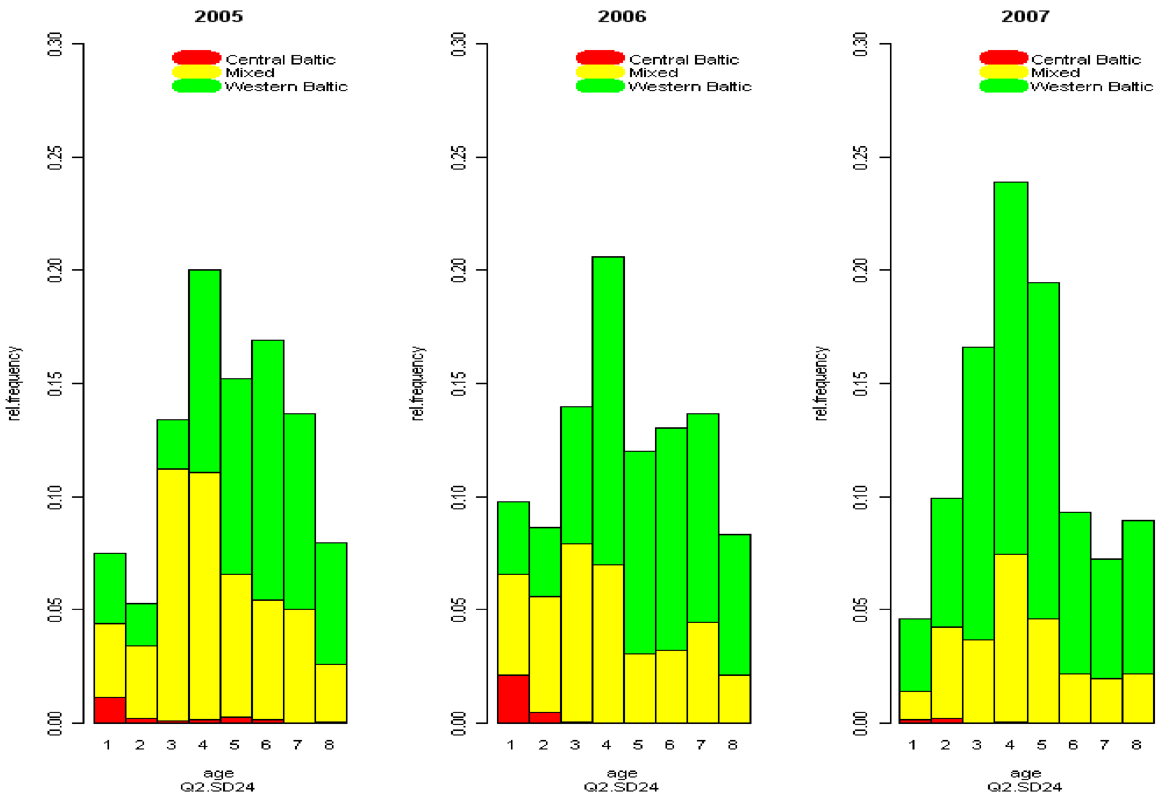


Fig. 11: Proportions of frequency for Central Baltic, Western Baltic herring and the mixed fraction; y- axis scaled by relative frequencies; year 2005- 2007; age groups 1-8 with age group 8 containing older individuals, too.

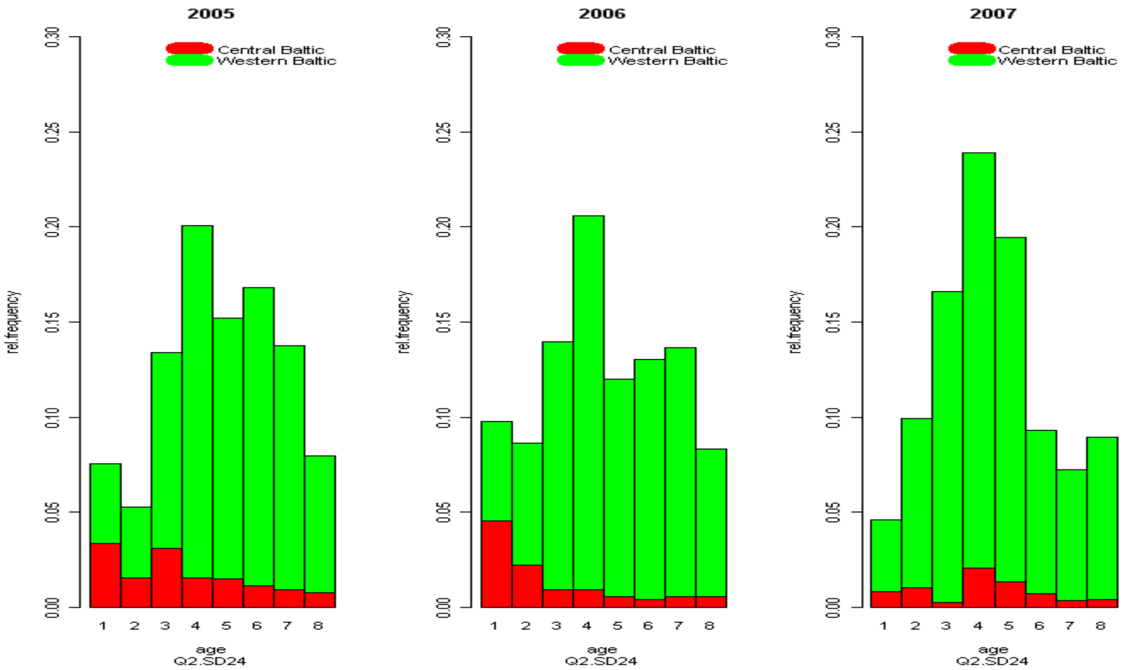


Fig. 12: Proportions of frequency for Central Baltic and Western Baltic herring; y- axis is scaled by relative frequencies; year 2005- 2007; age groups 1-8 with age group 8 containing older individuals, too.

These fractions in **Fig. 12** which are defined as Central Baltic herring and Western Baltic herring are now presented by their eye diameter and length class. The fractions of Fig. **12** don't show any clear differences in their eye diameter if all age groups of a year are compared at the same time **(**

Fig. **13** top left, Fig. **14** top left, Fig. **15** top left**)**. If, however, each age group is observed separately, then a clear distinction of Central Baltic herring and Western Baltic herring is found in most age groups **(**

Fig. **13**, Fig. **14**, Fig. **15**, age groups 1-8**)**.

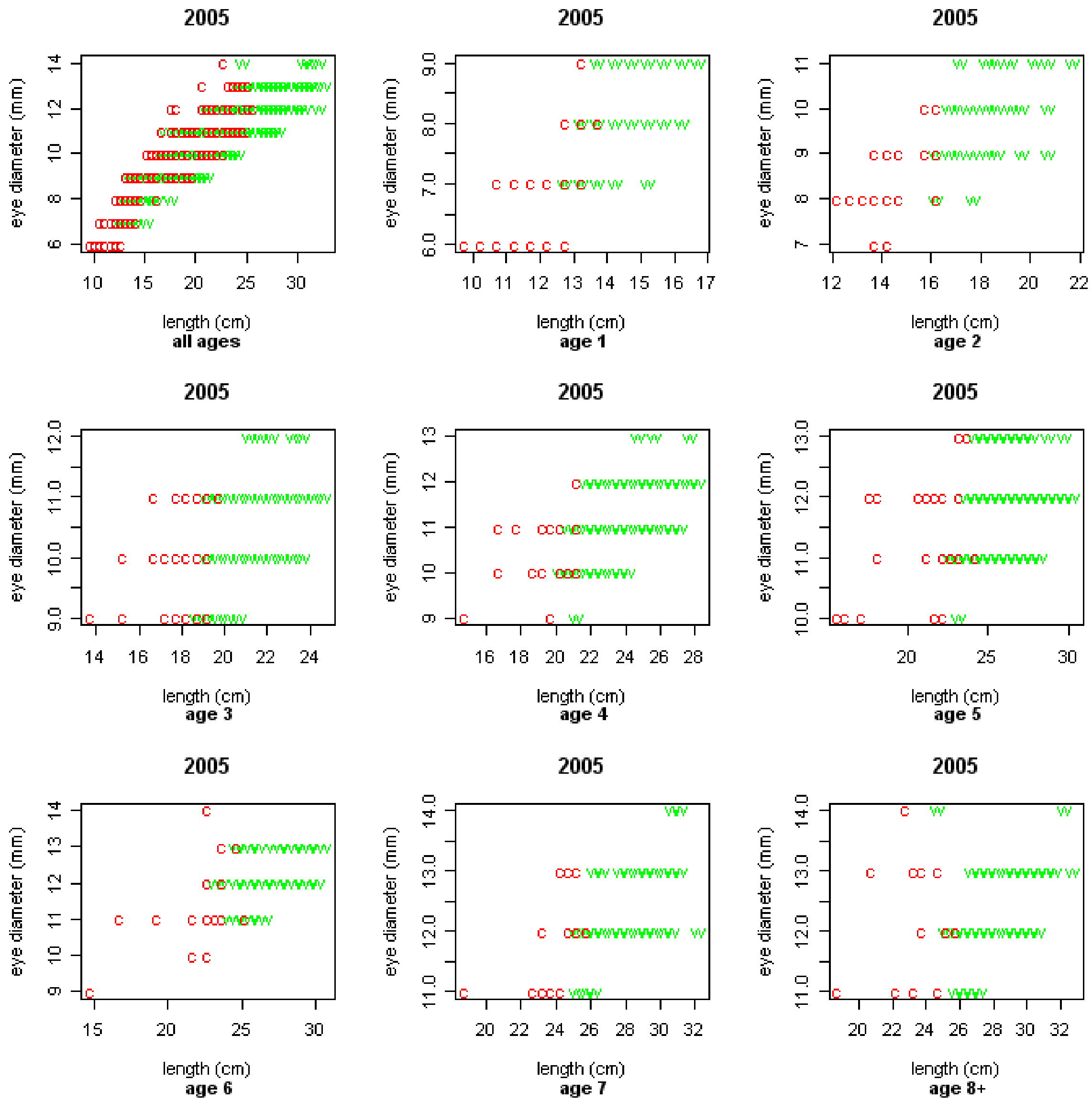


Fig. 13: Body length and eye diameter of separated Central Baltic and Western Baltic herring in 2005; given for all age groups together and each age group separately.

For each age group herring of the Central Baltic covers smaller length classes at the same level of eye diameter. This means that herring of this fraction has a larger eye diameter in relation to the total body length.

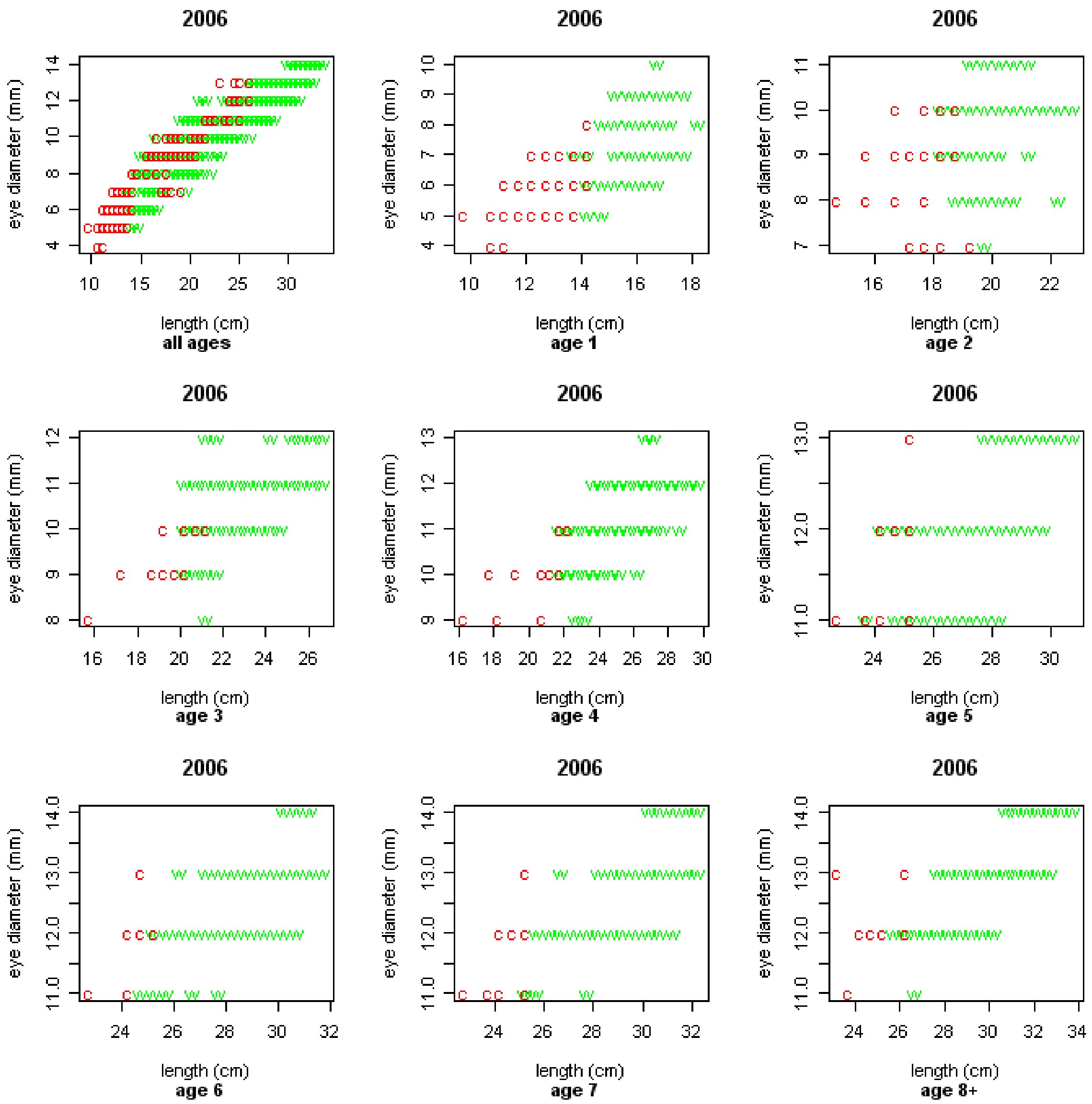


Fig. 14: Body length and eye diameter of separated Central Baltic and Western Baltic herring in 2006; given for all age groups together and each age group separately.

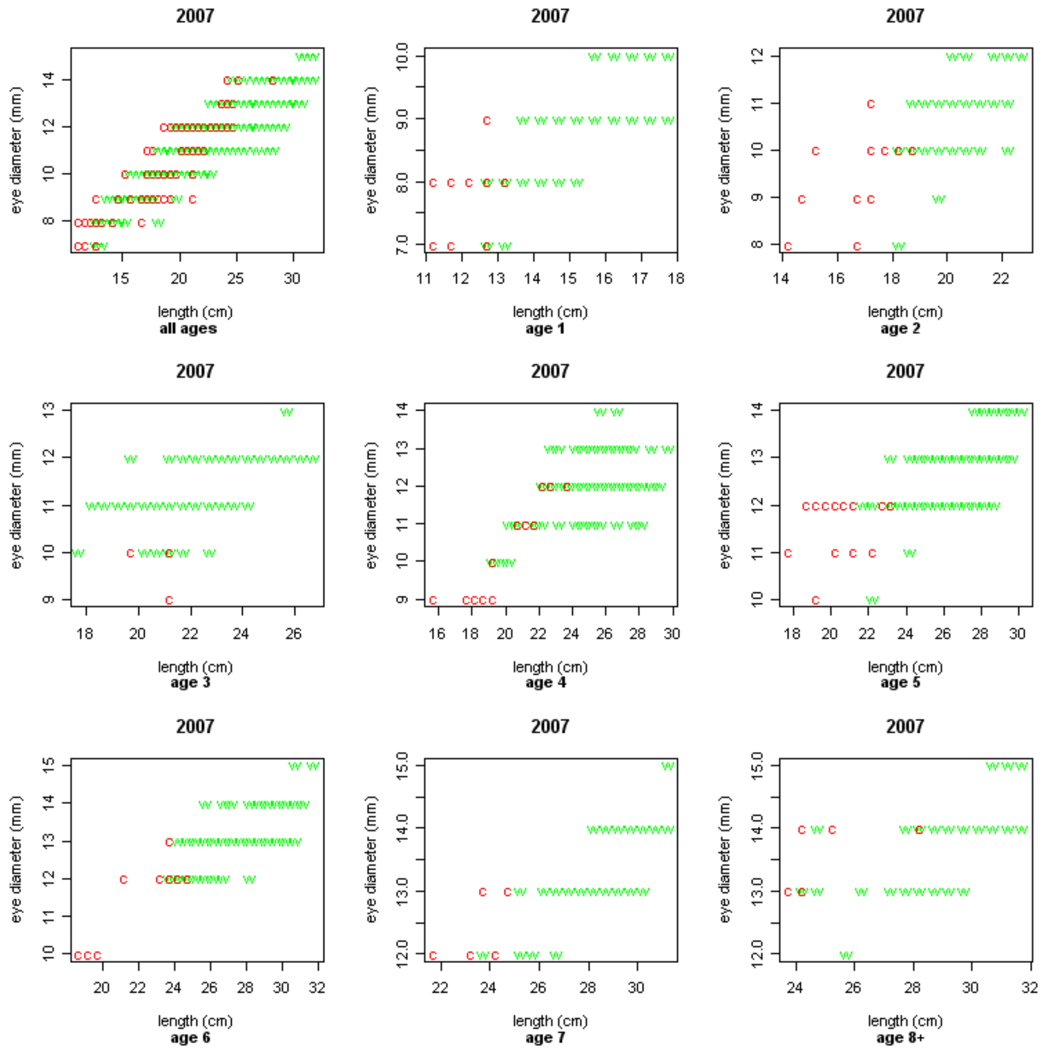


Fig. 15: Body length and eye diameter of separated Central Baltic and Western Baltic herring in 2007; given for all age groups together and each age group separately.

Even more it can be seen that the separation patterns change between years. E.g. age group 3 of the year 2007 hasn't such a good selectivity as age group 3 in 2005. Also it is mainly the younger age groups (age 1 and 2) which allow a clear distinction between the two herring fractions. Therefore, these age groups are given as examples for discriminant analyses following (**Fig. 16**).

2. Defining and testing a separation method

The separation method defined here is given by linear discriminant analyses (**Fig. 16**).

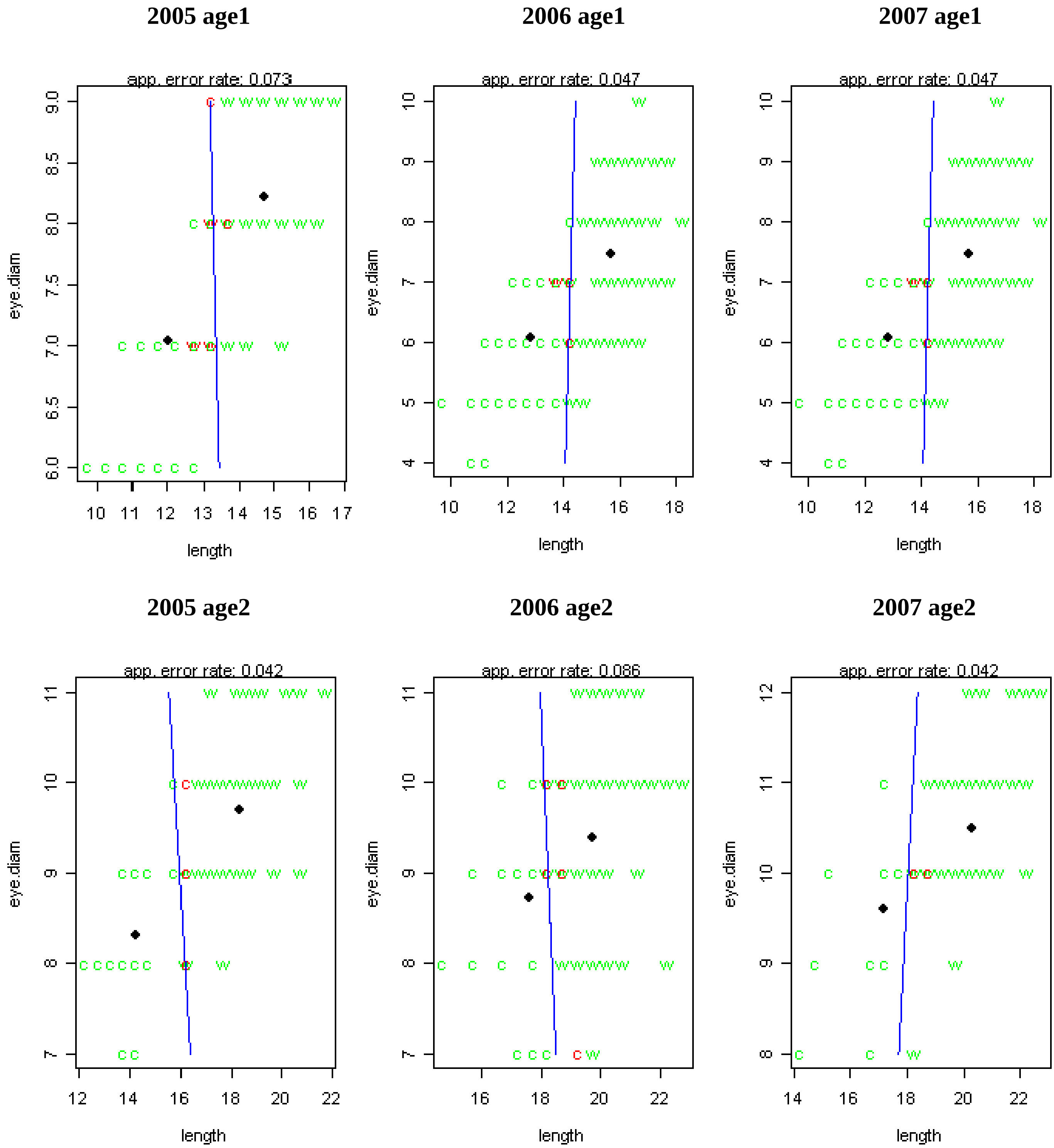


Fig. 16: Length and eye diameter of 1 and 2 year old herring in SD24 quarter 2 in years 2005-2007; c = Central Baltic herring, w = Western Baltic herring; black dots indicate centroids of the 2 herring groups; red letters represent predictions digressive

from original assignment; green letters = correct predictions; blue line represents discriminant rule according to the discriminant function.

The basis of discriminant analyses are discriminant functions distributing an object to a certain fraction. For each age group and year there is an own function containing particular coefficients (u1, u2) to calculate assignments for a single herring (**Tab. 3**).

Tab. 3: Results of discriminant analyses for age groups 1 and 2 respectively from year 2005- 2007; group mean for each parameter; coefficients u_1 and u_2 as used for discriminant functions; the proportion of herring predicted correctly by the discriminant function.

2005 age1	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	12,02049	14,73026		1,06602		0,9672131	0,8947368	0,9270073
eye diameter	7,032787	8,210526		0,09350286				
2005 age2	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	14,26786	18,33088		0,7745969		0,8214286	0,9852941	0,9375
eye diameter	8,321429	9,691176		0,1615474				
2006 age1	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	12,8625	15,69565		0,97108337		0,925	0,9782609	0,9534884
eye diameter	6,075	7,467391		-0,05744059				
2006 age2	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	17,59615	19,74115		1,037268		0,6666667	1	0,9144737
eye diameter	8,717949	9,389381		0,1363345				
2007 age1	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	12,33333	15,23148		0,8153596		0,6666667	0,962963	0,9090909
eye diameter	7,833333	8,833333		-0,1847056				
2007 age2	group means		coefficients of linear discriminants			proportion predicted correctly		
	c	w				c	w	sum
length	17,18333	20,28516		1,019233		0,6	1	0,958042
eye diameter	9,6	10,48438		-0,1702852				

In R the value for u_0 doesn't appear in the output of the programme but is still considered while calculating discriminant values in R. The quality of a function is given by the proportion of individuals predicted correctly in comparison to original assignments. It is in evidence that not all of the prior assignments are predicted by the discriminant function (red letters; app. error rate). However, all the functions cover a proportion of more than 90% of the values predicted correctly (**Tab. 3**).

Those functions can be calculated for any other year and age group in subdivision 24.

At last an example shall be given using a discriminant function.

Example:

We have an individual herring (2 years old) caught in SD24 quarter 2 in 2005 with morphometric measures of:

Body length = 13,75 cm and eye diameter = 7 mm

We use the following coefficients (year 2005, age 2):

$u_0 = -14,782$; $u_1 = 0,7745969$; $u_2 = 0,1615474$

*We need to calculate then: f(x) = u0+u1*length+u2*eye diameter (general form of a linear discriminant function), which is in this case*

$f(x) = -14,782 + 0,7745969 * 13,75 + 0,1615474 * 7 = -3,00061487$

Because the result is below 0 we can assign this particular herring to the group of Central Baltic herring. If it was larger than 0 we had to assign it to the group of Western Baltic herring.

Discussion

The first step of this work was to show differences between subdivisions of the Central and Western Baltic in terms of eye diameter of *Clupea harengus*. Raw data of eye diameter in relation to body length are not usable to distinguish between Central and Western Baltic herring. These data overlap over a broad range of values so that an individual herring can't be assigned to a certain region with sufficient certainty. Similarly the standardization of the raw data results in density distributions which don't allow a clear separation of herring. The reason for that lies in the natural variation of eye diameter for a particular body length, e.g. in quarter 2, SD22-SD29 and all years eye diameter data range from 8 mm to 14 mm for a body length of 20,75 cm. Alternatively, an eye diameter of 10 mm was found with specimen of 12,75 cm up to 26,25 cm. A considerable variation in eye diameter of a fish species having the same body length seems, however, to be a familiar problem. Ranges of eye diameter from 74% to 145% relating to predicted values of a regression model are described for the Africa fresh water sardine (*Limnothrissa miodon*) (Paulsen, 1993). Possible explanations for that discrepancy are given further below.

Another reason could be the way of measuring. Eye diameter was measured in discrete units of 1mm, which means there is no distinction between e.g. 7,5 mm and 8 mm. Therefore, a maximal methodical error of 1 mm (10% for an usual eye diameter of 1 cm) using the sliding calliper needs to be considered . In addition a subjective error of the measuring person is included.

A possible solution could be an automated procedure like image analyses reaching higher accuracy and being standardized.

At least differences between subdivisions based on *mean values* could be shown by cluster analyses. Also the two regression lines for subdivision 24 and subdivision 25 on the border of Central and Western Baltic (as representatives for these regions) differed significantly. The slope of subdivision 25 is significantly higher than of subdivision 24. A possible biological conclusion is that on average growth of eye diameter in respect to body length is faster for herring of subdivision 25 than for herring of subdivision 24. Generally the relative eye diameter of herring in the Baltic Sea seems to increase from the Southwest to the Northeast, while the mean length and growth rate seem to decrease (Parmanne, 1990). This gradient in length and growth rate from West to East respectively from South to North in the Baltic Sea can be explained by different availabilities of food resources. So the nutritional condition of a herring possibly influences its eye diameter. Actually, the eye size can correlate to the mesenteric fat content, which was shown for individuals of *Limnothrissa miodon*, a fresh water sardine in Lake Kariba (Zimbabwe) (Paulsen, 1993). According to this study, individuals with low fat content have significantly larger eyes than individuals with high fat content. Similarly herring of the Central Baltic Sea has larger eyes by same body length than herring of the Western Baltic Sea. This is also implicated by the fact that herring of the Central Baltic Sea has a lower mean weight than herring of the Western Baltic Sea.

Describing the correlation of eye diameter and body length, both a linear and a logarithmic regression model were proofed to describe this correlation well. However, linear models need to be interpreted as an approach for higher length classes as the model doesn't cross the coordinate system at (0/0). However, eye diameter and body length need to start at a value of 0 for biological purposes. Therefore it makes sense to use the logarithmic model describing the correlation between mean eye diameter and grouped body length $\boldsymbol{f(x)} = b_0 + b_1 * \log(x)$ (logarithmic model) (***eq. 4***). Assuming this model describes biological reality, the following interpretation can be done: The initial slope describing the growth relation of eye diameter and body length approaches to the value of 0. Mathematically this is $\lim f'(x) = 0$ (**eq. 5**).

So the eye diameter of an individual herring reaches its maximum prior to the maximum of its body length. At a certain range of body length eye diameter slows down in growing and nearly stops while the body length can still increase. This phenomenon is known as allometric growth. This kind of growth is also described for eye diameter and body length of the armoured catfish (*Corydoras aeneus)* by Huysentruyt et al. (2009).

The second part of this work seems to be contradictory to the first one. While subdivisions of the Baltic Sea could not be separated by the eye diameter of herring, a separation via eye diameter of Central Baltic herring and Western Baltic herring in subdivision 24 (mixing area) could be done. The big difference in the last part of this work is the joining of two additional biological parameters: *mean weight* at *age*. Using eye diameter and body length, a good distinction between Central Baltic herring and Western Baltic herring was achieved, after herring fractions were pre-sorted on basis of self defined separation rules using *mean- weight- at- age* values. This concept seems to be more complex and thus further away from the original intention to design a simple method just using eye diameter and total body length.

If, however, the eye diameter in accordance with mean- weight- at age values is used for separating, then more precise separation rules could be created in future studies considering further biological aspects or simply by calculating standard deviations of the mean weight at a certain age. Standard deviations e.g. could serve as tolerance area within which an individual herring is assigned to one of the discussed stocks (Central Baltic, Western Baltic).

Another aspect was that separation rules had to be redefined for each year due to interannual changes in mean weight-at- age values. The Finnish herring fishery even records fluctuations of weight at age for adult herring of 60% over the last decades (Rahikainen & Stephenson, 2004). Therefore discriminant functions for eye diameter and body length changed between years. Also different discriminant functions for each age group were needed. No general discriminating function for all years and age groups was found. As already mentioned above each year and age group should be considered separately.

Altogether the following statements can be made:

- Eye diameter by itself as an attribute for separating herring stocks is not sufficient.
- To separate herring stocks, a combination of several parameters like eye diameter, body length and age should be chosen.
- The parameters chosen to separate herring stocks should be redefined for each year due to possible iterannual changes.

Additionally to these statements (which might be a help for future studies) this work has given an estimation of the proportion of the Central Baltic herring in the mixed subdivision 24. The discriminant functions found - although considered critically- set limits for eye diameter and body length both for Central Baltic herring and Western Baltic herring and thus can serve as an orientation in future to assign an individual herring to a particular stock.

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and to other people of the Institute of Baltic Sea fisheries who were involved in my work.

Annex A- Tables

Tab. 4: Overview of samples available for the present study: number of catches are sorted by year, subdivision, catch method and the origin of samples (commercial samples/ hydroacoustic surveys)

		commercial samples			hydroacoustic surveys		
year	SD	quarter 1-4 * Gillnet	quarter 1-4* Trapnet	quarter 1-4* Trawl	May-June Trawl	Sep.-Oct. Trawl	Total
2005	21					422	422
2005	22					383	383
2005	23					501	501
2005	24	811	578	450	292	716	2.847
2005	25				535		535
2005	26				193		193
2005	27						0
2005	29						0
2005	Total	811	578	450	1.020	2.022	4.881
2006	21					471	471
2006	22	60				337	397
2006	23					598	598
2006	24	849	100	650	271	685	2.555
2006	25				310		310
2006	26				138		138
2006	27				210		210
2006	29						0
2006	Total	909	100	650	929	2.091	4.679
2007	21					340	340
2007	22	58		302		180	540
2007	23					638	638
2007	24	1.896	576	740	240	624	4.076
2007	25				566		566
2007	26						0
2007	27				248		248
2007	29						0
2007	Total	1.954	576	1.042	1.054	1.782	6.408
2008	21					344	344
2008	22	176				304	480
2008	23					404	404
2008	24	1.674	355	2.139	394	632	5.194
2008	25				520		520
2008	26				240		240
2008	27				252		252
2008	29				134		134
2008	Total	1.850	355	2.139	1.540	1.684	7.568
2005-2008	Total	5.524	1.609	4.281	4.543	7.579	23.536

* no samples from commercial fisheries in quarter 3; no surveys in quarter 3

Tab. 5: Mean eye diameter of herring speciemen in 1 cm length classes (given as cm below) from 8cm to 32 cm for SD22-SD29; year 2005-2008.

	8	9	10	11	12	13	14	15
SD22	NA	NA	6,89	7,00	8,00	7,94	8,50	8,95
SD24	NA	NA	5,67	6,53	6,83	7,41	7,93	8,50
SD25	NA	5,88	6,95	7,20	7,66	8,02	8,44	9,06
SD26	NA	NA	6,82	7,33	7,70	8,22	8,96	9,18
SD27	5,88	6,20	6,71	7,35	8,15	8,70	9,09	9,80
SD29	NA	5,82	6,30	7,00	8,20	8,30	9,00	10,20

Tabelle konvertieren (umdrehen), eine Tabelle draus machen

	16	17	18	19	20	21	22	23
SD22	9,44	10,00	10,15	10,75	10,95	11,40	11,75	11,89
SD24	8,86	9,46	9,82	10,00	10,35	10,70	11,03	11,37
SD25	9,65	10,22	10,63	11,06	11,37	11,91	12,28	12,69
SD26	9,85	10,12	11,05	11,24	11,40	11,74	12,31	12,50
SD27	10,17	10,88	11,32	11,60	11,88	12,26	12,71	12,83
SD29	10,80	10,70	11,10	11,70	11,50	NA	NA	NA

	24	25	26	27	28	29	30	31	32
SD22	11,90	12,14	12,40	12,61	12,90	13,29	13,63	13,72	NA
SD24	11,61	11,84	12,12	12,39	12,67	12,96	13,28	13,47	13,65
SD25	13,07	13,50	13,30	14,14	NA	NA	NA	NA	NA
SD26	12,19	12,90	12,75	NA	NA	NA	NA	NA	NA
SD27	13,08	NA	NA	NA	NA	NA	NA	NA	NA
SD29	NA	NA	NA	NA	NA	NA	NA	NA	NA

Tab. 6 a: Mean-weight-at-age; 2005; data by ICES expert working groups

	mean weight (g)	mean weight (g)
age	SD22-24	SD25-29, 32
1	18	10,6
2	38	14,5
3	68	19,5
4	83	29,5
5	112	34,3
6	132	42,8
7	156	44,6
8+	160	54,7

b: Mean-weight-at-age; 2006; data by ICES expert working groups

	mean weight (g)	mean weight (g)
age	SD22-24	SD25-29, 32
1	22	13.4
2	48	29.0
3	78	24.5
4	106	25.6
5	140	37.5
6	160	44.7
7	177	50.7
8+	179	58,1

c: Mean-weight-at-age; 2007; data by ICES expert working groups

	mean weight (g)	mean weight (g)
age	SD22-24	SD25-29, 32
1	16,04	9
2	48,98	26,4
3	56,51	28,4
4	82,05	32,6
5	109,61	31,5
6	122,4	41,3
7	136,21	49,4
8+	159,75	58,33

Tab. 7: Separation rules for 2005-2007; weights in (g); separation values were rounded; 3 fractions: Western Baltic herring, Central Baltic herring and mixed herring; mixed herring splitted into Western Baltic and Central Baltic herring.

2005

	western		central	
	weight	weight	weight	weight
age1	≥18	14<x<18	11≤x≤14	<11
age2	≥38	26<x<38	15≤x≤26	<15
age3	≥68	44≤x<68	20≤x<44	<20
age4	≥83	56<x<83	30≤x≤56	<30
age5	≥112	73<x<112	34<x≤73	≤34
age6	≥132	87<x<132	43≤x≤87	<43
age7	≥156	100<x<156	45≤x≤100	<45
age8+	≥160	107<x<160	55≤x≤107	<55
		mixed		

2006

	western		central	
	weight	weight	weight	weight
age1	≥22	18≤x<22	13<x<18	≤13
age2	≥48	39≤x<48	29<x<39	≤29
age3	≥78	51<x<78	25≤x≤51	<25
age4	≥106	66≤x<106	26≤x<66	<26
age5	≥140	89≤x<140	38≤x<89	<38
age6	≥160	102≤x<160	45≤x<102	<45
age7	≥177	114≤x<177	51≤x<114	<51
age8+	≥179	119≤x<179	58<x<119	<58
		mixed		

2007

	western		central	
	weight	weight	weight	weight
age1	≥16	13≤x<16	9<x>13	≤9
age2	≥49	38≤x>49	26<x>38	≤26
age3	≥57	43≤x>57	28<x>43	≤28
age4	≥82	57<x>82	33<x>≥57	≤33
age5	≥110	71≤x<110	32≤x<71	<32
age6	>122	82≤x≤122	41<x<82	≤41
age7	>136	93≤x≤136	49<x<93	≤49
age8+	≥160	110<x<160	61≤x≤110	<61
		mixed		

Tab. 8: Linear and logarithmic regression models for subdivisions 24 and 25; Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

		Linear model							
			Residuals						
	Min	1Q	Median	3Q	Max	Residual standard error		Degrees of freedom	
SD24	-0,88478	-0,19569	0,01960	0,31271	0,49241	0,3634		17	
SD25	-0,62425	-0,09432	0,03432	0,1514	0,29428	0,2514		17	
		Coefficients							
	Parameters	Estimate	Std. Error	t value	Pr(>|t|)	R^2	R^2 adjusted	F-statistic	p-value
SD24	Intercept	2,91547	0,25706	11,34	2.05e10***	0,9777	0,9766	920,4	< 2.2e-16
	x	0,3466	0,01142	30,34	<2e16***				
SD25	Intercept	2,15081	0,20319	10,59	6,69e09***	0.9905	0.99	1780	< 2.2e-16
	x	0,44428	0,01053	42,19	<2e-16***				

			Logarithmic model				
	Parameters	Estimate	Std. Error	t value	Pr(>|t|)	Residual standard error	Achieved convergence tolerance
SD24	a	-10,7179	0,15769	-67,97	<2e16***	0.08284	5,257e- 07
	b	6,99177	0,05197	134,53	<2e16***		
SD25	a	-11,6647	0,5485	-21,27	1,10e13***	0,2623	1,369e- 07
	b	7,6776	0,19	40,41	<2e-16***		

Tab. 9: Relative and absolute frequencies of Central Baltic herring (c), Western Baltic herring (w) and the mixed fraction (m) per age group; years 2005- 2007; line 1-3 = absolute proportions; lines 4- 6 = relative proportions; age group 8 also compromises age groups above 8 years.

2005

	age							
	1	2	3	4	5	6	7	8
c	21	4	2	3	5	3	0	1
m	59	58	202	199	115	96	91	46
w	57	34	40	163	157	209	158	98
c	0.011532	0.002196	0.001098	0.001647	0.002745	0.001647	0.000000	0.000549
m	0.0399	0.0350	0.110928	0.109280	0.063152	0.052718	0.049972	0.025260
w	0.031301	0.0186	0.02195	0.08952	0.08623	0.11471	0.08675	0.053818

2006

	age							
	1	2	3	4	5	6	7	8
c	37	8	1	0	0	0	0	0
m	78	90	138	123	54	56	78	37
w	57	54	106	239	157	173	162	109
c	0.021058	0.004553	0.000569	0.000000	0.000000	0.000000	0.000000	0.000000
m	0.044393	0.051223	0.078542	0.070005	0.030734	0.031872	0.044393	0.021058
w	0.032441	0.03073	0.06033	0.13602	0.0893	0.0984	0.0922	0.0620

2007

	age							
	1	2	3	4	5	6	7	8
c	2	3	0	1	0	0	0	0
m	18	58	53	106	66	31	28	31
w	46	82	186	237	214	103	76	98
c	0.001389	0.002084	0.000000	0.000694	0.000000	0.000000	0.000000	0.000000
m	0.012508	0.040305	0.036831	0.073662	0.045865	0.021542	0.019457	0.021542
w	0.0319	0.0569	0.1292	0.1646	0.14871	0.07157	0.05281	0.06810

Tab. 10: Absolute and relative fractions of Central Baltic herring (c) and Western Baltic herring (w) per age group; years 2005- 2007; line 1-2 = absolute proportions; lines 3- 4 = relative proportions; age group 8 also compromises age groups above 8 years.

2005

	age							
	1	2	3	4	5	6	7	8
c	61	28	56	28	27	21	17	14
w	76	68	188	337	250	285	233	131
c	0.033516	0.015384	0.030769	0.015384	0.014835	0.011538	0.009340	0.007692
w	0.0417	0.0373	0.1032	0.1851	0.1373	0.15659	0.12802	0.07197

2006

	age							
	1	2	3	4	5	6	7	8
c	80	39	16	16	10	7	10	10
w	92	113	229	346	201	222	230	136
c	0.045532	0.022196	0.009106	0.009106	0.005691	0.003984	0.005691	0.005691
w	0.0523	0.0643	0.1303	0.1969	0.1143	0.12635	0.13090	0.077404

2007

	age							
	1	2	3	4	5	6	7	8
c	12	15	4	30	19	10	5	6
w	54	128	235	314	261	124	99	123
c	0.008339	0.010423	0.002779	0.020847	0.013203	0.006949	0.003474	0.004169
w	0.0375	0.0889	0.1633	0.2182	0.18137	0.08617	0.06879	0.08547

Appendix B – Mathematical and statistical details

Cluster analyses **(explanation 1)**

The single linkage method creates cluster by taking those elements or groups together that are closest according to the dissimilarity matrix. The ward method tries to minimize the variance of values with respect to the mean of group while clustering.

Dissimilarities:

	SD22	SD24	SD25	SD26	SD27
SD24	2.913994				
SD25	3.400796	5.509449			
SD26	2.290421	4.899175	1.766810		
SD27	4.087868	6.907484	2.473611	2.342008	
SD29	3.924660	6.479653	3.112341	2.671695	1.706422

Height:[1] 2.913994 7.274764 1.766810 3.346258 1.706422 --- Ward – method

Height:[1] 2.290421 1.766810 2.342008 1.706422 2.913994 --- Single- linkage- method

Agglomerative coefficient: 0.7073341 --- Ward – method

Agglomerative coefficient: 0.3050273 --- Single- linkage- method

The agglomerative coefficient measures the clustering structure of the dataset. For each observation i, denote by m(i) its dissimilarity to the first cluster it is merged with, divided by the dissimilarity of the merger in the final step of the algorithm. The agglomerative coefficient is the average of all 1- m(i). Thus, clusters being merged at low heights reach high agglomerative coefficients, as soon as clusters are merged at high values we obtain lower agglomerative coefficients.

Regression models **(explanation 2)**

Both models contain estimated parameters and standard errors of the estimators. Null-hypothesis for parameters was defined as H_0: $\beta_i = 0$, for i = 0,1.Null- Hypothesis for the total model was defined as H_0:

$\beta_0 = 0$ **and** $\beta_1 = 0$.As the test results indicate H_0 had to be rejected in every model. Therefore these estimated model parameters can be accepted. The quality of these models given by the strength of correlation between body length and eye diameter can be assessed by R^2.The coefficient of determination (R^2) reaches values up to 1,0 for perfect correlation. Thus the closer R^2 gets to 1 the stronger the correlation is. The slopes of the 2 linear models differed significantly which could be shown by a two-sided t-test: H_0: $\beta_{1a} = \beta_{1b}$. Again H_0 had to be rejected, which means that the courses of the 2 regression lines were different in SD24 and SD25. Logarithmic model outputs contain convergence tolerances. These stand for tolerance regions within which model parameters lay. The smaller this region the more accurate are the estimated parameters. A goodness-of-fit measure is given by the residual standard error calculated on basis of the distances between theoretical and empirical values. The F- test refers to the quality of the whole model, t-Test refers to the quality of a single parameter within the model.

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