Changes in condition of herring (*Clupea harengus*) in Swedish coastal waters

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Abstract

The condition of the herring (*Clupea harengus*) in the Baltic Sea has decreased during the past 30-40 years. This decrease could be explained by different factors; (1) change in diet due to changes in zooplankton community, (2) changes in water temperature and salinity, (3) increasing nutrient inputs and (4) competition for food with other species such as sprat (*Sprattus sprattus*). In this study the change in condition was analysed using the Fulton’s condition index, and by looking at age and sex of the fish as well as the season and location the fish was caught, the differences between these factors were presented. Data from the national Swedish contaminant monitoring programme were used from four locations in the Baltic Sea and two locations at the Swedish West coast. The data was analysed using multiple regressions in R Commander. The result show that the condition, and the temporal trends in condition value, varies at different locations, with higher condition values and increasing temporal trends at the Swedish West coast, compared to the Baltic Sea with lower condition values and where three of four locations show decreasing temporal trends. The condition varied between spring and autumn caught herring as well, while age and sex showed less significant differences.

Keywords: Herring (*Clupea harengus*), Fulton’s condition index, environmental changes, Baltic Sea
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Introduction

The condition of the herring has decreased in the Baltic Sea during the past 30 to 40 years (Bignert et al 2009, Cardinale & Arrhenius 2000). Condition is an estimate of health of an individual or population (Stevenson & Woods 2006) and in this study the individual condition of the fish has been analysed using Fulton’s condition index. A high condition value is a sign of a healthy fish, and a low condition value indicates that the fish is less fat and maybe less healthy (Jones et al 1999). For example earlier studies have shown that condition and fat content of female herring was positively linked with hatching success and the survival of larvae (Laine & Rajasila 1999), i.e. with lower condition, a higher percentage of the herring eggs and larvae did not survive. Fish condition has also been shown to be related to fish mortality and the reproductive output, thus may have an important role for fish populations (Casini et al 2006). If the decrease in condition is very large, there may be severe consequences for both the individual herring, the herring population, and also for the rest of the Baltic Sea ecosystem through cascade effects.

The Baltic Sea is a sea with a relatively short, but fast changing history (Bernes 2005, Ojaveer & Kalejs 2005). During the last 15 000 years it has changed from a salt water sea connected to the Atlantic to a freshwater lake which feed from melting glaciers and back to a sea again (Zillén et al 2008), thus making it a brackish sea with large geographical variations in the salinity (Bernes 2005). The current water flux in the Baltic Sea is quite slow, with a turn over rate of approximately 30 years (Bernes 2005), making it possible for pollutants to stay in the Baltic Sea for a long time. These factors make the Baltic Sea a sensitive sea with special ecological conditions.

Herring is one of the most important commercial pelagic fish species in the Baltic Sea, and together with sprat (Sprattus sprattus) and stickleback (Gasterosteus aculeatus) the herring is the main planktivorous fish in the Baltic Sea (Möllman et al 2004). Thus, herring may have a large impact on the plankton community. Sprat and herring consume as much as 60 to 80 percentage of the annual zooplankton production according to Arrhenius and Hansson (1993). Herring is also an important prey for animals higher up in the food web, such as cod (Gadus morhua) (Möllman et al 2004), guillemot (Uria aalge) (Bignert et al 2009) and grey seal (Halichoerus grypus) (Sjöberg & Ball 2000), and thus play an important role in the Baltic Sea.
ecosystem. In the Swedish Environmental Monitoring Programme herring is the most frequently used indicator species for observations of contaminants (Bignert et al 2009).

The physiological characteristics of the herring varies along the Swedish coast and fish living in the Baltic Proper and the Gulf of Bothnia are smaller and less fat than fish living in the waters on the Swedish West coast (Ask & Westerberg 2009). These variations are known to be due to the physiological stress that the lower salinity have on the fish in the Baltic Proper and the Gulf of Bothnia (Fässler et al 2008). Despite the harsh environmental conditions in the Baltic Proper and the Gulf of Bothnia, herring can successfully reproduce in the whole of the Baltic Sea (Jørgensen et al 2008). Most of the herring populations have their spawning season in the spring, but some spawn during autumn as well (Ask & Westerberg 2009). In a study by Arrhenius & Hansson (1993) spawning date ranged from the 15th of April in the southern Baltic Proper, to the 6th of June in the northern Bothnian Sea. Spawning is determined by the water temperature, and thus happens earlier in warmer springs, sometime as early as in March (Arrhenius & Hansson 1996). At the Swedish West coast the herring length is 23-30 centimetres, and in the Baltic Proper between 15 and 24 centimetres, and the weight range from 40 and 200 grams (Ask & Westerberg 2009).

The fact that the condition of the herring has decreased in some parts of the Baltic Sea is shown in the Comments Concerning the National Swedish Contaminant Monitoring Programme in Marine Biota (Bignert et al 2009). The aim of this thesis is to look at the data used in the national Swedish contaminant monitoring programme and see if some biological factors or spatial variations can help explain the decrease in condition. The variation in the data is great, and by using different biological variables that may affect the condition value the variation may be lowered. Age, sex and season have been used as explanatory factors to analyse differences in condition over time in herring from the Baltic Sea and the Swedish West coast. The thesis is meant to be a starting point in a project concerning change in herring condition in the Baltic Sea at the Department of Contaminant Research at the Swedish Museum of Natural History.
Theories

**Condition factor**

Throughout this thesis the terms condition and condition factor is frequently used. The condition factor is a relationship between the weight and the length of the fish. For this thesis the Fulton’s condition index was used (Jones et al 1999). This index states the condition as follows:

$$C = 100 \cdot (W/L^3)$$

where C is condition, W is weight in grams and L is length in centimetres.

This index assumes isometric growth of the fish (Jones et al 1999), i.e. the growth rate of the fish is the same for both length, width and height. Fulton’s conditions index is one of many ways of calculating the condition of fish (Stevenson & Woods 2006), however, it is the most widely used index and is the same condition index used by Bignert et al (2009).

The condition of the herring is most likely influenced by a number of different biological and environmental factors, such as the age and sex of the fish, the salinity and the water temperature (Jørgensen et al 2008). The salinity at Väderöarna on the Swedish West coast is around 30 ppm, while the level in the Bothnian Bay is lower than 5 ppm (Bernes 2005). Since the herring is a marine species salinity stress affects the growth and fat content of the fish (Fässler et al 2008) and thus affects the condition value. Water temperature also affects herring (Arrhenius & Hansson 1993), for example one study show that the herring growth rate decreases with increasing water temperature (Rönkkönen et al 2004), and Möllman et al (2005) shows that the water temperature in the Baltic Proper has increased since the 1980s. Since the condition is based on the length and the weight different biological factors that affect the length and weight also affect the condition value of the herring. The age of the fish is one variable that affects the weight and length. The weight and length are also probably different between the different sexes, and thus its best to look at males and females separate.
Different theories explaining changes in condition value

There are different theories trying to explain changes in herring condition. The "junk-food" hypothesis and the competition with an increasing sprat population will be looked at in this study.

The junk-food hypothesis suggests that not only the abundance and availability of food is important but the quality of the food as well (Österblom et al 2008). In their article *Junk-food in marine ecosystems* (2008) Österblom et al (2008) describe a positive correlation between the body mass of the common guillemot (*Uria aalge*) and the condition of their pray sprat (*Sprattus sprattus*) in the Baltic Sea (Österblom et al 2006), indicating that the quality of the food, i.e. sprat, is important. For herring mainly feeding on zooplankton, a change in the zooplankton community may affect what prey are available for the herring and thus the nutritional composition, i.e. it may not necessarily lead to a lower abundance of food but food of poorer quality. In the Baltic Sea there is a mixture of marine, brackish and freshwater zooplankton species and the composition of these species are affected by changes in salinity (Peltonen et al 2004). The zooplankton communities in the Baltic Sea have changed during the past decades, and studies show that this has affected the herring condition (Möllman et al 2005). The change is partly due to an increasing water temperature and decreasing salinity levels, changes that are connected to the global warming and the climate change (Möllman et al 2004), but could also be explained by changes in chemical composition, mainly an increase in N and P since the 1960s (Ahlgren et al 2005). The whole food web in the Baltic Sea has been affected by this chemical change since the content of fatty acids in the plankton community have a great importance in aquatic food webs and the whole ecosystem as well (Ahlgren et al 2005).

Casini et al (2006) argues that the decrease in herring population in the Baltic Sea during the mid 1990s is due to the increasing competition of food which comes from an increasing sprat population. These two fish species have quite similar feeding preferences (Casini et al 2006), and since the sprat is more abundant, the competition for zooplankton is greater for the herring. This could mean that the herring experience a scarcity of food, or that they are forced to eat other, less preferred zooplankton, and thus fall into the "junk-food" hypothesis.
In more recent articles Casini et al (2009) talks about regime shifts and the sprat taking over as the dominant fish species instead of the cod. This is due to the fact that the cod abundance decreased during the late 1970s and 1980s which made it possible for the sprat stock to increase (Casini et al 2009). The reason that the sprat abundance increased, but not herring abundance, is because there is much higher predation, by cod, on sprat than on herring (Casini et al 2008). This shift has had a cascade effect down the food web in the pelagic Baltic Sea, from the decreasing cod down to primary producers (Casini et al 2008). The regime shift makes it difficult for the cod to return as a dominant fish species since many competitive interactions between the sprat and the cod are shown. For example, the increasing sprat population competes for food with cod larvae, thus making it hard for the cod stock to increase again (Möllman et al 2008). Even though this is a sprat and cod relationship, the herring may be affected by this regime shifts as well. An increasing sprat population will lead to an increasing competition for food between sprat and herring, which could negatively affect the condition of both species. The cod predation on the herring, and sprat, is mostly on small, slow-growing, individuals. When cod predation on herring decreases due to a smaller cod stock, more of the slow-growing individuals will survive, thus affecting the mean weight-at-age, WAA (Cardinale & Arrhenius 2000). Cardinale and Arrhenius (2000) also show that the WAA has decreased in the Baltic Proper between 1980 and 1996, as well as the condition and the fat content.

Rahikainen et al (2003) also suggests that the herring stock is influenced by the competition with sprat and the abundance of cod, as well as changes in the zooplankton community. All of these factors are affected by the salinity level which is controlled by the saltwater inflows through the Danish Sounds (Rahikainen et al 2003).
Methods

All data used in this study comes from the national Swedish contaminant monitoring programme which is financed by the Swedish Environmental Protection Agency (Bignert et al 2009). At first the data was divided into six data sets representing six different sampling sites or locations. These locations are all part of the National Swedish contaminant programme in marine biota (Bignert et al 2009). Data was only on female herring, except for Ängskärsklubb and Utlängan where male samples were used as well. Male and female herring were looked at separately which lead to eight different data sets from six locations (Table 1). No actual sampling where made during the work of this study, all the data used was already registered at the start of the thesis.

Data management and sampling

The analyses in this study have been based on previous samples of herring in the Baltic Sea and at the Swedish West coast, from the beginning of the 1970s to 2007. Herrings used in this study were caught at four different locations in the Baltic Sea, Harufjärden, Ängskärsklubb, Landsort and Utlängan and at Fladen in Kattegatt and at Väderöarna in Skagerack at the Swedish West coast (Figure, Table 1). All six sampling sites are part of the national Swedish contaminant programme in marine biota (Bignert et al 2009). Herrings were caught in the autumn at all the sites and in the spring at Ängskärsklubb and Utlängan. There are samples from 1972 to 2007 at Ängskärsklubb and Utlängan, from 1978 to 2007 at Landsort, from 1980 to 2007 at Harufjärden and Fladen and from 1995 to 2007 at Väderöarna (Table 1).

Table 1 The six different sampling locations, where data set is the name for the data sets used later in the study and n is the number of individual herring in each data set.

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>DATA SET</th>
<th>SEASON</th>
<th>SEX</th>
<th>YEARS(missing year/s)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harufjärden</td>
<td>HAFJ</td>
<td>Autumn</td>
<td>Female</td>
<td>1980-2007</td>
<td>693</td>
</tr>
<tr>
<td>Ängskärsklubb</td>
<td>ANGK-F</td>
<td>Autumn/Spring</td>
<td>Female</td>
<td>1972-2007 (1976)</td>
<td>861</td>
</tr>
<tr>
<td></td>
<td>ANGK-M</td>
<td>Autumn/Spring</td>
<td>Male</td>
<td>(1976)</td>
<td>394</td>
</tr>
<tr>
<td>Landsort</td>
<td>LAND</td>
<td>Autumn</td>
<td>Female</td>
<td>1978-2007 (1979)</td>
<td>505</td>
</tr>
<tr>
<td>Fladen</td>
<td>FLAD</td>
<td>Autumn</td>
<td>Female</td>
<td>1980-2007</td>
<td>616</td>
</tr>
</tbody>
</table>
The sample collection and preparation were made by staff at the Department of Contaminant Research at the Swedish Museum of Natural History at 17 different locations (Bignert et al 2009), but in this study only the six most frequently used locations where looked at (Figure 1, Table 1). For every fish a number of biological variables where measured. These were; total body weight, total length, body length, sex, age, reproductive stage, state of nutrition (fat content) and liver weight (Bignert et al 2009). Most of the fish analysed were female, and male herring was only analysed at two locations; Ängskärsklubb and Utlängan. Almost all of these variables were used in this thesis (Table 2).
**Data analyses**

The data sets analysed were eight in total, one for every location with only female herring and two with only male herring, one for Ängskärsklubb and one for Utlängan. The variables used in this study included biological data, i.e. length and weight etc, and other important information like location, accessions number (individual number) and which year and season (autumn, spring) the fish was caught.

A condition factor was calculated for every fish, using Fulton’s condition index\(^1\). Then the weight-at-age was calculated by dividing the weight by the age. All fishes aged 6 or older were not used, leaving only fishes aged 1 to 5 years. This was because the method used to estimate the age of the fish was not reliable for fishes over 5 years of age (Eklund et al 2000). The age is estimated by measuring growth of the scales of the fish (Bignert et al 2009) and this method is not reliable for older fish because the growth of the fish changes during the life cycle (Eklund et al 2000). In the *Comments Concerning the National Swedish Contaminant Monitoring Programme in Marine Biota* age 2 to 5 years were used (Bignert et al 2009). The fish were then grouped in three age classes; age 1-2 years, age 3-4 years and age 5 years. By looking at the catch data of the fish, every sample was categorised as either autumn- or spring catch, depending on which week during the year it was caught. Week 13-27 were regarded at as spring and week 30 to 51 as autumn. The variables used in the statistical analysis are shown in Table 2.

<table>
<thead>
<tr>
<th>NAME</th>
<th>VARIABLE TYPE</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>COND</td>
<td>Continuous</td>
<td>A condition value using the Fulton’s condition index</td>
</tr>
<tr>
<td>COND2</td>
<td>Continuous</td>
<td>A condition value de-trended by average year value</td>
</tr>
<tr>
<td>SEX</td>
<td>Categorical</td>
<td>The sex of the fish, i.e. male/female</td>
</tr>
<tr>
<td>YEAR</td>
<td>Continuous</td>
<td>Which year the fish was caught, between 1972 and 2007</td>
</tr>
<tr>
<td>SEAS</td>
<td>Continuous</td>
<td>Which week the fish was caught, from 13 to 51</td>
</tr>
<tr>
<td>SEAS2</td>
<td>Categorical</td>
<td>Which season, autumn/spring, the fish was caught</td>
</tr>
<tr>
<td>AGE</td>
<td>Continuous</td>
<td>The age of the fish, 1 to 5 years</td>
</tr>
<tr>
<td>AGE2</td>
<td>Categorical</td>
<td>The age of the fish, in three groups; 1-2 y, 3-4 y &amp; 5y</td>
</tr>
<tr>
<td>WAA</td>
<td>Continuous</td>
<td>Weight-at-age of the fish, i.e. weight divided by age</td>
</tr>
<tr>
<td>FPRC</td>
<td>Continuous</td>
<td>Content of fat, in percent</td>
</tr>
</tbody>
</table>

In all of the statistical analysis and modelling the condition factor was used as the response variable. The other variables were used as explanatory variables. The statistical modelling and

\(^1\) \(C = 100 \times (W/L)^3\) where \(C\) is condition, \(W\) is weight in grams and \(L\) is length in centimetres.
the plots were made in the statistical package R using R Commander (R Development Core Team 2009). For each data set, i.e. each sampling site, the relationship between condition and year was the main focus, except for some linear Regressions which looked at the correlation between condition and age, WAA and content of fat respectively. Regressions with a de-trended condition value and age where made too. The de-trended condition value was calculated by subtracting the yearly average condition value with the individual condition value, thus eliminating the time trend that could exist. This was done to try and find how well the age affected the condition value, without the influence of the year variable.

For all the locations a multiple regression was made, where the best linear model was found which showed possible significant interactions between the different explanatory variables. In the linear models age, season and year were explanatory variables and condition was the response variable. The modelling started with the following linear model:

\[
\text{COND} \sim \text{AGE}^2 : \text{SEAS}^2 : \text{YEAR}
\]

This model shows how the explanatory variables age, year and season affect the response variable condition, and the possible interactions between the explanatory variables. To get the best linear model to explain the possible significant interactions between the three explanatory variables, i.e. season, age and year, the models were simplified by eliminating the most complicated interactions which was not significant. This method is called backwards elimination, and the result is a linear model that best explains the interactions in the easiest way. To make sure no important interactions were eliminated by mistake, the Akaike’s Information Criterion (AIC) was used. The AIC compares all the linear models and calculate which one best explains the interactions (Crawley 2005). The result was eight different linear models, one for every data set.

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2 This model shows if the condition can be explained by the explanatory variables age (categorical), season (categorical) and year (continuous) separately, by two of them together or by a interaction with all three of them.
Results

Differences between male and female

Generally, the difference in condition between male and female herring was small. Data on males was available only at two locations, Ångskärsklubb and Utlängan, and at both sites fewer male samples were analysed (Table 1), which could explain why male herring showed less statistical significant overall. Male herring had a lower "start value" (in the year 1972) in condition, however, the difference evens out over time (Table 3). Male herring had a higher condition in autumn than in spring, and the same was true for female herring at Ångskärsklubb (Figure 2, Table 4). The correlation between condition and WAA and condition and fat content showed no differences between male and female herring (Table 5).

![Figure 2](image-url)  
*Figure 2* Plot of means showing mean values and confidence intervals in condition (Y-axis) during autumn and spring (X-axis) for male and female herring at Ångskärsklubb, n= 861 (female), n=394 (male), and Utlängan, n=942 (female), n=381 (male). Data from all years are used.
Table 3 Average condition values for different years; start year (for locations with samples from the 1970s), 1980, 1995 and 2007. NA means no samples from that year.

<table>
<thead>
<tr>
<th>DATA SET</th>
<th>SEX</th>
<th>AVERAGE CONDITION VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAFJ</td>
<td>F</td>
<td>NA*</td>
</tr>
<tr>
<td>ANGK-F</td>
<td>F</td>
<td>0.6538#</td>
</tr>
<tr>
<td>ANGK-M</td>
<td>M</td>
<td>0.5702#</td>
</tr>
<tr>
<td>LAND</td>
<td>F</td>
<td>0.6559#</td>
</tr>
<tr>
<td>UTLA-F</td>
<td>F</td>
<td>0.7178#</td>
</tr>
<tr>
<td>UTLA-M</td>
<td>M</td>
<td>0.6627#</td>
</tr>
<tr>
<td>FALD</td>
<td>F</td>
<td>NA*</td>
</tr>
<tr>
<td>VADO</td>
<td>F</td>
<td>NA**</td>
</tr>
</tbody>
</table>

* = Start Year 1980, # = Start year 1972, # = Start Year 1978, ++ = Start Year 1995

Figure 3 Effect plots from the linear models showing time trends in condition value for herring at Ångskärsklubb (female=a, male=b) and at Utlängan (female=c, male=d) for autumn and spring catches. Y-axis show condition value and X-axis show year, the black lines on the X-axis are individual years, from 1972 to 2007. Dotted red liens are confidence intervals. Same data used as in Figure 2.
**Differences between spring and autumn**

Samples were made at all locations during autumn, except for Ängskärsklubb and Utlängan where spring sampling was made as well. The temporal trend was negative at all locations during autumn but less coherent during spring (Figure 3, Table 4). The condition values for male and female herring were significantly higher during autumn than during spring at Ängskärsklubb (Figure 2) and there was a positive trend for female herring during spring (Figure 3, Table 4). At Utlängan female herring had a negative trend during spring (Figure 3, Table 4) and male herring had a higher condition value during autumn than during spring (Figure 2).

**Differences between age classes**

There were significant negative temporal trend for age class 3-4 years and age class 5 years at Harufjärden, but age class 1-2 years showed no significant trend (Table 4). At Ängskärsklubb age class 1-2 years had a significant negative temporal trend, while age class 2-4 years had a significant positive temporal trend and age class 5 years showed no significance (Table 4). The temporal trends at Landsort were negative for both age class 1-2 years and age class 3-4 years (Table 4) This was also true for female herring at Utlängan, while male herring showed no temporal trend for age class 1-2 years and no trends was found for age class 5 years either (Table 4). Fish in age class 1-2 years had a significant negative temporal trend at Fladen and a significant positive trend at Väderöarna and no significance was found for age class 3-4 at either of the locations at the Swedish West coast (Table 4).

The regressions between condition and age showed that three locations had a significant positive correlation, Ängskärsklubb, Fladen and Väderöarna, while Harufjärden and female herring at Utlängan had a significant negative correlation (Table 5). Using the de-trended condition value gave different results and showed only significant correlations at Harufjärden and Ängskärsklubb, where the positive correlation at Ängskärsklubb became negative and the negative correlation at Harufjärden became positive (Appendix 1, Table 5).
**Table 4** Results, time trends, from general linear models for different seasons and different age classes. NA means there was no values for that season or age class. Negative time trends are *italic* and positive time trends are **bold**.

<table>
<thead>
<tr>
<th>DATA SET</th>
<th>SEX</th>
<th>ALL DATA</th>
<th>YEAR &amp; SEASON</th>
<th>YEAR &amp; AGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td><strong>Year</strong></td>
<td><strong>Spring</strong></td>
</tr>
<tr>
<td>HAFJ</td>
<td>F</td>
<td>Negative</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>ANGK-F</td>
<td>F</td>
<td>No trend</td>
<td>Positive</td>
<td>Negative</td>
</tr>
<tr>
<td>ANGK-M</td>
<td>M</td>
<td>No trend</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>LAND</td>
<td>F</td>
<td>Negative</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>UTLA-F</td>
<td>F</td>
<td>Negative</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>UTLA-M</td>
<td>M</td>
<td>Negative</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>FLAD</td>
<td>F</td>
<td>Negative</td>
<td>NA</td>
<td>Negative</td>
</tr>
<tr>
<td>VADO</td>
<td>F</td>
<td>Positive</td>
<td>NA</td>
<td>Positive</td>
</tr>
</tbody>
</table>

**Table 5** Regression coefficients for main factors from linear regressions, COND = condition, COND2 = a de-trended condition value, WAA = weight-at-age, FPRC = Fat Content (%), n = number of observations, total, and number of observation missing Fat Content (%) values, in brackets.

<table>
<thead>
<tr>
<th>DATA SET</th>
<th>SEX</th>
<th>COND~AGE</th>
<th>COND2~AGE</th>
<th>COND~WAA</th>
<th>COND~FRPC</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>AGE</strong></td>
<td><strong>De-trended COND</strong></td>
<td><strong>Weight-at-age</strong></td>
<td><strong>Fat Content (%)</strong></td>
<td><strong>Missing values FPRC (n)</strong></td>
</tr>
<tr>
<td>HAFJ</td>
<td>F</td>
<td>-0.0280*</td>
<td>0.0060*</td>
<td>0.1382*</td>
<td>0.0607*</td>
<td>693 (225)</td>
</tr>
<tr>
<td>ANGK-F</td>
<td>F</td>
<td>0.0853*</td>
<td>-0.0070*</td>
<td>0.1045*</td>
<td>0.0496*</td>
<td>861 (132)</td>
</tr>
<tr>
<td>ANGK-M</td>
<td>M</td>
<td>0.0345*</td>
<td>-0.0010*</td>
<td>0.0990*</td>
<td>0.0519*</td>
<td>394 (85)</td>
</tr>
<tr>
<td>LAND</td>
<td>F</td>
<td>0.0021</td>
<td>0.0030</td>
<td>0.1224*</td>
<td>0.0714*</td>
<td>505 (87)</td>
</tr>
<tr>
<td>UTLA-F</td>
<td>F</td>
<td>-0.0183*</td>
<td>-0.0002</td>
<td>0.0574*</td>
<td>0.0563*</td>
<td>942 (186)</td>
</tr>
<tr>
<td>UTLA-M</td>
<td>M</td>
<td>-0.0053</td>
<td>-0.0046</td>
<td>0.0157*</td>
<td>0.0666*</td>
<td>381 (78)</td>
</tr>
<tr>
<td>FLAD</td>
<td>F</td>
<td>0.0210*</td>
<td>-0.0014</td>
<td>0.0946*</td>
<td>0.0735*</td>
<td>616 (98)</td>
</tr>
<tr>
<td>VADO</td>
<td>F</td>
<td>0.0331*</td>
<td>0.0011</td>
<td>0.0026*</td>
<td>0.0650*</td>
<td>249 (23)</td>
</tr>
</tbody>
</table>

*=significant, i.e. p < 0.05, *log* = the explanatory variable is logged
Differences between locations

Table 3 shows that the highest average condition values during the last year, 2007, were in the locations Fladen and Väderöarna, at the Swedish west coast. The lowest average value was in Harufjärden in the Bothnian Bay. Harufjärden was also the location with the biggest decrease in condition between 1980 and 2007 (Table 3). Male herrings at Utlängan showed a similar decrease, but female herring had a smaller decrease (Table 3). Fladen is the only location which had an increase in average condition value between 1980 and 2007. Looking at changes between 1995 and 2007, all locations except for Ängskärsklubb and Utlängan have an increase in average condition value, with the biggest increase at Landsort (Table 3). Ängskärsklubb had the biggest decrease in average condition value between 1995 and 2007 and the decrease for male herring was bigger than for female herring (Table 3).

The overall time trends for the locations show that four locations had a significant negative trend whereas Ängskärsklubb had no significant trend and Väderöarna had a significant positive trend (Table 4). The data have large variations, shown in box plots in Appendix 2. Ängskärsklubb, on the other hand, showed a significant positive trend for age class 3-4 years, but a negative trend for age class 1-2 years and no trend for age class 5 years (Table 4). All locations showed a positive statistical significant correlation between condition and WAA and condition and fat content (Table 5).
Discussion

Almost all of the statistical analyses in this study are based on the change in the herring condition during the past 30 to 40 years. Condition can be a problematic expression, and it is important to explain what is meant by condition value. In this study the condition of the individual herrings using Fulton’s condition index (Jones et al 1999) has been used. As mentioned before, this index is assuming isometric growth of the fish and was chosen because it is commonly used (Stevensson & Woods 2006) and used by Bignert et al (2009). A number of other condition indexes exist, and using one of them may show a different result in the statistical analyses (Le Cren 1951, Jones et al 1999, Stevenson & Woods 2006).

The general decrease in the condition of herring over time found in this study confirms what other previous studies have shown (Bignert et al 2009, Cardinale & Arrhenius 2000). All locations in the Baltic Sea showed a significant decreasing temporal trend, except for Ängskärsklubb in the southern Bothnian Sea, where no significant trend was found. At Väderöarna, located on the Swedish west coast, the results show a clear difference, i.e. an increasing trend, compared to the other locations. Here samples only existed from 1995 to 2007, which could explain the difference. However, the different environmental conditions at the West coast compared to the locations in the Baltic Sea could mean that the factor explaining the decrease in condition is connected with the Baltic Sea. Previous studies have shown that changes in the zooplankton community in the Baltic Sea could be explained by changes in the salinity level (Peltonen et al 2004) which both affects herring condition (Möllman et al 2005).

The herring population in the Baltic Sea is likely divided into separate sub-populations (Ask & Westerberg 2009). Therefore it could be different populations being caught at autumn and spring, explaining the variations in condition value between seasons. Another explanation, which could also explain the larger variation in spring caught herring, is related to spawning. It is likely that the condition is lowered after spawning due to the weight loss. The condition value may vary during the year and Arrhenius & Hansson (1996) show that the energy content varies between seasons, which could be an indicator of variations in condition as well. A previous study used spring spawning dates in the Baltic Sea between the 15 April and the 6 June (Arrhenius & Hansson 1993) i.e. dates that were used as spring caught herring in this study, which means that the herring could have been caught both before and after spawning.
This could be one explanation to the greater variation and the non-significant and different trends during spring.

The results showed a significant difference in condition between spring and autumn caught herring in the Baltic Sea, with a higher condition value in autumn than in spring. Arrhenius & Hansson (1993) found that the peak zooplankton consumption by herring and sprat occurs in July to October, which is mainly classed as autumn in this thesis\(^3\). This probably leads to a higher mean weight for herrings during autumn and could be one reason why the condition value at some locations are higher in autumn caught herring than in spring caught. In the same article Arrhenius & Hansson discuss a possible shift in herring diet during the 1980s which indeed could have had an effect on the condition of the herring (Arrhenius & Hansson 1993). Opposite to this, Möllman et al (2004) state that the feeding activity was highest during spring and summer when the calanoid copepods, a zooplankton species that herring prey upon, have their main reproductive period (Möllman et al 2004). Möllman et al further explain that the diet composition of the herring changed with the season, with a diet consisting of more mysids during winter (Möllman et al 2004). These could be another reason why the condition value was higher during autumn, since some of the sample weeks where closer to winter than to autumn, i.e. samples during week 49, 50 and 51.

The analysis between male and female herring showed little difference, except for the start year of 1972, when male condition was lower than female condition. Mainly female herring was used in this study, and in the literature little differences between male and female herring are shown. One study analysing fat content stated that there was no difference between male and female herring (Hjelm et al 2006) and it is possible that there was no difference in condition as well. The results in this study, however, still show some differences between male and female herring and it would be wise when analysing condition value to always reflect over both male and female herring.

The analyses of different age classes showed a temporal decrease in condition for young fish, aged 1-2 years in all the Baltic Sea locations except for Harufjärden and for male herring at Utlängan, where no significant trends were found. A decrease in condition was also found at Fladen. Fish in age class 3-4 years had a significant increase in condition at Ängskärsklubb

\(^3\) All herring caught before week 28 are classed as spring, and week 28 is often in the middle of June.
and a significant decrease in the rest of the Baltic Sea. At the West coast no significant trend was found for fish in age class 3-4 years and age class 5 years was missing. In the Baltic Sea age class 5 years showed a decrease only at Harufjärden, and were missing at Landsort.

The age influence on condition were looked at with two different condition values, first the condition value calculated from Fulton’s condition index, and then with a de-trended condition value where the possible temporal trend was eliminated. The first correlation, using Fulton’s condition index, showed a significant decrease in condition with age at Harufjärden, the northernmost location, and at Utlängan, for female herring. At the other locations in the Baltic Sea, and at the West coast, there was a significant increase in condition with age. A previous study show similar results with an increasing condition with age in the southern Baltic Sea and a decreasing condition with age in the North (Vainikka et al 2009). In the second correlation, with the de-trended condition value, the decrease in Harufjärden became an increase and vice versa for Ängskärsklubb thus showing the opposite of Vainikka et al. The other locations showed no significance using the de-trended condition value. What can be concluded is that at some locations in the Baltic Sea, Ängskärsklubb and Harufjärden, the age does affect the condition value and different age classes show different temporal trends.

Due to the large differences in environmental condition within the Baltic Sea and between the Baltic Sea and the West coast, which likely affects the condition value, the data were split up into different locations. The results show that there was a difference between locations, especially between the locations in the Baltic Sea and Väderöarna at the Swedish West coast. This could be explained by the length of the time series and not by variables affecting the condition, since sampling from Väderöarna only exists from 1995, compared to sampling from the 1970s and 1980s in the Baltic Sea. Only Ängskärsklubb and Utlängan show a decrease in condition value between 1995 and 2007, while the other four locations had an increase in condition. Väderöarna and Fladen had the highest average condition value during 2007, the last sample year. A higher condition at the Swedish West coast is likely due to the more preferable salinity level for herring (Fässler et al 2008).

A previous study shows that the salinity level has decreased in the Gulf of Finland since 1982 (Rönkkönen et al 2004). The Gulf of Finland and the Bothnian Bay are much alike when it comes to salinity due to the fact that they are far from the Danish Sounds and thus seldom get new saltwater inflows. In the Bothnian Bay the freshwater runoff is great, which further lower
the salinity levels (Bernes 2005). If the salinity has decreased in the Gulf of Finland, it is possible that it has decreased in the Bothnian Bay as well. Rönkkönen et al (2004) also argues that in low salinity conditions, herrings will feed on less valuable food, and thus following the “junk-food” hypothesis this means that the herring condition might be lower. This could be one explanation why the condition of the herrings has decreased in Harufjärden in the Bothnian Bay.

Casini et al (2006) states that water temperature in the Baltic Sea have been fairly static during the past two decades, while Möllman et al (2005) shows an increase in water temperature. Earlier studies have shown that a warmer water temperature has a direct negative effect on the growth of herring, and thus affects the condition as well (Rönkkönen et al 2004). If water temperature has increased in the Baltic Sea, this too could be an explanation for the decreasing condition value in the Baltic Sea locations. Further analysis with salinity and water temperature data from the Baltic Sea is needed to understand how the change in condition is correlated with changes in salinity and water temperature.

The theory about competition with an increasing sprat population is still interesting but have not been analysed in this study. Comparing the results from this study with population data on sprat, herring and cod from the Baltic Sea, is needed to evaluate how the competition with sprat may affect the herring condition.
Conclusions

The aim of this thesis was to use data from the national Swedish contaminant monitoring programme and try to explain the change in herring condition during the past 30-40 years and the try to explain the great variation in the data. I learned that the condition in the Baltic Sea have decreased since the 1980s at three of the four locations used in the study. At the Swedish West coast the condition has increased at the two locations between 1995 and 2007. There was some difference between male and female condition, but this was only analysed at two locations. Still, it is important to remember that the sex may affect the condition value, especially when analysing only male or only female samples.

There was a clear difference in condition between spring and autumn caught herring, which could be explained by different populations being caught at different seasons, by peak zooplankton consumption in autumn or by spawning effects mainly during spring. This could explain the variation in the data, and in future studies it would be better to divide the data by season as well as by location and sex. The condition of fish increases with age at the Swedish West coast and at Landsort and Ängskärsklubb and decreases with age at Harufjärden and Utlängan, when the main condition factor was used. When using a de-trended condition factor, only Harufjärden and Ängskärsklubb showed significant results, thus implying that age only affects herring in the northern Baltic Sea, i.e. the Bothnian bay and Bothnian Sea. Comparing sex, season and age it seems that season is the factor which have the largest impact on the condition value, whereas sex and age do not show any clear pattern in the analyses made in this study.

The results show clear differences in the change in condition value at different locations along the Swedish West coast. This was already shown in the Comments Concerning the National Swedish Contaminant Monitoring Programme in Marine Biota (Bignert et al 2009) and is still the most important factor that explains the condition value. This study have showed that apart from the spatial differences in condition, the season the fish was caught most likely affect the condition value and the age and sex of the fish may be an important factor as well.
Acknowledgements

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References


Hjelm, J., Hultgren, M., Cardinale, M. (2006) *Water uptake in herring (Clupea harengus) and sprat (Sprattus sprattus) as a function of area, salinity and fat content.* Fisheries Research, 81: 94-99


Öskarsson, G. J. (2008) Variation in body condition, fat content and growth rate of Icelandic summer-spawning herring Clupea harengus L. Journal of Fish Biology, 72: 2655-2676


Appendix 1

Scatterplots of Condition and age (a,c,e) and de-trended condition and age (b,d,f) for Harufjärden (a,b), females at Ängskärsklubb (c,d) and males at Ängskärsklubb (e,f).
Appendix 2

Boxplots, condition and year, for all datasets, i.e. six locations with female herring and two with male herring (Ängskärsklubb and Utlängan).

Harufjärden – Female

Landsort – Female