Reproductive biology and growth of the sprat (*Sprattus sprattus* L.) in the Kattegat and Skagerrak.

Mittermayer, Felix Hans

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Department of Marine Ecology
University of Gothenburg

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Felix Mittermayer

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**Department of Marine Ecology**
Göteborg University
Kristineberg Marine Research Station
SE-450 34 Fiskebäckskil, Sweden

**Institute of Marine Research**
Swedish Board of Fisheries
Turistgatan 5
SE-453 21 Lysekil, Sweden

Supervisors: Michele Casini
Leif Pihl

Examiner: Susanne Baden

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I Introduction

The sprat (Sprattus sprattus) is a pelagic planktivorous fish that is spread throughout the north-eastern Atlantic (Tøtsten, 1998; Power et al., 2000), the Baltic Sea (Kraus and Köster, 2004; MacKenzie et al., 2008), the Mediterranean Sea (Dulčić, 1998) and the Black sea (Avsar, 1995; Shulman et al., 2005). The sprat is an ecologically important species throughout Europe as prey for piscivore fishes, sea birds and marine mammals. Besides that it is an important plankton feeder. Sprat is also a commercially important species since it is used for human consumption and for fishmeal and oil.

The Skagerrak-Kattegat (Eastern North Sea) is inhabited by a sprat population which has not received particularly attention in literature during the past decades. Some work has been done on growth (Lindquist, 1972) and variations of mean length in different year classes (Molander, 1940), milieu forms (Molander, 1942), year classes strength (Lindquist, 1966), meristic and morphometric charaters (Lindquist, 1968) as well as on the distribution and abundance of the sprat (Lindquist, 1964) and sprat eggs and larvae (Lindquist, 1970). In Skagerrak, spawning areas have been found all along the Swedish and Norwegian coast as well as inside the fjords (Sund, 1911; Tøtsten and Gjøsæter, 1995). The spawning areas and time have been estimated with eggs and larvae sampling (Sund, 1911). Little information is on the other hand available for the Kattegat. No study has been performed in the Kattegat nor Skagerrak on gonadal maturation and seasonal variation of condition.

The fishing in the Kattegat is conducted by Sweden and Denmark with an average landing of 2000 t and 9700 t, respectively per year over the last ten years. In the Skagerrak the catches are divided between Denmark (4400 t), Sweden (7600 t) and Norway (800 t) (ICES, 2009). The landings are used for human consumption (canning) and to produce fishmeal and oil. The sprats are caught with different methods, i.e. smaller purse seiners and pelagic trawls. Sprat is also landed as by-catch when fishing for herring (Clupea harengus). Currently the sprat fishery is controlled by by-catch ceilings of herring and by-catch percentage limits (ICES, 2009).

Due to the lack of biological knowledge on sprat in the area, no analytical stock assessment can be conducted. The state of the stock in this area (ICES Division IIIa) has not been presented by ICES (International Council for exploration of the Sea) since 1985. The purpose of this study is to increase our knowledge about the sprat in this area that could create the bases for a future stock assessment.

In this study we investigate seasonal changes in condition, gonad development and maturity, as well as to compare growth of the sprat in Kattegat and Skagerrak. This information can be important for understanding the sprat population dynamics to be used in stock assessment (Vitale et al., 2006).

II Material and methods

Sprats were collected in Kattegat and coastal part of the Skagerrak (and its fjords) by different research and commercial vessels between 2003 and 2006 (Fig. 1). These are the areas of highest concentrations of sprat population (ICES, 2009). The data contain information about year and month of collection, location, total length, total and gutted weight, sex, gonads
weight, age and maturity stage. A macroscopic eight-stage maturity scale was used to
determinate the maturity state of the fish (Table 1).

Figure 1. Map over the sampling areas

Most of the Skagerrak fjords have a direct connection to the open sea. Only the Uddevalla
fjord system, due to its narrow thresholds, is partially isolated from the open sea (Lindquist,
1964). Fish from Uddevalla fjord system were excluded in this study.

The data were collected by surveys like IBTS (International Bottom Trawl Survey), acoustic
surveys and Coastal Monitoring and by commercial fishing vessels operating in the area. The
Swedish R/V Argos and the Danish R/V Dana usually take their samples offshore, while the
R/V Ancylus collect samples in more inshore areas. Trawlers or purse seiners constitute the
commercial group.
Table 1. Macroscopic scale for the determination of sprat maturity

<table>
<thead>
<tr>
<th>Stage</th>
<th>Macroscopic properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Virgin sprat. Gonads very small, threat like, 2-3 mm broad. Ovaries wine red. Testes whitish or grey brown.</td>
</tr>
<tr>
<td>2</td>
<td>Small gonads (virgin or fish that has not started to build gonads). The height of ovaries and testes about 3-8 mm. Eggs not visible to naked eye but can be seen with magnification glass. Ovaries bright red colour. Testes a reddish grey colour.</td>
</tr>
<tr>
<td>3</td>
<td>Gonads occupying about half of the ventral cavity. Breadth of sexual organs between 1 and 2 cm. Eggs small but can be distinguished with the naked eye. Ovaries orange; testes reddish grey or greyish</td>
</tr>
<tr>
<td>4</td>
<td>Gonads almost as long as body cavity. Eggs larger. Varying size, opaque. Ovaries orange or pale yellow; testes whitish.</td>
</tr>
<tr>
<td>5</td>
<td>Gonads fill body cavity. Eggs large, round; some transparent. Ovaries yellowish; testes milk white. Eggs and sperm do not flow, but sperm can be extruded by pressure</td>
</tr>
<tr>
<td>6</td>
<td>Ripe gonads; eggs transparent; testes white; eggs and sperm flow freely. <em>Spawning stage</em></td>
</tr>
<tr>
<td>7</td>
<td>Spent sprat. Gonads baggy and bloodshot. Ovaries empty or containing only a few residual eggs. Testes may contain remains of sperm.</td>
</tr>
<tr>
<td>8</td>
<td>Recovering spents. Ovaries and testes firm and larger than virgin sprat in stage II. Eggs not visible to naked eye. Walls of gonads striated; Blood vessels prominent. Gonads wine red colour.</td>
</tr>
</tbody>
</table>

For the calculation of maturity at length and age, individuals in maturity stages III to VIII were considered as spawning, whereas individuals in stages I and II as not spawning (Table 1). Sex was determined by the size, consistence, color and shape of the gonads. The age was determined by counting the winter rings on the sagitta otholites. To ensure accuracy, the age was independently estimated by two scientists. Juvenile individuals become 1-year old after January as well as older individuals add year too their age. The total length was determined to the mm below its actual length. The fish were weighted whole and with the gut and gonads removed to the nearest 0.1g and the removed gonads were weighted to the nearest 0.001g.

For each fish we estimated a modified Fulton’s condition index (FCI) based on gutted weight,

\[
(\text{I}) \text{FCI} = \frac{W_g}{TL}^{3.21}
\]

in which the exponent 3.21 is the slope of the regression between ln-length and ln-weight, \(W_g\) the weight of the fish with guts and gonads removed and TL the total length of the fish.

The gonodosomatic index (GSI) was calculated by the formula

\[
(\text{II}) \text{GSI} = \frac{G_o}{W} * W^{-1} * 100
\]
where GoW is the gonad wet weight and W is the wet weight of the whole fish. For our analyses we used GLM in the program Statistica. Due to the non-normal distribution of data, the modified Fulton condition index was ln-transformed and multiplied by 10^6 and the gonadosomatic index was square-root transformed.

**III Results**

**Seasonal Changes in Condition and Gonadal Maturity**

The seasonal changes in the FCI and GSI in Kattegat and Skagerrak are presented in Fig. 2 and 3. The condition of sprat in the Kattegat was low under winter and spring, and increased after summer reaching the highest values in autumn (Fig. 2a). An opposite pattern was shown by the GSI index: with highest values during May to July and lowest during autumn (Fig. 2b).

In the Skagerrak the seasonal patterns seemed to be similar as in the Kattegat (Fig. 3a,b). As we already observed for the Kattegat, the condition was decreasing towards the winter months and increased during autumn, while the GSI was highest in spring and lowest in late summer and early autumn. These trends were also visible when dividing the data into the different years. For this analysis, year, age and sex of the fishes were set as covariates. The high variance in the Skagerrak during August was due to the low sample size in this month.
Figure 3. a) Seasonal variation of the Fulton condition index (mean and SD, n=6-376) and b) gonadosomatic index (mean and SD, n=6-376) of sprats in the Skagerrak. Consecutive month are connected with lines.

The fishes in the Skagerrak had a significant higher condition than fishes from the Kattegat (Fig. 4a) (F=88,3; p<0,0001). On the contrary, the GSI was higher in the fishes from the Kattegat than from the Skagerrak (F=19,1; p<0,0001) (Fig. 4b). Year, month, age and sex of the fishes were used as covariates.

In both Skagerrak and Kattegat, females had a higher condition (F=43,8; p<0,0001) and higher gonadosomatic index (F=31,3 ; p<0,0001). Year, month and age of the fishes were integrated as covariates.

Figure 4. a) Differences in Fulton condition index between areas and sexes (n=3137) and b) differences in gonadosomatic index between areas and sexes (n=3120)

**Maturation and size**

In Fig. 5 a,b the variation in frequencies of the different maturity stages over the year is shown. Fishes in the pre-spawning and spawning stages (i.e. stage 5 and 6) were found from January to July, peaking between March and July in the Kattegat and in April-May in the Skagerrak. The first spent fishes (i.e. stage 7) were caught in March and April, in Kattegat and
Skagerrak respectively, but with low frequency. After August there were only very few fish in advanced stages of maturity, while the rest of the population had entered a resting stage (i.e. stage 8) are virgin or had started to build up new gonads (i.e. stages 1 and 2) for next year spawning. The percentage of immature fishes was at its top in September. After that, the percentage of immature fish decreased.

In Fig. 6a,b maturity ogives are shown. The L50 value, when 50% of the population is mature, occurred at a length 80-89 mm in Skagerrak and at 90-99 mm in the Kattegat. In the Kattegat 70 % of the 1-year sprats were already mature and in the Skagerrak it was as high as 80%, whereas from age 2 all sprats seem to be mature.

The growth for sprat in the Kattegat and Skagerrak is shown in Fig. 7. Sprat in the Skagerrak had a slightly higher length-at-age than the Kattegat (F=4,8; p=0,003; age and sex used as covariates). In both areas females grow faster than males (F=644,8; p<0,0001 in Kattegat, and F=340,8; p<0.0001 in Skagerrak; age used as covariate).
Discussion

In this study it has been shown that sprat condition was high in autumn-early winter and low in the spring-early summer. Variations in the GSI showed an opposite pattern. The variations in condition and maturity lead to the conclusion that the spawning period of the Kattegat-Skagerrak sprat was between March and July. This was confirmed by the highest proportion of mature individuals found in this period. The top of the spawning season was between April and June, during which the populations have the lowest condition index and highest GSI. This shows that sprat during spring allocate to gonads the energy accumulated during autumn. GSI seasonal changes and the maturity stages indicate that spawning may start earlier in the Kattegat population, since in this area some of the sampled fish were in stages of advanced maturity already in January and some fish were in the spent stage as early as March. The spawning duration of an individual has been estimated to vary between two and three month in the southern Baltic (Heidrich, 1925). These results are in agreement with study based on eggs and larvae (Sund, 1911).

The slight difference in spawning time between Skagerrak and Kattegat may be connected to different hydrological conditions. Previous studies have suggested that spawning starts when the water temperature reaches 5°C (Lindquist, 1964). The start of the spawning may also be connected to the onset of the zooplankton plankton productivity in the sea, which is also connected to the temperature and onset of primary production. The primary production is however regulated by light and stratification. Due to the more southern position of the Kattegat, the light intensity may reach the critical level earlier. The higher productivity could lead to a better survival of the larvae.

Previous studies have suggested that the border region between Skagerrak and Kattegat is an important spawning area for sprat (Sund, 1911). This region is important for recruitment of sprat along the northern Swedish coast and Norwegian coast as far north as 62°N (Torstensen, 1998). The only populations not taking part in this spawning are probably those from the Limfjord (Danmark) and the Uddevalla fjord system (Sweden), which are isolated due to fjord thresholds (Molander, 1942). These two fjord systems were not part of this
investigation. Little is known about the spawning and recruitment of sprat in the Kattegat. In our study we show that the Kattegat population was similar to Skagerrak population in terms of maturity development and variation in condition. However, the degree of exchange between the populations of the two areas is at present unknown. Further, it is not clear whether the sprat in the Kattegat is build up by larvae from local spawning or by drift from other areas and if the Kattegat population contributes to the Skagerrak population by larvae drift.

When looking at the average condition factor and GSI it seems that the sprat in the Kattegat invest relatively more into reproduction compared to the sprat in the Skagerrak. In fact, fish from this area have a lower condition but higher GSI than fish from the Skagerrak. Although in the winter-spring period condition was generally low, a temporary increase was observed in March in both areas. This might be explained by the increased zooplankton production, which leads to the temporarily higher condition. The low in condition factor during the winter months could be due to a lower zooplankton production.

The L50 value estimated in our study (80 to 100 mm) were similar to that of the sprat in the inshore waters of west Scotland (De Silva, 1973) and the Baltic (85 to 103 mm) (Grygiel and Wyszyński, 2003)

In the Kattegat and Skagerrak the majority (70% respectively 80%) of the sprat come into sexual maturity at age 1 and with a short lifespan (< 4 years), this creates a large natural variation in the stock size (Lindquist, 1964; ICES, 2009). In a geographically closed sprat population, like the Baltic, the percentage of mature 1-year-old sprat is only 17% (ICES, 2009), explained by the longer life expectancy. Both sexes reach their maturity at around the same length with the males slightly earlier.

The growth rate was different between the areas. Sprat in the Skagerrak had grown around 5 mm more when they reach age one than the sprat of the Kattegat. This difference is probably due to food availability and hydrological circumstances (ex. higher salinity in Skagerrak), as in the Baltic Sea where there is a south-north gradient in clupeid weight-at-age (ICES, 2009) increasing with salinity. However, stock density and fishery can also affect sprat growth rates by changing the amount of food available and mortality rates (Lindquist, 1972). The growth rate of the female sprat in the Kattegat and Skagerrak is higher likely in order to reach size at maturity and produce larger number of eggs early in life.

The information collected in this study is an important first step for a future stock assessment.

With the knowledge about the maturity ogives and growth we now have important parts for estimation of the spawning stock biomass. Together with mortality rates future harvest levels can be estimated.

Due to the variation in the growth rate survey sampling must cover both Kattegat and Skagerrak in order to produce accurate weight-at-age data to be used in assessment. It is also important that the samples are taken when the sprat is mature, i.e. during winter and spring. In future studies the sampling should be more regular and at the same time in both Kattegat and Skagerrak, in order to distinguish both populations. Also a genetic study, which can confirm the actual existence of the genetic different populations against a population under different environmental factors, may be interesting.
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