Technical note

Spatial variation in fecundity of Norwegian coastal cod, *Gadus morhua* (Linnaeus), along the coast of Norway

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A B S T R A C T

Fecundity of Norwegian coastal cod (NCC) was estimated at several locations along the coast of Norway. There was no significant difference in carcass weight, liver weight or potential fecundity (*F*<sub>P</sub>) between Lofoten and Verrabotn (Northern region) or between Bømlo and Langesund (Southern region). Fish caught in the Northern region had a higher liver weight and potential fecundity than fish caught in the Southern region.

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1. Introduction

Variations in reproductive parameters can impact the reproductive potential of fish populations and affect their resilience to a given level of fishing pressure. Coastal cod (*Gadus morhua*) in Norway are known to consist of genetically distinguishable populations where reproductive parameters (growth and age at maturity) vary between these different populations (*Berg and Albert, 2003; Salvanes et al., 2004; Jorde et al., 2007*). To investigate the possibility of whether potential fecundity also varies between coastal cod populations, fecundity was estimated from fish caught in four areas over two years.

2. Methods

Cod were sampled from four locations along the Norwegian coast; Lofoten, Verrabotn, Bømlo and Langesund during 2003 and 2004 (*Fig. 1; Table 1*). Fish were caught by local fishermen using Danish seine (Lofoten) and gillnets (all other areas). Sampling was timed to be as close to the beginning of spawning as possible; knowledge on approximate spawning time was based upon advice from local fishermen. In both Lofoten and Verrabotn there is an overlap in the distribution of coastal cod and North-East Arctic cod during the spawning season. Otoliths were used to distinguish between these two types (*Rollefsen, 1993; Stranksy et al., 2008*). To investigate the possibility of whether potential fecundity also varies between coastal cod populations, fecundity was estimated from fish caught in four areas over two years.

Potential fecundity was estimated using the Auto-diametric method (*Thorsen and Kjesbu, 2001*), which works on the principle that oocytes per gram of an ovary is inversely proportional to the average size of the oocytes. The diameter of 200 vitellogenic follicles were measured using a binocular microscope (Olympus SZX12 with a SZX-ILLB200 light foot) at 7× magnification, a camera displaying a live image and computer-aided automatic particle analysis. Potential fecundity was then estimated using the following equation:

\[
F_p = 2.14 \times 10^{11} \times D_o^{2.700} \times W_G
\]

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where \( D_0 \) = average oocyte diameter (\( \mu \text{m} \)). Leading cohort oocyte diameter (LC) was defined as mean of the largest 10% of vitellogenic oocytes and was used as an indicator of the stage of ovary development.

Length, weight, fecundity and liver weight were \( \log_\text{e} \) transformed to meet with normal distribution requirements. There were no significant differences in potential fecundity at weight or length between years in any area (ANCOVA, \( \log_\text{e} F_p = \log_\text{e} W + \text{year} \), \( \log_\text{e} F_p = \log_\text{e} L + \text{year} \), \( p > 0.05 \)) so fish from same area but different years were combined. The fish from the four areas were combined into two regions, termed Northern (Lofoten and Verrabotn) and Southern region (Bømlo and Langesund) as there were no difference in weight at length (ANCOVA, \( \log_\text{e} W = \log_\text{e} L + \text{area} \), \( p > 0.05 \)) or fecundity at weight (ANCOVA, \( \log_\text{e} F_p = \log_\text{e} W + \text{area} \), \( p > 0.05 \)) between the areas within these regions.

Differences in weight at length and fecundity between years, areas and regions were tested using ANCOVA. Multiple linear regression was used to establish the model which best explained the variation in fecundity within a region. The starting model was

\[
\log_\text{e} F_p = \log_\text{e} W + \log_\text{e} L + \log_\text{e} W_1 + W_C + L_C
\]

Insignificant terms were then sequentially removed. Explanatory variables in the final model were tested for collinearity using variance inflation factors (VIFs) (Zuur et al., 2009) in the car package for R (Fox and Weisberg, 2009). Liver weight was included as a continuous variable within regression models and ANCOVA as opposed to hepatosomatic index as it would give a better reflection of energy reserves within the statistical tests. Hepatosomatic index is a ratio between carcass weight and liver weight and so will vary, in addition to liver weight, with the weight of the carcass and doubt has been placed over the reliability of such ratios (Packard and Boardman, 1999).

### 3. Results

The regression model with the highest explanatory power for the Northern and Southern regions were

\[
\begin{align*}
\log_\text{e} F_p & = 0.82 (\log_\text{e} W_C) + 0.00083 (L_C) + 0.21 (\log_\text{e} W_C) + 7.77 \\
\log_\text{e} F_p & = 0.67 (\log_\text{e} W_C) + 0.27 (\log_\text{e} W_C) + 7.84
\end{align*}
\]

respectively (Table 2). The VIFs for all variables were <3 indicating that the collinearity among variables were within reasonable limits. Fish from the Northern region had a significantly higher fecundity (Fig. 2) (ANCOVA, \( \log_\text{e} F_p = \log_\text{e} W_C + \text{region} \), \( p < 0.001 \)) and liver weight (Fig. 3) (ANCOVA, \( \log_\text{e} F_p = \log_\text{e} W_1 = \log_\text{e} W_C + \text{region} \),

<table>
<thead>
<tr>
<th>Location</th>
<th>Latitude</th>
<th>Year</th>
<th>Dates</th>
<th>n</th>
<th>Length range (cm)</th>
<th>Age range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2004</td>
<td>16 Feb–20 Feb</td>
<td>27</td>
<td>56–112</td>
<td>5–8</td>
</tr>
<tr>
<td>Bømlo</td>
<td>59–60 N</td>
<td>2003</td>
<td>12 Feb–14 Feb</td>
<td>16</td>
<td>54–95</td>
<td>4–7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2004</td>
<td>2 Feb–3 Feb</td>
<td>7</td>
<td>63–91</td>
<td>3–6</td>
</tr>
</tbody>
</table>

Table 1: The number of fish sampled (n) in each location and year together with details on the latitude of the location, sampling period and the length range of the fish in each sample.

<table>
<thead>
<tr>
<th>Region</th>
<th>Northern</th>
<th>Southern</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>( R )</td>
<td>( R )</td>
</tr>
<tr>
<td>( \log_\text{e} ) Carcass weight (g)</td>
<td>0.79</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>( \log_\text{e} ) Liver weight (g)</td>
<td>0.03</td>
<td>(0.0001)</td>
</tr>
<tr>
<td>LC (( \mu \text{m} ))</td>
<td>0.02</td>
<td>(&lt;0.0001)</td>
</tr>
<tr>
<td>Total</td>
<td>0.84</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: The amount of variance explained and p-value (in brackets) in the linear model of fecundity by the different explanatory variables for the Northern and Southern region.

![Fig. 1](location.png) Location of the four sampling areas along the Norwegian coast.

![Fig. 2](fecundity.png) Fecundity versus carcass weight for fish caught in the Northern (♦) and Southern (○) region. Non-linear regression lines are shown for Northern (solid) and Southern (dashed) region.
p < 0.001) at a given carcass weight than fish from the Southern region (ANCOVA, p < 0.001). Carcass weight at length did not differ significantly between regions (ANCOVA, logₐ Wc = logₐ L + region, p > 0.05).

The lack of an effect of LC on fecundity in the Southern region (it was a significant factor for fish in the northern region) is likely due to a greater range in LC values in the Northern region (95% percentile: 440–832 μm) in comparison with the Southern region (95% percentiles: 525–839 μm). The regional difference in liver weight did not fully explain the difference in fecundity between regions (ANCOVA, p < 0.001). A theoretical cod with a carcass weight of 4000 g, an LC of 800 μm and a liver weight of 350 g from the Northern and Southern would have a FP of 3.75 and 3.20 million eggs respectively, i.e. the fecundity of a cod from the Southern region would have a FP of about 85% of that of a similar sized fish, with a similar liver and carcass weight, from the Northern region when close to spawning. This difference increased with increasing fish size.

4. Discussion

Many of the populations of coastal cod along the Norwegian coast are reproductively isolated from each other and there is distinct genetic variation (Jorde et al., 2007; Knutsen et al., 2007). This leads to the possibility that the division of energy between growth and reproduction will differ between areas representing adaptations to the local environment. However, due to the low number of age classes represented in the samples and also a difference between the distributions of age classes between regions made it difficult to establish growth curves or establish if there was a difference in length at age between areas. Thus it was not possible to establish if there was a difference in the division of energy between growth and reproduction between the regions studied. Therefore, whether genetic variations are a source of differences in fecundity between regions remains an open question.

Differences in abiotic factors such as temperature may also play a significant role in the differences in fecundity between the two regions. Temperature is known to have an effect on fecundity in cod with fecundity being positively correlated with temperature (Kjesbu et al., 1998; Kraus et al., 2000). Different day lengths between north and south may also have an effect as day length can affect both forage patterns and spawning time (Gjøsaeter and Danielssen, 2011).

Energy reserves influence FP in many species with a positive relationship between the two (Kennedy et al., 2007; Skjærøen et al., 2010). However, above a specific threshold of energy, while potential fecundity increases with increasing energy reserves, relative fecundity is not affected and remains constant. Below this specific threshold, there is a positive correlation between energy reserves and relative fecundity (Kjesbu, 2009). Such an effect has the potential to explain the difference in fecundity between the two regions as fish from the Southern region had smaller livers. There was, however, no significant correlation between relative fecundity and liver weight or hepatosomatic index in either region. A potential correlation could be confounded by the effect of maturation stage on liver size. As ovary development proceeds, lipids are mobilised from the liver to the gonad, thus liver size decreases towards spawning as seen for NEA cod (Skjærøen et al., 2010) which can affect the statistical relationship between liver energy and potential fecundity. To get a clearer picture, of whether this is the reason for the effect, samples with a lower variation in maturation stages are needed.

References


