Age-reading of lumpsucker (*Cyclopterus lumpus*) otoliths: dissection, interpretation and comparison with length frequencies


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**Abstract**

This paper describes the use of lumpsucker (*Cyclopterus lumpus*) otoliths for age determination, with focus on methods that were found practical, the precision achieved in the first documented age-reading workshop of this species, and comparisons with length composition of the stock. The otoliths are very small and special training is necessary to locate them. The zonation pattern is relatively distinct and it was usually easy to establish a set of rings assumed to be annuli. The precision of age estimates was reasonably high for ages 1–4, although no formal verification was available at the time of reading. After the workshop, the resulting age–length relationship was compared to new estimates of length composition of juvenile lumpsucker prior to and after the migration from the coast. This supported the applied reading method. The age estimates together with length frequencies from the spawning ground suggest that males may spawn for the first time at age 2–3, and females at age 3–4. This is at least 1–2 years less than all previous estimates of age at maturity. However, further verification (e.g., by tracing the edge properties throughout the year) should be done before age-structured data are used in assessments of this species.

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**Keywords:** Lumpsucker; *Cyclopterus lumpus*; Ageing; Otoliths; Precision; Verification

1. Introduction

The lumpsucker (*Cyclopterus lumpus* Cyclopteridae) is a pelagic species that, after the spawning season, usually occurs in the upper 50–60 m of the North Atlantic, and often over abyssal depths in the Norwegian Sea and the Northeast Atlantic (Blacker, 1983; Holst, 1993). In the spawning season the species is widely distributed in coastal areas on both sides of the North Atlantic, where the spawning occurs in the sublittoral zone on rocky substrate. Spent females subsequently move away, leaving the male to guard the nest until the young hatch 6–8 weeks later (Daborn and Gregory, 1983).

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In the North Atlantic, the lumpsucker is exploited for its high-valued roe, the males and the flesh of the females being often discarded. Thus, the commercial fishery is highly seasonal, in the north of Norway mainly 5–6 weeks within the period April to mid-June (Bertelsen, 1994) and from mid-March to the end of May/early June in the south (Torstensen, 1988). The mature females are caught with gillnets on the spawning grounds, mainly with small vessels.

Data of catch per unit effort (CPUE) have been collected from the commercial fishery in north of Norway since the 1980s (Bertelsen, 1994; Albert, 1999). An increased harvest since the late 1980s associated with a reduction in CPUE indicates an overexploitation. Maintenance of high landings throughout the 1990s was only possible with a marked increase in effort, resulting in a further increase in exploitation. In the lumpsucker fishery at Iceland, a similar trend of reduction in CPUE was observed during the first half of the 1990s (Anonymous, 1999).

Data on age composition are fundamental in stock assessments. Age structure and population dynamics of the lumpsucker have previously been described from Canada (Cox, 1920; Cox and Anderson, 1922), Denmark (Bagge, 1964, 1965, 1967), and Iceland (Sæmundsson, 1926; Schopka, 1974; Thorsteinsson, 1981). Sæmundsson (1926) considered them to be at least 5–6 years old at maturity and mentioned that Canadian scientists reached the same conclusion. Schopka (1974) estimated age at maturity as 3–4 years, with only a small proportion of the stock spawning more than once. In the North Sea, the spawning stock of lumpsuckers was found to include age groups 4–9 with a dominance of age groups 5 and 6, by Bagge (1967), who also found that only males were represented in the spawning stock at age 4 and were still dominating at age 5. Thorsteinsson (1981) showed that female lumpsuckers from Icelandic waters recruit to the spawning stock at an age of 5–10 years, while the males recruit as 4 years olds. The spawning stock in this area consisted mainly of 5–8 years old females and 4–7 years old males.

These differences in age at maturity may be attributable to real temporal or geographical variation. However, all these studies were based on interpretation of otoliths, using ageing methods that have not been fully verified, and in most cases not even described. The scientists working with the lump sucker today are new in the field, with poor knowledge on ageing this species. In fact, it was generally believed that it was nearly impossible to read the otoliths of this species. This was based on both anecdotal information from some of those that previously had tried, and on evaluation of the only published description of the reading method (Thorsteinsson, 1981). However, our own preliminary studies of otoliths from southern Norway indicated a relatively distinct zonation pattern. Therefore, it was felt necessary to establish the method more or less from scratch, and to co-ordinate the reading methods used by the different laboratories.

For this purpose, a workshop was arranged with the objective of evaluating the possibility of reasonably accurate and precise estimation of the age of lumpsuckers from otoliths. And if successful, to achieve consistency in the reading and standardise the ageing methodology between the laboratories involved. It was also realised that a practical way to locate, dissect and prepare the very small otoliths of this species had to be found and described. Further, a first approach for validation was also tried, namely comparison of the age estimates with length frequencies. Available length samples included catches by gears with assumed low size-selectivity (i.e. excluding gillnet samples). Samples of larvae near the coast, juveniles and adults in the high seas and adults from the spawning grounds were considered. Details from the workshop (i.e. participants and individual differences in the age estimation) are given by Albert et al. (2000).

This paper describes the use of lumpsucker otoliths for age determination, with focus on methods that were found practical, the precision achieved in the first international age-reading workshop of this species, and comparisons with length composition of the stock.

2. Material and methods

2.1. Participants, sampling and dissection

Five scientists participated in the workshop held at Institute of Marine Research, Flødevigen Marine Research Station, Arendal, Norway, 17–19 February 1999. This included those presently involved in
research on population ecology of the lumpsucker in Norway and Iceland. Printed paper pictures of selected otoliths were distributed among the participants prior to the meeting to be interpreted by all the participants before they met. Thus, when the workshop started, all participants had similar experience with lumpsucker otoliths.

Lumpsuckers were sampled from the North Sea, Iceland, Norwegian Sea and coastal waters of both southern and northern Norway. They were partly caught with pelagic trawl during research surveys, and partly with gillnet by commercial fishermen on spawning grounds. Total length and sex of individuals was recorded onboard. Table 1 gives an overview of the number and size ranges of lumpsucker sampled together with the sampling areas and periods. A total of 66 otoliths was read by five interpreters, giving 330 independent age estimates.

In addition, length samples were compiled from catches by three different types of gears, namely trawls, traps and seaweed-floats, and also from artificially reared fish (Table 2). The trawls sampled juveniles and maturing adults in the open sea. The trap sampled spawning fish at a coastal spawning ground, whereas small juveniles were sampled from the seaweed patches near this spawning ground. Although commercial catches are taken with gillnets, this is a highly size-selective gear and was avoided for length samples. However, both settling on seaweed patches and the subsequent migration into the open sea are probably also highly size-selective processes. The samples from seaweeds were included since no other field observations were available from the early juvenile phase. The different length samples of lumpsucker are from several projects at the authors institutions, and details of gears and procedures will be given in separate publications from the individual projects.

The otoliths of the lumpsucker are very small, often less than 1 mm, and thus difficult to find without a proper dissection method. Three methods were tried and each of them is reported in this paper. All the fish were dead, with no ventricular contractions, before cutting. This is important because blood would make it even more difficult to see the otoliths.

2.2. Preparation and reading method

In the present work otoliths were read whole. They were cleaned using a small brush, and dried for a few minutes before being mounted with the sulcus (inside) down, in an epoxy resin (Eukitt) on a black plastic tray. In addition to facilitate handling, the Eukitt also resulted in improved contrasts between the zones.

Otoliths were read with binoculars used together with a monitor screen and studied by reflected light. Age estimation was made by identifying and counting annuli following recommended procedures (Williams and Bedford, 1974). An annulus was defined as a hyaline (winter) zone assumed to be formed annually in the season with low growth. The opaque (summer) zones represent the seasons with increased growth. Age was determined as age-group, using 1 January as the “birthday”. Only catch dates were available during interpretation, since information on length and sex could influence the estimates.

<table>
<thead>
<tr>
<th>Area</th>
<th>Time period</th>
<th>Size range (cm)</th>
<th>Sample size (numbers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Sea</td>
<td>July 1998</td>
<td>24–28</td>
<td>5</td>
</tr>
<tr>
<td>Southern Norway</td>
<td>March 1998</td>
<td>27–38</td>
<td>10</td>
</tr>
<tr>
<td>Southern Norway</td>
<td>April 1998</td>
<td>27–43</td>
<td>6</td>
</tr>
<tr>
<td>Southern Norway</td>
<td>June 1998</td>
<td>7–53</td>
<td>19</td>
</tr>
<tr>
<td>Southern Norway</td>
<td>February 1999</td>
<td>29–36</td>
<td>8</td>
</tr>
<tr>
<td>Northern Norway</td>
<td>April 1993</td>
<td>42–53</td>
<td>22</td>
</tr>
<tr>
<td>Northern Norway</td>
<td>February 1999</td>
<td>43</td>
<td>1</td>
</tr>
<tr>
<td>Iceland</td>
<td>October 1997</td>
<td>28–44</td>
<td>5</td>
</tr>
<tr>
<td>Iceland</td>
<td>August 1997</td>
<td>15–35</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>7–53</td>
<td>66</td>
</tr>
</tbody>
</table>
Table 2
Overview of fish samples and gear types used for compilation of length frequencies

<table>
<thead>
<tr>
<th>Area</th>
<th>Time period</th>
<th>Sample size (numbers)</th>
<th>Gear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norwegian Sea</td>
<td>June–August 1992–1999</td>
<td>4781</td>
<td>Pelagic trawl (Harstad and Åkra), 11 mm cod-end linen, fishing depth 0–25 m</td>
</tr>
<tr>
<td>Barents Sea</td>
<td>June–August 1992–1999</td>
<td>1264</td>
<td>Pelagic trawl (Harstad and Åkra), 11 mm cod-end linen, fishing depth 0–25 m</td>
</tr>
<tr>
<td>Fjords of western Norway</td>
<td>June 1998</td>
<td>99</td>
<td>Pelagic trawl (Harstad and Åkra), 11 mm cod-end linen, fishing depth 0–25 m</td>
</tr>
<tr>
<td>North Sea and Skagerrak</td>
<td>June–July 1999</td>
<td>113</td>
<td>Pelagic trawl (Harstad and Åkra), 11 mm cod-end linen, fishing depth 0–25 m</td>
</tr>
<tr>
<td>Senja&lt;sup&gt;a&lt;/sup&gt;</td>
<td>April 1999</td>
<td>831</td>
<td>Traditional Norwegian salmon trap, 8 m high, 25 m wide, equipped with an 80 m guiding net from the shore</td>
</tr>
<tr>
<td>Senja&lt;sup&gt;a&lt;/sup&gt;</td>
<td>May 1999</td>
<td>474</td>
<td>Artificially constructed seaweed-patches and a small-meshed landing net</td>
</tr>
<tr>
<td>Senja&lt;sup&gt;a&lt;/sup&gt;</td>
<td>June 1999</td>
<td>650</td>
<td>Artificially constructed seaweed-patches and a small-meshed landing net</td>
</tr>
<tr>
<td>Artificially reared&lt;sup&gt;b&lt;/sup&gt;</td>
<td>18 March 2000</td>
<td>252</td>
<td>N/A, all individuals measured</td>
</tr>
</tbody>
</table>

<sup>a</sup> Sifjorden of the Senja Island in northern Norway.

2.3. Analyses

Precision estimates and comparisons of individual readers were made using a predefined EXCEL worksheet courtesy of Guus Eltink, Netherlands Institute for Fisheries Research, IJmuiden, the Netherlands. A basic concept of this worksheet is to compare individual age estimates with the modal age of individual fish. The modal age of an individual is the estimate that was most frequently given by all readers combined. In case of two or more ages with equal frequency, the age given by the most experienced reader was used. If the age estimates given to an individual fish by Reader 1–Reader 5 were 2, 3, 4, 4, and 3 years, respectively, then three were chosen as the modal age. The rationale behind this is that the readers were expected to be numbered according to previous experience with age determination of otoliths. If the modal age of an individual is considered as an approximation to the real age, then accuracy of individual estimates may be calculated.

3. Results

3.1. Dissection methods

Three methods were tried to locate and dissect the otoliths. They were termed the horizontal, vertical and medial cut, respectively. Each method is illustrated in Fig. 1 and briefly described below.

Fig. 1. Three different methods for dissection of lumpsucker otoliths: (a) The horizontal cut is placed just above the eyes. The otoliths are seen on each side of the brain as shown by the arrows. With a pair of pincers each otolith is lifted out together with the membranous labyrinth. (b) The vertical cut is placed two eye-diameters behind the eyes and exposes the brain cavity in the head-end of the cut. The pincers show the location of the otoliths. (c) The medial cut divides the head in two equal halves. The otoliths are found behind the brain halves, within a hole in the bone tissue (photography: Ø. Paulsen).
3.1.1. The horizontal cut

A horizontal cut is made over, but close to the eyes to expose the brain (Fig. 1a, upper). The otoliths are then seen in the sacculus on each side of the brain, located posterior to the three big brain-nerves and anterior to the four minor brain-nerves (Fig. 1a, middle). The otoliths (sagitta, lapillus and asteriscus) are found in the membranous labyrinth. Use a small pincer to lift out the membrane, as shown in the bottom of Fig. 1a. The otoliths are all very small and care must be taken to ensure that the sagitta is selected.

3.1.2. The vertical cut

A vertical cut is made approximately 2 eye-diameters behind the eyes (Fig. 1b, upper). The pincer in the bottom of Fig. 1b shows the location of the sagitta. Continue as in method 1. This procedure is as effective as the horizontal cut.

3.1.3. The medial cut

Use a medial cut to divide the head into two equal halves (Fig. 1c, upper). By removing the two brain halves you will find the otoliths located within the brain cavity (Fig. 1c, bottom). Continue as in method 1. This method is probably the most time consuming, but is less dependent on a precise cut.

3.2. Description of the otoliths and age interpretation

Thorsteinsson (1981) described the otoliths (sagitta) of lumpsuckers as rounded and smoothly curved with a wide, massive and smoothly rounded rostrum. This is demonstrated in Fig. 2.

The interpretations made by the readers are illustrated in Fig. 2a–o and described in Table 3. It was often difficult to separate true annuli from other checks, which appeared more or less regularly throughout the otoliths. The appearance of the areas near the centre and at the margin of the otolith was given particular consideration and generated much discussion. Light reflections at the margin often caused confusion in defining the edge as opaque or hyaline.

For fish sampled in March–April, we assumed that there should either be a very thin opaque zone at the margin, representing a newly started summer growth, or a wide hyaline zone representing a nearly completed winter zone (e.g. Fig. 2k with hyaline edge and Fig. 2l with opaque edge). In June–August, we expected a wider opaque zone at the edge (e.g. Fig. 2j). There were, however, also several otoliths with a different margin resulting in uncertainties of the true age. Fig. 2d shows an otolith with a wide opaque edge in February. In this case, we considered that the hyaline winter zone had not been deposited. Such inconsistencies in the zonation pattern are, however, common with otolith studies and should not be used to disqualify the ageing method. In future analyses this should be studied in more detail using digitised pictures and image analysis software. Other methods of mounting the otoliths may also be considered to get a quantitative expression for the marginal otolith evolution through the year.

The appearance of the nucleus and the first growth zone was also quite variable, probably related to the amount of overgrowth of opaque material in older specimen. In fact, the five readers regarded the uncertainty in locating the first opaque zone as the main reason for discrepancies in age estimates. For eight of the 66 otoliths considered (12%), difference in age estimate by individual readers was 2 years or more, indicating low accuracy. However, Fig. 2 shows that the size of the 0-group opaque summer zone was small compared to the I-group summer zone. For the otoliths shown the longest diameter of the 0-group opaque summer zone was small compared to the I-group summer zone. For the otoliths shown the longest diameter of the 0-group opaque growth zone was only 36% (S.D. = 4.3%) of that of the I-group. For the I-group compared to the II-group zone, the corresponding figure was 83% (S.D. = 3.7%). This means that the size of the innermost opaque zones may be used to distinguish between the zones of the 0- and I-group. If the first visible opaque zone is large (e.g. with a diameter greater than 60% of the next zone), then it may be regarded to include the I-group summer zone.

Based on the interpretations made by individual readers at the workshop, a modal age was defined for each fish. Fig. 3 shows a growth curve for lumpsuckers based on these modal ages. Although this curve was based on samples from different areas and years it may still be useful, since no other reliable growth estimate of lumpsucker exists at present. Estimated parameters of the von Bertalanffy’s growth equation were K = 0.421, L∞ = 45.7 and t0 = 0.57 when age was represented by months with April as birthday.
Mean length at age 2, 3 and 4 was 1, 3 and 6 cm larger for females than for males. The differences were not significant though (t-tests, \( p > 0.1 \)), as to be expected due to the low sample size of any combination of age and sex.

3.3. Precision

The precision of the WS readings is summarised in Fig. 4, which shows the distribution of individual age estimates for each modal age. There were no discrepancies in ageing of modal-age-one lumpsucker by the individual readers, as shown by the 100% agreement with modal age, but the discrepancy increased with age. For all readers combined, agreement with modal age was reasonably high (>70%) up to and including age 4, beyond which it dropped to around 50%. The mean age was generally close to modal age for all readers and ages. The absolute difference increased with age, and the highest values were \(-0.4\) and \(-0.6\) years for modal age 5. The remaining values were all within \(\pm 0.3\) years. Thus, the discrepancies seemed to be related to precision more than to any systematic disagreement between the readers.
Table 3
Examples of interpretation (illustration numbers refer to Fig. 2)

<table>
<thead>
<tr>
<th>Illustration No.</th>
<th>Length (cm)</th>
<th>Sex</th>
<th>Modal age</th>
<th>Edge</th>
<th>Location</th>
<th>Date</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>30</td>
<td>Male</td>
<td>4</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>February 1999</td>
<td>Wide hyaline edge</td>
</tr>
<tr>
<td>b</td>
<td>29</td>
<td>Male</td>
<td>3</td>
<td>Opaque</td>
<td>Southern coast of Norway</td>
<td>March 1998</td>
<td>All annuli distinct</td>
</tr>
<tr>
<td>c</td>
<td>29</td>
<td>Male</td>
<td>4</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>February 1999</td>
<td>Second annulus unclear</td>
</tr>
<tr>
<td>d</td>
<td>43</td>
<td>Female</td>
<td>4</td>
<td>Opaque</td>
<td>North Cape</td>
<td>February 1999</td>
<td>First annulus unclear</td>
</tr>
<tr>
<td>e</td>
<td>38</td>
<td>Female</td>
<td>5</td>
<td>Opaque</td>
<td>Southern coast of Norway</td>
<td>March 1998</td>
<td>Probably 4, misinterpreted as 5</td>
</tr>
<tr>
<td>f</td>
<td>31</td>
<td>Male</td>
<td>3</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>February 1999</td>
<td>Wide hyaline edge</td>
</tr>
<tr>
<td>g</td>
<td>27</td>
<td>Male</td>
<td>3</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>March 1998</td>
<td></td>
</tr>
<tr>
<td>h</td>
<td>37</td>
<td>Female</td>
<td>3</td>
<td>Opaque</td>
<td>Southern coast of Norway</td>
<td>March 1998</td>
<td></td>
</tr>
<tr>
<td>i</td>
<td>27</td>
<td>Male</td>
<td>3</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>April 1998</td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>28</td>
<td>Female</td>
<td>3</td>
<td>Opaque</td>
<td>Fjord of western Norway</td>
<td>June 1998</td>
<td></td>
</tr>
<tr>
<td>k</td>
<td>34</td>
<td>Male</td>
<td>3</td>
<td>Hyaline</td>
<td>Southern coast of Norway</td>
<td>April 1998</td>
<td>Very thin hyaline edge</td>
</tr>
<tr>
<td>l</td>
<td>32</td>
<td>Male</td>
<td>3</td>
<td>Opaque</td>
<td>Southern coast of Norway</td>
<td>April 1998</td>
<td>Very thin opaque edge</td>
</tr>
<tr>
<td>m</td>
<td>8</td>
<td></td>
<td>1</td>
<td>Opaque</td>
<td>Fjord of western Norway</td>
<td>June 1998</td>
<td>Sex unknown</td>
</tr>
<tr>
<td>n</td>
<td>34</td>
<td>Female</td>
<td>3</td>
<td>Opaque</td>
<td>Fjord of western Norway</td>
<td>June 1998</td>
<td>Wide opaque edge</td>
</tr>
<tr>
<td>o</td>
<td>36</td>
<td></td>
<td>3</td>
<td>Opaque</td>
<td>Iceland</td>
<td>October 1997</td>
<td>Sex unknown</td>
</tr>
</tbody>
</table>
The precision may be expressed as the coefficient of variation (CV) for all individual age estimates of each modal age. For all 25 combinations of reader and modal age (5 readers × 5 ages), 16 had CV less than 15% and 21 less than 20%. Weighted mean CV across age varied from 9 to 17% for individual readers, with a mean value of 15%. To illustrate this level of precision, we may consider the following example. If 10% of the otoliths were estimated to age two, 80% to age 3 and 10% to age 4, then the modal age would be 3 with a CV of 15%.

According to the preliminary length frequency analyses of the stock (Section 3.4), the length ranges 7–12 and 18–26 cm in June should consist exclusively of ages 1 and 2, respectively. In the WS readings, all 7–12 cm individuals were classified as age 1. Although there were only eight individuals in this group, this suggests that high accuracy and precision should be possible for age interpretations of the youngest individuals. For 18–26 cm lumpsuckers, the individual readers classified 56, 57, 69, 76 and 63%, respectively, as age 2, which seems to suggest rather low accuracy. Verification of the first few age groups is clearly crucial for further development of the interpretation method.

3.4. Comparison with independent length frequencies

Length compositions of small juveniles sampled with traps made of seaweed are shown in Fig. 5a and b. Juveniles collected in May were mainly in the range 1.5–4.0 cm, with an average length of 2.6 cm. In June they ranged between 2.0 and 5.0 cm, with an average of 3.6 cm. In this area, the spawning period is mainly from end March to end May (own unpublished observations) and in previous experiments the first registration of newly hatched juveniles was 9 June, when approximately 250 individuals were found attached to a float (own unpublished observations). These juveniles were only about 5 mm long. In July and August, their length was 5–10 mm.

In the light of these experiments, it seems probable that the juveniles in Fig. 4a and b were I-group, hatched in the preceding summer. In June a single individual, which measured 8.2 cm, was also collected. However, the experiments indicate that I-group lumpsuckers usually leave the littoral/coast when they reach a length of about 4–5 cm in June.

After leaving the coast, juvenile lumpsuckers are found pelagically in the high seas. Fig. 5c and d shows length frequency distributions of lumpsuckers caught in pelagic trawl in the Norwegian and Barents Seas during July–August 1991–1999 and Fig. 6 shows comparable data from the North Sea, Skagerrak and southern Norwegian fjords. It seems probable that the first modal group in each of these frequency distributions represents a single age group, while the second may represent one or a few age groups. The size range of the lower modal groups corresponds to the size of modal age I, while the second group cover lengths attributed to ages 2–6 (Fig. 3).

Fig. 7 shows that artificially reared II-group was approximately 20 cm in March. This is between the two modes from July to August (Fig. 5c and d). Thus, if growth in the wild is close to or slightly below that of the reared individuals, this is compatible with the interpretation of the lower mode in Fig. 5c and d as I-group.

The length distribution in Fig. 5e represents spawning lumpsuckers. They were caught with a trap, which is assumed to be almost none-selective for fish size. Similar experiments were made over 4 years, without any clear difference in length composition of the catches between years. Males and females constitute separate modal groups. The length of the male group corresponds to the length of modal age II–III, while the female group corresponds to modal age IV and
older (Fig. 3). Data from the artificially reared individuals showed that 86% of the males and 34% of the females matured as II-group (own unpublished results). However, the size of the mature part of the reared males and females (Fig. 7) was about 10 cm below that found in the wild (Fig. 5e). It is probable that maturation rate is lower in the wild than in reared conditions.

Based on the discussions above, the size-composition at the spawning ground, and the maturation rate of artificially reared male and female lumpsters, it is tempting to assume that the male spawners were mainly III-group and large II-group, whereas the females were mainly IV-group and older.

4. Discussion

4.1. Precision

The precision of the age estimates in the present work was expressed as the CV as recommended by Campana et al. (1995). The level of precision was 15%, varying from 9 to 17% for individual readers compared with the modal age. This seems to be within the upper part of the range in CV from comparable age-reading experiments. Recently published CVs of age estimates include the ranges 6–22% (Campana et al., 1995), 8–12% (Bergstad et al., 1998) and 3–13% (Kimura and Lyons, 1991). Based on simulation
modelling, Powers (1983) argued that a CV of 10% should be sufficient for using the age estimates to calculate population rate parameters (i.e. growth and mortality) for use in stock assessments.

Thus, although the current ageing seems reasonably precise as a first approximation, further work should be directed towards increasing precision further. One of the main problems encountered during age determination was defining the first few growth zones. However, our subsequent comparisons with length frequencies suggest that age of the youngest individuals may be determined from fish length. Also, the pattern of zone widths may probably be used to distinguish between the 0-group and the I-group.
growth zones. Precision would increase if the expected zonation pattern could be more clearly defined or if interpretation is based on more objective criteria (as length). To facilitate comparisons both within and between laboratories, it is also important that the methods used are described adequately. This has not been done previously. Therefore, this paper also details what was found to be practical methods for

Fig. 6. Length frequency distributions of lump sucker from southern Norway. Fish caught with pelagic trawl.

Fig. 7. Length frequency distributions of 2-year-old artificially reared lump sucker. All individuals were hatched in June/July 1997. Lengths were measured 18 March 2000.
dissection, preparation and reading of lumpsucker otoliths.

4.2. Interpretation and accuracy

Our interpretation of otoliths and length frequencies imply that those lumpsuckers of 3–4 cm length found attached to floating seaweeds in May and June were of the same age as those of 5–15 cm length found pelagically in the open sea in July–August. Both were interpreted as I-group. It may seem unreasonable that these two groups with vastly different modal length should be the same age. However, there are several arguments that suggest they are.

First, the two length distributions do overlap to some extent for lengths around 5 cm. Since it is reasonable to assume that the migration from the coast is related to growth, the individuals found attached to seaweeds may be the ones from only the extreme lower tail of the total length distribution of the I-group. Correspondingly, those found in the open sea would then represent the right-end part of the same distribution. Secondly, the alternative interpretation, namely that the lower modes in length frequency distributions from the open sea represents the II-group, may seem more unreasonable. If the two modes in Fig. 5c and d represent 2- and 3-year-old, respectively, then growth in length from age 1 to 2 has to be much lower than that from age 2 to 3. Thirdly, the zonation pattern in the otoliths was consistent with the hypothesis that the absolute growth during the I-group stage is very large compared to the growth of both 0- and II-group. Lastly, the growth pertaining to the interpretation of the lower mode in Fig. 5c and d as I-group is comparable with the observed growth from artificially reared lumpsuckers.

Our age estimates together with length frequencies from the spawning ground, suggest that male lump-suckers may spawn for the first time at age 3, and females at age 4. This is at least 1 year less than all previous estimates of age at maturity (Sæmundsson, 1926; Bagge, 1967; Schopka, 1974; Thorsteinsson, 1981). However, none of the other estimates of age at maturity of lumpsuckers were based on reliable descriptions of the reading method used. A direct comparison of our estimates with the previous ones is therefore not possible. However, it should be men-tioned, that all available assessments (Bertelsen, 1994; Albert, 1999; Anonymous, 1999) indicate that the stock size of lumpsucker in the north-east Atlantic has been severely reduced in the period since those previous estimates were made. From other fish stocks, it is known that age at maturity may be reduced at low population size (e.g. Pitt, 1975; Jørgensen, 1990). It is possible that similar processes may have occurred for the lumpsucker, and that the low age at maturity indicated in this paper is another warning signal for the present stock situation.

Indications of age composition and growth rate are important for stock assessments and management advice. It is therefore crucial that the ageing method is reliable and should preferably be verified using recommended procedures (Beamish and McFarlane, 1983; Geffen, 1992). However, since the duration and distribution of the lumpsucker in the post-larvae and early juvenile phase are poorly understood, the problem of representative sampling seems particularly difficult for this species. It may therefore not be possible to achieve a proper verification of the age determination method at present. However, in this paper, we make preliminary attempts to verify the age-reading by comparison with all available information on stock structure. The ageing was clearly supported by the analyses of length frequencies of juveniles sampled prior to and after the migration from the coast. It seems therefore possible to achieve plausible and reasonably precise age estimates of lumpsuckers from the otoliths. Still, further verification (e.g. by tracing the edge properties throughout the year) should be done before age-structured data are used in assessments of this species.

In addition, the focus of lumpsucker research in the future should be on the growth and duration of the coastal life, and the links between coastal and oceanic abundance and distribution areas, both regarding the outward migration of juveniles and inward migration of the spawning stock. A first approach may be to analyse spatial trends in abundance of individual length groups in the Norwegian and Barents Seas. Further, when the age of the lower modal group is established, a second age-reading workshop should be arranged, to secure consistent reading methods between laboratories and to achieve accurate estimates of growth and mortality in the stock.
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