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# A method to estimate annual larval production of Norwegian spring－spawning Atlantic herring (*Clupea harengus*)*

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**Abrtract** A comprehensive survey in the larva-distributed area of Norwegian spring－spawning herring along west Norwegian coast was carried out annually by the Institute of Marine Research, Bergen, during 1986～1990. Moreover, 2 small subareas were sampled repeatedly (usually twice a week) off Sunnmøre and at Buagrunnen during the hatching period each year. The daily larval production was worked out with the data obtained from the comprehensive survey covering the entire larva－distributed area. Data obtained from the subareas had been used to construct the hatching curve so as to get the daily larval production percentage in the annual larval production which could be estimated after then. The annual larval production from 1986 to 1990 were $1.7\times10^{12}$, $3.9\times10^{12}$, $35.4\times10^{12}$, $72.8\times10^{12}$ and $99.1\times10^{12}$ individuals.

**Key words** *Clupea harengus*, larvae, spring－spawning, larval production, Norway.

Field investigation of the eggs and larvae of marine fin fish is caried out mainly to assess the adult spawning biomass and the distribution of eggs and larvae, and to understand how the environmental variations and other species abundance changes affect the stock so that the abundance of the stock can be maintained[1].

Annual surveys of herring larvae for estimating spawning stock size have been widely used in the North Atlantic[2－4]. Cushing and Bridger[5] firstly demonstrated a relationship between larval abundance and spawning stock biomass in 1967.

The Norwegian spring-spawning herring (*Clupea harengus*) is the largest stock of the Atlanto－Scandian herring tribe. The spawning takes place from February to April; the spawning grounds are situated mainly along west Norwegian coast[6－8].

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## 1 Materials and methods

### 1.1 Sampling

The collections of herring larvae were conducted mainly in the area 61°30′N～66°00′N close to west Norwegian coast during March and April each year from 1986 to 1990. Sampling was carried out in two steps: 1) surveying the entire larva－distributed area with an ocean－going research vessel twice in a hatching season (only 1 cruise was arranged in 1990); 2) repeated sampling from a set of fixed stations off Sunnmøre and at Buagrunnen separately twice a week throughout the hatching season.

The herring larvae were sampled with a modified conical net (T 80, opening area 0.5m$^2$, mesh 375 μm[9]). The vertical hauls were taken from 150 m depth (or 5m above bottom) to the surface with haul-

ing speed 0.5 m/s[10]. The larvae in the sampling buckets were sorted and counted in terms of 50 inds (or all samples if less than 50), and their standard length (SL) were measured. The larvae were preserved in 2% or 4% formalin. In the laboratory, 20 larvae (or all the inds if less than 20) from each station were staged according to the scale given by Doyle[11]. Some larvae were staged when measured[10,12,13].

The mean duration of the different substages during the surveying years were set out by Fossum[10] based on several scientists' work. The standard lengths (SL) of larvae in each substage are only available for 1986[12] (Table 1).

**Table 1　Mean duration and mean standard length of yolk－sac larvae in different stages of Norwegian spring－spawning herring**

| stage | 1 a | 1 b | 1 c |
|---|---|---|---|
| duration/d | 3 | 4 | 3 |
| length/mm | 8.1(0.8) | 9.1(0.9) | 10.0(0.88) |

* Standard deviations for length measurement are given in parenthesis.

The number of larvae per $m^2$ surface ($N$) was calculated by the formula:

$$N=(n\times d)/v=(n\times d)/(a\times d)=n/a \qquad (1)$$

where, $n$, the number of larvae each sampling; $d$, the sampling depth; $v$, the water volume filtered through the net; a, the opening area of the net (0.5 $m^2$).

The sampling of one cruise a day was carried out at 7 fixed stations off Sunnmøre (62°00′N～63°00′N) and 5 at Buagrunnen (63°00′N～64°00′N), which was repeated twice a week throughout a hatching season starting before the first egg was hatched and stop ping after all eggs were hatched. All the stations were selected on the basis of previous spawning locations.

The sampling net and operation were the same as those applied in the survey of the entire larva－distributed area. The number of larvae under per $m^2$ surface was calculated applying equation (1). If bad weather prevented any station from being sampled in the cruises, attempts were made to take a sample at a location as close as possible to the original station[14].

### 1.2　Construction of the hatching curve

The hatching curves were plotted with the percentage of daily larval production versus the corresponding date. One curve was constructed with the data collected at the fixed stations off Sunnmøer, another with the data collected at the fixed stations at Buagrunnen.

One $m^2$ surface was taken as the standard unit area in the calculations. To obtain the average daily larval production per $m^2$ surface, at first, the number of 1b larvae sampled at each station was converted into the number per $m^2$ surface applying equation (1), then the average number of 1b larvae per $m^2$ surface at the stations was worked out. According to Table 1, the duration of the 1b larval substage is 4 d, i.e. the ages of the 1b larvae from 4th day to 7th day after they are hatched, and the average age of 1b larvae is, therefore, 5 d. Hence, the larval production estimated from the number of 1b larvae sampled in 1 day is the cumulative larval production during 4 d. It is given as follows: $N_0=N_t\cdot e^{M\cdot t}$ (2)

where $N_0$ is the cumulative larval production in 4 d; $N_t$ is the number of 1b larvae sampled in 1 day; $M$ is the daily larval mortality (a value of 0.1 per day was used)[15]; $t$ is the age of lavae in day (5 d on average for 1b larvae). Assuming that the daily larval production in the 4 d was constant, it is 1/4 of the cumulative larval production. Thus, the average daily larval production per $m^2$ surface from 7th to 4th day before the 1b larvae were sampled were obtained.

The beginning of the hatching season was indicated by the earliest hatching day of the larvae sampled in the cruises, and the end of the hatching season was indicated by the latest hatching day of the larvae, provided the entire hatching season was covered.

After the average daily larval productions per $m^2$ surface were worked out, they were converted into their percentage in the total annual larval production per $m^2$ surface. Assuming the average daily larval production per $m^2$ surface is representative of that in the entire larva-distributed area, the daily percentage

is representatitve of that in the total annual larval production on the given day.

Considering hatching was a continuous process, the hatching curves were smoothed using the equation: $P_j' = (P_{j-1} + 2P_j + P_{j+1})/4$ (3)

where $P_j'$ is the smoothed percentage of larval production on day $j$, $P_{j-1}$, $P_j$ and $P_{j+1}$ are the percentages of larval production on day $(j-1)$, $j$ and $(j+1)$ respectively.

It was assumed that the hatching curve off Sunnmøer represented the hatching pattern not only in the area 62°00′N～63°00′N but also in the surveyed area south of 62°00′N, and that the hatching curve at Buagrunnen represented the hatching pattern not only in the area 63°00′N～64°00′N but also in the surveyed area north of 64°00′N.

### 1.3 Calculation of daily larval production

The daily larval production was computed using the quantity of 1b larvae (9.0～9l.9 mm SL group in 1986) sampled by the ocean-going vessel. The larval abundance relating to a cruise investigation was calculated with a computer programme compiled by the Institute of Marine Research, Bergen[16].

The quantity of 1b larvae was used to calculate the number of newly hatched larvae with equation (2). Then the average daily larval production of 4 d could be obtained.

In 1986, the larvae sampled in the survey were not staged by yolk－sac development. As shown in Table 1, the standard length of 1b larvae was 9.1 mm (SD=0.9), hence, the abundance of the larvae in the 9.0～9.9 mm group was used to estimate the larval production in that year. According to Fossum[10], the growth rate of larvae (TL＜10 mm) in 1986 was 0.25 mm/d, which means it need 4 d for the larvae to grow from 9.0 to 9.9 mm. Assuming the average hatching length was 8 mm (Table 1), the ages of larvae in 9.0～9.9 mm group were from 5 d to 8 d, averaged 6 d. Therefore, the daily larval production can be obtained following the procedure outlined above.

### 1.4 Estimate of annual larval production

The annual larval production is given by the equation: $L = (N_0/\sum_{j=1}^{n} P_j) \times 100$ (4)

where $L$ is the annual larval production; $N_0$ is the larval production in a hatching period; $n$ is the days of hatching period.

As mentioned previously, 2 cruises were usually carried out in a hatching season. The estimate of annual larval production was weighted by the cumulative percentages in the 2 hatching periods as follows:

$$L = (N_{01} + N_{02})/\sum_{i=1}^{n}(P_{1i} + \sum_{j=1}^{m} P_{2j}) \quad (5)$$

where $N_{01}$ and $N_{02}$ are the numbers of hatched larvae in hatching period 1 and 2 respectively; $P_{1j}$ and $P_{2j}$ are percentages of daily larval productions in the hatching period 1 and 2 in the annual larval production; $n$ and $m$ are days of period 1 and period 2, respectively.

## 2 Results

### 2.1 Hatching curves

The difference of hatching season duration in an area can get to 16 d between years (Table 2). The annual larval production in the 2 areas was calculated separately. The hatching curves are shown in Fig.1.

**Table 2 Hatching season off the Sunnmøer and at the Buagrunnen spawning grounds (during 1986～1990)**

| year | Sunnmøer | | Buagrunnen | |
|---|---|---|---|---|
| | date | days | date | days |
| 1986 | 10/3～25/4 | 47 | 6/3～26/4 | 52 |
| 1987 | 5/3～25/4 | 52 | 8/3～22/4 | 46 |
| 1988 | 15/3～29/4 | 46 | 14/3～30/4 | 48 |
| 1989 | 14/3～19/4 | 37 | 11/3～15/4 | 36 |
| 1990 | 9/3～21/4 | 44 | 9/3～14/4 | 37 |

### 2.2 Estimate of annual larval production

The estimated annual larval productions were shown in Table 3.

**Table 3 Total larval production of Norwegian spring-spawning herring in each hatching season during 1986～1990**

inds

| year | 1986 | 1987 | 1988 | 1989 | 1990 |
|---|---|---|---|---|---|
| estimate/$\times 10^{12}$ | 1.7 | 3.9 | 35.4 | 72.8 | 99.1 |

## 3 Discussion

### 3.1 Use of yolk－sac in 1b larvae

The larvae of the Atlanto－Scandian herring off

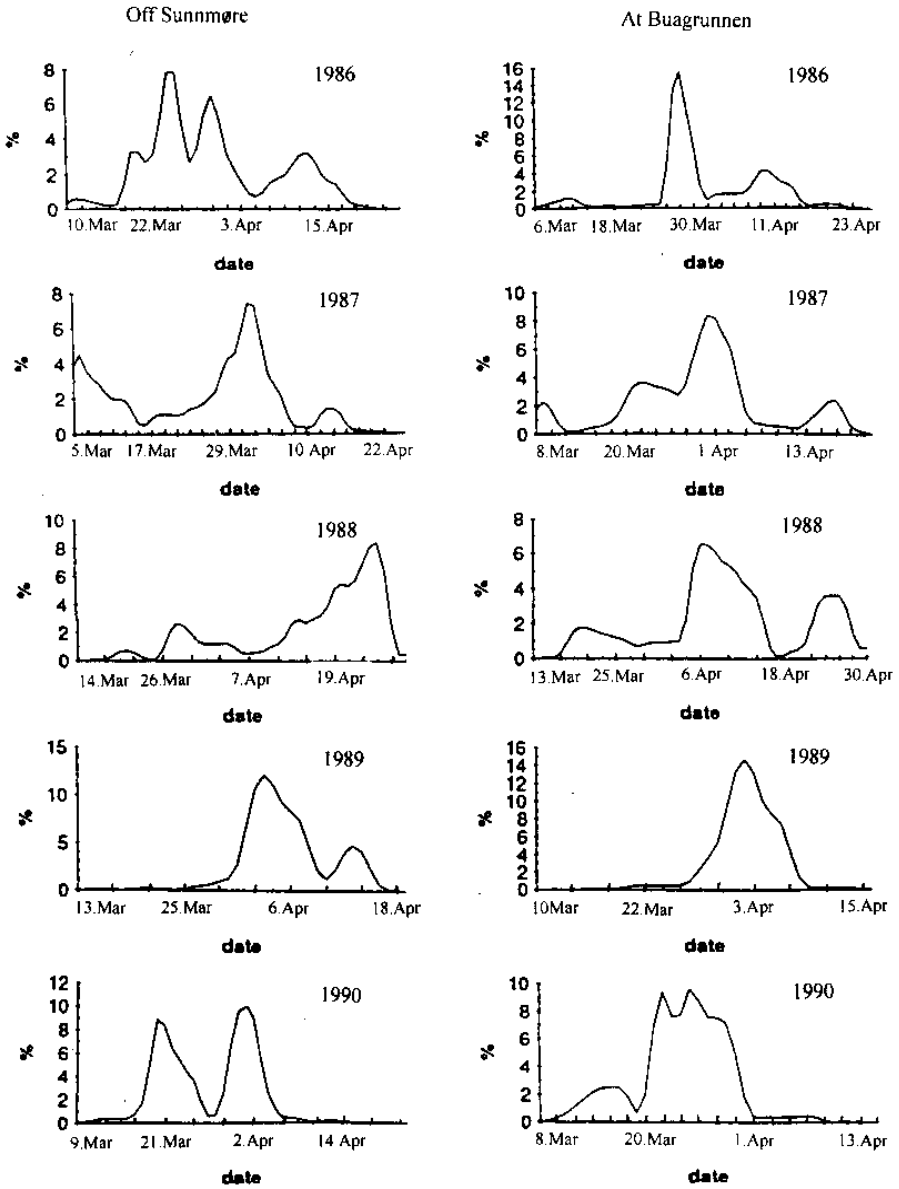


**Fig. 1　The hatching curves of the Norwegian spring - spawning herring off the Norwegian west coast in** 1986～1990

west Norwegian coast, Seliverstov[17] found that during the first 12 h they did not respond to light or had a weak negative phototaxis. Two days after hatching, most larvae were able to remain in mid - layer water and possessed a strong positive phototaxis. In the open sea, therefore, larvae presumably move to pelagic layers during the second day. Comparison of the age composition of larvae collected on the spawning grounds with that of larvae reared under artificial conditions showed that day-5 larvae predominated in the upper 50～100 m layer of the water in the sea, i.e. over 3～3.5 d they migrate for 50 m upwards if spawning depth is 100～150 m. Therefore, 1 b larvae are more available during the surveys than 1 a larvae.

At the end of substage 1 c, the larvae have absorbed their yolk – sac completely, and experience a high mortality if there is lack of suitable food[18,19]. If the number of 1 c larvae is used to estimate the spawning stock size, the inaccurate estimates of mortality would bring bigger error into the assessment of the annual larval production than those when the number of 1 b larvae is used. From an overall evaluation, the quantity of larvae in substage 1b was suitable to be used to estimate the herring larval production.

The duration of substage 1 a is affected by both the amount of yolk and the temperature, and the duration of substage 1 b is only affected by temperature[20]. The experiment done by Fossum[20] shows that the duration of substage 1 b is 1.2 d and 3.3 d at 9℃ and 6℃ respectively. According to the hydrography data collected during the larval surveys (supplied by the Institute of Marine Research, Bergen), the surface temperature in the entire larva-distributed area during the surve periods ranged from 4.5～5℃.

### 3.2 Sampling gear

The sampler used was T – 80 net, in front of which a bridle was fixed with a triangle attachment. When sampling the net was hauled vertically with a speed of 0.5 m/s. The catching efficiency of T – 80 net, compared with the high – speed Gulf Ⅲ sampler for sampling capelin larvae in the Barents Sea, was lower (H. Bjørke, Institute of Marine Research, Bergen, unpublished). The Gulf Ⅲ sampler caught 7～49 times as many as T – 80 sampler. The average body length of the sampled larvae was 9.82 mm in Gulf Ⅲ sampler and 8.87 mm in T – 80. The catch ratio was generally 9∶1 in favour of Gulf Ⅲ sampler.

The vital difference between both sampling devices may be that Gulf Ⅲ runs at a higher speed. Heath[1] stated that, in general, the low towing speed of framed nets precluded their use for quantitative sampling of active larvae. The high – speed (3m/s) Gulf – Ⅲ samplers are preferable[22], hence the optimum selection for estimate of larval production[22].

### 3.3 Larval damage during smpling

Some yolk – sac larvae were damaged with their yolk – sacs tearing away during sampling, which were excluded from the analysis except 1987 when 10%～25% of yolk – sac larvae were damaged.

The relative percentage of 1b larvae of the identifiable yolk – sac larvae varied considerably (30%～60%) among the years 1987～1990(Table 5). If the composition proportion of the damaged larvae is the same as that of the non – damaged larvae, the number of 1b larvae will be seriously underestimated in some years (e.g. 1988), consequently, the larval productions will also be underestimated.

**Table 5 Proportion of 1a, 1b, and 1c yolk – sac larvae among the sampled non – damaged larvae**

| stage | year | | | |
|---|---|---|---|---|
| | 1987 | 1988 | 1989 | 1990 |
| 1a | 14 | 9 | 26 | 47 |
| 1b | 53 | 56 | 30 | 36 |
| 1c | 33 | 35 | 44 | 17 |

This problem of underestimate can be overcome if the larval production was estimated with length data, which need more exact information or knowledge on the larval hatching length.

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# 挪威春季产卵的大西洋鲱仔稚鱼年孵化量的估算方法

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**摘　要**　1986～1990 年间，挪威卑尔根海洋研究所每年都对挪威西海岸春季产卵的大西洋鲱仔稚鱼的分布区进行一次综合性调查，每年在大西洋鲱的孵化期，都在 Sunnmøre 近岸和 Buagrunnen 的两个小区重复取样(通常每周 2 次)，并用覆盖整个孵化区的综合调查所得的资料计算出仔稚鱼日孵化量，用两个小区所得的资料作孵化曲线，从而得出在孵化期内仔稚鱼孵化量占年总孵化量的百分比。1986～1990 年间仔稚鱼年孵化量分别是 $1.7\times10^{12}$、$3.9\times10^{12}$、$35.4\times10^{12}$、$72.8\times10^{12}$和 $99.1\times10^{12}$尾。

**关键词**　大西洋鲱，仔稚鱼，春季产卵，孵化量，挪威