Ageing and Back-Calculating Growth Rates of Pacific Herring, *Clupea pallasii*, Larvae by Reading Daily Otolith Increments

Erlend Moksness and Vidar Wespestad

ABSTRACT: Newly hatched Pacific herring, *Clupea pallasii*, from eastern Bering Sea were released into an outdoor concrete basin and raised on natural plankton. The larvae were sampled frequently during the first two months, and a growth curve for that period was established. Otoliths from 52 herring larvae, collected over the entire experimental period, were examined for daily increments. Increments were formed on a daily basis from the end of the yolk-sac stage (age 8 days) and were found to be independent of the growth rate of the herring larvae. The increment widths, however, reflected the growth rate of the larvae.

Otoliths have been used to estimate daily age and growth since Pannella (1971) reported that the number of primary increments in otoliths approximated daily deposition. Brothers et al. (1976) raised northern anchovy, *Engraulis mordax*, and California grunion, *Leuresthes tenuis*, from eggs in the laboratory and verified that increment formation occurred daily. Jones (1986) found that daily increment analysis had been applied to at least 29 species of larval fish to estimate age, but validation of the technique was based on laboratory observations that may be invalid for wild populations. Atlantic herring, *Clupea harengus*, have been investigated for daily increment formation (Gjøsaeter and Øiestad 1981; Geffen 1982; Lough et al. 1982; Jones 1985; Messieh et al. 1987). Contradictory findings by various authors have created controversy concerning whether Atlantic herring deposit growth increments on a daily basis. Gjøsaeter and Øiestad (1981) found 99 increments in 97 d herring grown in a large outdoor enclosure; however, their sample size was too small to be conclusive (Jones 1986).

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The early life history of Pacific herring, *Clupea pallasii*, from the eastern Bering Sea was studied in the same enclosure as Gjøsaeter and Øiestad's (1981). All the herring were spawned on the same day, and larvae hatched over a 3 d period. Otoliths were examined periodically during the experiment and from surviving individuals at the termination of the experiment.

MATERIAL AND METHODS

Pacific herring eggs were collected from the spawning grounds in Bristol Bay, AK at low tide on 24 May 1986. The eggs collected had been deposited between 22 May and 23 May on intertidal rockweed, *Fucus* sp. Water temperature at the time of spawning was 4.5°C and salinity was 30‰. Further spawning did not occur (before or after) in the area in which the eggs were collected. *Fucus* fronds with light egg coverage (1–2 egg layers) were collected at random within the spawning area, packed into half liter plastic bags, filled with seawater, and sealed. A total of 25 bags were filled with about 2,000 eggs/bag. The bags were placed in insulated shipping containers with gel ice, which were shipped via air to the Flødevigen Biological Station in Arendal, Norway. Upon arrival at Flødevigen the eggs were unpacked and placed in hatching boxes, which were supplied with flowing seawater at 7.7°C and at salinity of 32‰.

The eggs began hatching on 10 June 1986 and finished by 12 June 1986. Fifty percent hatching (11 June) was defined as day 0 (age = 0) in the experiment. Newly hatched larvae were collected from incubation boxes in white plastic cups in groups of 5–25, counted, and transferred to 5 L cylinders, which were placed in an 8.1°C water bath. A total of 25,200 larvae hatched from an estimated total of 50,000. The eggs were not treated during incubation and a heavy fungus growth developed. This caused most of the egg mortality.

On 13 June (age 2 days) 24,840 larvae were released into a large artificial outdoor basin—2,000 m^3 in volume, 600 m^2 in surface area, and 3.5 m at maximum depth. The basin had been filled with seawater pumped from a depth of 19 m. At the time the larvae were introduced, phytoplankton and zooplankton production was high. The basin was drained on 12 August, and the remaining herring larvae in the basin were collected (age = 62 days).

The larvae in the basin were sampled daily using a two-chambered plankton net of 500 μm mesh and a total sampling area of 0.3 m^2. The net was drawn diagonally across the basin at a depth of 2 m and the total volume sampled was 7.5 m^3. All the sampled larvae were preserved in 80% buffered ethanol. A more detailed description of the basin experiment is given in Wespestad and Moksness (1989)[1]. The standard length (snout to the tip of the notochord or hyplural plate) of the larvae/juveniles were measured to the nearest 1.0 mm. The largest otoliths, the sagittae, were removed and mounted on a glass plate with clear nail polish. The dry weight of each individual was measured to the nearest ±1 μg, after drying at 60°C for 24 hours. Otoliths of herring juveniles over 30 mm had to be ground, to expose growth rings. This was done with fine grit paper (30 μm and then 0.3 μm). The maximum magnification that could be used to read the growth rings in the microscope was × 400, owing to insufficient light penetrating the section. Table 1 gives an overview of the number of larvae used in otolith analyses. A detailed description of the otolith analyzing system and the method used are given in Andersen and Moksness (1988).

TABLE 1.—The number of larvae examined for daily increments by date.

Date	Age	Number examined
25 June	14	1
3 July	22	2
10 July	29	5
14 July	33	5
18 July	37	5
21 July	40	5
27 July	46	10
12 Aug.	62	19

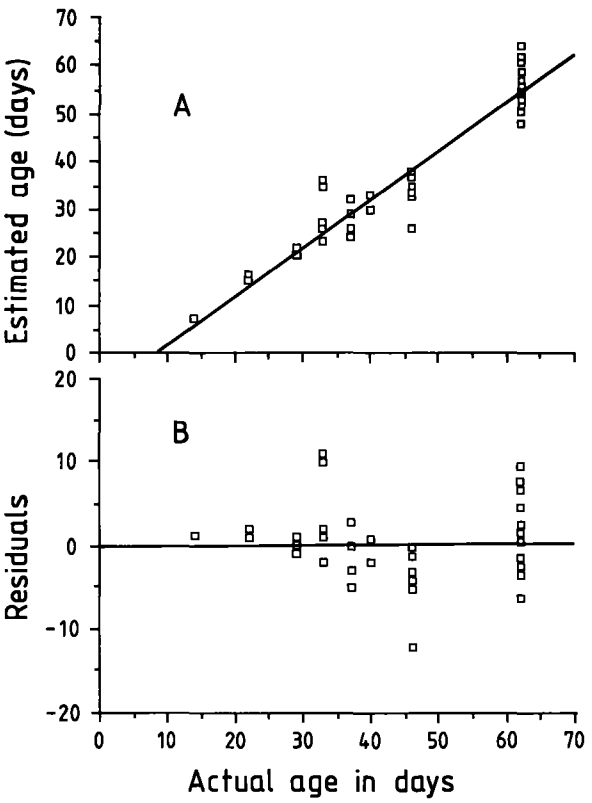

FIGURE 1.—Relationship between estimated and actual age of Pacific herring in days (A), $y = -8.3 + 1.0144\,x$, $r = 0.96$; and the pattern of the residuals (B).

RESULTS

The relationship between the estimated age (estimated number of rings) and the actual age of the herring larvae is shown in Figure 1. The residuals are shown in the same figure. The relationship was linear, and the deposition rate was not significantly different from one increment per day from age 8 days of the larvae (t-test; t = 0.08, df = 50). The residuals were equally distributed around zero indicating no trend in the data. The discrepancy did not tend to change sign or range with the age of the larvae (Fig. 2), indicating that the frequency of daily increments in the otoliths did not change with the age of the larvae. The standard deviation of estimated age from real age was ±4.2 days with a range from −12 to +11 days; therefore, there is little correlation between estimated age and length (Fig. 3). Apparently, there is no relationship between the rate of otolith ring deposition and larval growth.

All three relationships between larval standard length and otolith radius exhibited a good fit to the data (Fig. 4, $r > 0.96$), but the first, the

[1]Wespestad, V., and E. Moksness. 1989. Observations on the growth and survival during the early life history of Pacific herring, *Clupea pallasi*, from Bristol Bay, Alaska, in a marine mesocosm. Submitted Fish. Bull., U.S.

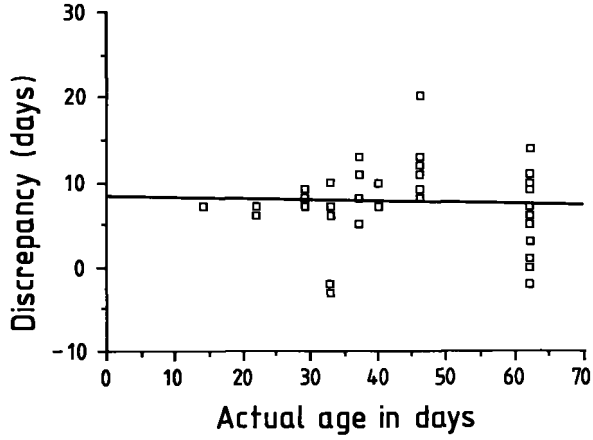

FIGURE 2.—Discrepancy between estimated age (real age minus estimated age) and actual age of Pacific herring as a function of actual age. $y = 8.3 - 0.014\,x$, $r = 0.05$.

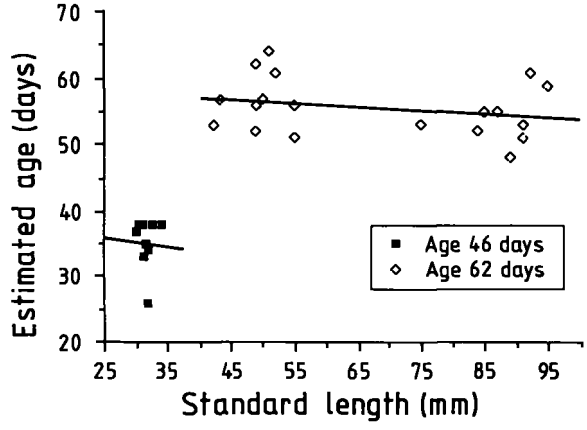

FIGURE 3.—Relationship between estimated age and standard length in Pacific herring larvae of same age. Age 46 days: $y = 39.63 - 0.14\,x$, $r = 0.04$; age 62 days: $y = 59.53 - 0.06\,x$, $r = 0.27$.

fourth order polynomial, provided the best fit to the initial length of the larvae.

The average daily growth rate (±1 SD) calculated from all otoliths with the fourth order polynomial is presented in Figure 5 along with the estimated minimum, maximum, and average growth rate obtained from the herring measured at termination of the experiment. The relationship shows that there is a high similarity in the trends of the growth curves between the different age groups. The daily growth rate calculated from the standard length of the larvae at termination of the experiment showed an average of 0.66 mm/d, a minimum of 0.31 mm/d, and a maximum of 1.48 mm/d. Estimation of the average growth rate, using these data, gives an average growth rate of 0.73 mm/d.

DISCUSSION

The results of this study show evidence of daily increments in the otoliths of Pacific herring, agreeing with earlier investigations on the same species (McGurk 1984a). A difference of eight days was observed between the estimated

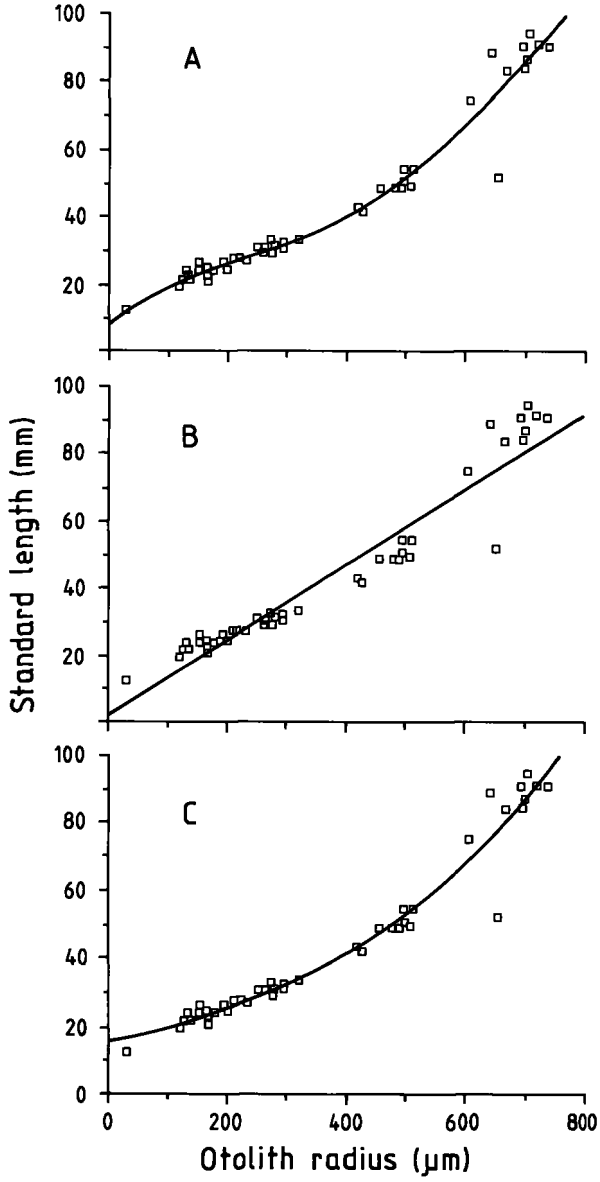

FIGURE 4.—Relationship between otolith radius (x) and standard length (y) of the Pacific herring larvae. A: $y = 8.1461 + 0.1542\,x - 4.875 * 10^{-4}\,x^2 + 9.651 * 10^{-7}\,x^3 - 5.038 * 10^{-10}\,x^4$, $r = 0.98$. B: $y = 2.6738 + 0.1123\,x$, $r = 0.96$. C: $y = 15.6952 * 10^{(0.0011\,x)}$, $r = 0.98$.

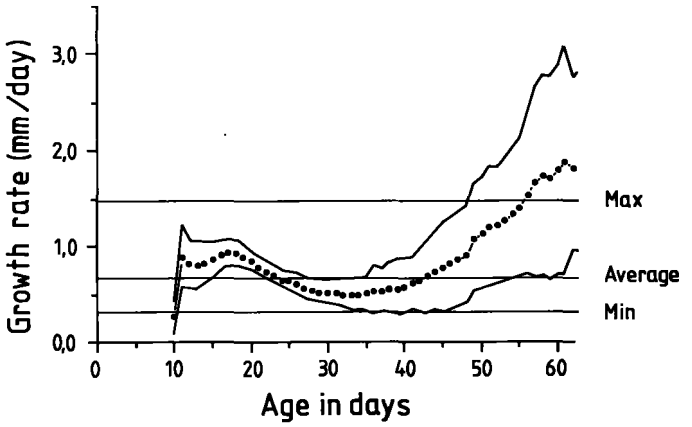

FIGURE 5.—The average daily growth rate (mm/day) estimated from otolith analyses (·) with ±1 SD. The minimum (min), average, and maximum (max) growth rate (mm/day) calculated from Pacific herring surviving to the termination of the experiment (day 62) are indicated.

and the actual age of the larvae; this difference corresponds well with the end of yolk-sac stage of the same larvae (Wespestad and Moksness fn. 1); it is three days later than that found by McGurk (1984b) for Pacific herring larvae at the same temperature (8.0°C).

The results are the same as earlier investigations on Norwegian spring spawning herring in a 4,400 m^3 outdoor basin (Gjøsaeter and Øiestad 1981) in which herring form one otolith increment per day. However, the results of one increment per day contradicts findings from laboratory experiments in which otolith increments were not formed daily. Geffen (1982) on Atlantic herring and McGurk (1984a) on Pacific herring found the growth rate of the larvae and the number of increments in the otoliths to be correlated, while our results show a poor correlation between growth and daily increments. The expected standard deviation was ±1 day, based on the observed range in hatching time; however, the estimated variation was much greater than this. A possible explanation for this discrepancy might be that the minimum growth rate (0.31 mm/d) observed in this study was greater than growth rates observed in laboratory studies.

Geffen (1982) reported that growth coefficient tended to increase with the increase in size of aquarium used—from the 120 L laboratory tanks up to 4,000 m^3 mesocosms. The difference in data between experiments using small and experiments using large rearing tanks results from an inability of larvae to form daily increments at low growth rates (Moksness et al. 1987). In our work, the average growth rate corresponded to the growth rate observed in nature. Checkley (1982)[2] reported otolith increments and fish length for juvenile herring captured in Bristol Bay in autumn 1981. From these data, we estimated the average daily growth rate over the first summer of life to be 0.74 mm/d, which is similar to the average growth rate observed in this experiment. Therefore, it appears that conditions in the basin were similar to the average conditions larvae experience in its natural habitat.

Otolith increment size was well correlated with the measured growth in standard length of the larvae. The preferred growth model (see Figure 4a), gave a good fit to the observed values, however small the sample size and especially for the smallest larvae, but the growth model did not rule out the applicability of other models. An exponential model might fit better with more available data. When fitting the data on dry weight of the larvae to the radius of the otolith, a very good fit was observed for the exponential equation.

The resulting daily length increment from the fourth order polynomial growth model approximated the calculated daily length increment based on observed length-at-age reported by Wespestad and Moksness (fn. 1). By estimating the relationship between the standard length of the larvae and the radius of the otolith, the daily length-increment of the fish could be described.

[2]Checkley, D. M. 1982. The ageing of juvenile Pacific herring by otolith analysis. Final Report, NOAA contract 82-ABA-1001. Northwest and Alaska Fisheries Center.

The range in the residuals and deviations reported in this paper are believed to be, in part, due to the use of × 400 magnification. This has been shown to be too low to give good resolution of the otoliths (Campana et al. 1987).

Three general conclusions can be drawn from this study: 1) Daily otolith increments in Pacific herring larvae are true daily increments at normal rates of growth. 2) The results, showing poor correlation between length and age, suggest that age in days can be estimated only from direct ageing and that attempts to establish age from age-length relationships may produce significant errors. These types of error may be important in stock separation studies such as distinguishing between spring and autumn spawned herring (Fossum and Moksness 1988). 3) Mesocosms may be a more appropriate environment for studying marine fish larvae and juveniles than laboratory-sized rearing tanks. Growth appears to be influenced by container size. Mesocosms have been shown to produce growth rates for other species such as capelin, *Mallotus villosus*, similar to that observed in the field (Gjøsaeter and Monstad 1985).

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