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Between-reader variation in herring otolith ages and effects on estimated population parameters

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Abstract

A set of otoliths from 196 Baltic herring (*Clupea harengus* L.) from commercial trap net catches was aged by the authors. All three readers agreed on 70% of the fish, and agreed pairwise on 72–85%. The majority of readings agreed to within ±1 year. The age distributions obtained were similar, but bias was present between all three pairs of readers. Variability was highest in the older fish, and the deviation between ages assigned correlated with fish size. Between readers, the calculated mean length at age differed for age-group 7 only. The fishing mortality, estimated by population analysis, varied among readers by 7–50% for ages 3–10.

The validity of herring otolith ages and the effects of age determination variation on the use of age-structured data are discussed.

Keywords: Otolith; Age determination; Clupea harengus; Baltic herring; Ageing error

1. Introduction

Age determination of fish from scales, otoliths, and other structures is a matter of routine with most exploited fish stocks. However, counting annual rings is open to many uncertainties. Apart from the problems of validating the methods (Beamish and McFarlane, 1983, 1995; Francis, 1995), check-marks are interpreted differently by different readers. Several statistical methods have been suggested to assess the degree of disparity between readers or between repeated age determinations (Beamish and Fournier, 1981; Chang, 1982; Kimura and Lyons, 1991; Campana et al., 1995). The variation in age data is commonly acknowledged, but few published studies have addressed the effects of age composition uncertainty on data derived from the ageing results (Brander, 1974; Barlow, 1984; Beamish and McFarlane, 1995).

Herring otoliths were first used for age determination by Jenkins (1902) and are today used routinely for ageing in all the Baltic countries. Much effort has been devoted to discerning differences between the otoliths of different Baltic herring stocks (e.g. Kompowski, 1971; Ojaveer et al., 1982; Fetter et al., 1991), and until recently, relatively little to resolve the uncertainties of the age determinations (ICES, 1986, 1997a,

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1998). The purpose of this paper is to assess the variation in the age estimates of three readers and, as an example, to demonstrate that this variation affects population parameters estimated by VPA using the age data.

2. Methods

Commercial trap net and trawl catches of Baltic herring (*Clupea harengus* L.) in the Airisto Inlet, SW Finland (ICES area 29) were sampled regularly in the spring of 1987. Random samples of about 100 fish were taken from the catch upon lifting the gear. The samples were frozen and later examined in the laboratory. For each fish, total length, total weight, sex, and gonad stage were recorded. The otoliths (sagittae) were removed and mounted in Euparal on transparent slotted plastic chips.

From these samples, a subset of 196 fish taken in late May–early June was chosen for the ageing comparison. The fish were taken on four different locations within some 10 km in the Airisto area. A description of the study area can be found in Rajasilta et al. (1992).

The sample consisted of 97 females and 98 males (1 undetermined). Most of the fish were spawning (86 ripe, 62 spent, 29 ripening, 18 immature adults and 1 juvenile). The length range was 15–29 cm, with a modal length of 19 cm for males and females alike.

Age determinations were made under the microscope at 12–35 times magnification in reflected light against a black background. Otoliths were viewed from the concave (outer) side. A general descripiton of the herring otolith is given by Härkönen (1986). In reflected light, the growth zones of the otolith appear as alternating broad opaque zones (bright) and narrow translucent zones (dark). An opaque zone and the following translucent zone were together regarded as a year's growth, and the age was determined as the number of translucent zones. A January 1st birthday was assumed. Discernable growth of the otoliths in the sampling year had not yet commenced. Each reader was aware of the sampling date, length, etc., of the fish, but not of the age assigned by the others.

Population size and fishing mortalities were estimated by cohort analysis run over 10 years. The yearly catch was assumed constant, and arbitrarily set as 1000 t. The age composition of the catch, natural mortality and terminal fishing mortality were assumed constant (M=0.2, terminal F=0.3) over the 10 years. For the last year of calculation, fishing mortalities for the age groups 1, 2, 3, 4 and 5+ were put as F=0.05, 0.15, 0.2, 0.25, and 0.3, respectively.

Using observed age distributions and mean weight at age as input data, the catch in numbers was calculated. To eliminate sources of variation other than the age, the same set of weight at age was used in all three calculations (Finnish Game and Fisheries Research Institute data for 2nd quarter of 1987, trap-netted fish from ICES rectangle 29, n=450). For the last year of calculation, population was estimated as $N_t = C_t(M + F_t)/(F_t(1 - \exp(-M - F_t)))$ and for other years back-calculated as $N_t = C_t \exp(M/2) + N_{t+1} \exp(M)$. Fishing mortalities were estimated as $F_i = -\ln(N_t/N_{t+1}) - M$ (Pope, 1972).

Agreement among readers was expressed as Index of Average Error (Beamish and Fournier, 1981), calculated as $\mathrm{IAE} = 1/N \sum\left(1/R \sum\left(\left|X_{ij} - X_j\right|/X_j\right)\right)$, where N is the number of fish aged, R the number of times each fish is aged, X_j the average age for the jth fish, and X_{ij} the ith reading of the jth fish. The statistical tests used for comparisons are mentioned in the text. The population analysis was made with software kindly made available by Dr. Sakari Kuikka of the Finnish Game and Fisheries Research Institute. Statistical analyses were made with the SAS statistical software (SAS Institute, Cary, NC 27513).

3. Results

Of the 196 fish, 195 were aged by readers 1 and 3, 193 by reader 2. The ages assigned ranged from 2 to 13 years, with a modal value of 4 years (Table 1). All three readers agreed in 135 cases (69%). Between pairs of readers, over 70% of the ages agreed, and about 95% of the age determinations agreed to within one year (Table 2).

The variation between readers increased with increasing age and size of the fish. The index of average error (Beamish and Fournier, 1981) increased from 0.00 for mean age 2 to 0.07 for ages 7 and 8 (Tables 3 and 4). Comparing the difference between readers (of 0, ±1, ±2, etc. years) with fish length, we found that for small fish the difference between

Table 1
Ages assigned by readers 1, 2 and 3[a]

Reader 1, age	Age assigned											Total
	2	3	4	5	6	7	8	9	10	>10	?	
By reader 2												
2	*2*											2
3		*34*	1									35
4		1	*63*								1	65
5			3	*21*								24
6				3	*22*		1					26
7					1	*12*	1				1	15
8					1		*4*	2				7
9						1	5	*4*	1			11
10						1			*2*	1	1	5
>10							1	1		*3*		5
?						1						1
Total	2	35	67	24	24	15	12	7	3	4	3	196
By reader 3												
2	*2*											2
3		*33*	1	1								35
4		4	*58*	3								65
5			6	*16*	2							24
6				11	*15*							26
7				4	3	*6*	1					15
8						4	*2*	1			1	7
9			1			1	3	*6*				11
10						2			*3*			5
>10								2	1	*2*		5
?						1						1
Total	2	37	66	35	20	14	6	9	4	2	1	196

[a] Identical ages in italics, figures are numbers of fish, ? denotes missing/unreadable ages.

Table 2
Difference in years between the age estimates of readers, e.g., reader 2 read the age as 1 year less than reader 1 in 13 cases

Readers		Difference								Total
		−2	−1	0	1	2	3	4	5	
1 and 2	*n*	1	6	167	13	2	2	1		192
	%	*1*	*3*	*87*	*7*	*1*	*1*	*1*		*100*
1 and 3	*n*	1	8	142	32	8	2		1	194
	%	*1*	*4*	*73*	*16*	*4*	*1*		*1*	*100*
3 and 2	*n*	2	10	150	23	5	1	2		193
	%	*1*	*5*	*78*	*12*	*3*	*1*	*1*		*100*
Length (cm)[a]		21.7	21.7	19.0	21.7	24.0	26.2	24.8	20.4	
S.D.[b]		4.8	3.6	3.2	3.5	2.2	3.3	4.0		

[a] Mean length.
[b] Standard deviation of length.

Table 3
Index of average error (IAE, Beamish and Fournier, 1981)[a]

Age	N	IAE	S.D.
2	2	0.000	0.000
3	34	0.004	0.023
4	68	0.020	0.048
5	24	0.029	0.042
6	26	0.040	0.051
7	13	0.067	0.087
8	9	0.069	0.047
9	10	0.054	0.053
10	3	0.029	0.050
>10	3	0.054	0.062
Total	192	0.029	0.051

[a] Age: arithmetical mean age, N: number of observations, S.D.: standard deviation.

readers was also small. The fish on which the readers agreed had a mean length of 19.0 cm, a difference of ± 1 years corresponded to a length of 21.7 cm, etc. (Table 2). The lengths differed significantly (Kruskal-Wallis test, chi square=88.4, d.f.=7, $p<0.001$).

The age distributions obtained by the three readers were similar (Fig. 1), with a mean age of 5.2 years for reader 1, 5.1 years for reader 2 and 5.0 years for reader 3 (Kruskal-Wallis test, chi square 0.75, d.f.=2, NS). Between pairs of readers, the ages were significantly biased (Fig. 2). Readers 2 and 3 both assigned lower ages to older fish than did reader 1. The Kruskal-Wallis test chi square values were 185.4, 170.6, and 173.1 for readers 1 and 2, 1 and 3, and 2 and 3, respectively (d.f.=10, $p<0.001$ in all three comparisons).

Mean length at age, calculated for the three readers separately, differed significantly for age 7 only (ANOVA, F=3.89, d.f.=2, $p<0.03$). The mean lengths differed by, at the most, 1.9 cm in age group 7 (Fig. 3). In the cohort analysis, the difference between the largest and smallest estimated population size is small for ages 1–5 and rises to about 20% of the larger estimate for ages 6 and over (Fig. 4). The corresponding difference between estimated fishing mortalities is larger and more variable. For ages 3–10, the difference between the largest and smallest F is 7–50% (Fig. 4).

4. Discussion

Herring otoliths have been used for age determination since Jenkins (1902) showed that alternate opaque and translucent rings are formed in the otoliths during the growth season and winter, respectively. In the strict sense of Beamish and McFarlane (1983), herring otolith ages have not been validated except for young fish (Watson, 1964; Messieh and Tibbo, 1970). There are no indications that the annual formation of rings demonstrated in young herring should stop or become irregular with increasing age of the fish. The otolith rings are therefore to be regarded as at least 'effectually annual' in the sense of Francis

Table 4
Input data for the cohort analysis[a]

Age	Age composition (%)			Catch (millions)			Mean weight (g)	Mortality	
	R1	R2	R3	R1	R2	R3		F	M
1	0	0	0	0	0	0		0.05	0.2
2	1	1	1	0.66	0.66	0.66	15.6	0.15	0.2
3	18	18	19	6.82	6.90	7.21	26.3	0.20	0.2
4	33	35	34	9.83	10.24	9.98	33.9	0.25	0.2
5	12	12	18	3.04	3.07	4.43	40.5	0.30	0.2
6	13	12	10	2.51	2.34	1.93	53.1	0.30	0.2
7	8	7	3	1.09	1.18	1.09	65.6	0.30	0.2
8	4	6	3	0.60	0.92	0.45	67.9	0.30	0.2
9	6	4	5	0.71	0.45	0.58	80.0	0.30	0.2
10	3	2	2	0.25	0.15	0.20	103.0	0.30	0.2
11+	2	2	2	0.23	0.20	0.19	107.6	0.30	0.2

[a] Weights from Finnish Game and Fisheries Research Institute data (ICES rectangle 29, trap-net, 2nd quarter 1987). Catch by number calculated from age composition and weight at age data assuming a total catch of 1000 t. R1: reader 1, R2: reader 2, R3: reader 3.

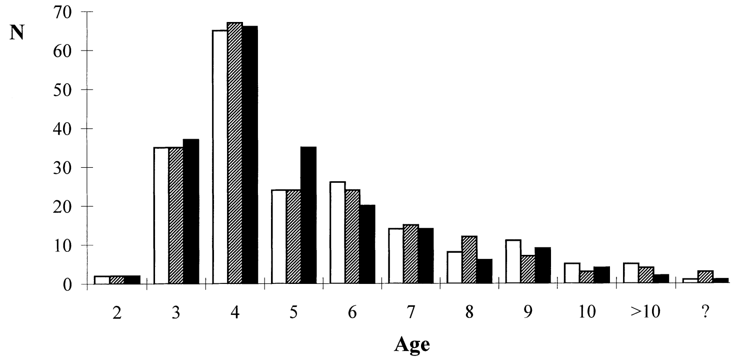

Fig. 1. Age distribution of sample. White bars: reader 1, hatched bars: reader 2, black bars: reader 3.

(1995). As otolith-readers know, the rings of the herring otolith are sometimes difficult to detect, and there are other marks and structures that can be confused with annual rings. The effects on the accuracy of age determinations of these error sources are identical with the effects of non-annual ring formation (Francis, 1995). Viewing the otolith, there is no way of validating any single ring (Williams and Bedford, 1974). The accuracy of herring otolith ages thus can be expected to vary between areas and laboratories,

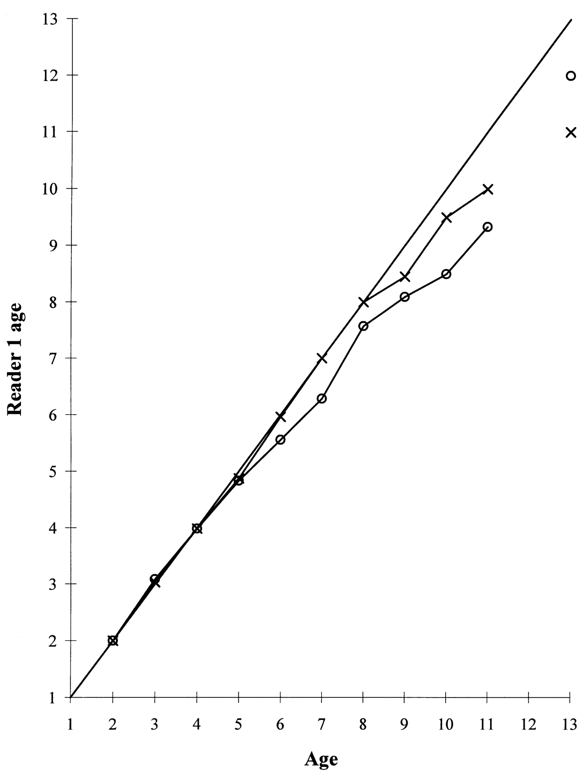

Fig. 2. Mean age assigned by reader 2 and 3 against reader 1 age. (×) reader 2, (○) reader 3, (straight line) reader 1 age.

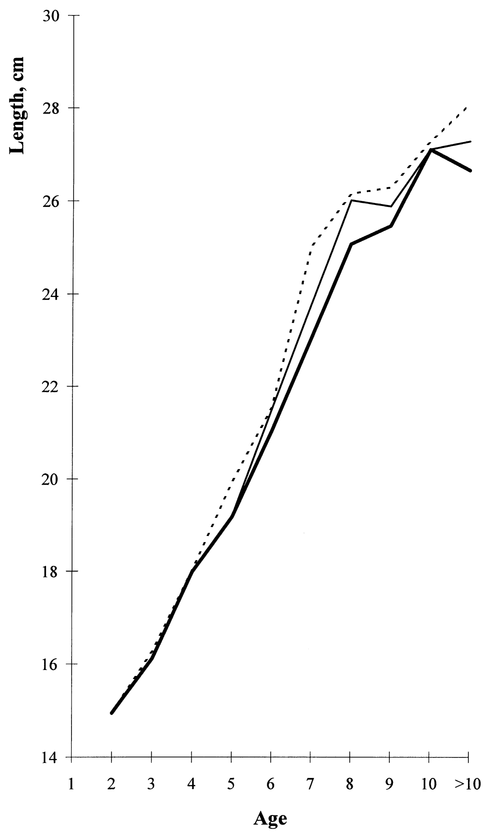

Fig. 3. Calculated mean length at age. Broken line: reader 1, thin line: reader 2, thick line: reader 3. The lengths differ significantly for age 7 (ANOVA $F=3.89$, d.f.=2, $p<0.03$).

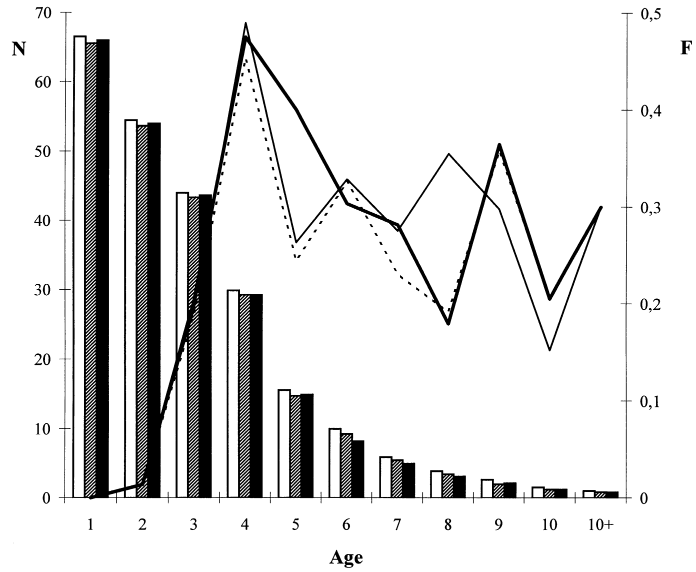

Fig. 4. Population size and fishing mortality estimated by cohort analysis. Catch age distribution assumed constant over years and set as reader 1, 2 or 3 sample age distribution. Total catch, weight at age, terminal fishing mortality (F=0.3) and natural mortality (M=0.2) assumed constant for all readers and years. Further explanations in the text, input data in Table 4. Bars: population, lines: fishing mortality. Reader 1: white bars, dashed line; reader 2: hatched bars, thin line; reader 3: black bars, thick line. N: population in millions, F: fishing mortality.

depending on both the growth characteristics of the fish and the experience of the readers.

Variability in precision is inherent in all methods of age estimation (Beamish and McFarlane, 1995). Variability, expressed as variation between readers or between repeated readings, in itself carries information about the method, the readers and the growth pattern of the fish. In Baltic herring, spring samples, where otolith growth of the current year is small or has not yet commenced, are often easier to age than autumn and winter samples (ICES, 1997a). In this study, comparing age estimates for a spring sample, the three readers agreed on about 70% of the otoliths. Bias of the age estimates for old fish was present among all three pairs of readers, and also, deviation among readers tended to increase with the size of the fish. The results indicate that the age estimates for fish older than 5–6 years are uncertain.

Our results agree with those reported earlier. In the ICES workshop on herring age-reading (ICES, 1986), the readers agreed with the mode (majority reading) for 40–87% of the fish. In the 1997 herring otolith exchange (ICES, 1997a, 1998), bias among readers was common and the degree of agreement also varied between areas. Messieh and Tibbo (1970) found that in Atlantic herring, otolith and scale ages agreed up to age 5, while for older fish, the otolith age was lower than the scale age. Also in Baltic herring, otolith and scale ages are reported to agree rather well for ages 2–6, while here, in older fish, scale age was lower than otolith age (Kornilovs and Fetter, 1996).

Despite the disagreement on individual ages, the sample age distributions obtained by the three authors were similar. As pointed out by Beamish and McFarlane (1995), random over- and underestimates will balance in the sense of not changing the overall age distribution, while at the same time 'smearing' the age-group frequencies and possibly obscuring variation between year-classes. In the northern Baltic, age groups 0–5 make up about 85% of the herring catch in numbers (ICES, 1997b, 1974–1996 data), and high variation or bias of the age determinations of older fish will not necessarily affect the statistical comparison of age distributions obtained by different readers. However, variation and bias of the age estimates will multiply as errors into any parameter calculated from the age. Barlow (1984) showed that mortality estimates will be biased by imprecise (and inaccurate) age estimates, even when the ages themselves are not biased. When age data are used to derive new parameters for individual fish, as in back-calculation of length, imprecision of the age estimates may lead to serious errors.

In our example, the multiplicative nature of ageing errors is demonstrated by the variation between readers in calculated lengths at age. Also, introducing the three age distributions as input data for the cohort analysis produces high variation in the estimated fishing mortalities. The variation is caused by the differences in age composition, as other input parameters did not vary between readers. Introducing the actual weights at age calculated for each reader into the calculation will increase the variation in estimated F and population size. The estimated fishing mortalities were insensitive to changes in the input F for the last year of the analysis.

Input fishing mortalities were chosen to correspond to those estimated by ICES for the Baltic main basin and Gulf of Finland for 1987–1996 (ICES, 1997b, Herring 25–29 and 32+ Riga). The estimated F's correspond roughly to those of the ICES stock asessments, albeit with lower mortality for ages 1–2 and higher for age 4. This may be a random effect of the very small sample, and also, a result of the sample representing only spawning or pre-spawning fish in the trap-net catch, not the entire recruited population nor the entire fishery. The actual Finnish herring catch in the northern Baltic (ICES area 29, which includes the study area) was about 30 000 t in 1987 (Official Statistics of Finland, 1993). The catch level chosen for the calculations, 1000 t, is of no consequence for the estimated mortalities. The point we wish to make in this connection is that there is considerable variation in the mortality estimates, in spite of the differences between the three age distributions being statistically insignificant and that ageing uncertainty will affect the outcome of, e.g., population assessments and management advice relying on these data.

Our results are in line with Beamish and McFarlane (1995), who demonstrated how inaccurate age-determinations produce faulty population assessments and management advice for Walleye Pollock in the Pacific Ocean. Brander (1974), working with North Sea cod, concluded that in the age-length key, the ages of old fish are uncertain, but that this has little effect on the estimation of population parameters. Recently, Bayesian methods have been applied to age-structured catch data in fisheries models to provide probability functions for the estimated parameters (McAllister and Ianelli, 1997). We suggest that, also, the variability of the age determinations should be taken into account as part of the data, and possibly incorporated as an error factor in, e.g., population assessments.

The actual importance of age variability in population modelling and fisheries management depends on the variability of other data used in the models, on the type of calculations, and also on the lines of management action that are considered. In Baltic herring, subject to the rapid changes in the ecosystem of the Baltic sea (Cederwall and Elmgren, 1990; HELCOM, 1990, 1993; Rudstam et al., 1994), the imprecision of the age determinations constitutes a risk of misinterpreting biological signals both in fisheries management and in environmental monitoring.

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