How to determine the age and growth of fish?

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The use of hard parts

The examination of hard parts is the most frequently used method for age determination in fish. Parts used to determine the age in fish include scales, otoliths, fin spines, fin rays, cleithra, vertebrae, opercular bones, and dentary bones.

The use of hard parts is based on the appearance of marks, which have been given a variety of names including annual marks, annual rings, or *annuli* (*annulus* is the singular).
In the vegetative period, at the time of the active diet, a brighter area is formed due to the higher concentrations of limestone (consists of a minimum of 50% CaCO₃). In the winter period, when the diet is reduced, limestone concentrations are lower and the darker area is formed.

*Annulus* marks one year at age.
Bony structures (i.e. otoliths, cleithra, vertebrae, opercular bones, and dentary bones) require sacrificing the fish.
Descriptive statistics

The sample mean is the most commonly used measure of central tendency and is expressed by the equation:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}.$$  

Statistics of dispersion characterizes the spread of sample measurement about a statistics ($\bar{x}$) used to express central tendency. Common measures of dispersion that describe this sampling variation are the range, sample variance ($s^2$), and sample standard deviation ($s$):

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}.$$  

A statistic closely related to the standard deviation is the coefficient of variation ($CV$). This measure provides a measure of precision by expressing the standard deviation as a percentage of the sample mean:

$$CV = \frac{s}{\bar{x}} \cdot 100.$$  

Because this measure is not influenced by the magnitude of the original measurements, it is a useful tool for comparing variability between two or more samples. This is especially true if the intervals of the values obtained for the samples are quite different.
Why the growth?

The growth is one of the most important and most reliable indicators of fish health, population productivity and habitat quality.

Birds and mammals have limited growth; gradually increasing the body to sexual maturity, followed by a gradual slow down and at one point complete growth cessation.

Fish, amphibians and reptiles have continuous growth; it lasts for a lifetime and varies on the amount of food available, and on climatic conditions and slow down with the aging of the animal.
What kind of growth can be?

Isometric – the mass and length variables are uniform.
Alometric – the mass and length variables are not uniform.
Positive alometric – faster progression in mass.
Negative alometric – faster progression in length.
The nature of growth

The nature of growth is obtained from the length-mass relationship:

\[ m = a \cdot L^b \implies \log_{10} m = \log_{10} a + b \log_{10} L, \]

- \( m \) is a mass
- \( L \) is a length (standard \( SL \) or total \( TL \))
- \( a \) is a constant
- \( b > 3 \) means that alometric growth of fish is positive
- \( b < 3 \) means that alometric growth of fish is negative
- \( b = 3 \) means that growth is isometric

The functional exponent \( b \) (usually between 2.5 and 4.0), which describes the curve of the relationship, is generally different among species and can be sensitive to biotic and abiotic influences, leading to different values of \( b \) between sexes or localities, even within the same species.
Length-mass relationship of the Illyrian chub *Squalius illyricus*

\[ m = 0.01 \cdot TL^{2.97} \]

\[ R^2 = 0.91 \]
Different methods to express growth numerically (I)

Absolute growth is expressed by the equation

\[ \Delta L_a = L_2 - L_1, \]

where \( \Delta L_a \) is absolute growth, \( L_1 \) is initial length, and \( L_2 \) is final length.

Relative growth is expressed by the equation

\[ \Delta L_r = \frac{L_2 - L_1}{L_1} \cdot 100, \]

where \( \Delta L_r \) relative growth, \( L_1 \) is initial length, and \( L_2 \) is final length.

Both absolute and relative growth can also be expressed as a rate in terms of growth per unit time:

\[ G_a = \frac{L_2 - L_1}{t_2 - t_1}, \]

\[ G_r = \frac{L_2 - L_1}{L_1(t_2 - t_1)}, \]

where \( G \) is growth rate either absolute or relative, \( t_1 \) is initial time, \( t_2 \) is final time, and \( L_1 \) and \( L_2 \) are the corresponding lengths for those times.
Different methods to express growth numerically (II)

In case that the growth is exponential over a short period of time \((t_2 - t_1 < 1 \text{ year})\) it is best reported as an instantaneous rate:

\[
G = \frac{\log_{10} L_2 - \log_{10} L_1}{t_2 - t_1}.
\]

These calculations of growth rates yield an estimate of growth that is appropriate over short time scales (days to months). Growth over longer time periods tends to deviate from these simple, linear, or exponential estimates and requires more complex models.
Back-calculation of length from calcified structures (I)

If we assume that the growth of calcified structures is proportional to the overall fish growth, a direct proportion method can be used to back-calculate size at annulus formation.

If we know the length of the fish, the radius of the calcified structure, and the radius to each annulus, we can use the equation

$$\frac{L_i}{L} = \frac{S_i}{S} \implies L_i = \frac{S_i L}{S},$$

where $S_i$ is the radius at annulus formation, $S$ is the overall radius, $L_i$ is the length at annulus formation, and $L$ is the fish length at capture.

Although this relationship generally holds true, fisheries scientists have noticed that it often results in an underestimation of length when scales are used.

A tactic assumption of proportionality is that scales are formed early in the development. For many species, this is not true. Scales may not form in some species until an individual reaches the length of 5 cm or greater.
Back-calculation of length from calcified structures (II)

Work done by Fraser (1916) and Lee (1920) suggested that a correction factor $a$ be added to the equation to account for the delay in scale formation. The resulting equation,

$$L_i = \frac{L - a}{S} S_i + a,$$

where $a$ is the size of the individual at the time of scale formation, provides an unbiased estimate in length when scales are used and is referred to as the Fraser-Lee or intercept-corrected direct proportion model.

While this formula is widely used, it may not be the most precise estimate of length at age.
Growth in length

A number of models have been used to model length, but the model developed by von Bertalanffy (1938) generally fits fish length data well. It has become a standard among fisheries scientists. The model is represented as

\[ l_t = L_\infty \left( 1 - e^{-K(t-t_0)} \right), \]

where \( l_t \) is length at time \( t \), \( L_\infty \) is the asymptotic length, \( K \) is a growth coefficient, and \( t_0 \) is a time coefficient at which length would theoretically be 0.

Most statistical and graphics software packages now contain programs that calculate nonlinear regression parameters such as those in the von Bertalanffy growth equation.
Examples of von Bertalanffy growth equations

\[ L_t = 23.9 \cdot (1 - e^{-0.19\cdot(t+1.03)}), \text{ for the Monkey goby} \]
\[ L_t = 37.4 \cdot (1 - e^{-0.07\cdot(t+1.48)}), \text{ for the Round goby} \]
\[ L_t = 28.7 \cdot (1 - e^{-0.12\cdot(t+0.80)}), \text{ for the Bighead goby} \]

Highest growth coefficient has been determined for the Monkey goby and lowest for the Round goby.
The asymptotic length that can reach the Monkey goby was smaller than asymptotic length of the other two species.
Back calculated and von Bertalanffy total lengths of Monkey goby, Round goby and Bighead goby

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Age</th>
<th>n</th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$L_t$</th>
<th>$r_L$</th>
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<tbody>
<tr>
<td>Monkey goby ($Neogobius$ $fluvialis$)</td>
<td>I</td>
<td>23</td>
<td>6.51</td>
<td></td>
<td></td>
<td></td>
<td>7.65</td>
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<td></td>
<td>II</td>
<td>28</td>
<td>4.78</td>
<td>8.67</td>
<td></td>
<td></td>
<td>10.46</td>
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<td>III</td>
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<td>4.92</td>
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<td>11.09</td>
<td></td>
<td>12.79</td>
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<tr>
<td></td>
<td>∑</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Mean</td>
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<td>8.00</td>
<td>11.09</td>
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<tr>
<td>Round goby ($Neogobius$ $melanostomus$)</td>
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<td></td>
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<td>Bighead goby ($Ponticola$ $kessleri$)</td>
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<td>4</td>
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<td>9.73</td>
<td>11.70</td>
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Von Bertallanfy growth curves and mean total lengths
The modification to von Bertalanffy equation

In some mark-recapture studies, we may know the size at capture and recapture and time at large, but we may not know the age. Fabens (1965) proposed a modification of von Bertalanffy equation to model growth under this unique circumstance. This model is useful for work on relatively rare or endangered species for which the collection of materials on which to base the age is impractical or on marine reptiles and other organisms for which a method to determine age has not been identified. The Faben model is

\[ R_i = M_i + (L_\infty - M_i)(1 - e^{-K\Delta t_i}) \]

where \( R_i \) is the length at recapture of the \( i \)th individual, \( M_i \) is the length at marking (or first capture) of the \( i \)th individual, \( L_\infty \) and \( K \) are parameters of the von Bertalanffy growth equation, and \( \Delta t_i \) is the time at large. Model parameters can be estimated using a nonlinear fit program, as with von Bertalanffy model.
Other growth models

Richards (1959):

\[ l_t = D + (L_\infty - D)(1 + He^{-k(t-t_0)})^{-1/H}, \]

Gompertz (1825):

\[ l_t = L_\infty e^{-ke^{-gt}}, \]

Verhulst (1838):

\[ l_t = \frac{L_\infty A}{A + (L_\infty - A)e^{-kt}}. \]

In these models, \( l_t \) is the size at time \( t \), \( L_\infty \) is the asymptotic length, \( t_0 \) is the time at size 0, \( k \) and \( g \) are generalized growth parameters that vary slightly in definition between models, and \( A, D, \) and \( H \) are position parameters used to constrain the inflection point. These models are not commonly employed in fisheries but are frequently used for other organisms.
Ooh! What if I ask them to critique this model of...