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ON LENGTH-WEIGHT RELATIONSHIPS. PART I: COMPUTING THE MEAN WEIGHT OF THE FISH IN A GIVEN LENGTH CLASS

by

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When working with length frequency data, we often need to compute the mean weights of the fish in the various classes. One example is the computation of the weight of a sample in order to be able to raise length frequency samples to total catch.

The computation of the mean weight of the fish in each length class usually will be done based on a length-weight relationship of the form

$$W = a*L^b \qquad (1)$$

The mean weight of the fish with length between L_1 and L_2 is then sometimes estimated as the weight of a fish having the mean length in the class, i.e. as $a*\bar{L}_{12}^{\,b}$ where

$\bar{L} = L_{12} = (L_1 + L_2)/2$

is the midpoint of the length class. However, this produces an underestimate of the mean weight because the bigger fish in the length class (i.e. the 50% of the class population with lengths from L_{12} to L_2) contribute relatively more to the mean weight than the smaller fish in the length class (i.e. the 50% of the class population with lengths from L_1 to L_{12}). If, instead, we use the midpoint of the weight class, i.e.

$$W_{12} = (W_1+W_2)/2$$

then an overestimate of the mean weight is obtained because there will be more fish in the first half of the weight class (i.e. from W_1 to W_{12}) than in the second half (i.e. from W_{12} to W_2) due to the non-linear transformation by Eq. (1) of lengths into weights.

The correct mean weight of the fish in the length class is located in between these two estimates, i.e.

$$a*L_{12}{}^b < \bar{W} < W_{12}$$

The mean weight is obtained by integration over the uniform distribution in the length-class and the result is

$$\bar{W} = 1/(L_2-L_1)*a/(b+1)*[L_2{}^{b+1}-L_1{}^{b+1}] \quad (2)$$

or by using Eq. (1),

$$\bar{W} = 1/(L_2-L_1)*1/(b+1)*[L_2W_2 - L_1W_1] \quad (3)$$

Example 1

$$\text{If } W= 0.009L^{3.193} \quad (4)$$

then the length class from, say L_1 = 10 cm to L_2 = 10.5 cm will have a mid-length of L_{12}=10.25 cm, corresponding to a weight of $0.009(10.25)^{3.193}$ or 15.187 g. The class limits in weight become

$W_1= 0.009(10)^{3.193}$ = 14.036 g

and

$W_2= 0.009(10.5)^{3.193}$ = 16.402g.

Notation:

L_1, L_2 = Lower and upper limits of the length class.

L_{12} = Midpoint of the length class.

$\bar{L}$ = Mean length of the fish in the length class ($\bar{L}=L_{12}$).

W_1, W_2 = Lower and upper weight limits of the class.

W_{12} = Midpoint of the weight class.

$\bar{W}$ = Mean weight of the fish in the length class (Note that $\bar{W} \neq W_{12}$).

a = Constant of proportionality in the length-weight relationship.

b = Power in the length-weight relationship where

$W_1 = a*L_1{}^b$ and $W_2 = a*L_2{}^b$

which gives a midpoint of

W_{12} = (14.036 + 16.402)/2 = 15.219 g

The correct mean is to be found somewhere in between these two estimates, i.e.

$$15.187 < \bar{W} < 15.219$$

and from Eq. (2) we obtain

$$\bar{W}=\frac{1}{0.5}*\frac{0.009}{4.193}*[(10.5)^{4.193}-(10.0)^{4.193}]$$

= 15.198 g

Example 2

The difference between the correct estimate of the mean weight and the biased estimate increases with increasing class interval. As an example we may again consider the length-weight relation in Eq. (4), but with a one cm class length.

L_1=10cm, L_2=11cm, $L_{12}=\bar{L}$=10.5cm.

W_1=14.036g, W_2=19.029g, W_{12}=16.532g.

The mean length of 10.5 cm corresponds to a weight of 16.402 g and the correct mean weight is obtained from Eq. (3):

$$W = \frac{1}{4.193}*[(11*19.0287)-(10*14.0360)]$$

= 16.446 g.

We could illustrate this computation by considering, say 10 fish, uniformly distributed in the class interval from 10 to 11 cm (Table 1).

The mean weight based on these 10 fish is 16.445 g. With a large number of fish an estimated value of 16.446 g would be obtained from Eq.(2) or Eq.(3). It is clear that the differences between the various estimates are, in general, extremely small compared to the other uncertainties involved. However, computation of mean weights are done over and over again so we may as well use the correct basis.

Table 1. Hypothetical example of a mean weight calculation based on 10 fish, uniformly distributed in the class interval from 10 to 11 cm.

Fish (no.)	Length L (cm)	Weight $W=0.009\ L^{3.193}$ (g)
1	10.05	14.2613
2	10.15	14.7194
3	10.25	15.1874
4	10.35	15.6656
5	10.45	16.1540
6	10.55	16.6528
7	10.65	17.1621
8	10.75	17.6819
9	10.85	18.2125
10	10.95	18.7539
Sum (10 fish)	105.00	164.4509
Mean	10.50	16.445

In order to indicate one of the other uncertainties involved in the computation of weights Eq.(4) can be used as a good example. The power b=3.193 is here given with a four-digit precision but the coefficient a = 0.009 is only given with one digit precision. The zeroes in front do not count! It will be much more important in any weight computation that the estimates of a is also given with a 4-digit precision (such as, say, a=0.009274), than introducing the correct computation of the mean weight which usually only shows up on the third or fourth decimal.

In connection with these comments on precision it may be noted that it is always recommended to use maximum precision in carrying out various computations on your calculator or PC's. However, final results should of course be given by rounding off to a reasonable number of significant digits (such as one digit more that the precision obtained by measuring the quantity in real life).

Another aspect of precision in the present context, pertains to the power b in the length-weight relationship (Eq.1). In the example used here, b = 3.193, i.e. less than 10% greater the power 3 of isometric growth. In estimating b (as the slope of the regression line in the plot of

$$Y_1 = \log_e W_1 \text{ on } X_1 = \log_e L_1$$

using a number of individual (L_1, W_1) observations) it is worthwhile to test the hypothesis of b = 3. If the data available do not permit us to consider b significantly different from 3 (e.g. the value of 3 is within a 95% confidence interval of the estimated value of b) then it is sensible to choose b=3 because this value is based on the biological reasoning of isometric growth. This means that a new estimate of a, the constant of proportionality must be obtained. This is

$$a = \exp(\bar{Y} - 3\bar{X}).$$

Acknowledgments

This note deals with one of those many technical details we are faced with over and over again but usually never get around to finish once and for all. I wish to thank Dr. Daniel Pauly for being persistent in suggesting this publication and thus producing this first contribution to Fishbyte from the FAO/Danida group. We will try to be more active in the future and look forward to learning more from all our friends and colleagues among the readers of Fishbyte.