Can We Use Traditional Length-Based Fish Stock Assessment When Growth Is Seasonal?

PER SPARRE
Marine Resources Division
Food and Agriculture Organization
Via delle Terme di Caracalla
00100 Rome, Italy

Abstract

Based on simulated catch data, this contribution shows that standard length-converted catch curves cannot be used for accurately estimating total mortality when growth oscillates seasonally. Some implications for length-based stock assessment methodology are discussed, and the need for the development/implementation of methods not requiring length-to-age conversions is emphasized.

Introduction

By "traditional length-based fish stock assessment" I mean the methods which include conversion of length into age. Here I shall use length-converted catch curve analysis as an example. All considerations below are important only in the case of short-lived animals, notably shrimps, squids and small pelagics. For long-lived species, seasonal growth oscillations can be neglected.

The answer to the question raised in the title is "no" when:

(i) growth rate is zero during a certain period of the year, and/or

(ii) there is more than one cohort per year.

The reasons are quite simple:

When growth rate is zero, there is no "one-to-one" correspondence between age and length, i.e., one cannot convert length into age. Fig. 1 shows an example of this. A shrimp of length 13 cm, and following growth curve A can have any age between t_1 and t_2 (or it may be a cohort B shrimp of age t_3).

If there are two cohorts per year (which is probably the case in most penaeid shrimp stocks), there is again no "one-to-one" correspondence between age and length. Fig. 1 also illustrates this. Cohort A has its birthday at time O and cohort B has its birthday at time t. At length 4 cm, cohort A has age a and cohort B has age b. Thus, one cannot convert a length of 4 cm into age, because one does not know which animal in a given length sample belongs to which cohort.

In other cases, one can (in theory) use the traditional methods. If the seasonalized growth curve is used to convert length into age, the same growth model must be used throughout the entire analysis. For example, when using the length-converted catch curve

$$\ln(N/\Delta t) = a - Z * t \quad ...1)$$

the values of Δt (the time it takes to grow through a length class) can be calculated using

$$L_t = L_\infty(1-\exp(-K(t-t_o) - (CK/2\pi)\sin(2\pi(t-ts)))) \quad ...2)$$

if growth rate indeed varies seasonally. I mention this because I have seen papers where the authors used the seasonalized model to describe growth, and then used the ordinary von Bertalanffy model when estimating mortality rates.

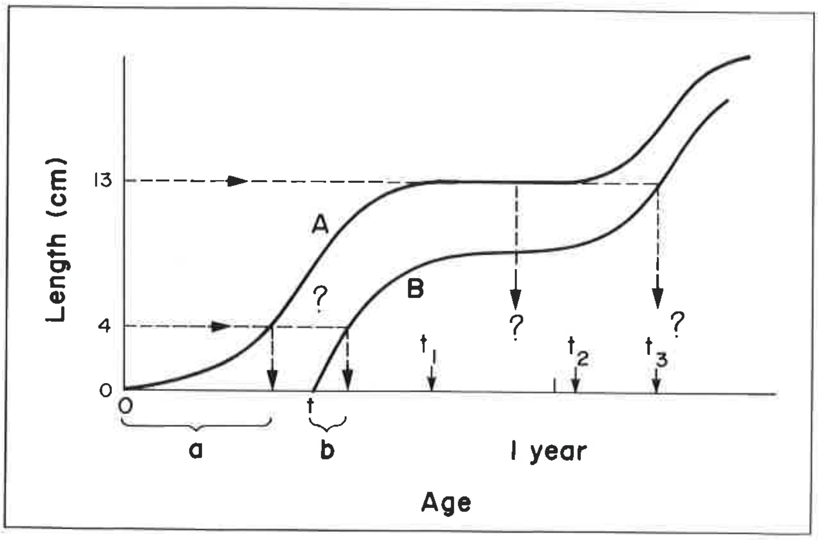

Fig. 1. Schematic representation of problem occurring when attempting to convert length into age when growth is strongly seasonal (this example refers to a penaeid shrimp exposed to a marked seasonal cycle of temperature, leading to C = 1).

My personal view on seasonality of growth is that one should not consider it unless there is really convincing evidence that seasonality is important (because we rarely have the high quality of unbiased data required to estimate seasonality). For example, migration of animals may have a bias effect on the modal progression analysis which makes it look like seasonality of growth (see Chapter 11 in Sparre et al. 1989). However, this is another story. Let us assume here that seasonalized growth occurs (I do believe that all animals have seasonalized growth, more or less).

Results of Simulations

To study the effect of seasonalized growth on length-converted catch curves, I did a number of computer simulations, where I assumed one cohort per year and calculated stock numbers and numbers caught by length group, assuming various types of seasonality of growth.

Thus, for example, the number of survivors corresponding to the end of a length class, $N_{t+\Delta t}$ was calculated by

$$N_{t+\Delta t} = N_t * \exp(-Z\,\Delta t) \quad ...3)$$

where N_t is the number corresponding to the beginning and Δt is the time it takes to grow through the length class. The time period, Δt, was calculated from the seasonalized growth curve (equation 2). Fig. 2 shows the growth curves of the four cases I simulated, with C = 0, 0.33, 0.66 and 1. Note that for C = 1, growth rate is approximately zero for about 3 months.

Fig. 3 shows the results of the simulations in all four cases. Note that the more pronounced the seasonality is (C close to 1) the higher numbers are caught in the length class where growth is slow (length 20-35 in the example). This is, of course, because the shrimps stay for a long period of time in these length classes, while fishing continues.

Fig. 3 also shows the length-converted catch curve analyses. The lines with the open dots represent the correct analysis, i.e., the one where Δt is calculated from the seasonalized growth curve. In all cases, this procedure gave Z = 4 $year^{-1}$, which is known to be the correct result, as it was used to create the simulated data. Note that the distance between the dots indicate the value of Δt.

The lines with the black dots represent the wrong way of doing the analysis, namely calculating the Δt from the ordinary von Bertalanffy growth curve, and forgetting about seasonality. As can be seen, the bias resulting from ignoring seasonality can be considerable.

Discussion

There are problems similar to the ones discussed above with the other methods requiring conversion of

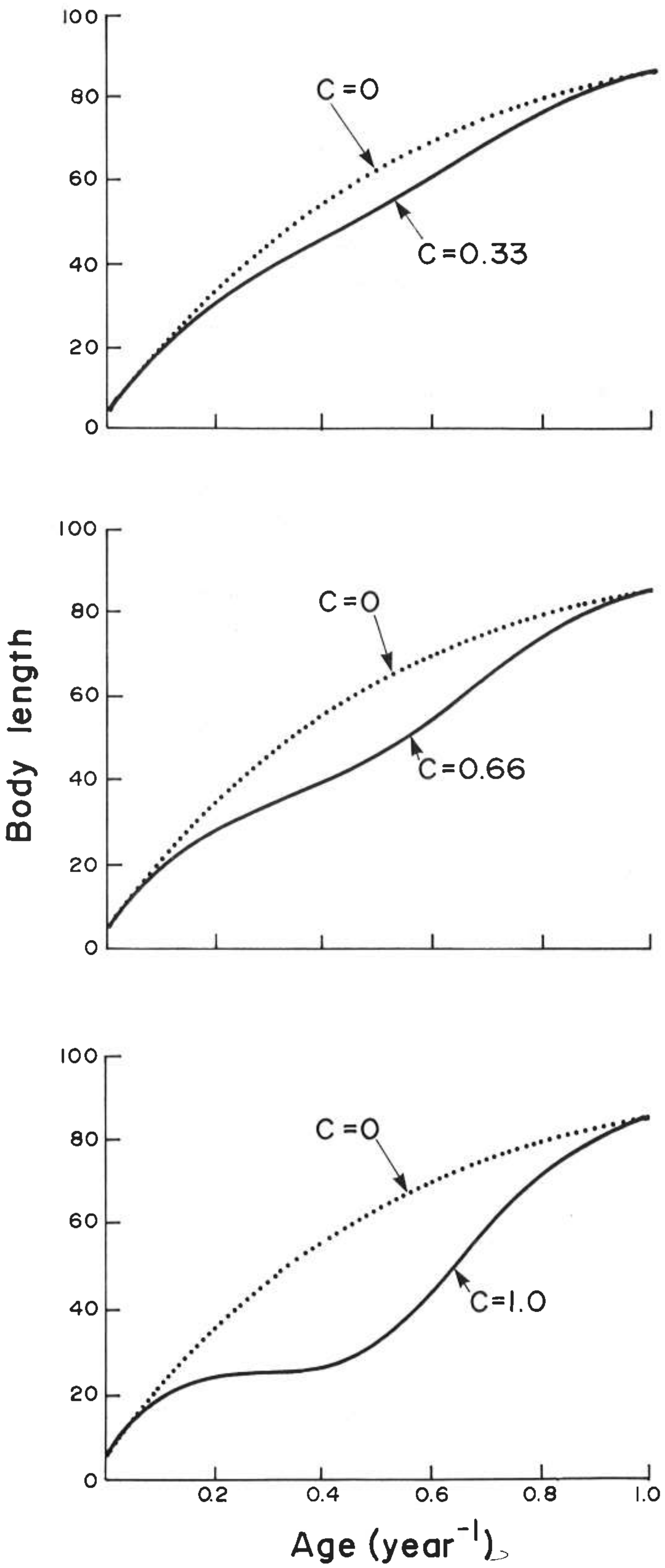

Fig. 2. Effect of the parameter C of equation (2) on growth curves with L_∞ = 100, K = 2 $year^{-1}$, WP = 0.8, t_o = -0.15 and C = 0, 0.33, 0.66 and 1.

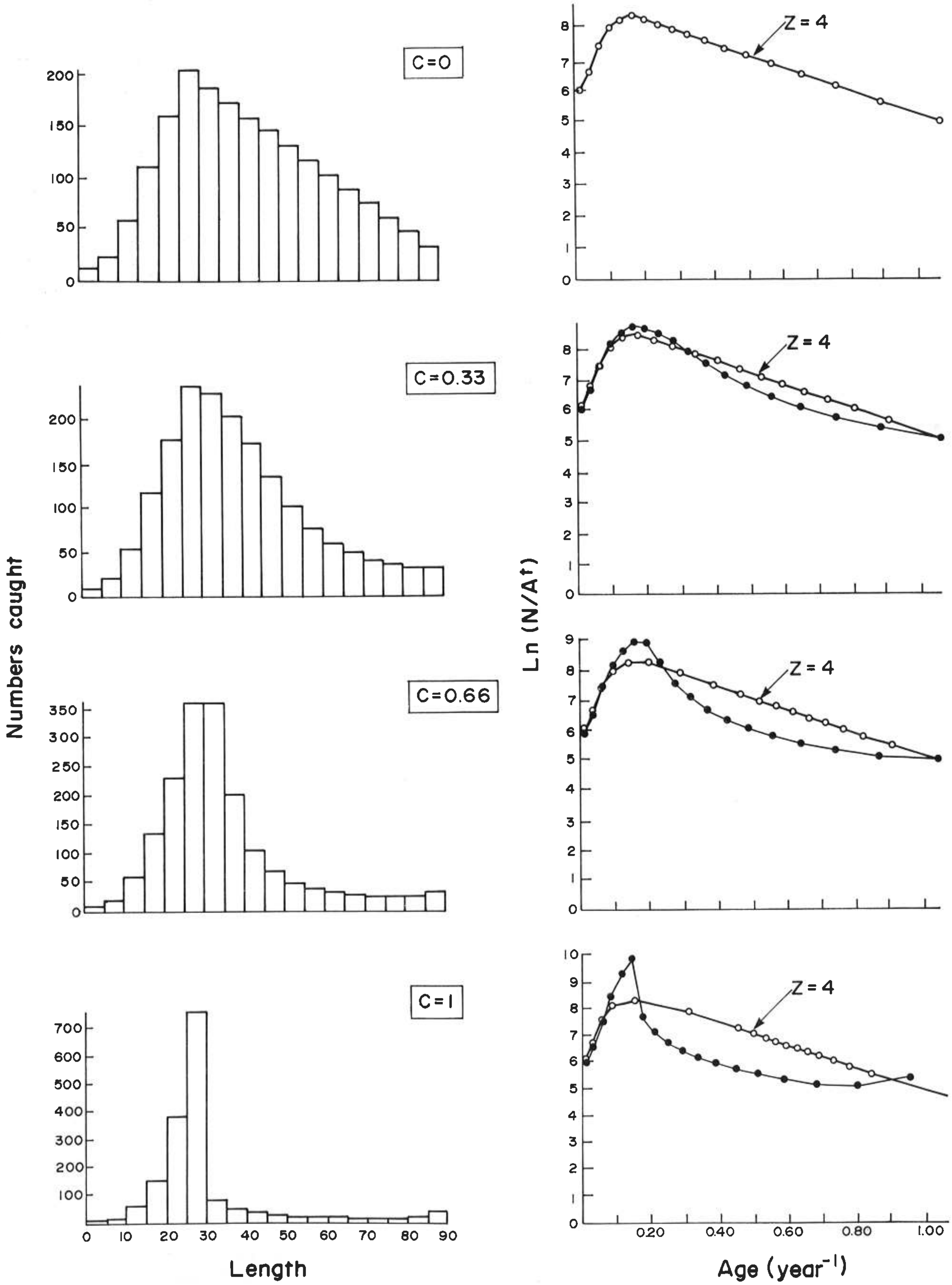

Fig. 3. Results of simulations based on $L_\infty = 100$ (%), $K = 2$ year^{-1}, $t_s = 0.8$, $M = 3$ year^{-1} and $F = 1$ year^{-1} (and hence $Z = 4.0$ year^{-1}). The graphs on the left show the numbers caught, those on the right show length-converted catch curves, with open dots accounting for seasonal growth oscillations and filled dots ignoring these (in both cases, the distances between dots represent the Δt values for the corresponding length classes). Note large differences between two curve types. Also note that the (erroneous) catch curves defined by the full dots have no clearly identifiable straight segment from which Z could be estimated.

length into age, notably with the length-structured cohort analysis of Jones (1981).

Other methods, usually not considered elements of length-based methodology, but which assume the ordinary von Bertalanffy growth model also have to be modified. This applies to the Beverton and Holt yield-per-recruit model (Beverton and Holt 1957, 1966), and their method for calculation of Z from mean length (Beverton and Holt 1956), and to the method of Wetherall (1986) as well.

The solution of this problem is to give up the idea of converting length into age. A methodology based on the inverse conversion, namely from age into length will not have the problems discussed above, as "growth in age" has no seasonality. Thus, we can assume that to each age, there is one (and only one) corresponding average length. The reader may now ask the question: "If it is really that simple, why did we not do it right from the beginning"? The answer is that it is not a simple thing to do.

I made one attempt at implementing such approach in an earlier paper (Sparre 1987). This paper shows that the mathematics involved in such attempt becomes somewhat complicated. However, it also shows that it is possible to use an alternative methodology. This paper presented only one of the first attempts to develop such alternative methodology; it does not represent a complete theory. If we want to include seasonality in length-based fish stock assessment, there is still a long way to go before we can start using it in practice.

The big problem here is, of course, that we do not know the age of the animals. (Otherwise there would be no need for "length-based fish stock assessment").

Sparre (1987) suggested a solution involving an iterative process:

A. Make a guess on ages (or growth parameters);

B. Simulate (or predict) numbers caught by length group (this involves only conversion of age into length);

C. Compare simulated and observed numbers caught by length group (using maximum likelihood or chi-squared tests);

D. If the agreement in the comparison (C) is not fair, then modify the growth parameters (and thereby the ages) and return to B.

The computations of the above procedure, which, as mentioned above, are somewhat complicated, were done with a mainframe computer. Unfortunately no microcomputer version is yet available.

Another aspect which should be looked into is the bias of length-frequency samples created by the migratory behavior of fishes and other animals.

I believe that many cases of apparent seasonality of growth observed are actually biases created by migration. It is a well-established fact that marine animals move, but it is less recognized that these movements can bias the length-frequency samples so that growth appears to be seasonal, even if the animals follow the ordinary von Bertalanffy growth curve. In some cases, it may even appear as if growth was negative (Sparre et al. 1989). I conclude by suggesting that perhaps seasonality is less important, and perhaps there are some other aspects which are much more important to investigate.

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