Development of a Combined Model of Growth in Weight for Juvenile and Adult Queen Conch (*Strombus gigas*) and Its Application to the Population Off La Parguera, Puerto Rico

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ABSTRACT

Modelling of growth in queen conch is difficult due to separate juvenile and adult growth patterns. Juveniles grow in shell length; adults do not grow in length, but progressively thicken the shell. For the conch population offshore of La Parguera, Puerto Rico, von Bertalanffy models of shell growth plus size-weight relationships for both juveniles and adults were used to produce composite weight-age data. Separate analyses were made for wet meat weight and total wet tissue weight. These data were modelled with the Gompertz function using nonlinear regression. Results show that compared to juvenile growth there is a marked decrease in weight growth upon reaching maturity. This indicates the following:

1. Extrapolation of juvenile growth rates into adult ages is not valid.
2. Optimum yield-per-recruit will occur prior to sexual maturity.

Management decisions based strictly on the latter point could lead to recruitment overfishing.

INTRODUCTION

The task of stock assessment is facilitated if fisheries scientists have appropriate biological information in a readily applicable form. A key factor in stock assessment is knowledge of growth rate, particularly in terms of weight. Growth can often be described with a simple mathematical function, which can be used, with additional information, to assess the effects of current or proposed management strategies on yield, population biomass, and spawning stock biomass.

The queen conch (*Strombus gigas* L.) is heavily exploited throughout its range. As yet there is no complete assessment of its growth in weight. Studies of *Strombus* generally rely on changes in shell size to assess growth, because shell measurements can be easily taken and do not harm the animal. Assessment of growth in *Strombus* using shell measurements, however, is complicated by its two-stage growth pattern: juveniles increase in shell length, whereas adults cease growing in length and instead produce the characteristic flared shell-lip, which is then thickened over time.

The specific objectives of this paper are:

- To provide a simple methodology for determining the growth in weight of *S. gigas;*

- To develop a simple mathematical model of growth suitable for stock assessment (*e.g.*, incorporation into yield-per-recruit analyses);
- To model growth in weight for the queen conch population off La Parguera, Puerto Rico; and
- To discuss its implications for stock assessment.

METHODS

The method I propose combines growth curves developed separately for juveniles and adults. Growth curves for adults (based on shell-lip thickness) and for juveniles (based on shell length) have been published for the La Parguera population (Appeldoorn, 1988; in press, a). In conjunction with size-weight regressions, shell growth can be converted to growth in weight. For juveniles, the relationship between shell length (L_t) and age (t) can be expressed using the von Bertalanffy function as follows (Appeldoorn, in press, a):

$$L_t = 46.0\,(1 - e^{-0.25(t-0.244)}) \qquad (1)$$

where age is in years and length in centimeters. Appropriate length-weight regressions for wet tissue weight (TW) and wet meat weight (MW) are listed in Appeldoorn (1988):

$$\mathrm{Log(MW)} = \quad -2.535 + 3.486\,\mathrm{Log(L)} \qquad (2)$$
$$\mathrm{Log(TW)} = \quad -2.286 + 3.459\,\mathrm{Log(L)} \qquad (3)$$

where weights are in grams and L is shell length in centimeters. Tissue weight is the weight of the entire animal minus the shell. Meat weight is the weight after removal of the visceral mass, but with the animal otherwise intact. Using Equations 2 and 3 with Equation 1 allows one to estimate weight-at-age for juveniles.

For adults, the von Bertalanffy function was used to model growth in shell-lip thickness (LP) over time (Appeldoorn, 1988):

$$LP_t = 54.9\,(1 - e^{-0.3706t}) \qquad (4)$$

where lip thickness is in millimeters. Here time is expressed in adult age, *i.e.*, years since lip formation. Lip thickness can be used to estimate the meat weight (MWG) and tissue weight (TWG) gained since maturation (Appeldoorn, 1988):

$$\mathrm{Log(MWG + 100)} = 1.797 + 0.232\,\mathrm{Log(LP)} \qquad (5)$$
$$\mathrm{Log(TWG + 100)} = 1.764 + 0.403\,\mathrm{Log(LP)} \qquad (6)$$

To estimate true adult weight, the weight gained since maturation must be added to the weight attained at the time of maturation. The latter is primarily a function of shell length at the time of maturation (Appeldoorn, 1988); hence estimates will differ for different sized animals. For the analysis I used the average adult shell-length in the population. Off La Parguera this is 24 cm. According to Equation 1 this size is attained in 3.2 yrs, and corresponding weights can be determined from Equations 2 and 3: meat weight = 190 g and tissue weight = 309 g. Thus two growth curves are developed:

1. Juvenile weight-at-age in absolute time, and
2. Adult weight-at-age in relative (adult) time.

The exact starting point of adult age cannot be determined directly. Theoretically it is the point at which lip-thickness is zero, but the lip has a finite size when formed. Starting time could be considered as the time at which the lip first starts to form; a fully developed lip takes less than three months to form (Appeldoorn, 1988). However, shell length is still increasing as the final whorl of the shell is produced during lip formation. Thus, there is overlap between the time maximum length is reached (the end of juvenile growth) and the beginning of lip formation (the beginning of adult growth). As such, there is no clear transition point where one can switch between estimates of weight based on juvenile growth and those based on adult growth.

In order to resolve this, I assumed that any growth change in weight occurring at the time of maturation is not sudden; rather it occurs over a brief, but finite, period of time. A reasonable assumption is that any transition is on the order of time required for lip formation or for complete development of reproductive structures (*i.e.*, male verge or female egg groove). In Puerto Rico, this is two to five months (Appeldoorn, 1988). With this assumption, it is necessary only to fit the two growth curves together in a manner that yields a smooth transition between the two, given the constraint that the transition point occurs within a few months of 3.2 years, the time at which average adult length is reached. Joining the curves with a smooth transition is best accomplished by switching from juvenile growth to adult growth at the point where the slopes of the two curves are equal.

This process is illustrated using data for growth in tissue weight for conch from La Parguera. In Figure 1, the upper curve (B) represents adult growth in weight as predicted for a 24 cm individual. The exact horizontal position of this curve on the graph is imprecise because the exact starting age of adult growth is unknown. This curve is shifted to the left until it is tangent to the curve describing juvenile growth in weight (A). The age corresponding to the point of

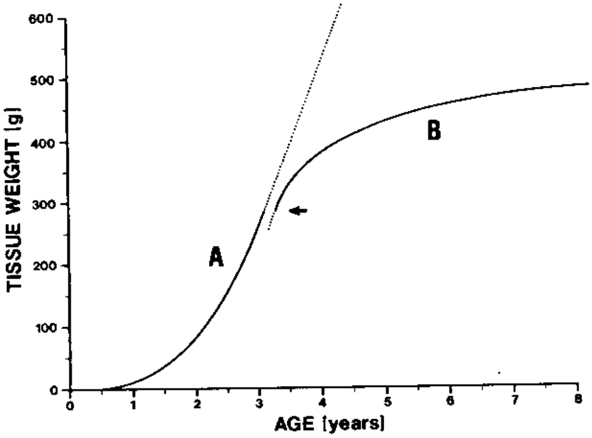

Figure 1. Graphical procedure for combining juvenile (A) and adult (B) growth curves. Data are for tissue weight of *Strombus gigas* from La Parguera, Puerto Rico. Curve B s shifted to the left until tangent to curve A (see arrow). The combined resultant curve would be represented by the solid lines.

tangency is the transition age, and is added to adult age to get absolute age. The point of tangency can be found directly from the mathematical models describing juvenile and adult growth. However, this involves iteratively solving two nonlinear equations (Appendix 1). Since my objective is to offer a simple method, I used the proceeding graphical approach in developing descriptions of growth in tissue weight and meat weight.

Points of weight-at-age predicted by the combined curve can then be used to develop a mathematical model. The best mathematical expression for modelling the resultant curve is determined empirically, based on its ability to describe the data accurately. As such, no biological significance need be placed on model parameters. Here, I used the Gompertz function (Ricker, 1975) fit to the data with nonlinear least-squares regression (Saila *et al.*, 1988).

RESULTS

To achieve a smooth transition when combining adult and juvenile growth curves for the La Parguera population, it was necessary to shift the adult curve to the left 0.25 yr and 0.23 yr for meat weight and tissue weight, respectively. This compares favorably with the transition period between growth in shell length and lip thickness.

Data points used to estimate model parameters and their respective growth curves are shown in Figures 2 (meat weight) and 3 (tissue weight). Respective model equations are as follows:

$$MW = 4.394 \times 10^{-7}\, e^{20.12\,(1 - e^{-1.275\,t})}$$

$$TW = 1.263 \times 10^{-5}\, e^{17.44\,(1 - e^{-1.126\,t})}$$

DISCUSSION

The graphical procedure employed here generated combined growth curves consistent with the known biology and growth patterns of queen conch. Slight variations in positioning the adult growth curve on the graph, as might occur between investigators, would not significantly affect results. The resulting Gompertz functions for meat and tissue weight easily lend themselves to further analyses, such as incorporation into Ricker's yield-per-recruit analysis (Ricker, 1975).

There still exist limitations to the above approach and subsequent results. First, the model is specified only for individuals reaching a given size at maturation. Mean length of adults was used here. Thus the models do not account for the variance around mean growth of juveniles. Separate models for small and large adults could be constructed based on variance estimates of juvenile von Bertalanffy growth parameters (*e.g.*, Appeldoorn, in press, a). This approach assumes that all conch mature at the same age, regardless of length; this is presently unknown. Second, while the Gompertz models fit the combined data exceedingly well (Figures 2 and 3), they are not exact. This may introduce a slight bias in yield-per-recruit estimates. If greater accuracy is required yield-per-recruit could be calculated using the two separate juvenile and adult functions, switching from the former to the latter at the point of transition.

Despite these limitations, two points emerge upon inspection of the graphs. First, extrapolation of juvenile growth rates into adulthood is not valid for queen conch. There is a sharp decrease in the rate of growth in weight at maturity, and predictions of adult weight based on juvenile growth rate would be significantly overestimated. This is illustrated in Figure 1, where the dotted portion of curve A represents the extrapolation of juvenile growth. The unusually marked decrease in growth at maturity is consistent with the equally unusual characteristic of determinant growth in *Strombus*. Similarly, Sanders (1988) found no measurable growth in tissue weight in adults of the fighting conch (*S. pugilis*).

The sharp decrease in growth rate at maturity also implies there would be little gain in yield-per-recruit by letting conch live beyond the onset of sexual maturity. If yield-per-recruit is the only consideration in management decisions, this could lead to recruitment overfishing (Appeldoorn, in press, b).

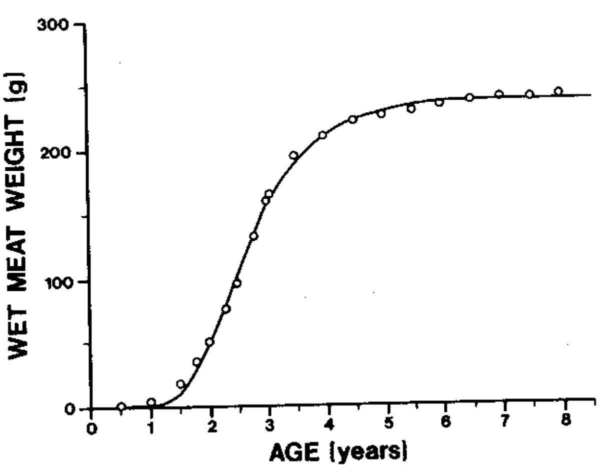

Figure 2. Growth in meat weight for *Strombus gigas* of average length (24 cm) from La Parguera, Puerto Rico. Points represent data used to determine parameters of the Gompertz function. Solid line represents the fit of the resulting model.

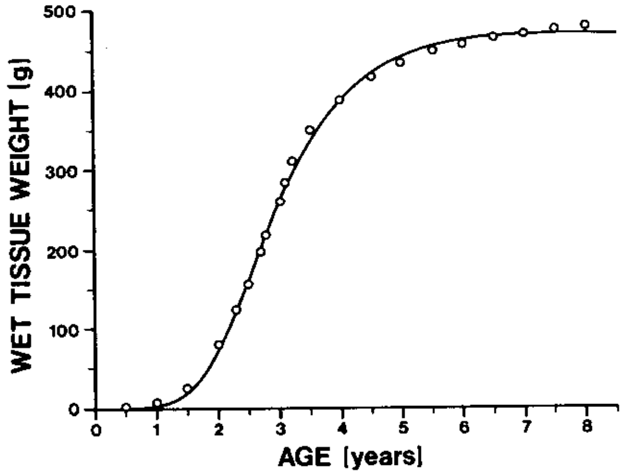

Figure 3. Growth in tissue weight for *Strombus gigas* of average length (24 cm) from La Parguera, Puerto Rico. Points represent data used to determine parameters of the Gompertz function. Solid line represents the fit of the resulting model.

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APPENDIX 1

The von Bertalanffy growth function for weight is defined as

$$W_t = W_\infty (1 - e^{-k(t-t_0)})^3 \qquad (7)$$

where W_t is weight at time t, and W_∞, k, and t_0 are model parameters. The point of transition between von Bertalanffy curves of juvenile and adult conchs will be the point where one curve is tangent to the other. At this point their slopes will be equal and their predicted weights (W_t) will be equal. Slopes are given by the first derivative of the von Bertalanffy function (Pauly, 1979):

$$\frac{dw}{dt} = W_\infty{}^3 \; [1 - e^{-k(t-t_0)} \;]^2 \, k \; e^{-k(t-t_0)} \qquad (8)$$

The parameter k can be taken directly from von Bertalanffy models of growth in shell length (juveniles: *e.g.* Equation 1) and shell lip-thickness (adults: *e.g.* Equation 4). The same is true for t_0 for juveniles. W_∞ for juveniles is obtained by converting the length-based parameter L_∞ to weight using a length-weight regression (*e.g.*, Equations 2 and 3). In a similar manner one can obtain W_∞ for adults from the lip-thickness based growth model. However, this value is for weight attained since maturation and must be added to the average weight at the time of maturation (*e.g.*, 309 g tissue weight for the La Parguera population) to get true adult W_∞. The adult model must be put in terms of absolute time (age); however, t_0 for adults is unknown.

Thus, there exist two equations:

1. Equality of slopes of the juvenile and adult growth curves (from Equation 8), and
2. Equality of their predicted weights (W_t) (from Equation 7).

These can be used to solve for the two unknowns: t and adult z-t_0. The point of transition is equal to t.