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Two-step Procedure Based on the Least Squares and Instrumental Variable Methods for Simultaneous Estimation of von Bertalanffy Growth Parameters

Ivelina Yordanova Zlateva, Technical University of Varna, Varna, Bulgaria
Nikola Nikolov, Technical University of Varna, Varna, Bulgaria

ABSTRACT

Advanced in the present article is a Two-step procedure designed on the methods of the least squares (LS) and instrumental variable (IV) techniques for simultaneous estimation of the three unknown parameters L∞, K and t0, which represent the individual growth of fish in the von Bertalanffy growth equation. For the purposes of the present analysis, specific MATLAB-based software has been developed through simulated data sets to test the operational workability of the proposed procedure and pinpoint areas of improvement. The resulting parameter estimates have been analyzed on the basis of consecutive comparison (the initial conditions being the same) between the results delivered by the two-step procedure for simultaneous estimation of L∞, K and t0 and the results obtained via the most commonly employed methods for estimating growth parameters; first, use has been made of the Gulland-and-Holt method for estimating the asymptotic length L∞and the curvature parameter K, followed by the von Bertalanffy method for estimation of t0.

KEYWORDS

Asymptotic Length, Biological Objects, Fish, Gulland-Holt Plot, Individual Growth, MATLAB, Modeling, Parameter estimates, System Identification

INTRODUCTION

Determining the fish growth parameters plays a fundamental role not only in the correct detection of the fish stock age and size structure, but also in the process of stock assessment procedure, studies of the population dynamics and sustainable stock management in terms of fish stock exploitation restrictions or specific recommendations for minimum limits on the size (length) of species to be caught legally, selectivity of the fishing gears and equipment, etc. Historic data on growth parameters estimates has been successfully used as a basis for analysis of the stock biological development over time in addition to the analysis of the impact of environmental factors – food availability, variability in specific environmental conditions, such as water temperature, the concentration of dissolved oxygen, the types of species interactions and others. Several functions have been developed to model the growth of fish (Gompertz growth model, Schnute-Richards, logistic, etc.), however the von Bertalanffy model is the most popular and is in the scope of the present material.

The von Bertalanffy mathematical model of individual-based approach to predicting fish growth expresses the length $\left(L\right)$ as a function of the age of the fish $\left(t\right)$:

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$$L\left(t\right) = L_{\infty}\left[1 - \exp\left(-K\left(t - t_0\right)\right)\right] \tag{1}$$

where: t is the age of the respective fish, L_{∞} - is the asymptotic length (or mean length of the cohort at age equal to infinity when the study refers to population dynamics), K is a curvature parameter which shows how fast a given individual approaches its asymptotic (finite) length, t_0 – is the initial condition parameter (determining the point in which the length of the fish is =0) (Cadima, 2003, Sparre & Venema, 1998).

Equation (1) has three unknown coefficients K, L_{∞} and t_0, to be determined analytically on the basis of given experimental data (i.e. the length and age measurements of the species under analysis). A great number of methods for estimating von Bertalanffy growth parameters have been successfully implemented in practice, with their main disadvantage being the requirement for regularity of the corresponding measurements. Failure to collect and process the data on a regular basis distorts the results of the methods discussed so far except for the Gulland-and-Holt plot, and what is more, they usually provide estimates for only 2 of the 3 unknown parameters (Sparre & Venema, 1998), with the exception of (Melnikova, 2009).

Norbert Winner and Ludwig von Brtalanffy conclusively proved in their works the existence of close similarities in the operation and control of the machines and the living organisms. It follows, therefore, that the common principles, methods and approaches developed for the analysis and control of large technical systems can be successfully modified or adapted in the research and modeling of biological objects and systems. The System theory and more specifically the development of the System identification scientific area appear to be very suitable theoretical basis for further improvement and elaboration of the object/system modeling methods and principles (Eykhoff, 1974; Genov, 2004; Hoffman & Frankel, 2001; Soderstrom & Stoica, 1989).

The Least Squares Method (LSM) techniques are well-known and widely applied in various scientific areas for experimental data processing and its subsequent fitting to a model (Stigler, 1981; Walter & Pronzato, 1997). The LSM is a standard approach in regression analysis to approximate the solution of overdetermined systems, i.e., sets of equations in which the number of equations is much higher than the parameters unknown. "Least squares" means that the overall solution minimizes the sum of the squares of the residuals made in the results of every single equation. It is widely practiced in engineering for solving regulator synthesis problems and system modeling, where a variety of LSM modifications have been developed aiming at obtaining general improvement of the accuracy in parameter estimates. The LSM also takes place in modeling and parameter estimation of biological objects. Its wide applicability is generally assumed to be associated with normal distribution of input data used for analysis provided that the number of data should exceed the number of the unknown (estimated) parameters. The present article proposes a two-step procedure designed on the methods of least squares and instrumental variables for simultaneous estimation of the three unknown parameters in von Bertalanffy growth model equation - L_{∞}, K and t_0.

BACKGROUND

For the purposes of the present analysis and development of the method proposed and the corresponding algorithm, the von Bertalanffy growth equation will be re-stated as follows:

$$L\left(t\right) = L_{\infty} - L_{\infty}e^{-K\left(t-t0\right)} \tag{2}$$

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