Decision Support for Pond Aquaculture: Parameter Estimation for Simulation Models

Work Plan 7, DAST Study 5

John P. Bolte and Shree S. Nath
Department of Bioresource Engineering
Oregon State University
Corvallis, USA

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Introduction

Users of the *POND* decision support system may often be interested in tailoring the models to one or more fish species at a given location. Manual calibration of the fish bioenergetics model in POND for Nile tilapia *(Oreochromis niloticus)* growth has previously been reported (Bolte et al., 1995). However, estimating suitable parameters for complex, non-linear simulation models by manual calibration can be extremely tedious, because of the potentially high degree of interaction between variables and the large size and dimensions of parameter spaces to be searched.

Several traditional approaches to non-linear parameter estimation have been developed in the past. These traditional approaches typically involve definition of an objective function (e.g., error sum of squares between predicted and observed values' absolute error) that is to be minimized, and a procedure for finding a set of parameters which in fact minimize this function. Thus, model parameter estimation may be considered to be an optimization process. In general, numerical algorithms for minimizing the objective function require evaluation of partial derivatives of the objective function with respect to each of the parameters to be estimated (Fig. 1). Such derivative evaluations for large models can rarely be accomplished analytically, and are usually calculated numerically (Bard, 1974). However, it is difficult to achieve accurate results with numerical methods for derivative calculations, and the techniques that do exist tend to be relatively computation-intensive. In general, the difficulties associated with these methods have severely limited their application in biological models.

Recently, however, a new class of non-linear optimization strategies has been developed which show considerable promise for non-linear model estimation. This class includes genetic algorithms (GA's), a fairly recent optimization technique that attempts to overcome the problems of traditional methods (Schwefel, 1981; Davis, 1992). A GA may be thought of as an implementation of the process of natural selection or evolutionary adaptation on a computer (Holland, 1975), evaluating populations of solutions based on natural selection, and allowing the most fit of these solutions to combine and reproduce until highly suited individuals emerge, representing good solutions to the problem at hand. GA's have been previously used as a tool for parameter estimation of complex agricultural simulation models (Sequeira and Olson, 1995). A study was initiated to examine the use of GA's for estimating suitable bioenergetic parameters for different pond species.

Methods

Three species were chosen to examine the suitability of a GA-based parameter estimation technique for the POND models. The selected species were channel catfish *(Ictalurus punctatus)*, tambaquí *(Colossoma macropomum)* and pacu *(Piaractus mitrei)*. Growth, water temperature and feeding data were obtained from the following sources:

Channel catfish: Robinson and Li (1995)
Tambaquí: Merola and Pagan-Font (1988)
Pacu: Lima et al. (1988)

Table 1. Bioenergetic parameters for channel catfish, tambaquí, and pacu estimated by the use of GAs.

| PARAMETER	CATFISH	TAMBAQUÍ	PACU
Anabolism parameters			
Efficiency of assimilation	0.7865	0.6695	0.7719
Anabolism exponent	0.6327	0.6855	0.7154
Food consumption coefficient	0.2885	0.2863	0.2415
Catabolism parameters			
Feeding catabolism coefficient	0.1133	0.1057	0.0529
Catabolism exponent	0.5118	0.5336	0.5332
Minimum catabolism coefficient	0.0227	0.0146	0.0094
Temperature parameter	0.0119	0.0111	0.0290
Temperature scalers			
Minimum	13.31	14.40	17.46
Maximum	35.96	38.58	31.36
Optimum	30.81	29.04	28.09
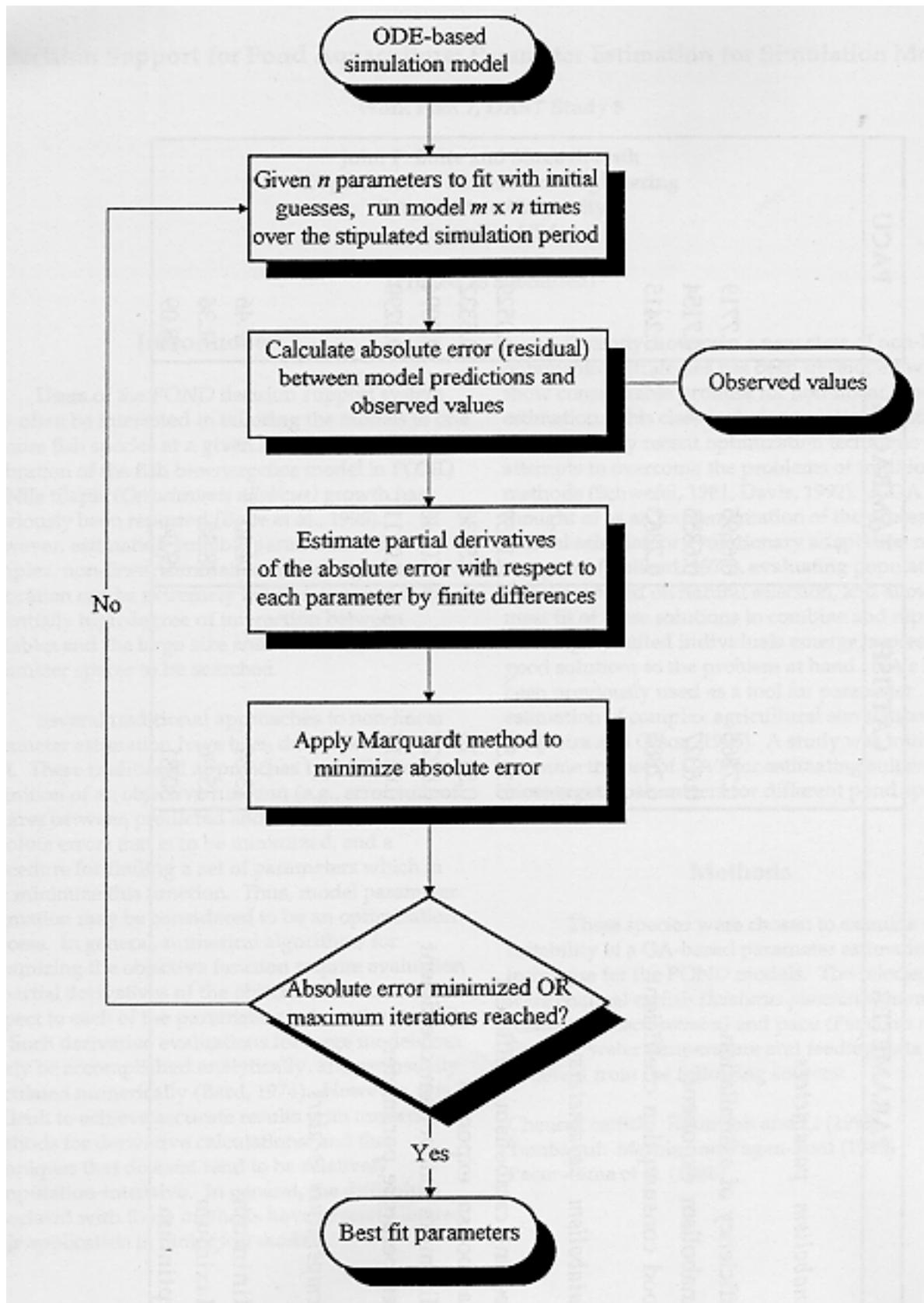
Figure 1. Summary of the procedure for parameter estimation for an ordinary differential equation (ODE) based simulation model by a non-linear regression technique (Marquardti's method).
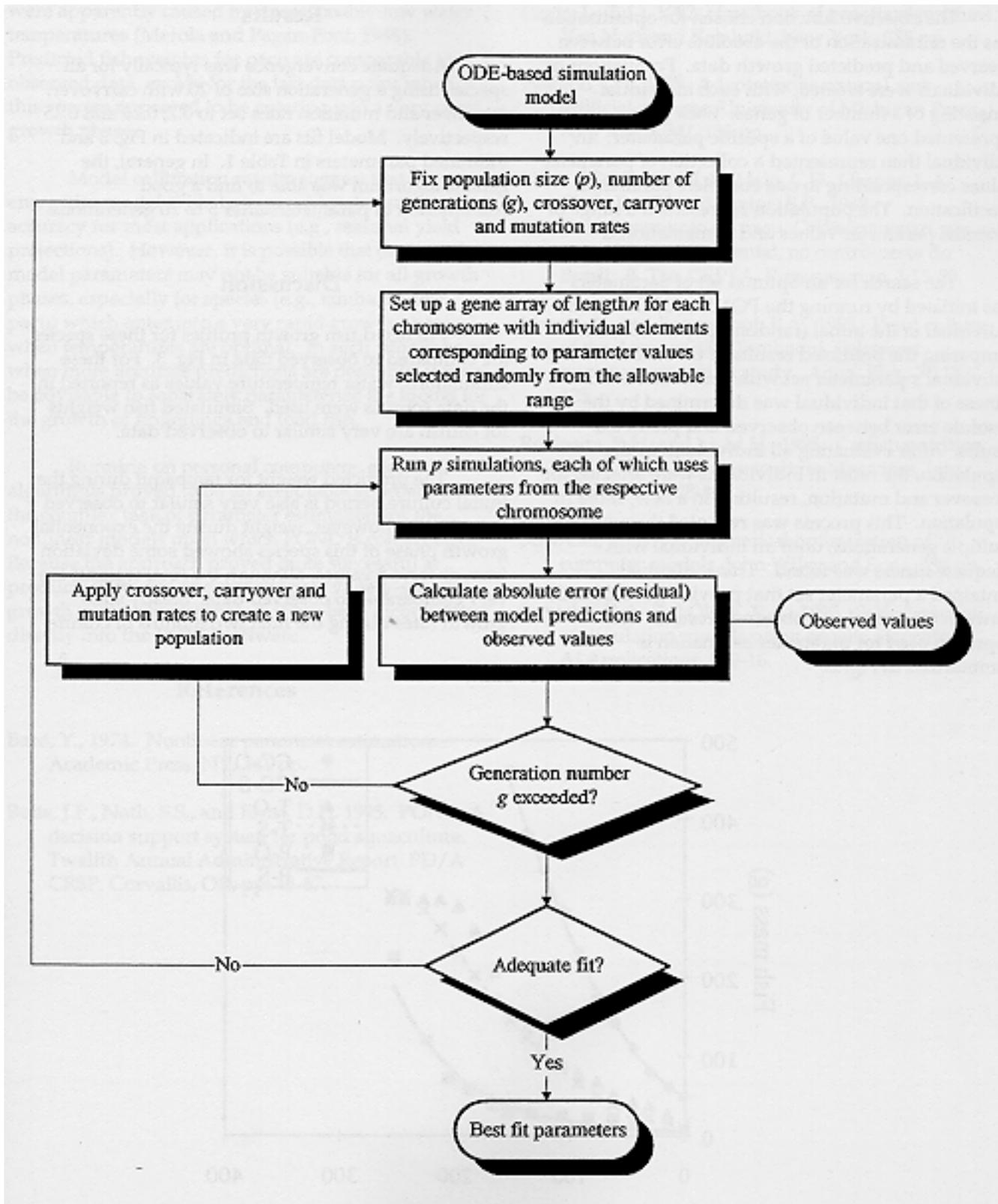
Figure 2. Summary of the procedure for parameter estimation for an ordinary differential equation (ODE) based simulation model by GAs.

The objective function chosen for optimization was the minimization of the absolute error between observed and predicted growth data. Populations of individuals were created, with each individual consisting of a number of genes. Each gene represented one value of a specific parameter; an individual then represented a collection of parameter values corresponding to one complete parameter specification. The population represented a range of potential parameter values and combinations.

The search for an optimal set of parameters was initiated by running the POND model for each individual in the initial (random) population, and comparing the predicted results of the model for that individual's parameter set with observed results. Fitness of that individual was determined by the absolute error between observed and predicted results. After evaluating all individuals in the population, the most fit individuals were selected for crossover and mutation, resulting in a new, more fit population. This process was repeated through multiple generations, until an individual with adequate fitness was found. This individual contained a parameter set that provide good fit with between the model and observed results. The approach used for parameter estimation is summarized in Fig. 2.

Results

Adequate convergence was typically for all species using a generation size of 20 with carryover, crossover and mutation rates set to 0.2, 0.25 and 0.15 respectively. Model fits are indicated in Fig. 3 and estimated parameters in Table 1. In general, the genetic algorithm was able to find a good combination of parameters after 5 to 10 generations.

Discussion

Predicted fish growth profiles for these species are compared to observed data in Fig. 3. For these simulations, water temperature values as reported in the data sources were used. Simulated fish weights for catfish are very similar to observed data.

The predicted weight for tambaquí during the initial culture period is also very similar to observed data (Fig. 3); however, weight during the exponential growth phase of this species showed some deviation from observed values, although the final weights are very comparable to observed data. Steady state growth rates during the final two months of culture
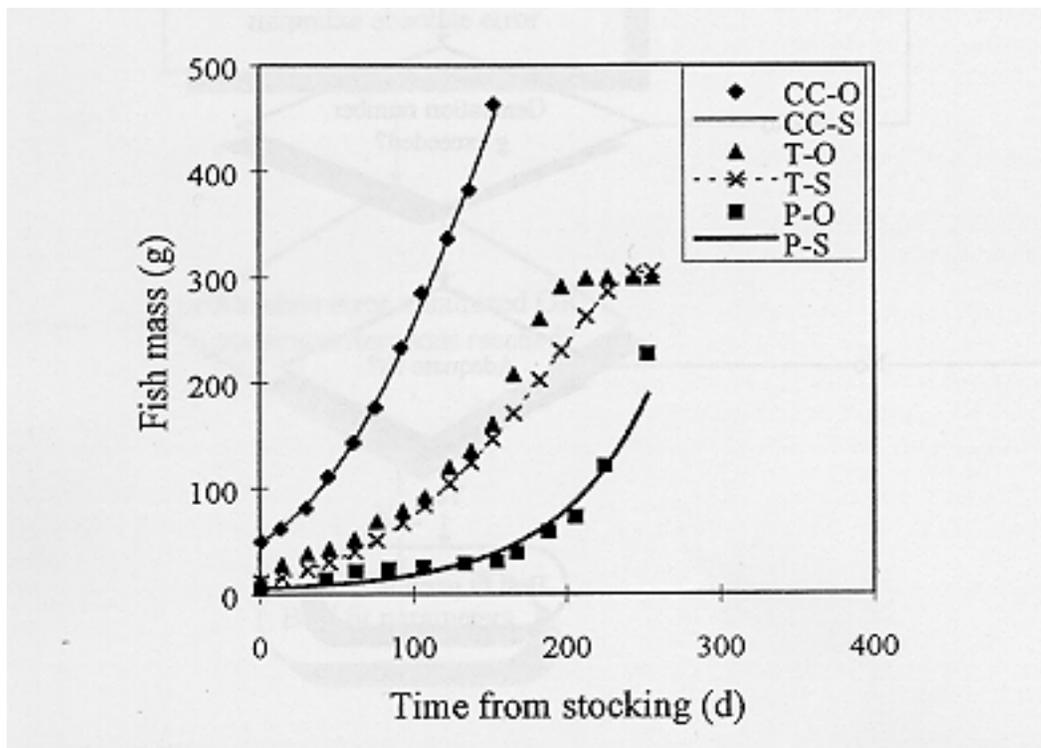

Figure 3. Simulated (S) and observed (O) fish growth profiles for channel catfish, tambaquí, and pacu. All the simulated profiles generated by the use of the POND models with parameters estimated by GAs.

were apparently caused by unseasonably low water temperatures (Merola and Pagan-Font, 1988). Predicted fish weights for pacu are comparable to observed data, except for the last data point when this species appeared to be entering into a very rapid growth phase.

Model calibration results suggest that the energetics model is likely to provide adequate accuracy for most applications (e.g., seasonal yield projections). However, it is possible that one set of model parameters may not be suitable for all growth phases, especially for species (e.g., tambaquí and pacu) which enter into a very rapid growth phase when temperatures are optimal. In such situations or when more accurate predictions are desirable, it may be advisable to separately parameterize the model for the growth of fingerlings and food fish.

Running on personal computers, genetic algorithms proved to be an acceptable approach for the complex task of parameter estimation for the nonlinear models upon which POND is constructed. Because the approach proved quite successful at producing site-specific and species/variety-specific growth parameter estimated, it has been incorporated directly into the POND software.

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Central Data Base

Hilary Berkman
Consultant
Corvallis, Oregon, USA

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Summary of Activities

At the time the Central Data Base was transferred to the University of Hawaii it was complete through the Fourth Work Plan and nearly complete through the Fifth Work Plan. Since then data from two experiments in Rwanda and two experiments in Thailand were added to the Fifth Work Plan data.

The Sixth Work Plan included 19 experiments to be conducted between September 1, 1991 and August 31, 1993. Supplemental Work Plans included nine more experiments to be conducted during that period. All data collected using standard CRSP methods, and which the database could accommodate, were to be reported. (See Sixth Work Plan, page 1). Currently, the CRSP data base includes the following Sixth Work Plan data: two experiments from Honduras, three experiments from the Philippines and five experiments from Thailand. There are no data from Rwanda reported in the data base. In summary, ten experiments from the Sixth Work Plan have been included in the data base.

The Seventh Work Plan experiments covered the period from September 1, 1993 to August 31, 1995. Nine experiments were to be conducted in Honduras; none are reported in the database. Ten studies were to be conducted in Thailand; the results of four of those studies are included in the data base. Two experiments from the Philippines are reported. No data from Egypt are included in the database. Rwanda data are understandably absent. In summary, six experiments from the Seventh Work Plan have been added to the database.