ADVANCES IN THE POND© SOFTWARE: WIZARD DEVELOPMENT AND MODEL REFINEMENTS

Eighth Work Plan,
Decision Support Systems Research 1A, 1B, and 1D (DSSR1A, 1B, and 1D)

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INTRODUCTION

The POND© software developed by researchers at Oregon State University is in its third phase of iterative refinement. The first phase of software development was incorporated in POND© Version 2.0. POND© Version 3.0 included second phase refinements—the consideration of water budgets, preliminary assessment of feed quality and of nutrient fluxes in pond sediments, improved routine fertilization guidelines, and parameter estimation techniques. This report documents improvements that have been made to POND© in terms of model refinements and enhanced capabilities for decision support.

POND© WIZARDS

Our interaction with POND© users over the past few years has indicated that occasionally a lack of understanding exists concerning the types of problems POND© analyzes and the procedures required to accomplish analysis. An effort was therefore initiated to add several "wizards" or "experts" to the software to automate the procedures for undertaking analyses of pond facilities. The wizards currently available include:

- A *pond setup* wizard that enables users to define new ponds at their facility;
- A *lot setup* wizard that enables users to define new lots that are associated with specific ponds;
- A *fertilizer* wizard that generates routine pond fertilization recommendations;
- A *liming* wizard that estimates lime requirements for ponds with specific soil types;
- A *feed optimizer* wizard that generates feed schedules to minimize the amount of feed needed for a specified fish target weight; and

- A *simulation* wizard that conducts facility-level simulations at a given site and presents simulation results in graphical and tabular formats.

Each wizard performs its designated tasks in a consistent manner that involves a series of dialog boxes which query the user for information relevant to the task in question (Table 1). Users are able to proceed once the information requested in a specific dialog box has been provided and have the opportunity to return to a previous dialog box if any settings are to be edited. This flexible design may be beneficial to a range of POND© users, from beginners to experienced personnel. The incorporation of "wizards" in POND© software has been well received by potential users, including selected attendees of the National Aquaculture Extension Conference (8-11 April 1997) held in Annapolis, Maryland.

Model Refinements

As with any long-term systems analysis activity, refinement of POND© software models is an ongoing effort. Model refinements that have either been completed during the past year or that are presently being evaluated include the following:

- Fertilization effects on fish growth;
- High biomass effects on fish growth in fed ponds;
- Feed type (moisture, protein, and energy content) and feeding level effects on fish performance;
- Phosphorus flux in pond water and sediments; and
- Polyculture interactions in ponds.

Fertilization Effects on Fish Growth

In the previous version of POND©, Version 3.0, the models used at the simplest level of analysis (i.e., Level 1) did not directly account for the effects of fertilization rates on fish growth. Users were required to adjust the critical standing crops or critical fish biomass (CFB) upward or downward to reflect higher or lower fertilization rates, respectively. Estimating fish growth in fertilized ponds requires consideration of the amount of natural food produced and the effects of fish biomass on this food resource.

In the present version (4.0) of POND©, we assume that the amount of natural food produced can be evaluated in terms of the predicted gross primary productivity (GPP) relative to the maximum primary productivity value possible for the site (GPP_{max}) (See Nath, 1996 for a description of the model used to estimate GPP.) Values generated from the natural food scaler ($N = GPP/GPP_{max}$) fall within the range of 0 to 1; higher values indicate good productivity and therefore abundant natural food. However, once the fish standing crop exceeds a user-specified maximum critical fish biomass (CFB_{fert}), natural food availability is expected to decrease. The previous version of POND© (Bolte et al., 1995) expressed the effect of fish biomass using the function CFB_{fert}/CFB; however, this value is further scaled by the use of the parameter N. The overall approach generates profiles of fish growth that vary according to site properties (e.g., light availability), pond performance, and fertilizer application rates. Variation in fish growth profiles is due to the effects of these variables on GPP (Figure 1).

High Biomass Effects on Fish Growth in Fed Ponds

In addition to the effects of fertilization of on fish growth at Level 1, the previous version of POND© also did not account for the possible influences of high fish biomass on growth in ponds that receive supplemental feed. The actual mechanisms, deterioration of water quality, and behavioral change, by which these effects occur can not be adequately addressed without adding substantial complexity to the Level 1 models in the software. The alternate approach currently being implemented involves defining a critical fish biomass below which growth is not adversely affected in fed ponds (CFB_{feed}). To account for high fish biomass effects, the daily fish growth rate (g d^{-1}) is calculated using the POND© fish bioenergetics model and is then multiplied with a biomass scaler (B; 0-1) that is calculated as follows:

$$B = \begin{cases} 1.0 & \text{if } FB < CFB_{feed} \\ CFB_{feed}/FB & \text{if } FB \geq CFB_{feed} \end{cases} \qquad (1)$$

The effect of this scaler on fish growth is indicated for a hypothetical pond stocked with African catfish (*Clarias gariepinus*) in Figure 2. The advantages of this scaler are that it:

1. Enables consideration of biomass effects on growth in fed ponds; and

Table 1. A listing of the wizards in POND©—their functions, the types of information requested from users, and the outcome once the wizards have executed their tasks.

Wizard Name	Function	Information Accessible (by Dialog Box Number)					Outcome
		Box 1	*Box 2*	*Box 3*	*Box 4*	*Box 5*	
Pond Setup	Specify ponds	Pond name Site location	Dimensions	Water balance options	—	—	New pond defined
Lot Setup	Specify lots	Lot name	Species type Associated pond Daily mortality	Stocking date Stocking density Stocking weight	Harvest options	Feeding options	New lot defined
Fertilizer	Estimate fertilizer needs	Pond selection	Model parameters and predictions	Selection of fertilizer(s)	—	—	Least-cost fertilizer mix for weekly addition
Liming	Estimate lime requirements	Pond selection	Associated soil type	Selection of liming material	—	—	Amount and cost of lime required
Feed Optimizer	Optimization of feed use	Site and pond selection	Associated lot parameters	Target fish weight Allowable feed levels	—	—	Optimized feed schedules for culture period
Simulation	Perform facility simulation	Site selection	Selection of ponds to simulate	Associated lot parameters	Graphical or tabular output Enterprise budget	—	Production statistics[1], detailed simulation output, and automated economic analysis

[1] Includes final fish weights, net fish yields, feed requirements and food conversion ratio (if artificial feed is used), and fertilizer and water requirements itemized by ponds and lots.

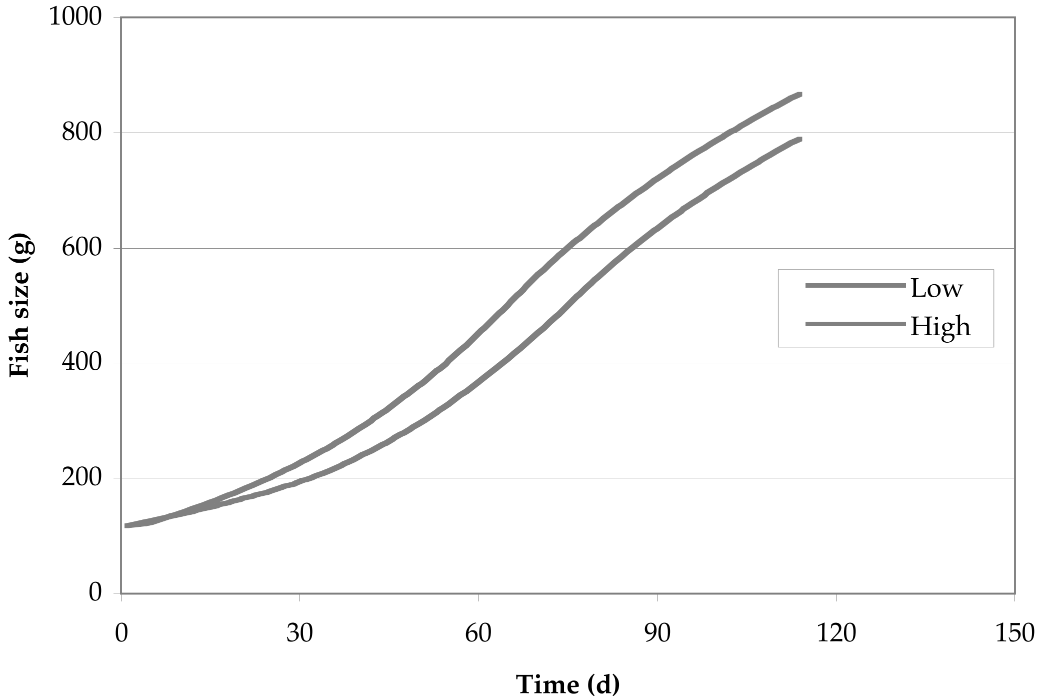

Figure 1. Predicted growth of African catfish in ponds maintained at low (approximately 4 g C m^{-3} d^{-1}) and high (approximately 6 g C m^{-3} d^{-1}) levels of gross primary productivity.

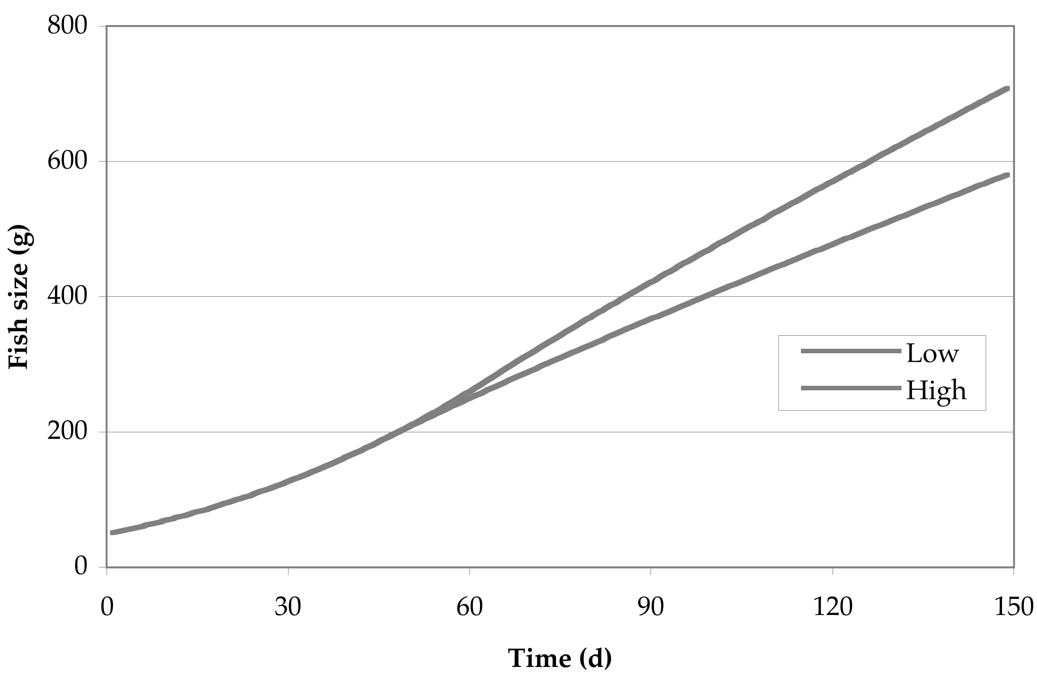

Figure 2. Predicted growth of African catfish in ponds where growth was assumed to be limited at a low (> 3500 kg ha^{-1}) and high (> 5000 kg ha^{-1}) fish biomass.

2. Helps to identify when fish biomass should be thinned to permit the remaining population to continue growing at a rapid rate. Additionally, the scaler may also be useful for determining when improvements to water quality are necessary.

Feed Type and Feeding Level Effects on Fish Performance

A fundamental assumption of the POND© Version 3.0 fish bioenergetics model was that the composition of fish and their diet is identical. This assumption has its roots in Ursin's (1967) growth model which is the basis of our work in the area of fish bioenergetics. However, to adequately account for the effects of supplemental feeds of different quality (primarily in terms of moisture, protein, and energy content) on fish performance, it is necessary to remove the above assumption. Further, the previous version of the bioenergetics model in POND© assumed digestibility to be a constant, even though it depends on the feeding level and other factors. In this section we discuss changes made to the POND© bioenergetics model that account for the effects of the variables discussed above.

Moisture Content

In the present version of POND© (4.0), the ratio of dry matter content of fish (DM_{fish}; g dry matter per g fish) to that of feed (DM_{feed}; g dry matter per g feed) is used to adjust the daily ration (R; g feed per day) for differences in moisture content between fish and the feed material supplied. The expression used is:

$$R = \frac{Wf_s}{q} \times \frac{DM_{fish}}{DM_{feed}} \qquad (2)$$

where

W = fish mass (g),

f_s = fraction of the diet that comprises artificial feed, and

q = feed quality coefficient.

Protein Content

According to Hepher (1988) dietary protein (d_p), expressed as a percentage of dry matter, does not affect fish growth if it is above a critical level (P_{crit}) that is species dependent. As the dietary protein level reduces from P_{crit}, growth tends to decrease at an increasing rate. The following protein scaler (P_s; 0-1) used in the present version of POND© captures this effect:

$$P_s = 1.0 - \exp[p_1 d_p] \qquad (3)$$

where p_1 is a parameter that controls the rate at which P_s changes as d_p decreases.

Energy Content

To account for situations where the dietary gross energy value drops below a critical level (E_{crit}; kcal g^{-1}) that is again species dependent, an approach similar to the one for protein in POND© is used. The corresponding equation is as follows:

$$E_s = 1.0 - \exp[p_2 d_e] \qquad (4)$$

where E_s = energy scaler (0-1), and p_2 is a parameter that controls the rate at which E_s changes as the gross dietary energy value d_e (kcal g^{-1}) decreases.

It is difficult to evaluate growth response to diets that are sub-optimal in both protein and energy content. For simplicity, we assume that when both protein and energy are below the respective critical levels required by the species, the scaler that is most limiting reduces the anabolic term in the bioenergetics model.

Feeding Levels and Digestibility

It is well established that the digestibility (b) of food decreases as the amount consumed by fish increases (Hepher, 1988; Meyer-Burgdorff et al., 1989). In the present POND© bioenergetics model, we assume that digestibility decreases linearly with increased levels of feeding (from maintenance to full satiation). The slope (e) of this relationship is estimated as follows (Figure 3):

$$e = \frac{(b_{max} - b_{min})}{(1.0 - f_{maint})} \qquad (5)$$

where

b_{max} = maximum digestibility coefficient (assumed to occur at a maintenance ration),

b_{min} = minimum digestibility coefficient (at satiation); and

f_{maint} = feeding level parameter in the POND© bioenergetics model corresponding to a maintenance ration.

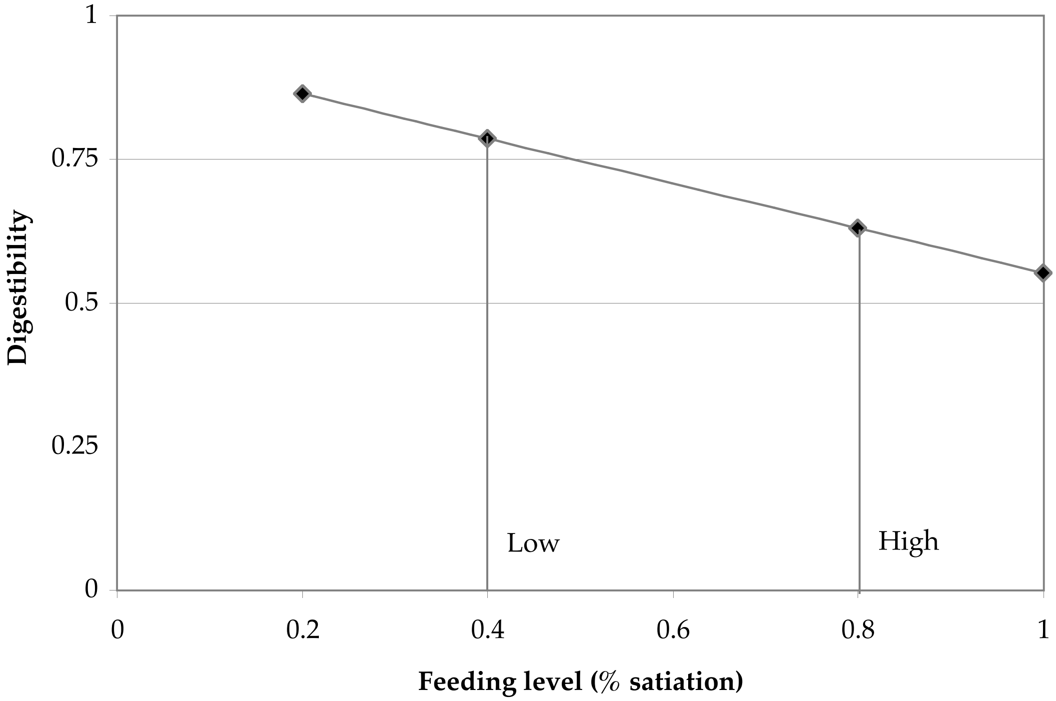

Figure 3. Relationship between digestibility and ration size ranging from a hypothetical maintenance ration to a maximum amount at full satiation. Digestibility values for a low (40% satiation) and a high (80% satiation) ration are also indicated.

Once the slope (e) from Equation 5 is estimated, the actual digestibility coefficient is obtained as follows:

$$b = b_{max} - e(f - f_{maint}) \qquad (6)$$

where

f = feeding level parameter (0-1) for the actual feeding rate.

To use Equations 2 through 6, it is necessary to estimate six new parameters (P_{crit}, E_{crit}, p_1, p_2, b_{max} and b_{min}) , in addition to the previous ones used in the fish bioenergetics model (Bolte and Nath, 1996). Among the six parameters, P_{crit} and E_{crit} can be obtained from bioenergetic studies of different species (reviewed by Hepher, 1988). Four other new parameters have been added to the automatic model calibrator in POND© (Bolte and Nath, 1996), which estimates appropriate values using an adaptive, non-linear search algorithm in conjunction with actual experimental data from pond trials.

At present, the new version of the fish bioenergetics model is calibrated for common carp (*Cyprinus carpio*) and African catfish (*Clarias gariepinus*). A similar calibration for Nile tilapia (*Oreochromis niloticus*), based on growth trials at all the CRSP locations, is presently in progress. Effects of moisture content on carp feeding rates (%BWD) are indicated in Figure 4 for fish that are assumed to have been fed to satiation. The effects of dietary protein and energy content on carp growth are shown in Figures 5 and 6, respectively. Finally, the effects of different feeding levels on the food conversion ratio (FCR) for common carp are shown in Figure 7. The relationship between FCR and ration in the latter figure is consistent with studies that have experimentally demonstrated this profile (e.g., Brett, 1979; Balarin and Hatton, 1979).

In a broader context, the refinements to the POND© bioenergetics model will enable users to perform simulations with different types of feeds and feeding levels and evaluate the implications of simulation results on pond performance, fish growth, and production economics.

Models for Phosphorus Flux in Pond Water and Sediments

A major drawback of current pond aquaculture models is that they do not address the sediment-water interface (Colman and Jacobson, 1991) and

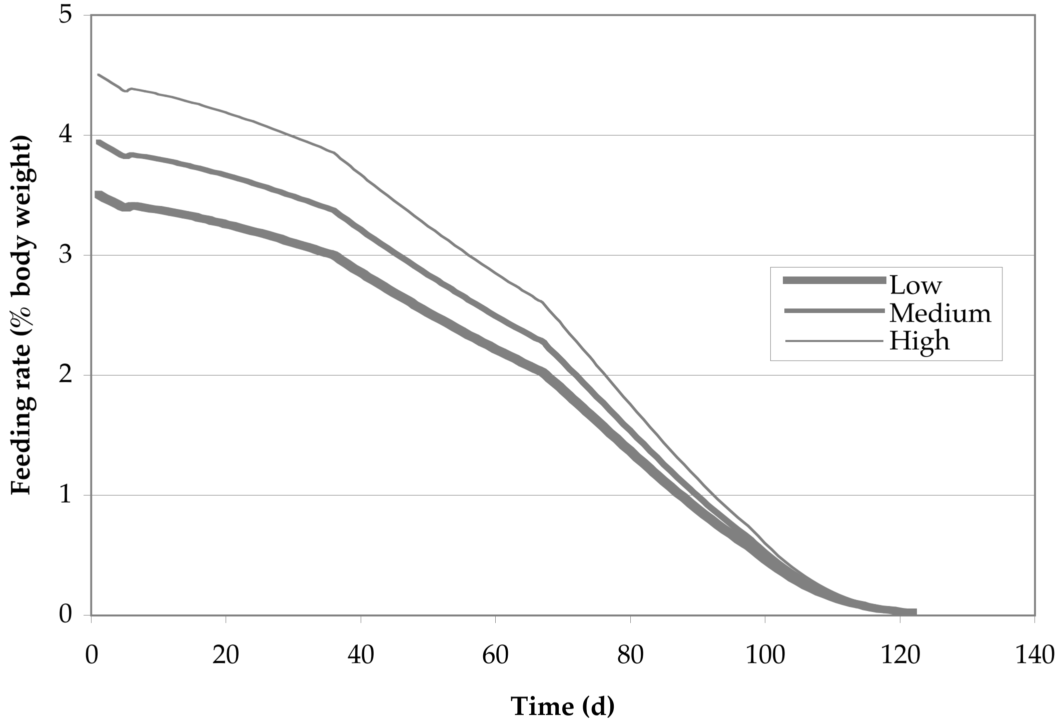

Figure 4. Fish feeding rates predicted by the POND© energetics model for common carp that received low (10%), medium (20%), and high (30%) moisture diets.

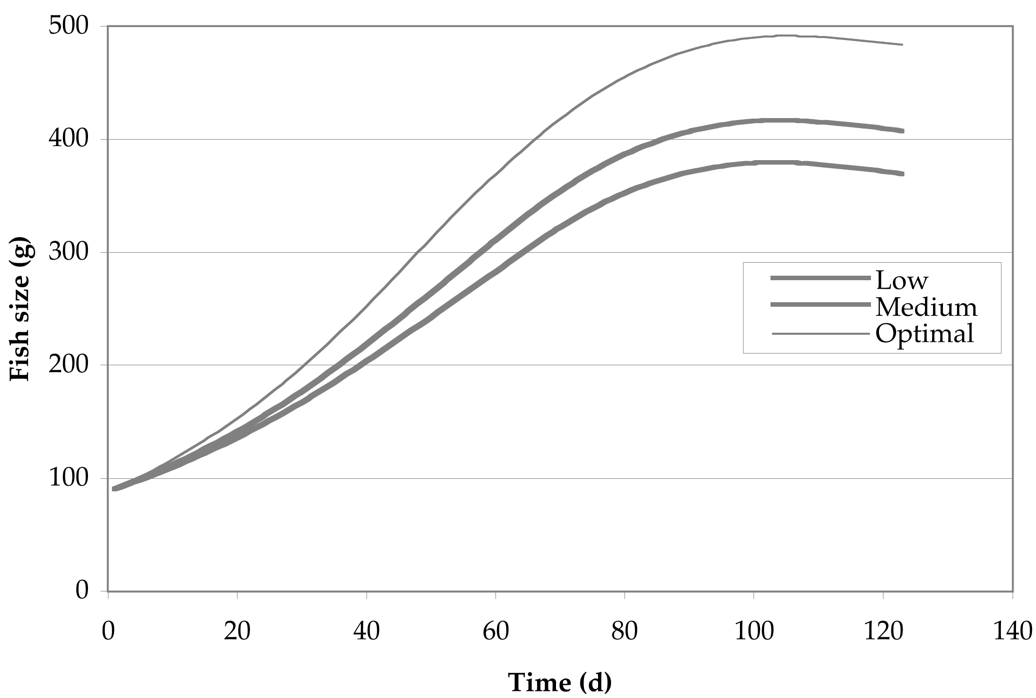

Figure 5. Growth profiles predicted by the POND© energetics model for ommon carp that received diets with low (20%), medium (25%), and optimal (30%) protein contents.

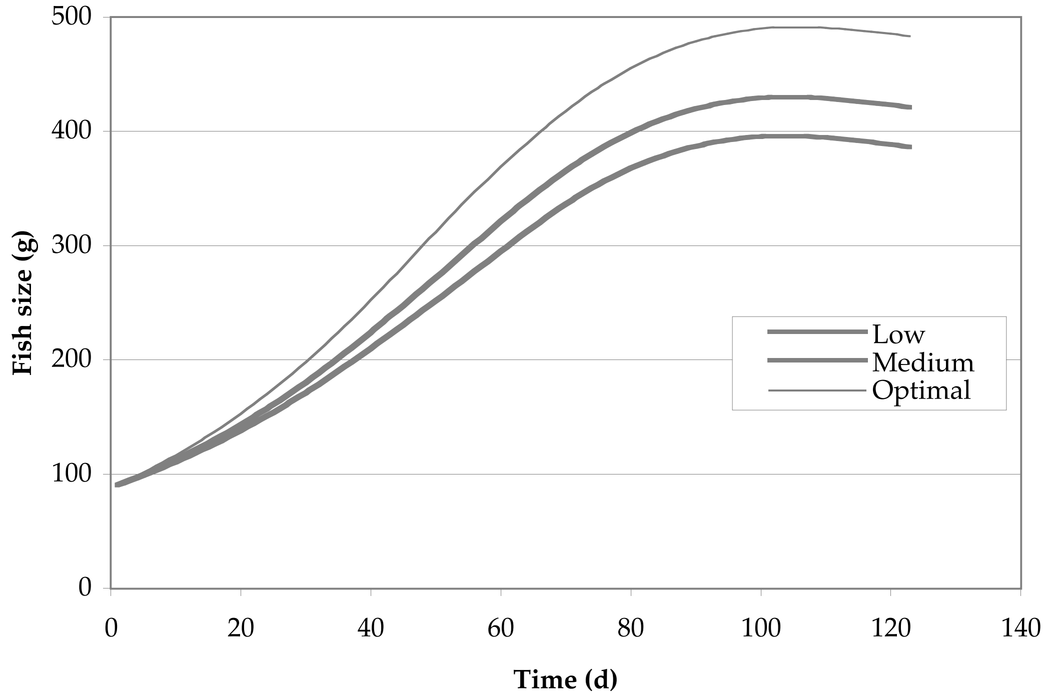

Figure 6. Growth profiles predicted by the POND© energetics model for common carp that received diets with low (2.0 kcal g^{-1}), medium (2.5 kcal g^{-1}) and optimal (3.1 kcal g^{-1}), gross energy contents.

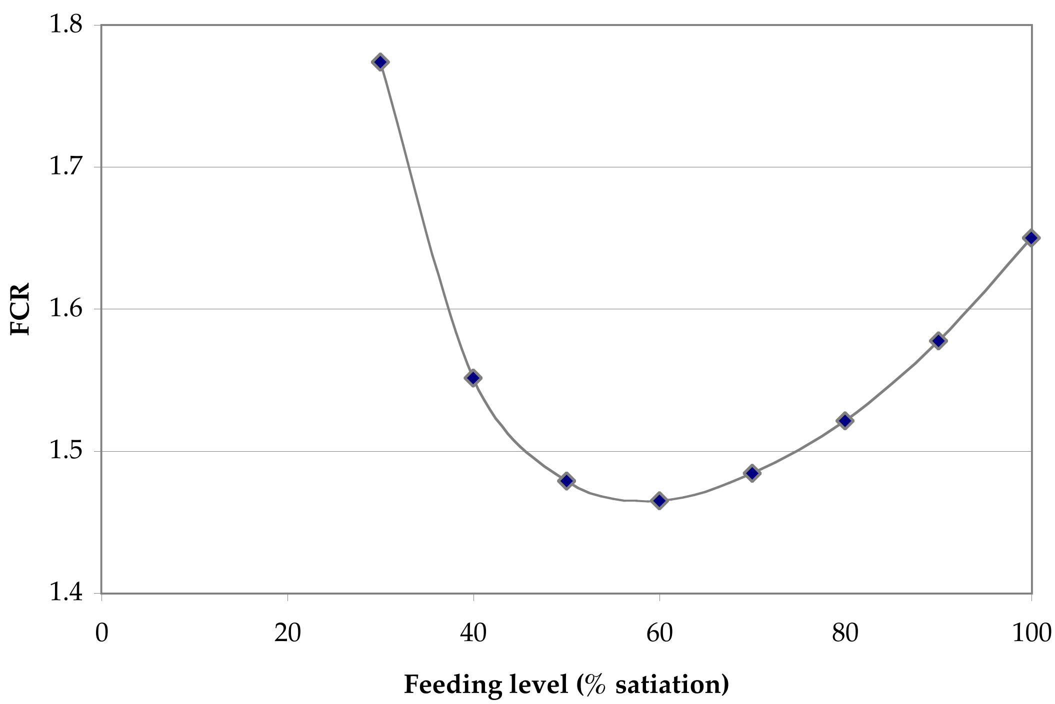

Figure 7. Relationship between the food conversion ratio (FCR) and feeding level for common carp as predicted by the POND© energetics model.

its underlying processes, which have not been adequately studied in ponds. The sediment-water interface appears to influence the flux of nitrogen, organic matter, oxygen, and phosphorus in pond aquaculture systems (Schroeder and Berner-Samsonov, 1986; Boyd, 1994). Through the development of models, an opportunity exists to better understand such processes and to design experiments to test model hypotheses.

In the Thirteenth Annual Report (Nath et al., 1996), we listed state variables that were considered in the POND© models at Levels 1, 2, and 3. During the current reporting period, the process descriptions for nutrient fluxes in pond water and sediments in the POND© software were implemented. A listing of these processes for phosphorus is given in Table 2. Model calibration and testing are in progress.

Polyculture Interactions in Ponds

Polyculture has been practiced in various parts of the world for centuries. Decisions regarding species selection and estimation of appropriate stocking densities, however, are typically based on empirical experience partly because interactions among various species within the pond environment are not very well understood. We have successfully used a resource substitution model to describe theoretical relationships between Nile tilapia and phytoplankton/zooplankton growth in ponds (Bolte et al., 1995; Nath, 1996).

In order to extend the resource substitution model approach to other species (e.g., carps), particularly under polyculture conditions, it is necessary to add descriptions of other natural food resources in pond systems. It is also important to describe changes that occur in natural food uptake when artificial feed is added to a pond. In addition to phytoplankton and zooplankton as natural food resources, we have implemented descriptions for a 'bacterial' component in POND© at Level 3 (Table 2). This component is intended to reflect the heterotrophic pathway of fish food availability in pond systems.

We have also developed an iterative method (see Nath, 1996 for a complete description) to describe supplemental feed uptake under conditions where natural food is also present in ponds. An iterative method is required because the proportion of supplemental feed consumed is not known *a priori* and cannot be assumed to equal the difference between the target feeding level and the amount derived from the natural food base (the approach used at Level 1). This is because the proportion of supplemental feed in the diet is likely to be a function of fish species preference for feed, among other factors. For example, if feed is added to a pond with fairly abundant natural food (although inadequate to reach the target level), some species may preferentially consume supplemental feed, whereas others may not. In other words, the proportion of natural food in the diet of a given fish species will likely differ depending on whether feed is present or not. At the present time, we are testing the performance of the POND© Level 3 models to predict fish performance for different species in polyculture and in fertilized versus fed systems.

Macro-Level Agroecological System Analysis

We have recently commenced two efforts in this area (Decision Support Systems Research 1D of the OSU-DAST project). The first effort involves developing the capabilities of the POND© software to simulate integrated farming systems. Models will be implemented that simulate crop growth in plots adjacent to aquaculture ponds. The process descriptions of the crop model component developed by UC Davis researchers is being reviewed to determine the best approach for integrating the model in POND©.

The second effort involves integrating the POND© fish growth and water temperature models within a Geographical Information System (GIS) to assess aquaculture potential in Africa. This project, in collaboration with the FAO, is similar to the recently completed Latin American project (Kapetsky and Nath, 1997). Presently, FAO personnel are using the POND© temperature model to make temperature projections and the recently refined fish growth models to project crop output under subsistence and commercial farming scenarios for Nile tilapia, common carp, and African catfish across the African continent.

In addition to fish yield data, Decision Support Research Study 1D will consider economic and production factors, including water requirements, urban market potential, potential for farm gate sales, availability of agricultural by-products as feed/fertilizer input, and engineering and terrain suitability for pond construction. Results from the GIS study are expected to be useful for PD/A CRSP personnel involved with the development and

Table 2. A summary of process descriptions for phosphorus flux as implemented in the three POND© modeling levels. Source and sinks affecting bacterial biomass in ponds are also indicated. Processes directly manipulated by management practices are italicized.

Variable	Model Level	Sources	Sinks
WATER-COLUMN PHOSPHORUS (P)	1, 2, 3	*Influent water*	*Effluent discharge*
Total-P	2, 3[b]	Fish respiration + excretion	Non-flow related volume changes[a]
Dissolved Inorganic-P	1	*Wasted feed* Phytoplankton respiration + death Zooplankton respiration + death Bacterial respiration + death *Fertilization*	Phytoplankton uptake Bacterial uptake Sediment sinks/sources[a] Miscellaneous sinks/sources[a]
Inorganic-P	3	Mineralization	
Organic-P	3		Mineralization
SEDIMENT-P	2, 3	Supply of water column material:	Water-column sinks/sources[a]
Total-P	2, 3[b]	From fish excretion, wasted feed, and phytoplankton, zooplankton and bacterial death.	
Sediment Inorganic-P	3	Mineralization	
Sediment Organic-P	3		Mineralization
BACTERIA	3	*Influent water*	*Effluent discharge*
		Growth	Non-flow related volume changes[a] Respiration and death Zooplankton consumption Fish consumption

[a] Can be either a source or a sink.
[b] Calculated from concentrations of inorganic and organic forms at Level 3.

implementation of regional planning studies for sub-Saharan Africa.

Anticipated Benefits

POND©, providing a powerful framework for analyzing the dynamics of warmwater pond systems, has been of primary benefit to technical users. The development of simpler user interfaces to assist in task completion in POND© will allow the software to serve a broader audience. Similarly, improvements in the algorithms used on POND© makes it more broadly useful and accurate in the development of more optimal management strategies and facility plans.

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