Decision Support Systems for Fish Population Management and Scheduling in Commercial Pond Aquaculture Operations

Ninth Work Plan, Decision Support Systems Research 2 (9DSSR2)
Progress Report

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Abstract

This study is focused on developing software tools for the analysis of fish population size distributions, focusing initially on commercial catfish operations in the southeastern United States but generalizable to other types of operations and locations. Progress has been made in two primary areas: 1) modeling size distributions and their dynamics through time related to biological and management factors and 2) software development for the decision tool deliverable from this study. The current status of both is described in this progress report.

Introduction

A study was initiated to develop decision support software to assist commercial aquaculture producers in managing fish population dynamics and variability in stock size and weight resulting from biological and management factors. The objectives of this study are:

1) To modify previously developed fish growth models so as to enable simulation of population growth of multiple fish lots in pond environments;
2) To develop methods for estimating fish biomass in ponds that are stocked and harvested at various time intervals in continuous production systems;
3) To implement software support for inventory management of fish stocks in operational farms; and
4) To provide training to farmers on the use of decision support software for routine pond management.

Progress has been made in the first three of these objectives as described below. This report documents model development for size distribution analysis and software development for decision support. Presentation of the growth models has been described previously (Nath, 1996).

Approach and Results

Models for Size Distribution Analysis

Explicitly describing the distribution of fish sizes within a pond population is one of the required features for the population management model. Few models exist which offer a mathematical description of size classes within a population. None were found that describe differential growth with respect to fish size within a fish population. Since no acceptable models were found, a new model of population size distribution has been developed. The model is based on the concept of mass balances. Let $P(w)$ describe the fraction of the population that has mass w. Then

$$\frac{\partial}{\partial t}P(w) = input - output$$

where *input* is the fraction of the population that grows to size w and *output* is the fraction of the population that grows out of size w. We can define *input* and *output* by first defining a function $\delta(w_1,w_2)$ that describes the fraction of fish at mass w_1 that grows to mass w_2. Now *input* and *output* can be described as:

$$input_{w_0} = \int_0^\infty P(w)\,\delta(w,w_0)\,dw, \text{ and}$$
$$output_{w_0} = \int_0^\infty P(w_0)\,\delta(w,w_0)\,dw,$$

where w_0 is a constant. Furthermore,

$$output_{w_0} = P(w_0)$$

because $P(w_0)$ is constant with respect to the variable of integration and the integral is equal to 1. So we have:

$$\frac{\partial}{\partial t}P(w) = \int_0^\infty P(w)\,\delta(w,w_0)\,dw - P(w_0).$$

This system can easily be discretized by first defining n weight intervals, w_i, $i = 0\ldots n$ and letting $P_{i,k}$ be the fraction of the population at weight w_i at time interval k. Then:

$$P_{i,k} = \left(\sum_{j=0}^{n} P_{j,k}\,\delta(w_j,w_i)\right) - P_{i,k}.$$

It is shown via the fundamental theorem of calculus that:

$$\lim_{n\to\infty}\sum_{j=0} P_{j,k}\delta(w_j,w_i) = \int_0^\infty P(w)\,\delta(w,w_0)\,dw.$$

Let P^k denote the columns of $P_{i,k}$ so that P^k is a vector of fractions for each size class at time interval k. If we define a matrix, D, such that:

$$\Delta_{j,i} = \delta(w_j,w_i),$$

then

$$P^{(k+1)} = \Delta P^k.$$

This allows computation of P^k for all desired k assuming that Δ does not change significantly with time. What still remains, however, is a definition for δ.

δ represents the amount of growth of a fish at a certain weight. The bioenergetics model (BE) provides this information; however, we cannot use it directly. The BE model (as it is used in POND©) can be represented in a simplified form as:

$$\frac{\partial}{\partial t}W(t) = H(t)w^n - k(t)w^m .$$

The first term represents anabolism and the second catabolism. This equation represents the growth of a fish at a certain weight, based on anabolic and catabolic balances. To use the bioenergetics model as δ, we must first make an assumption about the distribution of growth within the population. If we assume that growth for a given size class is normally distributed with variance s and mean given by:

$$\mu = w_1 + g(w),$$

where g(w) is the growth predicted by the BE model, then we can define δ by using the probability density function for the normal distribution:

$$\delta(w_1, w_2) = \left[\frac{1}{2}\frac{\sqrt{2}}{\sqrt{\pi\sigma}}\right] e^{\left(-\frac{1}{2}\frac{(w_2-\mu)^2}{\sigma^2}\right)}.$$

Figure 1 shows some sample calculations of P at various time intervals. These calculations were made assuming a fairly large (and constant) $\sigma = 0.4$. Notice that the distribution "flattens out" as time increases. This would be characteristic of an underfed population where a significant portion of the population was not reaching its full growth potential.

The drawbacks of the model are twofold. First, it requires a large amount of computational resources. Computing the difference matrix used in Figure 1 took five minutes using Mathcad on a 400Mhz Pentium II computer. This time could be reduced to under one minute via some optimization techniques. Long computation times will reduce the level of interactivity that will be possible with the software. Also, given that the range of size classes will vary over several orders of magnitude (a few grams to a few kilograms) the difference matrix must be large enough to provide reasonable accuracy. A difference matrix for 5,000 weight classes would require approximately 4 MB of RAM. The second problem is with the assumption that growth is normally distributed. Suitable values for the variance parameter, σ, must be determined using field data. The variance essentially represents the effects of competition for resources. These factors are likely to change as the population changes. Thus, fixed values of σ may not provide acceptable accuracy.

The model does have several advantages. First, it is fairly straightforward. This will simplify statistical analysis and software development. Second, it is practical. The existing POND© software contains growth calculations that are essentially the growth function, g(w), needed for the model. Third, the model can be fast in certain situations. If the difference matrix can be held constant, the only computation required is a vector-matrix multiplication of each time step. Finally, since weight classes are modeled explicitly (via the P^k vector), the user will be able to edit the distribution of size classes without modifying the difference matrix. Since harvest operations basically involve editing the distribution vector, the difference matrix will not need to be recomputed. Thus, changing harvest dates will not incur significant computational overhead, and the desired level of interactivity can still be maintained.

Software Design and Development

A requirements and specifications document has been developed in collaboration with Steve Killian. The document describes the features and functionality that will be provided by the inventory management software. The complete document is available online at <biosys.bre.orst.edu/hillyer/catfish_req.htm>.

It was decided that a high degree of interactivity and visual feedback was needed to best provide decision support for scheduling harvest operations and assessing economic outcomes. A slider-based interface coupled with rapid update of the interface will allow the user to experiment with scheduling harvest and stocking operations. This will allow the user to easily determine what is both optimal and practical for his

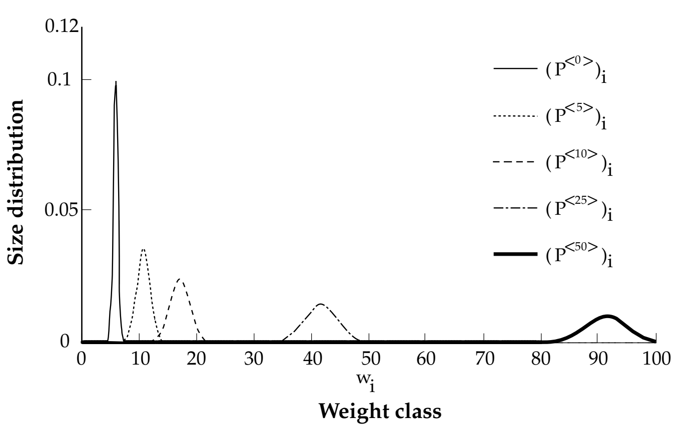

Figure 1. Size distributions at five time intervals. The size distribution is the fraction of the population within a given weight class. Weight classes are defined by the mass of a fish in the population.

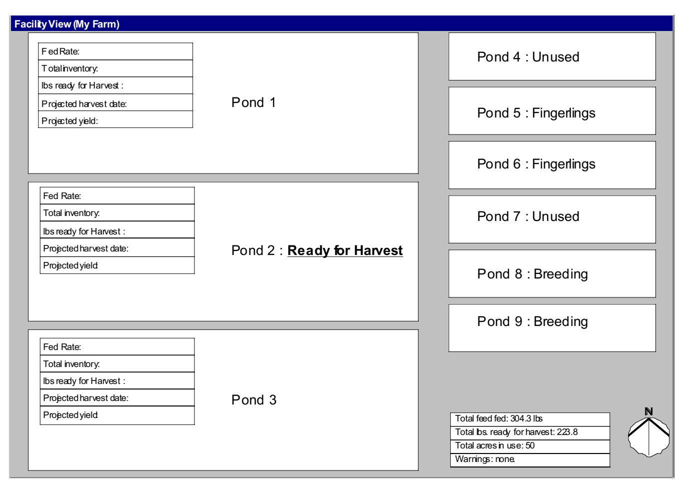

Figure 2. Facility-level view showing a schematic of the entire farm, as provided by modeling software.

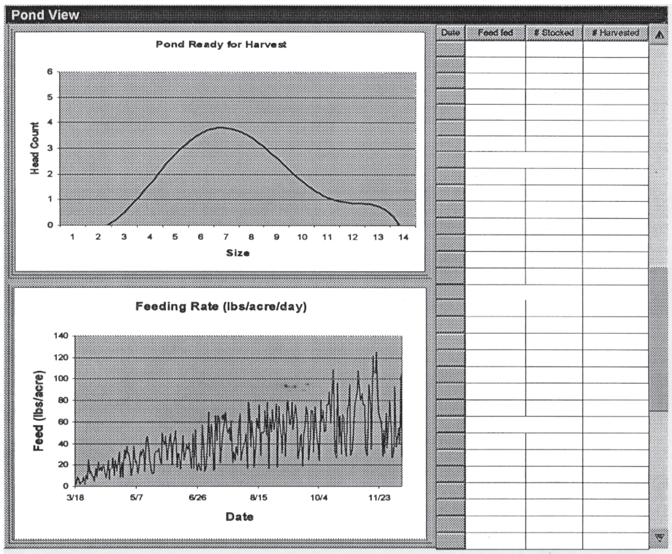

Figure 3. Pond-level view showing fish size distribution, feed rate history, and data spreadsheet, as provided by modeling software.

or her operation. Also, by integrating POND©s economic functionality, users will be able to base their decisions on financial criteria as well as yield.

The software will provide two principle views, a facility-level view and a pond-level view. Examples of these are shown in Figures 2 and 3. The facility view shows a schematic of the entire farm, focusing on the production ponds. The view will show summary data for each pond and will color ponds so that the user can quickly and easily view a pond's readiness for harvest. Other pond statistics can also be displayed (e.g., dissolved oxygen warnings) using color as the key indicator. Users will also be able to click on a pond and view it in greater detail using the pond view.

The pond view (Figure 3) is divided into three sub-areas. First, the estimated pond inventory (upper left) is displayed as a distribution of fish sizes. Second, a plot of the feed rate history (lower left) is shown. Finally, an editable spreadsheet display of the feeding, stocking, and harvest data is shown on the right. When changes are made in the spreadsheet, the pond inventory and feed history will be automatically updated to reflect the changes.

Conclusions

We are continuing to develop the models presented here and are implementing them in software. Current challenges include integrating the sophisticated bioenergetic growth models contained in the POND© software into this decision tool. Further outreach to the grower community will be developed during the remaining portion of the study, in cooperation with University of Arkansas at Pine Bluff extension staff.

Anticipated Benefits

The proposed study is expected to result in the following benefits:

1) Models for projecting fish weight distributions over time and estimating harvest events;
2) Improved capabilities for managing multiple fish lots and their distributions in ponds;
3) Support for inventory management of ponds and lots in existing facilities;
4) Improved support for economic analysis of commercial pond operations; and
5) Farmers trained to apply decision support software for real-time management.

Literature Cited

Nath, S.S., 1996. Development of a decision support system for pond aquaculture. Ph.D. dissertation, Oregon State University, Corvallis, Oregon, 273 pp.

Cite as: [Author(s), 2001. Title.] In: A. Gupta, K. McElwee, D. Burke, J. Burright, X. Cummings, and H. Egna (Editors), Eighteenth Annual Technical Report. Pond Dynamics/Aquaculture CRSP, Oregon State University, Corvallis, Oregon, [pp. ___.]