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Dynamic Fish Growth Modeling for Tailwater Fishery Management

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Abstract

Tailwater fisheries below hydroprojects are affected by variable flows and water quality in dam releases. The Tennessee Valley Authority (TVA) identified undesirable flow regimes, low dissolved oxygen (DO) concentrations, and undesirable temperatures as having the greatest biological impact on tailwater, and steps are being taken to mitigate impacts at numerous dams. To help evaluate mitigation efforts, an interdisciplinary team of water quality modelers, fisheries biologists, and environmental engineers developed a one-dimensional dynamic fish growth model. This model was coupled with previously developed dynamic flow and water quality models. The model results were compared to (1) fish growth data in Norris Dam tailwater under pre- and post-mitigation conditions and (2) rainbow trout growth in aquaria studies with differing DO concentrations. Model was found to reproduce impacts of DO on fish growth.

Introduction

Variable reservoir release patterns and water quality can affect growth of fish in the tailwater. Dynamic flow and water quality models have been developed in TVA to simulate time-varying flow, surface elevation, temperature, DO and related variables at selected locations along a tailwater (Hauser, 1989). In this study, these models were coupled with a bioenergetic fish model modified from Cuenco et al. (1985a,b) to simulate fish growth as a function of changing water quality and food availability in the tailwater. The tailwater fish growth model was tested against growth data for rainbow trout in the tailwater below Norris Dam and in aquaria studies.

Fish Bioenergetic Model

Time-varying flow and water quality in the tailwater were computed by a one-dimensional hydrodynamic flow and water quality model (Hauser, 1989). Computed water quality was then provided to a bioenergetic fish model to simulate fish growth. A schematic flowchart of the various models is shown in Figure 1. Mathematically, the bioenergetic fish model can be described as:

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$$dW/dT = GR*W$$

and

$$GR = AR*EAT-RES$$

where W is fish weight at time T, GR is the rate of change in energy of the body or growth, AR is the assimilation ratio of food ingested by the fish, EAT is the food consumption rate, and RES is the respiration rate. For each time step (day), the model first computes a potential appetite and respiration as a function of fish body weight and water temperature. These potential rates are adjusted for DO effects. Food consumption is determined by the lesser of potential appetite and food availability. A constant assimilation ratio is used to convert food consumption (in terms of energy) to fish growth. Fish weight at the end of each time step is calculated as the old weight plus the difference between assimilated food and respiration during the time step.

Growth-Temperature Relationship

In Cuenco's model, temperature relationships for food consumption and metabolism (or respiration) for brown trout were determined using regression coefficients derived by fitting data of Elliott (1975,1976). Food consumption rate increases with temperature until temperature reaches TEOPT, the temperature at which the food consumption rate is maximum. As temperature rises beyond TEOPT, food consumption rate decreases rapidly to zero. Metabolic rate increases exponentially with increasing temperature. This function can compute a metabolic rate which is unrealistically high at temperatures beyond TEOPT.

In this study, a double s-curve introduced by Thornton and Lessem (1978) was used. This formulation divides the response function into an optimum zone and two diminishing zones at higher and lower temperatures defined by four user supplied temperatures (see Figure 2). Temperatures T1 and T4 represent mortality limits while T2 and T3 define the optimum temperature range. The fitted response functions for food consumption and respiration are based on Elliott (1976) for brown trout (50 grams). This convenient formulation has gained widespread use in ecological models in recent years.

Food Availability

Fish growth is the overall result of a number of factors including river flow (depth and velocity), water quality (temperature and DO), food availability, and size and age of the fish. For this study, food availability was calculated on a per unit weight basis, adjusted by an exponent that depends on body weight:

$$AFOODi = UFOODi * W**FADJ$$

where AFOODi is effective food availability per fish per day (mg/day) at location i, UFOODi is the available food per unit weight of fish per day (mg/mg/day) at location i, W is the weight of fish (mg), and FADJ is the weight adjusting exponent. FADJ is species dependent and UFOOD is site dependent. The present model does not include competition for food or predation by other fish.

Model Simulations in the Tailwater Below Norris Dam

Bioenergetic model results were compared to observed growth of stocked rainbow trout in the Norris tailwater for the periods: (1) 1974-75 (without DO and flow enhancement), (2) 1984-86 (with DO improvement through turbine venting but without reregulation weir in the first year), and (3) 1985-86 (with both turbine venting and increased minimum flow through reregulation weir). Model results at

representative sites up and downstream of the weir along with water temperature and DO are presented in Figure 3. Observed monthly average fish weights from data in river reaches up and downstream of the weir were also plotted.

For May 1974 stocking, observed fish weights displayed a seasonal pattern with depressed growth (negative net growth) in September and October during the low DO period. The bioenergetic model matches well with the seasonal pattern of creeled fish except that better fish growth was modeled further downstream from Norris Dam due to higher river DO. Creeled fish showed no significant differences between above and below weir areas. Unrestricted movement up and downstream before the weir may have caused this more uniform weight distribution. The bioenergetic model does not simulate fish movement between river reaches.

Turbine venting at Norris Dam started in 1981. However, the July 1984 stocking still showed reduced growth during the low DO period, indicating DO improvement alone may not be enough for the tailwater fishery. Operation of the reregulation weir started in June 1984. Construction of the weir and a massive flood after completion of the weir adversely affected fish growth. In late 1984, creeled trout from the ponded area above the weir grew consistently better than fish below the weir. Greater food availability due to habitat enhancement (deeper water and lower velocities) may have contributed to this better growth (Yeager et al., 1987).

The June 1985 stocking provided the first opportunity to examine the combined effects of turbine venting and the reregulation weir on fish growth in the Norris tailwater. Data showed consistently better growth above the weir than below the weir. Comparing 1985 bottom fauna data with those of previous years, Yeager et al. (1987), showed a significant increase in organisms such as caddisflies, mayflies, stoneflies, snails and crayfish in the 1985 survey. He also showed that the LeCren relative condition (plumpness or robustness) of rainbow trout calculated from creeled fish, which previously declined from July through November, remained higher in 1985 than in previous years. Condition of trout collected in the fall samples actually increased in 1985. This provides further evidence that fish growth benefitted from habitat improvement in the tailwater through either enhanced flow directly and/or increased food supply because of improved habitat for prey organisms.

Despite the fact that the model does not simulate fish mobility and there was no good method of estimating food availability spatially or temporally, the match between model and creel data was encouraging.

<u>Rainbow Trout Simulation in Aquaria Studies</u>

The aquaria study consisted of 7 replicated microcosms, each with a different DO treatment (Isom, 1986). Replicate microcosms (A & B) were each stocked with 10 four-inch rainbow trout. Fish were fed high protein trout "chow" at 3 percent initial body weight equivalent per day. The study lasted 42 days (from 01/17/86 to 02/26/86). Each fish was weighed before and after the study. Temperature and DO were monitored four times a day. The bioenergetic model developed for the tailwater below Norris Dam was used for the simulation. Model results for three tests with different DO treatments along with mean, minimum and maximum of measured fish weights were compared in Figure 4. Computed and observed fish growths both show improvement with higher DO. However, observed fish weight distributions before and after the study indicate a dominant/submissive hierarchy among the fish. This leads to a few fish getting the bulk of the food and the remainder

getting little food. Using a constant feeding rate of 3 percent initial body weight, the model overpredicted on smaller fish and underpredicted on bigger fish. Overall, the model results show promise.

Summary

A bioenergetic model was developed to model fish growth in response to fluctuating temperature and DO in the tailwater below a hydroproject. The model was used to simulate fish growth in the Norris tailwater for three periods, before and after minimum flow and DO improvements. Results show the model can reproduce impacts of low DO on fish growth. In addition to temperature and DO, food availability plays a decisive role in fish growth, especially during the first few months after the fish was stocked. After including variability in food availability, the model reproduced the inverse fish growth (high upstream of the weir and low downstream of the weir) observed in the creel data. However, estimating food availability in a tailwater is, at present, more of an art than science. Results of rainbow trout simulation (without food limitation) in the aquaria study were promising.

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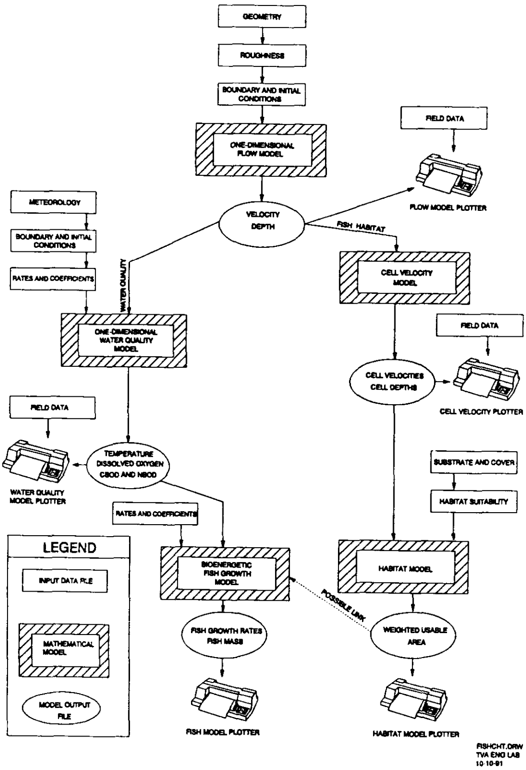

Figure 1. TVA Dynamic Flow, Water Quality, Bioenergetic and Habitat Modeling

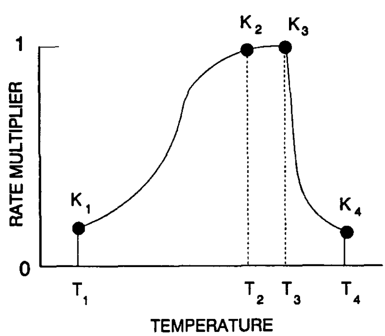

Figure 2. The Temperature Rate Multiplier (from Thornton and Lessen, 1978)

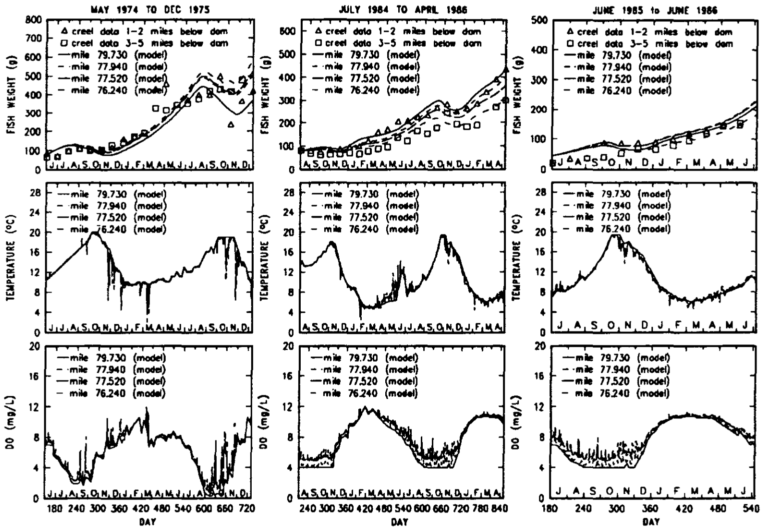

Figure 3. Simulation of Rainbow Trout in the Norris Tailwater

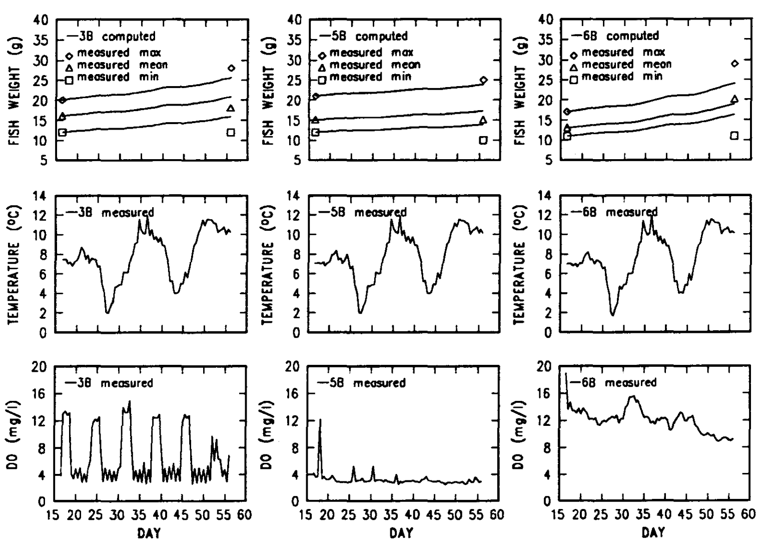

Figure 4. Simulation of Rainbow Trout in Aquaria Studies