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Validation of a bio-energetic model for juvenile salmonids using growth data from a production-scale feeding study

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ABSTRACT

The long-term goal of this project has been to develop a reliable and practical model that can be used to predict food consumption, growth, and waste by-product generation associated with hatchery reared juvenile salmonids. This process began with the earlier development and validation of a bioenergetic model using growth data from two independent laboratory-scale feeding studies. The efficacy of this model is extended here using data from a production-scale growth and feeding study. During the first phase of the current study (135 days), commercial feed was provided to four separate groups of coho salmon (*Oncorhynchus kisutch*). One group received satiation rations, the next group was fed excess rations, another group was fed at about 75% satiation, and the final group was fed a maintenance ration of about 50% satiation. During the next phase of the study (116 days), the coho that were grown on the excess rations during the first phase were provided a maintenance ration, and the original maintenance ration coho were fed to apparent satiation. The growth and proximate composition of the coho were measured approximately every two weeks during the entire study. Bioenergetic model calculations closely matched the measured growth data during both phases of the study following calibration for the maximum consumption and apparent respiration rate coefficients. The model performed equally well when the coho energy density was expressed either as a direct function of time or approximated with correlations with coho body weight. The strong performance of the model was first apparent when compared with independent laboratory-scale data. The proficiency of the model is demonstrated again here using production-scale growth data. These results support the contention that the bioenergetic model can be reliably used as a hatchery management tool to determine appropriate feeding levels, predict the growth of juvenile salmonids, and ultimately quantify the rate of waste by-product generation.

1. Background

The State of Michigan Department of Natural Resources (MDNR) operates the Platte River State Fish Hatchery (PRSFH) located on the Platte River 18 km upstream from Big Platte Lake and 29 km upstream from Lake Michigan (44° 39′ 45.56″ N, 85° 56′ 10.84″W). This facility produces coho salmon (*Oncorhynchus kisutch*) to provide ecosystem balance and to address overabundant alewife populations in the Great Lakes. The Michigan coho salmon strain is a fall-run fish having origins from the Columbia River in Oregon and the Toutle River in Washington.

The PRSFH is located in a region of oligotrophic lakes and operates under strict effluent restrictions that have been mandated to protect the water quality of the downstream Big Platte Lake. These loading limits have largely been attained using micrometer filtration, ferric chloride precipitation of phosphorus in the waste stream, and application of a low phosphorus diet. Despite this advanced treatment technology, the phosphorus discharge limits have been violated on occasion and these infractions carry significant financial penalties.

Hatchery managers need quantitative and real-time predictive tools to help them meet production targets at optimal cost while maintaining waste by-product loading compliance. An important component of such a robust effluent management plan is a fish growth model based on energy balance and bioenergetics. The model must be capable of predicting the growth, feed requirements, and waste products as a function of temperature and food composition and ration.

2. Study objective

The overall goal of this study was to develop and validate a reliable and practical model that can be used to predict food consumption, growth, and waste by-product generation associated with juvenile salmonid hatchery operations. The first step in this process (Canale et al., 2013) was to develop and calibrate a bioenergetic model using data collected during two independent laboratory-scale feeding studies published by Shearer et al. (1997) and Neely et al. (2008). The model simulations of these laboratory data were consistent with observed

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growth for eight different combinations of ration, food composition, and coho strain when the consumption rate was adjusted to characterize differences in the stomach size and the apparent respiration rate was adjusted to account for variations in ration and body lipid content. The next step, as described here, is to expand these analyses and further validate the model using data from full or production-scale growth and feeding studies performed at the PRSFH.

3. Description of production-scale feeding study

The study was conducted in four separate production-scale linear raceways (length = 13.5 m, width = 1.5 m, and water depth = 0.75 m). The tanks had a common surface water supply and were located adjacent to each other to minimize environmental effects. Each raceway contained about 27,000 coho salmon. Water flow through each tank was about 5 m^3/min. The flow velocity in the tanks was about 7.5 cm/sec or 0.5 body lengths/sec for a typical sized 20 gram coho salmon. The food used in the study was BioOregon BioDry that contained 50% protein, 18% lipid, 13% carbohydrate, 15% water, and 4% ash. The gross energy content of the food was calculated to be 4,917 cal per gram using the energy density of lipids (8,660 cal/g), proteins (5,650 cal/g), and carbohydrates (4,100 cal/gm) following methods in Brett and Groves (1979).

Phase 1 of the study began on July 18, 2011 (day of year = 199) and continued until November 30, 2011 (day = 334). The fish in the Tank 1 were provided 548 kg of food that was equivalent to about 100% apparent satiation. The fish in Tank 2 were provided 815 kg of food that was about 50% in excess of apparent satiation. Unused food was routinely observed in Tank 2 during Phase 1 as expected. The fish in Tank 3 were provided 369 kg of food that was equivalent to about 75% apparent satiation. The fish in Tank 4 were provided a maintenance ration of 232 kg of food that was equivalent to about 50% apparent satiation. Feed was provided six times daily in a manner to facilitate equal consumption opportunities for all fish. The total feed provided was measured daily. Fig. 1 shows the accumulative food provided to the coho in the four treatment tanks during Phase 1 and 2 of the study.

Phase 2 of the study began on December 1, 2011 and continued for another 116 days ending on March 26, 2012. This phase was designed to further test the robustness of the model to changing ration and temperature conditions. The food supply to the previously well-fed fish in Tank 2 was reduced to maintenance levels during Phase 2. The total weight of food provided to Tank 2 during Phase 2 was 186 kg. The food supply to the previously poorly-fed fish in Tank 4 was increased to apparent satiation during Phase 2. The total weight of food provided was 306 kg. The feeding and growth studies of the coho salmon in Tanks 1 and 3 were discontinued at the end of Phase 1.

Note that because of the large number of fish used in the study it was not possible to observe the feeding rate of individual coho salmon. Therefore, characterizations of satiation used here are based on experienced cultural staff observations and estimates from previous model calculations. Mortality was measured daily and was less than 1% over the duration of the study. Coho salmon size and proximate composition (moisture, protein, lipid, and ash) were measured about every two weeks during the study. The proximate composition of a composite sample of the BioOregon feeds was measured at the mid-point and end of the study.

4. Fish sampling methods

Random batch fish samples were taken by net from each tank approximately every two weeks during the entire study period. A single batch sample contained an approximately equal number of fish from the head, middle and tail of each treatment raceway. The average batch sample contained 427 fish with as many as 941 for smaller sized fish and as few as 215 for larger fish. The batch sample was weighed following the removal of excess water. The weight of the average fish in the batch sample was determined by dividing the total batch weight by the total fish count. Fish were returned to tanks after measuring. A total of over 20,000 coho were weighed and counted during this study.

In addition to the batch sampling, 16 samples each containing 100 individual fish were collected approximately every 30 days. The fish from these samples were individually measured for total length and weight to estimate the variance and confidence intervals associated with the batch sample fish weights.

5. Laboratory Methods

Lipids were extracted from the fish and food samples using petroleum ether and measured to within 5% using AOAC (1995) procedure 960.39. Protein was calculated by multiplying the Kjeldahl nitrogen content by 6.25 using AOAC (1995) procedure 981.10. Ash was calculated after attaining a constant weight at 550 °C in a muffle furnace using AOAC (1995) procedure 920.03. Water content was determined after drying in a convection oven at 100 °C for 18 hours using AOAC (1995) procedure 920.03.

6. Measurement results

Fig. 2 shows the measured average batch whole body coho weight as a function of time in all four tanks and the sample 95% confidence intervals. The growth attained at the end of Phase 1 was in rough proportion to the ration. During Phase 1, the temperature gradually decreased in all four tanks from about 15 °C to 6 °C (see Fig. 3). The food provided to

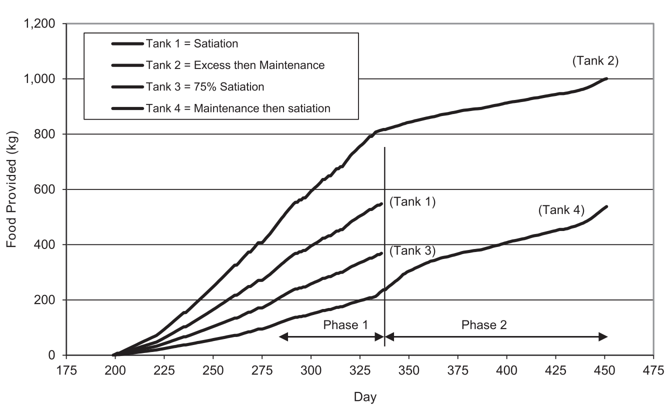

Fig. 1. Accumulative food provided to coho during Phases 1 and 2. Tank 1 = Satiation; Tank 2 = Excess then maintenance rations; Tank 3 = 75% satiation; Tank 4 = Maintenance then satiation rations.

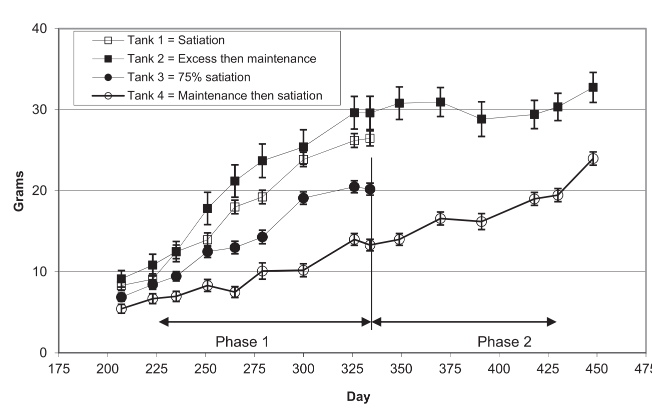

Fig. 2. Growth of the average coho wet weight from batch samples measured during Phases 1 and 2. Tank 1 = Satiation; Tank 2 = Excess then maintenance rations; Tank 3 = 75% satiation; Tank 4 = Maintenance then satiation rations.