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A bioenergetic approach to manage production and control phosphorus discharges from a salmonid hatchery

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ABSTRACT

The environmental effects of fish culture operations are important issues in Michigan as well as many other parts of the world. The State of Michigan Department of Natural Resources operates the Platte River State Fish Hatchery (PRSFH) located near Honor, Michigan (USA). This facility has a restrictive discharge permit that limits the input of phosphorus into the Platte River that subsequently drains into a downstream oligotrophic lake (Platte Lake). The permit has been violated on occasion in recent years. Hatchery managers and operators need to understand the cause of these violations and prevent them in the future; and at the same time meet production goals to satisfy fishery management objectives. This paper describes the development and application of models designed to quantitatively analyze these issues. First, a bioenergetic growth and consumption model is developed for juvenile coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) salmon to quantify the relationship between fish production and by-product phosphorus loads. Next, phosphorus mass balance equations are used to calculate the phosphorus discharge from the facility as a function of the by-product phosphorus load and the efficiency of various phosphorus removal equipment and processes. The accuracy and consistency of the energy and mass balance equations are verified using extensive measurements. The ability of the model to successfully match various aspects of system performance supports the contention that the bioenergetic modeling approach developed here can provide reliable estimates of salmonid growth and feed requirements for a variety of food compositions, rations, and temperatures. This capability, along with knowledge of the effectiveness of phosphorus removal equipment, forms the basis of a practical operational and management tool. An example of model utility is presented that analyzes the PRSFH phosphorus discharge and provides insights into why permit violations occurred in 2009 but not in 2010. The model demonstrates how to avoid food waste caused by over feeding, lower the food conversion ratio, and evaluate the effectiveness of phosphorus removal treatment processes. A steady-state version of the model can be used by managers to establish production goals that avoid future violations of the phosphorus discharge limits.

Statement of relevance

The environmental effects of fish culture operations are important issues in many parts of the world. This paper describes the development and application of models designed to quantitatively analyze the relationships among fish production, by-product phosphorus loads, and the phosphorus concentration of the discharge following treatment. The ability of the model to successfully match various aspects of system performance supports the contention that the bioenergetic modeling approach developed here can provide reliable estimates of salmonid growth and feed requirements for a variety of food compositions, rations, and temperatures. This capability, along with knowledge of the effectiveness of phosphorus removal equipment, forms the basis of a practical operational and management tool. The model demonstrates how to avoid food waste caused by over feeding, lower the food conversion ratio, and evaluate the effectiveness of phosphorus removal treatment processes. A steady-state version of the model can be used by managers to establish production goals that avoid future violations of the phosphorus discharge limits.

1. Background

The environmental impacts of hatchery effluents are critical issues regarding the current and future sustainability and expansion of fish

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culture operations world-wide (Bureau and Hua, 2010; Cho and Bureau, 2001; Michael, 2003). The State of Michigan Department of Natural Resources operates six fish hatcheries that discharge into high quality surface waters and effluent management is an increasing system-wide concern. One of the hatcheries where this issue has become particularly important is the Platte River State Fish Hatchery (PRSFH; 44.6632N, 85.9363W) located on the Platte River 18 km upstream from Platte Lake (44.672314N, 86.094375W) as shown in Fig. 1. Algal growth in oligotrophic Platte Lake is limited by phosphorus availability; therefore the PRSFH operates under strict effluent phosphorus loading restrictions. These requirements are the repercussions of inadequate control of algal nutrients in the discharge in the past and subsequent legal settlement agreements. A highly restrictive phosphorus discharge limit of 80 kg P/year, with no more than 25 kg P in any three month period, was mandated in the year 2000 to protect the water quality of Platte Lake.

The phosphorus discharge from the PRSFH varies seasonally and is a function of temperature, the size and number of fish in the rearing tanks, the feed supply rate and phosphorus content, and the variable operation and efficiency of phosphorus removal equipment and processes. The discharge permit was violated in 2009 as a result of a lack of timely information on how fish were using feed and real-time estimates of the phosphorus concentration in the effluent flow. These limitations delayed the implementation of effective management strategies to reduce phosphorus loadings and clearly indicated that additional operational and management tools were warranted.

2. Objectives

The goal of this paper is to determine if bioenergetic growth and consumption models coupled with phosphorus mass balance models can be used as real-time predictive tools to help operators and managers meet fish production targets while maintaining effluent loading compliance. The following sections in this paper describe the development, validation, and application of such a model that can predict the growth, feed requirements, and associated production by-product phosphorus loads as a function of inventory number, fish size, temperature, food composition, and ration. The utility of the model is demonstrated using the PRSFH as a case study.

3. Description of hatchery operations

3.1. Production activities

Coho and Chinook salmon were introduced into the Great Lakes in 1966–67 to create a new sport fishery and control overabundant alewife populations. These are fall-run fish originally from Oregon and Washington rivers. The coho salmon mature at Age 2 + and the Chinook mature at Ages 3 to 4 +. Eggs are collected in the fall from weirs located on the Platte River and other nearby rivers. After hatching, the Chinook salmon eggs grow to a weight of about 5 g/individual (200/kg) in 4 to 5 months and then are released into the Great Lakes and tributary streams. Coho salmon require about 15 months to attain a weight of approximately 32 g/individual (31/kg) and are then released into Great Lakes tributary streams. The annual average mortality loss rate during the rearing period is about 3%. The annual production is approximately 2.0 million spring fingerling Chinook salmon and 1.6 million yearling coho salmon.

3.2. Physical components

Fig. 2 shows a simplified diagram of the main physical components of the PRSFH. The system consists of 22 indoor starter tanks that hold the fish until they reach a size of about 10 g/individual. The fish are then transferred to 26 outdoor covered raceways. The total volume of the raceways is 1563 m^3. The term rearing or culture tanks as used below refers to the combined volume of the starter and raceway tanks. The rearing water used in the system has an annual average flow of about 28,500 m^3/day. The nominal residence time of the outdoor raceways is 0.06 days which is equivalent to about 17 water exchanges per day. Fig. 3 shows the measured weekly average temperature in the rearing tanks for 2009 and 2010.

The outflows from the rearing tanks pass through a series of rotating-drum, continuous-flow disk filters. The mesh size of the filters has varied from 20 to 40 μm. The flows from the rearing tanks can

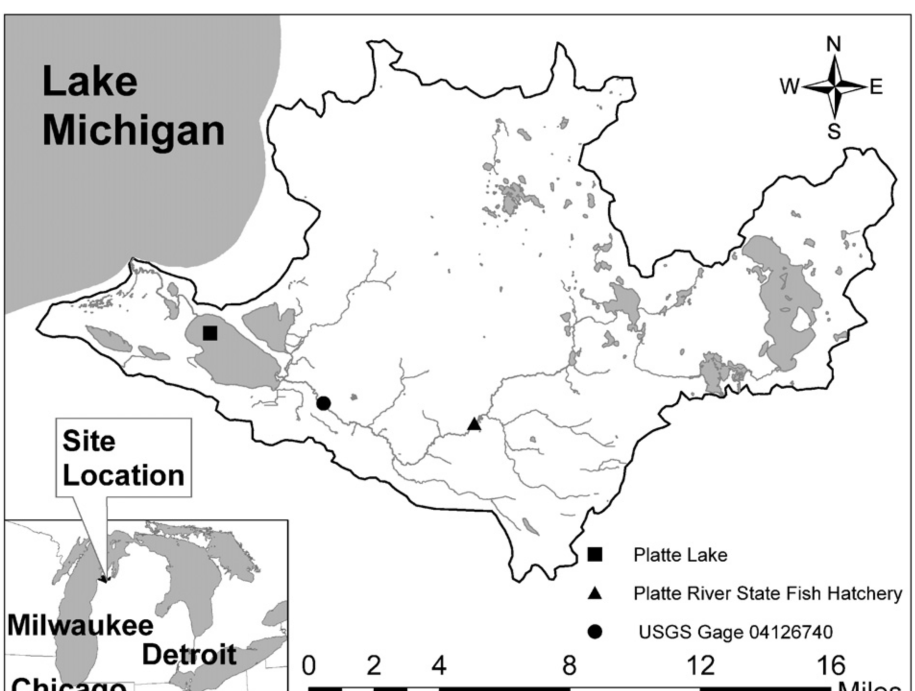

Fig. 1. Platte River watershed showing the location of Platte Lake, USGS gaging station, the Platte River State Fish Hatchery.