Ecological Modelling 336 (2016) 1–12

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Test of a foraging-bioenergetics model to evaluate growth dynamics of endangered pallid sturgeon (*Scaphirhynchus albus*)

David Deslauriers[a,*], Laura B. Heironimus[b], Steven R. Chipps[c]

[a] Department of Natural Resource Management, South Dakota State University, SNP Box 2140B, Brookings, SD 57007, USA
[b] U.S. Fish Wildlife Service, Lodi Fish & Wildlife Office, 850 South Guild Ave., Suite 150, Lodi, CA 95240, USA
[c] U.S. Geological Survey, South Dakota Cooperative Fish and Wildlife Research Unit, Department of Natural Resource Management, South Dakota State University, SNP Box 2140B, Brookings, SD 57007, USA

ARTICLE INFO

Article history:
Received 6 December 2015
Received in revised form 26 May 2016
Accepted 27 May 2016
Available online 9 June 2016

Keywords:
Pallid sturgeon
Foraging ecology
Bioenergetics
Model evaluation
Error analysis
Activity

ABSTRACT

Factors affecting feeding and growth of early life stages of the federally endangered pallid sturgeon (*Scaphirhynchus albus*) are not fully understood, owing to their scarcity in the wild. In this study was we evaluated the performance of a combined foraging-bioenergetics model as a tool for assessing growth of age-0 pallid sturgeon in the Missouri River. In the laboratory, three size classes of sturgeon larvae (18–44 mm; 0.027–0.329 g) were grown for 7 to 14 days under differing temperature (14–24 °C) and prey density (0–9 Chironomidae larvae/d) regimes. After accounting for effects of water temperature and prey density on fish activity, we compared observed final weight, final length, and number of prey consumed to values generated from the foraging-bioenergetics model. When confronted with an independent dataset, the combined model provided reliable estimates (within 13% of observations) of fish growth and prey consumption, underscoring the usefulness of the modeling approach for evaluating growth dynamics of larval fish when empirical data are lacking.

1. Introduction

The pallid sturgeon (*Scaphirhynchus albus*) is an endemic species of the Missouri and Mississippi rivers that was placed on the endangered species list in 1990 due to population declines across its range (Dryer and Sandvol, 1993). One of the main issues attributed to the specie's endangered status is the lack of recruitment of early life stages (Bergman et al., 2008). Several hypotheses have been proposed to explain recruitment failure in pallid sturgeon. Drift studies have shown that the presence of mainstem impoundments has altered downstream migration, significantly reducing the distance needed for the larval drift phase (Kynard et al., 2002; Braaten et al., 2011). Moreover, habitat studies in reservoir headwaters have shown that abiotic conditions may be unsuitable for larval pallid sturgeon, where anoxic environments can reduce survival of drifting larvae (Guy et al., 2015). Changes to other riverine habitats such as reduced turbidity, loss of shallow water areas, and decreased water temperature, are believed to contribute to declines in native fish species (Kaemingk et al., 2007; Dzialowski et al., 2012; Gosch et al., 2013).

Historically, the Missouri River was characterized by a wide, braided channel with abundant sandbars and woody debris (Wildhaber et al., 2011). Much of this changed through dredging, channelization, and construction of the main stem dams. In particular, the loss of shallow water habitat (<1.5 m depth; <0.6 m/s velocities) has been singled out as a primary reason for the decline of the pallid sturgeon (USFWS, 2003; Gosch et al., 2013). In response to this finding, a range-wide stocking program was implemented (Webb et al., 2005) and the U.S. Army Corps of Engineers (USACE) has been actively constructing shallow water habitat in the Missouri River by increasing off-channel habitats, such as chutes and backwaters, and modifying or removing existing control structures (Gosch et al., 2013). It remains unclear, however, whether restoring shallow water habitat alone will provide adequate habitat to rebound the pallid sturgeon population.

Natural reproduction by pallid sturgeon results in very few larvae collected in the Missouri River each year (0–3/year; Hrabik et al., 2007; Boley and Heist, 2011). As a result, empirical data on *in situ* habitat requirements and foraging behavior of larval pallid sturgeon is absent. Pallid sturgeon begin feeding exogenously at lengths of about 19 mm (Kynard et al., 2002; Snyder, 2002). At the onset of exogenous feeding, larval pallid sturgeon briefly (<2 days)

* Corresponding author. Present address: Department of Biological Sciences, Room W375 Duff Roblin Building, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada.
E-mail address: david.deslauriers@umanitoba.ca (D. Deslauriers).

http://dx.doi.org/10.1016/j.ecolmodel.2016.05.017
0304-3800/

feed on small zooplankton before settling to the benthos, where they feed almost exclusively on Chironomidae and Ephemeroptera larvae (Rapp, 2015). Feeding rates among larval fishes have been found to be affected mostly by water temperatures and fish size (Miller et al., 1992) but can be affected by other factors such as prey size, prey type, substrate, and flow (Nunn et al., 2011). Similarly, energy acquisition by larval pallid sturgeon is limited by their ability to find, capture, and digest prey but can be reasonably predicted as a function of body size and water temperature using models that incorporate functional feeding response and gut residence time (Jeschke and Hohberg, 2008; Deslauriers, 2015). Environmental conditions due to anthropogenic impacts such as the construction of dams have been known to alter temperature regimes, benthic habitats for invertebrates, and water velocity (Bergman et al., 2008), and can significantly influence the growth and survival of fish. Thus, linking information on food acquisition by young pallid sturgeon with their energetic requirements provides a robust approach for evaluating growth dynamics of free-ranging fish.

Bioenergetics models partition ingested energy into metabolic costs (i.e., routine metabolic rate, activity costs, specific dynamic action) and waste loss (i.e., egestion and excretion) functions, with the remaining energy available for growth (i.e., somatic and gonadal; Kitchell et al., 1977; Hanson et al., 1997). Bioenergetics models have been used to address impacts of environmental stressors on the growth of green sturgeon (*Acipenser medirostris*; Mayfield and Cech, 2004), white sturgeon (*Acipenser transmontanus*; Bevelhimer, 2002), and shortnose (*Acipenser brevirostrum*) and Atlantic sturgeon (*Acipenser oxyrinchus*) (Niklitschek and Secor, 2009). Similar applications could be used for pallid sturgeon, where bioenergetics models have been developed and evaluated for larvae (Heironimus, 2015) and juvenile fish (Chipps et al., 2009). Linking a bioenergetics model with a foraging model developed for age-0 pallid sturgeon (Deslauriers, 2015) could provide a reliable approach for evaluating growth potential of early life stages (Hayes et al., 2000). However, the usefulness of a foraging-bioenergetics approach for evaluating growth dynamics in pallid sturgeon is dependent on the accuracy of model output that can be evaluated using independent data (Chipps and Wahl, 2008).

The objective of this study was to evaluate the performance of a foraging-bioenergetics model for pallid sturgeon by comparing model predictions with independent observations of growth across a range of abiotic (e.g., temperature) and biotic (e.g., prey density, predator size) conditions. An error analysis on model parameters was conducted to verify which inputs were more likely to affect growth of fish under simulated riverine conditions. The outcome of this work will provide support for the use of the growth model to evaluate site-specific habitat quality in the Missouri River as a means of documenting suitable rearing areas and(or) identifying bottlenecks to recruitment.

2. Methods

2.1. Fish source and husbandry

Larval pallid sturgeon (1-d post-hatch) were obtained from the US Fish and Wildlife Service, Gavin's Point National Fish Hatchery (Yankton, SD) on June 17th 2014. To increase genetic variability among larvae, fish from four family lots were obtained from the hatchery, mixed in a single hauling tank, and transported to the Fisheries Research Unit (Brookings, SD) where they were placed in 40 L tanks (n = 60; 0.125 m^2 bottom area; ∼20 larvae/L) in 17 °C water. Three recirculation systems were used for the experiments where water temperature was adjusted at a rate of ±1 °C/h until experimental temperatures of 14, 18 or 24 ± 1 °C were reached. Water quality parameters (dissolved oxygen, pH, ammonia) were measured daily to ensure that temperature was the only condition that differed across systems. Fish were acclimated for at least 5 days prior to beginning feeding and growth trials. Larvae were fed a mixture of Otohime Marine (Kyowa Hakko Kogyo Co., Ltd., Cape Girardeau, MO) and Cyclopeeze (Argent Laboratories, Redmond, WA) diet (Kappenman et al., 2011) once exogenous feeding began (∼18 mm total length, L) until they reached about 30 mm. Following this period, the fish were fed *ad libitum* daily rations of thawed, Chironomidae larvae (Hikari USA Inc., Hayward, CA).

2.2. Feeding and growth

We conducted a series of feeding and growth trials with larval pallid sturgeon to evaluate the performance of a combined foraging-bioenergetics model (see below) at predicting sturgeon growth. Feeding and growth were measured for three size groups of larvae (means = 18, 21, or 44 mm), fed one of four feeding treatments (0, 3, 6, or 9 chironomids/day corresponding to 0, 315, 631, or 947 chironomids/m^2) at water temperatures of 14, 18 or 24 °C (Table 1). Each feeding-by-water temperature combination was replicated five times. Individual fish were placed in cylindrical aquaria (900 mL; 0.0095 m^2 bottom area) and starved for 24 h before live chironomid larvae were introduced. The aquaria were submerged in 40 L tanks to allow for water exchange to occur while a fine meshed screen was placed at the top of the aquaria to avoid the loss of uneaten chironomid larvae. Uneaten prey were removed, counted, and replaced with live prey between 8:00 and 9:00 am each day. Any fish that died during a trial was removed from the experimental tank and data were not included in the analyses. At the end of the experimental period, the fish were euthanized using Tricaine-S (Western Chemical Inc.; 200 mg/L), and measured for total length (nearest mm) and weight (nearest mg). Initial lengths and wet weights were taken from a sub-sample of sturgeon that were not included in the growth trials (Table 1). This procedure was necessary because preliminary trials showed that young pallid sturgeon are extremely sensitive to handling and air exposure.

Live chironomid larvae used during the growth trials were collected from a local pond and were sorted using 250 μm (small size class), 500 μm (medium size class) and 750 μm (large size class) screen mesh. To determine the mean size of chironomids fed to sturgeon each day, three digital photographs of 10 chironomids were taken from the sample of invertebrates. Photographs were imported into ImageJ (Abràmoff et al., 2004) where lengths were quantified. A sub-sample of chironomids was weighed wet (in groups of 10) and then placed in a drying oven at 60 °C and dried to a constant weight (≥48 h). The ratio of dry-to-wet weight was

Table 1
Initial length and weight of age-0 pallid sturgeon characteristics used in feeding and growth trials at water temperatures of 14–24 °C. For each trial, a total of 5 replicates were used for each temperature and feeding rate combination. Initial lengths and weights were determined from a random sample of 20 fish that were not used in the trials. Values in parentheses represent standard deviations.

Trial	Mean pallid sturgeon length (mm)	Mean pallid sturgeon weight (g)	Duration (d)	Temperature (°C)	Feeding rate (no. chironomids/d)	Mean chironomid length (mm)	Mean chironomid weight (g)	Prey energy density (J/g)
1	18 (0.10)	0.027 (0.000)	7	14, 18, 24	0, 3, 6, 9	6 (1.52)	0.002 (0.001)	2872
2	21 (0.42)	0.043 (0.003)	7	14, 18, 24	0, 3, 6, 9	6 (1.52)	0.002 (0.001)	2872
3	44 (1.09)	0.329 (0.023)	14	14, 18, 24	0, 3, 6, 9	11 (1.63)	0.010 (0.002)	3239