Animal Nutrition xxx (2016) 1–15

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: http://www.keaipublishing.com/en/journals/aninu/

Original Research Article

Development of growth rate, body lipid, moisture, and energy models for white sturgeon (*Acipenser transmontanus*) fed at various feeding rates

Seunghyung Lee [a, 1, 2], Ozan Sonmez [b, 1], Silas S.O. Hung [a], James G. Fadel [a, *]

[a] *Department of Animal Science, University of California, One Shields Avenue, Davis, CA 95616, USA*
[b] *Department of Statistics, University of California, One Shields Avenue, Davis, CA 95616, USA*

ARTICLE INFO

Article history:
Received 19 August 2016
Accepted 31 October 2016
Available online xxx

Keywords:
Specific growth rate
Body composition
Optimum feeding rate
Sturgeon

ABSTRACT

The objectives were to develop and evaluate: 1) growth rate models, 2) body lipid, moisture, and energy models for white sturgeon fed at various feeding rates (FR; % body weight [BW] per day) and then evaluate responses at proportions of optimum feeding rate (OFR) across increasing BW (g). For objective 1, 19 datasets from the literature containing initial BW, FR and specific growth rate (SGR; % BW increase per day) were used. For objective 2, 12 datasets from the literature (11 from objective 1) containing SGR, FR, final BW, body lipid (%), protein (%), ash (%), moisture (%), and energy (kJ/g) were used. The average rearing temperatures was 19.2 ± 1.5°C (mean ± SD). The average nutrient compositions and gross energy of the diets were 45.7 ± 4.3% protein, 14.8 ± 3.2% lipid, and 20.4 ± 1.3 kJ/g, respectively. The logistic model was used for objectives 1 and 2 to develop a statistical relationship between SGR and FR, then an iterative technique was used to estimate OFR for each dataset. For objective 2, the statistical relationship between body lipid, energy, and moisture and FR was established. Using the OFR estimate, SGR, body lipid, energy and moisture were computed at various FR as a proportion of OFR. Finally, a nonparametric fitting procedure was used to establish relationships between SGR, body lipid, energy and moisture (responses) compared with BW (predictor) at various proportions of OFR. This allows visualization of the effect of under- or over-feeding on the various responses. When examining the differences between OFR at 100% and various proportions of OFR, SGR differences decrease and moisture differences increase as BW increases. Lipid and energy differences decrease as BW increases. To our knowledge, these are the first description of changes in nutrient compositions when white sturgeon are fed at various FR. Because physiological and behavioral properties that are unique to sturgeon, results from this study are specific to sturgeon under the conditions of this study and cannot be compared directly with salmonids even if some of the results are similar. This research provides insight to designing future nutritional studies in sturgeon.

1. Introduction

White sturgeon (*Acipenser transmontanus*) is an ecologically and commercially important species (Moyle, 2002; Lee et al., 2014). Furthermore, this species has some biological uniqueness, which is different from the commonly cultured salmonids. These differences include: 1) long life span of more than 100 years in the wild compared with 2 to 4 years in salmonids (Moyle, 2002); 2) late sexual maturity of 4 years for males and 7 to 8 years for females raised in captivity instead of 1 to 3 years in salmonids (Doroshov et al., 1997); 3) a unique fat storage organ (gonadal body fat; Scarnecchia et al., 2007; Lee et al., 2016) instead of

* Corresponding author.
E-mail address: jgfadel@ucdavis.edu (J.G. Fadel).
[1] These authors contributed equally to this paper.
[2] Present address: Aquafeed Research Center, National Institute of Fisheries Science (NIFS), Pohang 791-923, Republic of Korea.

Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.aninu.2016.10.005
2405-6545/

Please cite this article in press as: Lee S, et al., Development of growth rate, body lipid, moisture, and energy models for white sturgeon (*Acipenser transmontanus*) fed at various feeding rates, Animal Nutrition (2016), http://dx.doi.org/10.1016/j.aninu.2016.10.005

viscera in salmonids; 4) and sturgeon are nibblers (Cui et al., 1997) instead of meal feeders like salmonids (for salmonids see Shearer, 1994).

Feeding rate (% body weight per day) is a major element affecting growth in fish (Brett and Groves, 1979), and thus determination of optimum feeding rate (OFR; %), defined as the rate at which growth is maximal, is critical for success of aquaculture operations. In a previous study, we demonstrated how to develop an OFR model that can predict an OFR at a given body weight of white sturgeon ranging from 0.05 to 800 g (Lee et al., 2014). The approach used previously to find an OFR at different weight classes (Lee et al., 2014) can be expanded using a different modeling approach to evaluate specific growth rate (SGR) at different body weights considering different proportions of OFR (i.e., 30% to 110% of OFR). This new approach will allow researchers to examine the feeding rate-dependent growth performance under different OFR proportions. Understanding the relative differences between proportions of OFR can also be valuable when extending this information to applied aquaculture settings.

Due to the high correlation between growth and nutrient partitioning in association with feed availability (Storebakken et al., 1991; Lee et al., 2016), developing body composition and energy models for white sturgeon at a given feeding rate will also enhance our understanding of nutrient and energy content changes in relation to feeding rate. To our knowledge, these types of models have not been developed for white sturgeon. Therefore, our objectives of the current study were development and evaluation of 1) growth rate models and 2) body compositions (lipid, moisture) and energy models for white sturgeon when fed at various proportions of OFR across increasing body weight. The current study is unique because we demonstrate dynamic relationships for these responses at various proportions of OFR for white sturgeon from first exogenous feeding to young of the year.

2. Materials and methods

2.1. Description of datasets

Nineteen datasets were used for objective 1 to describe how growth rate changed when white sturgeon were fed at increasing feeding rates and to also describe growth rate when fed at different proportions of OFR across a range of average initial body weights varying from 0.05 to about 800 g. Every dataset represents a different weight class of sturgeon. Observations taken at different feeding rates were independent from each other. The datasets were obtained from 6 published studies (Hung and Lutes, 1987; Hung et al., 1993, 1995; Deng et al., 2003; De Riu et al., 2012; Lee et al., 2016) which were carried out to evaluate the effects of feeding rate on growth performance in white sturgeon across body weights. Many of the diets that were used in the studies are commercial feeds that have been used on white sturgeon farms in California, USA. Some of them were formulated diets developed to meet nutrient requirements of white sturgeon. The average nutrient compositions and gross energy of the diets were 45.7 ± 4.3% (mean ± SD) crude protein and 14.8 ± 3.2% crude lipid, and 20.4 ± 1.3 kJ/g, respectively.

The 19 datasets contain initial and final body weights (g; weight class), various feeding rates (FR; % body weight per day; independent variable), and specific growth rates (SGR; % body weight increase per day; dependent variable) (Table A). Among 19 datasets in objective 1, 2 groups of datasets were dependent, i.e., datasets 9 to 12 and datasets 14 to 18 because the measurements were taken from the same set of fish at different body weight stages. However, they were treated as independent datasets due to the following reasons. Firstly, the interpretation of the results showed no difference when these datasets were pooled and considered as a single dataset. Secondly, most importantly, the second step which involved using nonparametric curve fitting using estimates from each dataset were improved dramatically due to the higher number of sample size (i.e., 19 datasets compared with 12 datasets when considering the datasets 9 to 12 and 14 to 18 were independent). Finally, insufficient data points were available such that a mixed effects model would result in variance−covariance matrix that would have an unstable structure.

Twelve independent datasets were used for objective 2 to describe how body lipid, energy, and moisture content changed when white sturgeon were fed at increasing FR and to also describe body lipid, energy, and moisture content when fed at different proportions of OFR across a range of average final body weights varying from 0.10 g to about 700 g. Again, these datasets represent different body weights. These datasets were obtained from the aforementioned published studies, except the study from Hung et al. (1995) where the fish were not slaughtered, and another study from Lee et al. (2015) which was added. Because the values of body composition and energy content were acquired through sacrificing animals at the end of a growth trial, 2 groups of the datasets from objective 1 (datasets 9 to 12 and 14 to 18) that were used in objective 2 were pooled. All fish were slaughtered in objective 2, and all datasets were independent. The 12 datasets, including average final body weights (g; weight class), various FR (%; independent variable), and body compositions (lipid, moisture; % as wet basis) and energy (kJ/g as wet basis) (dependent variables), are listed in Table 1. Protein and ash content were not considered in the current study because these 2 variables showed little change when body weight was larger than ca 30 g. All data points including moisture, protein, lipid and ash content are presented in Fig. 1.

2.2. Model development (objectives one and two)

In order to describe the relationship between various FR and response variables (e.g., growth rate, body composition and energy) for the given datasets, it was necessary to have an OFR estimate for each dataset. We defined the OFR as the rate at which growth is maximal or approaches maximal. Then the OFR can be used as a standard to examine other FR as a proportion of OFR. In our previous study (Lee et al., 2014), a prediction model for estimating an OFR for white sturgeon was developed. In summary, the OFR for the 19 datasets, which were the same datasets used in objective 1 of the current study, were estimated using a quadratic broken-line model that was selected as the best-fit model among the tested models (one-slope straight broken-line, two-slope straight broken-line, second-order polynomial models) on the basis of model selection criteria (e.g., adjusted coefficient of correlation, corrected Akaike information criterion). Then, the relationships between the 19 estimated OFR and transformed initial body weights were investigated via various regression models, and the best-fit model was a bi-exponential regression model that can predict OFR for a given body weight ranging from 0.05 to about 800 g. That modeling approach, although valid, did not capture the non-linear nature of the response. To overcome this drawback, a logistic growth curve was utilized for estimating the OFR in both objectives 1 and 2, where the FR and the SGR were the predictor and the response, respectively. Feed conversion ratio (FCR) was not used as the response because feed intake was not measured and as FR approaches OFR and beyond, more feed is wasted. Hence, the