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ORIGINAL RESEARCH

Growth performance of hybrid striped bass (*Morone chrysops* × *M. saxatilis*) fed with commercial pike perch and trout diets

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Abstract Two commercial trout diets (*Oncorhynchus mykiss*) and one commercial pike perch diet (*Sander lucioperca*) were fed to hybrid striped bass (*Morone chrysops* × *M. saxatilis*) (mean initial weight ± SD of 60.7 g ± 12.1; mean initial length SD of 17.2 cm ± 1.1) for 69 days at rations of approximately 1% average body weight. While final body weight (FBW), final length (FBL) and condition factor (Cf) were not significantly influenced by diets, specific growth rate (SGR) in hybrid striped bass fed with the pike perch diet (1.15) was significantly higher than those fed with either of the two trout diets (1.04 and 1.07). The feed conversion ratio (FCR) in hybrid striped bass fed with the pike perch diet (1.0) was significantly lower than the FCR in hybrid striped bass fed with either of the two trout diets (1.1 and 1.2). When hybrid striped bass (mean initial body weight: 65.7 ± 4.5 and 127.7 ± 2.9 g) were fed with the pike perch diet twice per day until satiation for 52 days, the SGR was 1.7 and 1.15% d^{-1} in fishes with an average body weight of 116 and 183 g, respectively. Present results demonstrate that growth performance in hybrid striped bass can be improved when fishes are fed with commercial pike perch diets rather than using commercial trout diets as is the current practice.

Keywords Hybrid striped bass · Commercial diets · Trout · Pike perch · Growth · Nutrition

Introduction

The hybrid striped bass (*Morone chrysops* × *M. saxatilis*) is considered an ideal candidate for aquaculture because of its fast growth, temperature tolerance, flexibility to environmental parameters, disease resistance (Kohler 2004; Morris et al. 1999). Moreover, hybrid striped bass can be produced in basically all production systems such as ponds, tanks (closed or semi-closed recirculating aquaculture systems) or cage systems (FAO 2016; Lougheed and Nelson 2001). The United States is the most significant producer of hybrid striped bass with annual production of around 6000 tons (D'Abramo and Frinsko 2008) though also other countries in Europe and Asia have recently started the production of hybrid striped bass.

Despite their commercial importance, no tailored commercial diets are available for hybrid striped bass. Basic macronutrient requirements of hybrid striped bass have been determined. Reported requirements for protein range from 40 to 41% (Brown et al. 1992; Jaramillo and Gatlin 2004; Liu and Liao 1999; Nematipour et al. 1992; Webster et al. 1995). Energy–protein ratio requirements are between 8 and 9 kcal/g

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(Keembiyehetty and Wilson 1998; Nematipour et al. 1992). Maximum growth with intermediate lipid deposition levels was obtained with dietary lipid levels between 10 and 15% (Gaylord and Gatlin 2000). Though several of the essential amino acids, essential fatty acids, and vitamin and mineral requirements have been determined (Brown et al. 1993; Deng and Wilson 2003; Gaylord and Gatlin 2000; Gaylord et al. 2005; Griffin et al. 1994; Keembiyehetty and Gatlin 1997; Kocabas and Gatlin 1999; Sealey and Gatlin 1999), a complete profile of all amino acid and fatty acid requirements is missing. This knowledge gap is the main reason why commercial feeds formulated for other species are currently used in practice. Diets tailored to salmon were reportedly best suited for hybrid striped bass (Tucker Jr 2012). Growth, feed conversion and physiological indices were near optimum in hybrid striped bass weighing between 38 and 130 g and fed with a commercial salmon feed (45% protein, 12% lipid) at daily rations of 1.0–1.5% (Hung et al. 1993). However, commercial salmon diets generally contain lipid levels in excess of 12% and excess dietary lipid levels (15%) impaired health and product quality in hybrid striped bass (Gaylord and Gatlin 2000). Catfish diets have also been tested but were not suitable for hybrid striped bass (Tucker Jr 2012). Information on performance of hybrid striped bass fed with trout diets is scarce. However, striped bass (*Morone saxatilis*) fed with commercial trout feed was smaller, contained less body lipid and had necrotic liver tissue compared to those fed with a salmon diet (Lemm et al. 1993). These diet-related histological changes in the livers were related to inadequate type and level of dietary essential fatty acids (Lemm et al. 1993). However, this previous observation stating that trout diets are nutritionally inadequate for hybrid striped bass dates back almost 25 years, when nutritional knowledge even for highly commercial aquaculture species like trout was largely incomplete. To our knowledge, the suitability of 'modern' trout diets and alternative 'modern' diets in general for the culture of hybrid striped bass has not been investigated yet. The aim of this study was to evaluate the suitability of a diet formulated for pike perch to culture hybrid striped bass. Suitability was evaluated on the basis of digestibility, feed conversion ratio, condition factor and maximum growth rate.

Materials and methods

Two commercial trout diets were used as reference diets. Experiments were conducted at the Centre for Aquaculture Research (ZAF, Alfred Wegener Institute Bremerhaven, Germany).

Three commercially available diets were compared in the present study: Metabolica, 3 mm (52% Protein, Aller Aqua GmbH) subsequently referred to as 'pike perch' diet; Supreme 15, 3 mm (46% Protein, Coppens International BV) subsequently referred to as 'trout 1′ diet; Efico Alpha 715, 3 mm (44% Protein, Biomar Group) subsequently referred to as 'trout 2' diet. All diets were coated with sunflower oil (100 g kg^{-1}) and Yttrium oxide (Y_2O, 0.1%) as an external marker for subsequent determination of proximate composition and apparent digestibility (Hillestad et al. 1999).

Fish and rearing conditions

Hybrid striped bass ($n = 180$) were obtained from a commercial local fish farm (Fischzucht Hagedorn, Bargstedt-Ohrensen) and were transferred to the ZAF research facility where fishes were acclimatized to the rearing conditions prior to the start of the feeding experiments. The rearing/experimental system consisted of 9 rectangular glass tanks (0.4 $m.^{-2}$ bottom area and a total water volume 250 L per tank). All tanks were connected to a recirculation aquaculture system equipped with a mechanical filter (foam matt), a moving bed filter and a UV unit. Conditions were maintained as follows: (photoperiod 12L:12D; dissolved oxygen > 84%; temperature 21.6 ± 0.7 °C; total ammonia nitrogen < 0.14 mg L^{-1}; nitrite nitrogen < 0.31 mg L^{-1} and nitrate nitrogen < 201.78 mg L^{-1}). The pH was kept above 6.18 except for one day where the pH was at 5.57. The pH was controlled by periodically adding sodium bicarbonate to the system.

Growth experiments

Two controlled feeding (growth) experiments were conducted:

In experiment 1—restricted rations, three commercial diets formulated to meet the nutritional requirements of trout (two diets) and pike perch were fed at restricted rations of approximately 1% average body weight (ABW). Hybrid striped bass were weighed and length was measured individually to the nearest of 0.1 g and 0.1 cm. Fishes (mean initial weight ± SD of 60.7 g ± 12.1; mean initial length SD of 17.2 cm ± 1.1) were randomly assigned to nine experimental tanks at a density of 20 fishes per tank. The nine tanks were randomly assigned to one of the three dietary treatments (three tanks per diet). Fishes were fed twice per day at 09:00 and 16:00 h. Feed was completely consumed, so no uneaten feed needed to be recovered for actual intake utilization calculations. At the end of the experimental period after 69 days, fishes were removed from the tanks and individually weighed and length measured.

In experiment 2—satiation, only the pike perch diet was fed twice per day to apparent satiation. Upon arrival hybrid striped bass were weighed individually to the nearest 0.1 g. In total sixty, 30 smaller fishes (mean initial weight SD of 65.7 g ± 4.5) and 30 larger fishes (mean initial weight SD of 127.7 g ± 2.9) were selected and randomly assigned (only separated by weight) to six experimental tanks at a density of 10 fishes per tank. During the acclimatization period of 4 days, all fishes were fed with the artificial feed at a level of 0.3% average body weight. During the experimental feeding period, fishes were fed twice per day to apparent satiation (at 09:00 and 16:00 h). Previous observations showed no increase in daily feed intake when feed was provided at three meals per day or two meals per day (pers. obs.). Uneaten feed was not recovered from the tanks to avoid stress to the fish (pers. obs.). At the end of the experimental period after 52 days, fishes were removed from the tanks and weighed individually.

Proximate composition and digestibility of the diets

Prior to the digestibility trial, hybrid striped bass (originating from the previous satiation experiment) were weighed individually to the nearest 0.1 g. In total, 48 fishes (mean weight of 312.5 g) were randomly assigned to six experimental tanks at a density of 8 fishes per tank. During the acclimatization period of 5 days, fishes were fed the randomly assigned diet for their treatment tank (without the external marker) at a level of 1.5% average body weight ABW. During the experimental feeding period, fishes were fed twice per day to apparent satiation (at 09:00 and 16:00 h). Feces were siphoned out twice per day, dried and subsequently stored for further analysis. At the end of the experimental period after 28 days, fishes were removed from the tanks and weighed individually.

Analytical methods and calculations

Feed and fecal samples were dried, pooled on tank basis (applied for feces only) and homogenized by grinding before subsequent analyses of dry matter, nitrogen, energy, lipid and yttrium oxide. Samples were analyzed for dry matter according to 'Bundesamt für Verbraucherschutz und Lebensmittelsicherheit'(2004c–07b), crude protein (total nitrogen * 6.25) was determined by the Kjeldahl method according to 'Bundesamt für Verbraucherschutz und Lebensmittelsicherheit'(2004–07a), ash (gravimetrically 520 °C incineration) according to 'Bundesamt für Verbraucherschutz und Lebensmittelsicherheit'(2004–074) and crude fat (gravimetrically after extraction with petroleum ether) according to 'Bundesamt für Verbraucherschutz und Lebensmittelsicherheit'(1980–09). Proximate analysis was done at the laboratory facilities of the University of Applied Sciences (Bremerhaven, Germany). The dietary carbohydrate content (i.e., nitrogen-free extract, NFE) was calculated subtracting the sum of crude protein, crude fat and ash from 1000 in g kg^{-1} DM. Gross energy (GE) was determined using an automated oxygen bomb calorimeter (Parr 6100 calorimeter, Parr Instrument GmbH, Germany) at the facilities of the AWI The digestion indicator was determined using the acid-insoluble ash (AIA) method according to, Bundesamt für Verbraucherschutz und Lebensmittelsicherheit' (2004–07).

Mean initial body weight (IBW) and mean final body weight (FBW) were calculated per tank biomass. The specific growth rate (SGR in %) was calculated as $((\ln(\mathrm{FBW}) - \ln(\mathrm{IBW}))/t$, where t is the experimental period (days) of the growth study. Daily feed intake (DFI; g DM $fish^{-1}$ d^{-1}) was calculated as $\mathrm{TFI}/(t * n)$, where TFI is the total FI per tank over the experimental days and n is the number of fishes per tank. No mortalities occurred during the experiment; hence, calculations were based on eight fishes per tank. Feed

conversion ratio (FCR) was calculated as DFI/(FBW−IBW) being expressed on DM basis. Apparent digestibility of the dietary nutrients and energy (ADC) was calculated as$100 \times (1 - \text{dietary Y2O level}/\text{faecal Y2O Level} \times \text{faecal nutrient or energy level}/\text{dietary nutrient/energy level})$ (Maynard et al. 1979). The condition factor (C_f) was calculated FBW/(FBL^3), where FBL is the final body length of the fish.

Statistical analysis

Data were log transformed to fulfill the ANOVA requirements of homoscedastic normal distribution of residuals. The effect of diet on performance parameters was analyzed by one-way ANOVA. In case of a significant effect of diet, a *t* test was used for pairwise comparisons. Statistical significance was tested at a 0.05 probability level. All data were analyzed using the statistical software R version 3.3.1. (released 2016-06-21).

Results

The Pike perch diet exhibited markedly higher crude protein and lower nitrogen-free extract than the Trout diets (Table 1). The cumulative feed (restricted rations experiment) given to each tank over the experimental period was 753 g.

Final body weight, final length and condition factor were not significantly affected by diets (Table 2, experiment 1; $P = 0.245$, $P = 0.141$ and $P = 0.869$ for final body weight, final length and condition factor, respectively). The FCR was significantly influenced by diet ($P = 0.010$) with FCR in hybrid striped bass fed the pike perch diet significantly lower than in those fed the trout diets. The SGR was significantly affected by diet ($P = 0.015$). The SGR in hybrid striped bass fed with the pike perch diet was significantly higher than the SGR in hybrid striped bass fed with the trout diets.

Discussion

The present study showed that commercially important hybrid striped bass fed with a commercially available diet formulated for pike perch grew faster (SGR) and showed better FCR values than hybrid striped bass fed with either of two trout diets (experiment 1, Table 2). Previous observations stating that trout diets are nutritionally inadequate for hybrid striped bass date back to 1993 (Lemm et al. 1993), in which nutritional knowledge even for highly commercial aquaculture species like trout was largely incomplete. It may have been expected that hybrid striped bass perform well on advanced 'modern' trout diets.

Table 1 The proximate composition and apparent digestibility coefficients (ADC in %) of commercial pike perch and trout diets after coating with sunflower oil (100 g.kg^{-1}) and Yttrium oxide (0.1%)

	Pike perch	Trout 1	Trout 2
Analysis (g.kg^{-1})			
Dry matter (g kg^{-1} WW)	914.64	918.63	928.51
Crude protein (g kg^{-1} DM)	538.83	455.82	478.89
Crude lipid (g kg^{-1} DM)	180.87	191.71	168.66
Ash (g kg^{-1} DM)	65.13	53.43	59.62
NFE (g kg^{-1} DM)[a]	215.17	299.04	292.83
Gross energy (kJ g^{-1} DM)	23.45	22.27	21.7
Apparent digestibility (%)			
Dry matter	72.06	69.87	68.22
Protein	74.19	76.58	73.16
Lipid	88.47	87.59	89.79
Energy	79.22	76.66	73.97

[a]NFE (nitrogen-free extract) calculated subtracting the sum of crude protein, crude lipid and ash from 1000 in g kg^{-1} DM

Table 2 Growth performance in hybrid striped bass (initial body weight: 60.7 ± 12.1 g fed with restricted rations of pike perch and trout diets (two diets) over a period of 69 days (experiment 1), and growth performance in hybrid striped bass (initial body weight: 65.7 ± 4.5 g (a) and 127.7 ± 2.9 g (b)) fed with the pike perch diet twice per day until satiation over a period of 52 days (experiment 2)

Diet	Experiment 1—restricted ration						Experiment 2—satiation			
	Pike Perch	SD	Trout 1	SD	Trout 2	SD	Pike Perch[a]	SD	Pike Perch[b]	SD
Final body weight (g)	134.2	3.67	124.7	2.32	127.2	1.91	167.78	5.85	239.77	3.46
Final total length (cm)	20.7	0.08	19.8	0.15	20	0.52	–	–	–	–
Specific growth rate (%)	1.15[a]	0.04	1.04[b]	0.03	1.07[b]	0.03	1.71	0.08	1.15	0.06
FCR	1.03[a]	0.05	1.18[b]	0.04	1.13[b]	0.04	0.98	0.02	0.88	0.03
Feed intake ($g.fish^{-1}.d^{-1}$)	0.55	0	0.55	0	0.55	0	1.82	0.12	1.79	0.13
Condition factor	1.52	0.04	1.6	0.04	1.59	0.11	–	–	–	–

Values are means of triplicate tanks ($n = 20$ per tank) ± SD (experiment 1) or (n = 10 per tank) ± SD (experiment 2). Values without a common superscript letter differ significantly ($P < 0.05$) as calculated by one-way ANOVA and t test significant difference test

The absence of superscript indicates no significant difference between treatments (only applies for experiment 1; no statistical analysis was done in experiment 2)

In the present study, apparent nutrient and energy digestibility coefficients of trout and the pike perch diet were similar (Table 1). Therefore, the higher FCR in hybrid striped bass was not related to poor digestibility of the trout diet. Lemm et al. (1993) suggested that type and level of dietary essential fatty acids of trout diets do not reflect the requirements of hybrid striped bass which may also explain the present observed lower performance of hybrid striped bass fed the present trout diets. The better performance of hybrid striped bass fed with the pike perch diet was, however, somewhat unexpected because the pike perch diet showed the highest protein excess of all present diets (Table 1, 54% compared to the reported requirement of around 40% (Brown et al. 1992; Nematipour et al. 1992; Webster et al. 2001)). In addition, the dietary lipid level of the pike perch diet (Table 1, 18%) was in excess of the species requirement which was estimated between 10 and 15% (Gaylord and Gatlin 2000).

It is known that excess dietary protein and lipid levels can negatively influence the SGR and FCR in fish (Brown et al. 1992; Hatlen et al. 2007; Peres and Oliva-Teles 1999; Saravanan et al. 2012). Excess dietary lipid increases adiposity, which is thought to exert a negative feedback on feed intake via lipostatic regulation mechanisms (Johansen et al. 2002). This should have been reflected by low intake and low growth rates when pike perch diet is fed in unrestricted rations. No intake values and growth rates were found for hybrid striped bass of similar size. However, present SGR values (experiment 2, SGR of 1.7 and 1.15% d^{-1} in fish of 60.7 and 183 g IBW, respectively) are similar to values previously reported in hybrid striped bass of considerably smaller size; Juvenile hybrid striped bass (around 20–40 g IBW) fed diets formulated based on the known nutritional requirements showed SGR of 1.1–1.8 (Bowzer et al. 2016; Thompson et al. 2000) Similar sized juvenile hybrid striped bass fed a commercial salmonid diet showed SGR of 1.5% (Hung et al. 1993). In addition, the moderate excess of dietary lipid in the pike perch diet (18%, Table 2) did not seem to negatively influence FCR. In fact, present FCR values (Table 2, 0.88–0.98) compared favorably to FCR values previously reported in hybrid striped bass fed with diets of optimized dietary lipids levels of 12% (FCR of 1.1–1.5% (Bowzer and Trushenski 2015; Thompson et al. 2000)). The absence of negative effects on FCR fed diet moderately in excess of dietary lipids requirements is in line with previous observations. Higher dietary lipid levels > 15% did not negatively influence feed efficiency in hybrid striped bass; however, the deposition of lipid in the liver and peritoneal cavity increased whereas the muscle yield decreased (Gaylord and Gatlin 2000). This was also observed in the present study. In this study, random individuals were sampled and showed excessive body fat depositions (unpubl. observation). The ADC values (Table 1) obtained in hybrid striped bass fed with the pike perch diet (and in those fed the two trout diets) are in the lower range of ADC values for feedstuff of animal origin previously reported for hybrid striped bass (Sullivan and Reigh 1995). However, considering the adequate FCR values, present ADC values may rather be a result of an inadequate fecal sampling method than related to low ingredient quality. In this study, settled feces were recovered twice per week. The recovery of settled feces may facilitate under estimation of digestibility due to disintegration/

separation of feces, or leaching of nutrients and/or marker from the fecal matter (Cho and Kaushik 1990). Disintegrated feces (as in the present study) are more susceptible to nutrient loss by leaching (Cho et al. 1985).

In conclusion, present results demonstrate that growth performance in hybrid striped bass can be improved when fishes are fed with commercial pike perch diets rather than using commercial trout diets as is the current practice. Key performance data in terms of growth (SGR) and growth by feed input (FCR) were better in hybrid striped bass fed with the pike perch diet compared to two trout diets. Acceptable growth rates were obtained when hybrid striped bass were fed with unrestricted rations of pike perch diet.

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