# Novel feed from invasive species is beneficial to walleye aquaculture

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## Abstract

Carnivorous fishes, such as walleye (*Sander vitreus*) are nutritionally demanding for fish meal. A promising alternative to marine-origin fish meal, the supply of which has been stagnant in recent decades, is fish meal derived from undesirable freshwater species, such as the White sucker *Catostomus commersoni*. To evaluate the relative value of such ingredients, we examined the growth performance of Walleye juveniles. Two dietary treatments were tested: an experimental diet (EXP) that was manufactured using White sucker as fish meal in comparison with a commercial (COM) diet, EWOS micro (EWOS Canada Ltd). The protein content was 50.4% and 57.6% for EXP and COM diets, respectively. The energy content was 5,098.76 ± 9.23 cal/g (mean ± SD) for the EXP diet and 5,134.47 ± 10.05 cal/g for the COM diet. Starting at 27 d posthatch, Walleye juveniles (initial weight [mean ± SD) = 0.03 ± 0.008 g; initial length = 15.7 ± 1.5 mm) were reared for 6 weeks in three replicate tanks for each treatment. Condition factor (0.83), final weight (1.12 ± 0.3 g), and weight gain (1.09 ± 0.06 g) were higher in EXP fish. Similarly, the energetic lipid content of fish in the EXP treatment group (mean ± SD = 5.01 ± 0.45 g/kg) was also higher than that of fish fed the COM diet (3.30 ± 0.53 g/Kg). Although the polar lipid content (membrane lipids) was similar in fish from the two treatments, the nutritional ratio for COM juveniles was over 1.5 for arachidonic acid and docosahexaenoic acid, indicating selective incorporation by juveniles and a potential diet ±imbalance of these fatty acids. Furthermore, the higher observed selective incorporation of oleic acid in juveniles fed the EXP diet suggested that a higher value of this fatty acid in the EXP feed could have increased Walleye growth performance. Threonine was the main essential amino acid (AA; > 18.5% of total AAs) while serine and glycine contributed the highest percentages of the nonessential AAs (> 31% and 8.5% of total AAs,

respectively). All three AAs, often considered limiting ingredients, are important to support growth and are involved in metabolic processes in some fish species. Our results demonstrate that feed pellets made with white sucker fish meal improved growth in walleye juveniles and can be suitable and probably lower-cost alternative to marine fish meal in feeds for carnivorous fishes.

**Key words:** Walleye (*Sander vitreus*), white sucker (*Catostomus commersoni*), invasive species, juveniles, diet, fatty acid, amino acid.

## Introduction

Traditional marine-based protein sources derived from pelagic marine fisheries are no longer available in quantities that meet the current increased demands of intensive fish-farm production (FAO, 2016). Stagnant supply, greater demand, and rising prices have prompted the search for substitutes. Indeed, fish meal prices doubled from US$694 to $1,379 per metric ton between 2007 and 2008 (Tacon and Metian, 2008).

A potential alternative to marine-origin fish meal is a freshwater meal rendred from invasive and/or undesirable species, such as the White sucker *Catostomus commersonii*. Previous studies have evaluated the potential of Asian carp *Hypophthalmichthys* spp. as fish meal in pelleted feeds (Bowzer et al., 2013). Invasive Asian Carp were demonstrated to be a cost-effective alternative protein source (US$600 permetric ton; Bowzer and Trushenski, 2015) to traditional marine origin fish meal in the diets of carnivorous fishes, such as hybrid Striped Bass (White Bass *Morone chrysops* × Striped Bass *M. saxatilis*), Rainbow Trout *Oncorhynchus mykiss*, and Cobia *Rachycentron canadum* (Bowzer et al., 2013; Bowzer and Trushenski, 2015).

The White Sucker is widespread in Canada, the U.S. Midwest, and the U.S. East Coast. It is both a predator and prey of Walleye *Sander vitreus* (Barton, 2011). White Suckers were introduced in Quebec, Canada, by sport fishermen who used it as a baitfish to capture Walleyes or Brook Trout *Salvelinus fontinalis* (Magnan et al., 1990; Duchesne, 1994; St-Laurent, 2002). White Suckers are found in small streams, rivers, and lakes, where they feed on worms, eggs, and fish larvae (e.g., Walleye larvae). The species is tolerant of turbid and polluted waters that are often unsuitable for other fish species (Beamish, 1973; Trippel and Harvey, 1987). This ability allows White Sucker populations to reach high abundances and increase their dispersal. It has been demonstrated that White Sucker is a pest species for Brook Trout and a competitor of Yellow Perch *Perca flavescens* (Duchesne, 1994). White Suckers are found on the same spawning grounds as Walleyes and breed at the same time of the year (Barton, 2011). In 1995, Forêt Faune et Parcs Québec initiated a control program aimed at the mass removal of adult White Suckers in five Quebec lakes (Magnan et al., 1990; Duchesne, 1994; St-Laurent, 2002). Although we do not have a precise estimate for the price per metric ton for this species, we think it is comparable or lower to Asian carp (US$600 per metric ton), which is considerably lower than current pricing for marine-origin fish meal (US$1,488 per metric ton, estimated to be 13% higher in 2030) (WBG, 2013). Additionally, an industry must be established to produce the product to supply the market. Due to the initial high risk of investment in a new product, White Sucker meal production facilities have not yet been developed. Based on the potential volumes and the facilities necessary to process White Suckers, it will likely only be a regional alternative to traditional fish meal sources.

The Walleye is an important freshwater sport and commercial fish in North America (Hartman, 2009; Johnson and Summerfelt, 2015). Only one available commercial grower feed (Walleye Grower [WG-9206]) has been developed for Walleye larvae and juveniles, and knowledge about their nutrient requirements is still very scarce. Walleyes have been farmed and

juveniles have been used in stocking programs for almost 100 years (Webster, 1978). The culture of Walleye juveniles by using pelleted feeds has a much shorter history. Walleyes were first cultured with pelleted feeds in the 1970s using Abernathy Salmon diet and trout granules in private hatcheries and universities in the USA (McCauley, 1970; Beyerle, 1975). The earliest open-formula diet (W series; W7, 14, 15, 16) were developed by the U.S. Fish and Wildlife Service in the 1970s (Beyerle, 1975). The W-16 diet has been used as starter, conversion, and grower diet (Summerfelt and Clayton, 2007, Kuipers and Summerfelt 1994). To date, the grower diet, WG-9206, developed in the early 1990s (Barrows and Lellis, 1996), is the only commercially manufactured diet for walleyes (Nelson & Sons, Inc., Murray, Utah) and has been used continuously to the present at Iowa Department of Natural Resources hatcheries in the USA (Summerfelt and Clay, 2007). Most W-series are available for importation in Canada. However, the cost of importation and the sometimes uncertain availability of pelleted feeds for exportation (i.e. WG 9206) make it hard for farmers in Quebec, Canada, to secure a stable access of Walleye grower feeds. For instance, in 2001, bovine spongiform was found in beef cattle in Japan, and U.S. importation of the BioKyowa FFK formulation (which had been used as habituation diet for Walleyes for 12 years) has halted indefinitely. The same happened with Otohime C2 pellets (used as habituation food for Walleyes) in 2016, where Canadian importation was stopped for an unknown reason. At Most farms in Quebec, Walleye juveniles and broodstock are given frozen fish, and sometimes pelleted diet formulations for salmons are used to feed juvenile Walleyes (Mejri et al. 2014; *Pêche sportive du Réservoir Baskatong*, Grand Remous , Quebec; personal communication). Thus, development of a pelleted diet is necessary for Walleye production in Canada to increase. Ideally, such a diet should not only be more sustainable, but should also allow faster and more efficient weight gain than the diets currently in use. We tested the potential use of an undesirable species (the White Sucker) as fish meal for the culture of an economically important

fish species (the Walleye). The objective of this study was to test whether White Sucker can be used as a main ingredient in feed for Walleye juveniles, thus making use of the removed fish and creating a more sustainable approach. We tested the hypothesis that an artificial diet based on White Suckers can support or improve juvenile Walleye development compared to the commercial diet developed for salmonids that is currently used in some Canadian farms. This approach would make it possible not only to valorize an undesirable species that competes with species of high economic importance but also to produce an affordable and nutrient-dense feed.

## Materials and Methods

### Fish culture

All experimental procedures were evaluated and approved by the Ethical-Scientific Committee for Animal Experimentation of the Université du Québec à Rimouski (Certificate number CPA-65-16-176).

The 6-week experiment was carried out at the PSRB aquaculture facility, Grand Remous, Quebec. Eggs were collected from wild broodstock in the P*hilomène* River, Grand Remous, and then were incubated and hatched at PRSB facilities. Larvae started feeding at 3-4 d post hatch (dph) on Otohime B-1, B-2, C-1, and C-3 (premium Japanese fish nutrition, Japan; pellets used here were imported by PSRB in 2015, with some left to be used in 2016; Canadian importation of Otohime was halted in 2016]). The fish were then switched to EWOS Micro (0.5, 0.7 mm, complete fish feed for salmonids; EWOS Canada Ltd) for 3 weeks. Juveniles used in this experiment were 27

153 dph when the feeding trial started; and initial average weight was 0.03 ± 0.01 g (mean ± SD) and
154 initial average length was15.7 ± 1.5 mm.

155 At the start of the trial, approximately 200 fish/ tank were randomly distributed into six
156 900-L circular tanks to obtain three replicate tanks for each dietary treatment. Tanks were provided
157 with natural freshwater from an external pond and connected to a recirculation system, where water
158 was drum filtered, sand filtered, and vacuum degassed before use. The water within each tank was
159 completely exchanged every 2 h, 16 min. The water renewal of the total system was 7.2% daily.
160 Water temperature (range = 21–24 °C) and dissolved oxygen (≥ 7 mg/L) were monitored daily in
161 each tank throughout the experiment. The photoperiod applied was constant (16 h light: 8 h dark),
162 and the light intensity at the surface of the rearing tanks was 630 lx (artificial blue light). Fish were
163 fed daily using an automatic belt feeder that supplied a constant feed ration over two 8-h periods
164 (i.e., from about 0700 to 1500 hours and from 1500 to 2300 hours). Fish were fed to satiation, as
165 indicated by the presence of excess feed in tanks after the two feeding cycles. Tanks were cleaned
166 daily, and dead fish were removed and weighed each day.

167

168 **Experimental feeds**

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170 After the 3-week acclimation period, two dietary treatments were tested: an experimental
171 (EXP) diet and a commercial (COM) diet. The EXP diet was formulated to meet or exceed all
172 known nutrient requirements for Walleye juveniles (Summerfelt and Johnson, 2015) and was
173 prepared at the Département des Sciences Animales at Université Laval, Quebec, Canada,
174 following the recipe of Bharadwaj et al. (2002) for Walleye juveniles (Walleye grower pellet) but
175 substituting the fish meal (menhaden) with White Sucker fish meal. To make the fish meal, filets
176 were removed from White Suckers (20-22 adults weighing 0.894 ± 0.086 kg) captured in the

177 Philomène River during late April 2016. The heads, skin, and viscera were discarded. Briefly,
178 fillets were washed, autoclaved for 1.5 h at 120 °C, dried for 48 h at 65 °C, and ground to make
179 the fish meal. Ingredients for the EXP pellets (size = 1.0–1.2 mm) are listed in Table 1. The dry
180 ingredients were mixed and steam pelleted; the pellets were then dried in a forced-air oven (30 °C,
181 24 h), sieved, coated with mackerel oil, and stored at -20 °C until used. The ingredients of the COM
182 pellets (EWOS micro, 1.0–1.2 mm) are listed in Table 1. Both pellets were slightly pulverized
183 during the first days of feeding to ensure that small individuals had access to the feed.
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185 **Sampling and data collection procedures**
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187 At the beginning and at the end of the experiment, all fish from each tank were individually
188 weighed and their TLs were recorded. From each tank (6 tanks total; 3 tanks/treatment), five
189 replicate samples of five juveniles were frozen in liquid nitrogen and stored at -80 °C for further
190 biochemical analysis.
191 The following indices were calculated:
192
193 • Weight gain, $WG = \text{final weight (g)} - \text{inital weight (g)}$
194 • Feed conversion ratio, $\text{FCR} = \frac{\text{Weight of feed consumed (g)}}{\text{Weight gain (g)}}$
195 • Specific growth rate, $\text{SGR} = 100 \times \frac{\ln \text{final body weight (g)} - \ln \text{initial body weight (g)}}{\text{rearing time (days)}}$
196 • Survival (%), $\text{S} = 100 \times \frac{\text{Starting N individuals}}{\text{Final N individuals}}$
197 • Condition factor, $\text{K} = \frac{\text{Mass}}{\text{Length}^3} \times 100$
198

To obtain an indicator of nutitional quality of the two diets, we used the ratio of the polar fraction of fatty acids (phospholipids constituting cell membranes) in juveniles to the polar fraction of fatty acids present in the diets. This ratio indicates the juveniles' selective incorporation or elimination of a given dietary fatty acid in polar lipids in the cell membranes.

**Chemical analysis**

Walleye body water content was determined by drying the samples to a constant weight for 24 h at 70 °C. Proximate analyses were performed in accordance with standard methods (AOAC International 2012; ash [Mthod 942.05], crude protein [Method 990.03], fat [Method 954.02], and moisture [Method 930.15] by New Jersey Feed Laboratory (Trenton, New Jersey).

Lipids were extracted using the Folch method (Folch et al., 1957). Lipids were separated into neutral and polar lipid fractions using silica gel (30 × 5 mm internal diameter, packed with Kieselgel 60, 70–230 mesh; Merck, Darmstadt, Germany) hydrated with 6% water and were eluted with 10 mL of chloroform : methanol (98:2 volume/volume) for neutral lipids followed by 20 mL of methanol for polar lipids (Marty et al., 1992). The neutral lipid fraction was further eluted on an activated silica gel with 3 mL of hexane and diethyl ether to eliminate free sterols. All fatty acid methyl esters (FAMEs) were prepared as described by Lepage and Roy (1984) and analyzed in MSMS scan mode (ionic range = 60–650 m/z) on a Polaris Q ion trap coupled to a Trace GC (Thermo Finnigan, Mississauga, Otario) equipped with a Valcobond VB-5 capillary column (Valco Instruments Co. Inc., Broakville, Ontario). The FAMEs were identified by comparison of retention times with known standards (37-Component FAME Mix, PUFA-3, BAME, and menhaden oil; Supelco Bellefonte, Pennsylvania) and quantified with tricosanoic acid (23:0; i.e. 23 carbon atoms

and zero double bonds) and nonadecanoic acid (19:0) as internal standards. Chromatograms were analyzed using the Xcalibur version 1.3 (Thermo Scientific, Mississauga, Ontario).

For amino acid (AA) analysis, samples of either whole body tissues of juveniles or pellets were diluted with 2 mL distilled water and hydrolyzed with equal parts of 12-N HCl plus 0.1% phenol at 110 ℃ for 24 h. After HCl removal by evaporation under vacuum, determination of o-phtalaldehyde derivatives of AAs were made by high-performance liquid chromatography separation, as detailed in Kaushik et al. (1994).

Total energy (cal/g) was analyzed using a bomb calorimeter (Parr 6200; Preiser Scientific, Inc., St. Albans, West Virginia), employing benzoic acid as a standard with a known weight and energy content.

**Statistical analysis**

Weight, weight gain, length, FCR, SGR, survival, condition factor, and moisture and ash content were tested with one-way analysis of variance (ANOVA) followed by Hsu's a posteriori multiple comparisons tests after assumptions of homoscedasticity and normality had been verified by Levene and Shapiro-Wilk tests, respectively. These analyses were performed with the JMP Pr 12 package (SAS Institute Inc., Cary, NC). Permutational multivariate analysis of variance (PERMANOVA with 9999 permutations), including a posteriori pair-wise comparisons, was performed on fatty acid and amino acid profiles in experimental and commercial pellets. Fatty acids from neutral and polar lipid fractions and AA profiles in walleye juveniles were tested with one-factor PERMANOVA (dietary treatment, EXP and COM). Assumptions of homoscedasticity were verified with a PERMDISP test and data were transformed (arcsine square root) when necessary. To analyze the similarity between the profiles, non-metric multi-dimensional scaling (n-MDS) and

SIMPER analyses were performed using a Bray-Curtis similarity matrix with PRIMER 6 (v. 6.1.12) and PERMANOVA+ (v. 1.0.2) (Anderson, 2001).

# Results

## Diets

The dry weight percentage from White sucker filets was 20.8 ± 0.5%. (mean ± SD). Proximate composition of ECP and COM pellets is presented in Table 1.

## Growth and fish quality parameters

At the end of the 6-week feeding period, no significant difference was observed between the two dietary treatments for Walleye TL, *S*, moisture content, or and ash content (Table 2). Survival percentages decreased significantly 4 weeks after the start of the experiment (Fig. 1). No significant difference was seen for FCR or SGR values. However, K, final weight, and WG were significantly higher in fish fed that were fed the EXP diet (hereafter "EXP fish"). Similarly, the neutral lipid content (energetic lipids) of EXP fish (mean ± SD = 5 ± 0.5 g/kg) was also found to be higher than that of fish receiving the COM diet (hereafter, "COM" fish"; 3.3 ± 0.5 g/ kg), while the polar lipid content (lipids in cell tissues) was similar between fish from the two treatments. Total protein content was not different between the two dietary treatments (EX fish; mean ± SD = 115 ± 10 g/kg; COM fish: 107 ± 11 g/kg).

## Nutrient composition of the diet

Percentages of different fatty acids in the EXP and COM diets are presented in Table 3. The AA percentages of COM and EXP pellets are presented in Table 4. Threonine (THR) was the most prominent of the essential AAs (EAAS; Table 3). Serine (SER), glycine (GLY), proline, and taurine quantitatively dominated the nonessential AAs (NEAAs; Table 4).

## Nutrient composition of juveniles

Neutral lipids

At the start of the experiment (day 0), the fatty acid composition of the neutral lipids was similar in all Walleye juveniles ($p = 0.69$). However, this composition varied according to diet at the end of the experiment (pseudo-$F_{\text{diet}\,[1,\,4]} = 16.34$, $P = 0.005$; Table 5). The fatty acid profiles of COM fish did not resemble those of the EXP fish, with both profiles resembling those of the diets. Oleic acid (18:1[n-9], where the number to the left of the colon is the number of carbon atoms, the number to the right of the hyphen is the position of the first double bound from the methyl end), docosahexaenoic acid (DHA; 22:6[n-3]), and total polyunsaturated fatty acids (PUFAs) were highest in COM juveniles. However, 20:1(n-9), 22:1(n-9), 20:4(n-6), and total monounsaturated fatty acids (MUFAs) were significantly higher in EXP fish than in COM fish.

Polar lipids

293 The same tendency was observed in the polar lipid fraction as in the neutral lipid fraction:
294 there was no difference in fatty acid composition between juveniles at the start of the experiment
295 ($P$ = 0.56), whereas the fatty acid composition in juveniles at the end of the experiment varied
296 according to the diet they were fed (pseudo-$F_{diet\,[1,\,4]}$ = 17.71, $P$ = 0.003; Table 5). For polar lipids,
297 20:1(n-9), 22:1(n-9), MUFA, and 20:4(n-6) were significantly higher in EXP juveniles, while DHA
298 was higher in COM juveniles.
299
300 Nutritional ratio
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302 For COM juveniles, the observed juvenile : diet ratio was above 1.5 for ARA and DHA
303 (Fig. 2). indicating selective incorporation or these fatty acids. For EXP fish, the was around 2 for
304 oleic acid, indicating potential selective retention of this fatty acid by Walleye juveniles and
305 suggesting its importance for cell membranes integrity under the rearing conditions. Results for
306 18:2(n-6) and 18:3(n-3) showed no difference between diets, with the ratio less than 0.5 for both
307 diets, indicating elimination of this fatty acid in the cell membrane.
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309 Amino acids
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311 Both at the start and at the end of the experiment, the AA composition of juvenile tissues
312 did not vary with diet (start: $P$ = 0.329; end: $P$ = 0.196). Threonine, an EAA, represented more than
313 18% of the total AAs. Serine and GLY (NEAAs) constituted over 31 and 8% of total AAs,
314 respectively (Table 6).
315

## Discussion

Because of the continuous expansion and development of aquaculture worldwide, it is urgent that sustainable alternatives for pelagic fish meal be investigated, developed, and introduced for use in feed formulations. The use of an undesirable and/or invasive fish species as feed for the culture of the economically important Walleye is a very interesting sustainable approach. The White Sucker is a regionally feasible alternative to traditional fish meal sources. The results from this study indicate that the White Sucker, which is considered an undesirable species in Quebec lakes, has the potential to be used as such. Pellets incorporating White sucker as the fish meal were readily accepted by Walleye juveniles, who showed better WG, higher K, and significantly higher energy lipid accumulation compared to those that received the COM diet. Our results suggest that the EXP pellet generally was nutritionally balanced but could have been improved with additional oleic acid. In contrast, the COM diet showed some potential imbalanced proportions of DHA and ARA, and COM juveniles had lower WG than EXP fish..

### Growth

Growth was better in the EXP diet, indicating that White Sucker fish meal was readily accepted by Walleye juveniles. Bharadwaj et al. (2002) indicated that salmon and trout grower diets could be used satisfactorily for Walleye juveniles pending more information on their nutritional needs. In our study, final weight, WG, and K were higher in juveniles that were fed the EXP diet compared to those receiving the COM diet formulated for salmonids diet. The SGR was not different between the two dietary treatments, ranging between 8.6% and 8.9% per day, and was

339 similar to observations reported for other percid juveniles (Hilge and Steffens, 1996; Kestemont
340 and Mélard, 2000; Mandiki et al., 2004; Nyina-Wamwiza et al., 2005; Schulz et al., 2006; Schulz
341 et al., 2007; Lepič et al., 2017). However, in contrast to our results, previous investigations on
342 percid fish have shown relatively low SGRs. Indeed, SGR values ranged from 2.1% to 3.5% per
343 day for Zander *Sander lucioperca* juveniles that either were given commercial diets formulated for
344 Rainbow trout or were fed natural diets (Zakes and Demska-Zakes, 1996; Schulz et al., 2006). High
345 FCR may be related to the territorial behavior of dominant individuals, therefore a high daily
346 feeding ratio (25% of total biomass per 24 h) was chosen to ensure adequate feed intake for all fish.
347 However, this resulted in excessive amounts of uneaten feed and probably led to the overestimation
348 of FCR values. A negative impact on FCR by possible aggressive feeding behavior of dominant
349 individuals has also been described for other percid fish, such as the Eurasian Perch *Perca*
350 *fluviatilis* (Schulz et al., 2007). Survival rates of Walleye juveniles in this study were less than
351 50%. Such high mortality was most likely caused by the small initial size of the juveniles (15.7
352 mm; 0.03 g). In agreement with our results, Summerfelt and Johnson (2015) observed low survival
353 rates (ranging from 26 to 69.7%) in Walleye juveniles. Malison and Held (1996) also reported that
354 35- 46 mm (0.3-0.5 g) fish had a survival rate of 33.9%.
355
356 **Fatty acid and nutritional ratio**
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358 The body fatty acid profiles reflected those of the diets (Tables 3,). Although the
359 percentages of ARA were relatively low in both treatments, tissue levels were influenced by levels
360 supplied in the diet. A higher proportion of ARA in the EXP diet was reflected in a higher
361 percentage of ARA in the polar and neutral lipids of the whole fish. Furthermore, we observed the
362 selective incorporation of ARA in COM juveniles, suggesting that this fatty acid is essential for

363 juvenile Walleye growth. In comparison, the EXP diet showed no selective incorporation of ARA,
364 indicating that this diet meets the physiological ARA needs of juvenile Walleyes. Several studies
365 have indicated the importance of ARA in fish metabolism, and it is known to be the main fatty acid
366 precursor of eicosanoids in fish (Bell et al., 1983; Henderson and Tocher, 1987; Bell and Dick,
367 1990; Bell et al., 1994). In addition, research has been conducted on dietary ARA in several fish
368 species, and these studies have confirmed that elevated ARA can improve growth and survival
369 (Bessonart et al., 1999; Bae et al., 2010) as well as resistance to handling stress (Koven et al.,
370 2001). In addition to the selective incorporation of ARA in COM Walleye juveniles, we also
371 observed a higher selective incorporation of DHA in COM fish compared to EXP fish. These
372 results suggest that ARA and DHA levels may be imbalanced in the COM diet. In comparison,
373 juveniles receiving the EXP diet showed a weak selective incorporation of DHA and EPA but a
374 marked selective retention of oleic acid. Thus the use of White Sucker fish meal in the EXP diet
375 seems so support the physiological essential fatty acid needs, but oleic acid could be increased as
376 a potential energy source for Walleyes. Previous studies have demonstrated that oleic acid is a good
377 energy substrate for Totoaba *Totoaba macdonaldi* juveniles (Zapata et al. 2016) and Walleye larvae
378 (Mejri et al. 2014). Thus, the EXP diet, as prepared in our study, should be adjusted to contain
379 higher proportion of oleic acid.
380
381 Most PUFAs were found in the polar lipids. The preferential conservation of PUFAs in the
382 polar portion indicated a strong metabolic response of Walleye juveniles. Polyunsaturated fatty
383 acids are the major constituents of structural lipids and are therefore important in maintaining the
384 structural integrity of biological membranes. Previous studies have shown that when PUFAs are
385 insufficient or limited, they are removed from the neutral lipids and conserved in the polar lipids
386 (D'Abramo and Sheen, 1993; Mejri et al., 2014).

Our results clearly demonstrate that feeding juvenile Walleyes the EXP pellets resulted in significantly higher energy lipid (neutral lipid) accumulation, better *K*, and modified fatty acid composition in the juveniles. The higher energy reserves of EXP juveniles indicates that these fish have a higher nutritional condition compared to those fed the COM diet.

**Amino acids**

The AA composition, especially EAA, is another excellent indicator of how the nutritional needs are satisfied. Amino acids have essential roles in fish growth and diet costs (Wilson and Poe, 1985; Conceição et al., 2003). High percentages of THR, SER, and GLY in the EXP and COM pellets were reflected in juvenile AA profiles. Studies conducted on early stages of Walleye have determined the importance of methionine (MET) and SER during embryogenesis, suggesting the need for minimal levels of 0.1% MET and 6% SER in the total AAs (Mejri et al., 2014; Mejri et al., 2017). Compared to the other AAs, SER levels were the highest in Walleye juveniles from both treatments, suggesting its potential role as an energy source. The MET levels were over 2% of total AAs, which should meet the nutritional requirement for Walleyes (Mejri et al., 2017). After lysine and MET, THR is generally one of the most limiting EAAs in feed ingredients (Saldana et al., 1994; Yu et al., 2015). In our study, THR was the most prominent EAA (> 18% of total AAs), showing no significant difference between the COM and EXP groups. Threonine deficiency resulted in retarded growth and poor feed efficiency values in Red Drum *Sciaenops ocellatus* juveniles (Boren and Gatlin, 1995), Olive Flounder, *Paralichthys olivaceus* (Alam et al., 2003), and Rainbow Trout (Rodehutscord et al., 1997). Feng et al. (2013) showed that THR enhanced growth and increased the digestive and absorptive capacities in Jian Carp (a variant of the Common Carp *Cyprinus carpio*.

## Conclusions

This study has demonstrated the beneficial effects of using White Sucker as the main fish meal in feed pellets. Reducing feed costs by the substitution of marine fish meal (expensive ingredient) with more cost-effective White Sucker meal can also assist the growth of the aquaculture industry, mainly on a regional scale. The EXP feed resulted in improved growth of Walleye juveniles, and its use may contribute to reducing costs related to the elimination of this undesirable fish species, thus contributing to environment protection. Additional work should be done to optimize the fatty acid composition of pellets made using White Sucker fish meal by supplementing with oleic acid.

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## References


Alam, M.S., S. Teshima, S. Koshio, S. Yokoyama, M. Ishikawa. 2003. Optimum dietary threonine level for juvenile Japanese founder, *Paralichthys olivaceus*. Asian fisheries science 16: 175-184.

Anderson, M.J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology 26: 32-46.

AOAC (Association of Official Analytical Chemists) International. 2012. Official methods of analysis of AOAC International, 19th edition. AOAC Internation, Gaithersburg, Maryland.

Atalah, E., M. Hernadez-Cruz, E. Ganuza, T. Benítez-Santana, R. Ganga, J. Roo, D. Montero, and M. Izquierdo. 2010. Importance of detary arachidonic acid for the growth, survival and stress resistance of larval European Sea Bass (*Dicentrarchus labrax*) fed high dietary docosahexaenoic and eicosapentaenoic acids. Aquaculture Research 42: 1261-1268.

Bae, J.Y., D.J. Kim, K.Y. Yoo, S.G. Kim, J.Y. Lee, S. Bai. 2010. Effects of dietary arachidonic acid (20:4n-6) levels on growth performance and fatty acid composition of juvenile Eel, *Anguilla japonica*. Asian-Australasian Journal of Animal Sciences 23(4): 508-514.

Barrows, F.T., and W.A. Lellis. 1996. Diet and nutrition. In: Summerfelt, R.C. (Ed.) Walleye culture manual. NCRAC culture series 101. North Central Regional Aquaculture Center Publications Office, Iowa State University, Ames, pp.315-321.

Barton, B.A. 2011. Biology, management, and culture of walleye and sauger. Bethesda, Maryland, American Fisheries Society

455 Beamish, R.J. 1973. Determination of age and growth of populations of the white sucker
456 (*Catostomus commersoni*) exhibiting a wide range in size at maturity. Journal of the
457 Fisheries Research Board of Canada 30(5): 607-616.
458 Bell, J.G., F. Strachan, W.J. Roy, C. Matthew, P. McDonald, F.T. Barrows, M. Sprague. 2016.
459 Evaluation of barley protein concentrate and fish protein concentrate, made from
460 trimmings, as sustainable ingredients in Atlantic salmon (*Salmo salar* L.) feeds.
461 Aquaculture Nutrition 22(2): 326-334.
462 Bell, J.G., D.R. Tocher, J.R. Sargent, J.R. Sargent. 1994. Effect of supplementation with 20:3(n-
463 6), 20:4(n-6) and 20:5(n-3) on the production of prostaglandins E and F of the 1-, 2- and 3-
464 series in turbot (*Scophthalmus maximus*) brain astroglial cells in primary culture.
465 Biochimica et Biophysica Acta - Lipids and Lipid Metabolism 1211: 335-342.
466 Bell, M.V., J.R. Dick. 1990. Molecular species composition of phosphatidylinositol from the brain,
467 retina, liver and muscle of cod (*Gadus morhua*). Lipids 25(11): 691-694.
468 Bell, M.V., C.M.F. Simpson, J.R. Sargent. 1983. (n−3) and (n−6) polyunsaturated fatty acids in the
469 phosphoglycerides of salt-secreting epithelia from two marine fish species. Lipids 18(10):
470 720-726.
471 Bessonart, M., M.S. Izquierdo, M. Salhi, C.M. Hernández-Cruz, M.M. González, H. Fernández-
472 Palacios. 1999. Effect of dietary arachidonic acid levels on growth and survival of gilthead
473 sea bream (*Sparus aurata* L.) larvae. Aquaculture 179(1): 265-275.
474 Beyerle, G.B. 1975. Summary of attempts to raise walleye fry and fingerlings on artificial diets,
475 with suggestions on needed research and procedures to be used in future tests. North
476 American Journal of Aquaculture 37(2): 103-105.

Bharadwaj, A.S., N.L. Gould, P.B. Brown, M.R. White, A. Moore. 2002. Evaluation of experimental and practical diets for walleye *Stizostedion vitreum*. Journal of the World Aquaculture Society 33(3): 244-253.

Boren, R.S., D.M. Gatlin. 1995. Dietary threonine requirement of juvenile red drum *Sciaenops ocellatus*. Journal of the World Aquaculture Society 26(3): 279-283.

Bowzer, J.C., J.T. Trushenski, and D.C. Glover. 2013. Potential of Asian carp from the Illinois River as a source of raw materials for fish meal production. North American Journal of Aquaculture 75:404–415.

Bowzer, J.C., and J.T. Trushenski. 2015. Growth performance of hybrid striped bass, rainbow trout, and cobia utilizing Asian carp meal-based aquafeeds. North American Journal of Aquaculture 77:59–67.

Conceição, L.E.C., H. Grasdalen, I. Rønnestad. 2003. Amino acid requirements of fish larvae and post-larvae: new tools and recent findings. Aquaculture 227(1): 221-232.

D'Abramo, L.R., S.S. Sheen. 1993. Polyunsaturated fatty acid nutrition in juvenile freshwater prawn *Macrobrachium rosenbergii*. Aquaculture 115(1): 63-86.

Duchesne, J.-F. 1994. Facteurs déterminants de la structure des populations et des paramètres du cycle vital. Quebec, Canada, Université du Québec à Trois-Rivières, pp. 101.

FAO, 2016. The state of world fisheries and aquacultur. Food and Agricultural Organisation of the United Nations (FAO). Rome, Italy, pp. 200.

Feng, L., Y. Peng, P. Wu, K. Hu, W.D. Jiang, Y. Liu, J. Jiang, S.H. Li, X.Q. Zhou. 2013. Threonine affects intestinal function, protein synthesis and gene expression of TOR in Jian carp (*Cyprinus carpio* var. Jian). PLoS ONE 8: e69974.

Folch, J., M. Lees, G.H. Sloane Stanley. 1957. A simple method for the isolation and purification of total lipides from animal tissues. Biological Chemistry 226(1): 497-509.

501 Hartman, G.F. 2009. A biological synopsis of walleye (*Sander vitreus*). Canadian Manuscript
502 Report of Fisheries and Aquatic Sciences 2888: 48.
503 Hilge, V., W. Steffens. 1996. Aquaculture of fry and fingerling of pike-perch (*Stizostedion*
504 *lucioperca* L.)-. A short review. Journal of Applied Ichthyology 12(3): 167-170.
505 Kaushik, S.J., J. Breque, D. Blanc. 1994. Apparent amino acid availability and plasma free amino
506 acid levels in Siberian sturgeon (*Acipenser baeri*). Comparative Biochemistry and
507 Physiology. Part A: Physiology 107(2): 433-438.
508 Kestemont, P., C. Mélard. 2000. Chapter 11 Aquaculture. In: Craig, J.F. (Ed.) Percid fishes
509 systematics, ecology and exploitation. Blackwell Science, Oxford, UK, pp. 191-224.
510 Koven, W., Y. Barr, S. Lutzky, I. Ben-Atia, R. Weiss, M. Harel, P. Behrens, A. Tandler, 2001. The
511 effect of dietary arachidonic acid (20:4n−6) on growth, survival and resistance to handling
512 stress in gilthead seabream (*Sparus aurata*) larvae. Aquaculture 193(1): 107-122.
513 Kuipers, K. L., and R.C. Summerfelt. 1994. Converting pond-reared Walleyle fingerlings to
514 formulated diets: effects of diet, temperature, and stocking density. Journal of Applied
515 Aquaculture 4: 31-57.
516 Lepage, G., C. Roy. 1984. Improved recovery of fatty acid through direct transesterification
517 without prior extraction or purification. Journal of Lipid Research 25: 1391-1396.
518 Lepič, P., M. Buřič, J. Hajíček, P. Kozák, 2017. Adaptation to pelleted feed in pikeperch
519 fingerlings: learning from the trainer fish over gradual adaptation from natural food.
520 Aquatic Living Resources 30: 1-6.
521 Magnan, P., P. East, M. Lapointe. 1990. Modes de contrôle des poissons indésirables: revue et
522 analyse critique de la littérature. Université du Québec à Trois-Rivières pour le ministère
523 du Loisir, de la Chasse et de la Pêche du Québec et la fondation de la faune du Québec.
524 Rapport Technique, pp. 198.

525 Malison, J.A., Held, J.A. 1996. Habituating pond-reared fingerlings to formulated feed. In:
526 Summerfelt, R.C. (Ed.) Walleye culture manual. NCRAC culture series 101. North Central
527 Regional Aquaculture Center Publications Office, Iowa State University, Ames, pp. 199-
528 204.
529 Mandiki, S.N.M., G. Blanchard, C. Mélard, J. Koskela, D. Kucharczyk, P. Fontaine, P. Kestemont.
530 2004. Effects of geographic origin on growth and food intake in Eurasian perch (*Perca*
531 *fluviatilis* L.) juveniles under intensive culture conditions. Aquaculture 229(1): 117-128.
532 Marty, Y., F. Delaunay, J. Moal, J.F. Samain. 1992. Changes in the fatty acid composition of *Pecten*
533 *maximus* (L.) during larval development. Journal of Experimental Marine Biology and
534 Ecology 163(2): 221-234.
535 McCauley, R.W. 1970. Automatic food pellet dispenser for walleyes. North American Journal of
536 Aquaculture 32(1): 42-42.
537 Mejri, S., C. Audet, G.W. Vandenberg, C.C. Parrish, R. Tremblay. 2014. Biochemical egg quality
538 in a captive walleye (*Sander vitreus*) broodstock population relative to ovulation timing
539 following hormonal treatment. Aquaculture 431: 99-106.
540 Mejri, S., R. Tremblay, G. Vandenberg, M. Moren, I.B. Khemis, C. Audet. 2017. Differences in
541 nutrient content of eggs and larvae as indicators for improvement of broodstock nutrition
542 in walleye (*Sander vitreus*) production. Canadian Journal of Zoology 95(5): 299-310.
543 Nickum, J.G. 1978. Intensive culture of walleyes; The state of the art. Washington, D.C. American
544 Fisheries Society.
545 Nyina-Wamwiza, L., X.L. Xu, G. Blanchard, P. Kestemont. 2005. Effect of dietary protein, lipid
546 and carbohydrate ratio on growth, feed efficiency and body composition of pikeperch
547 *Sander lucioperca* fingerlings. Aquaculture Research 36(5): 486-492.

548 Rodehutscord, M., A. Becker, M. Pack, M. Pack, E. Pfeffer. 1997. Response of rainbow trout
549 (*Oncorhynchus mykiss*) to supplements of individual essential amino acids in a semipurified
550 diet, including an estimate of the maintenance requirement for essential amino acids.
551 Journal of Nutrition 127(6): 1166-1175.
552 Saldana, C.I., K. Da, K.Q. Owen, K.G. Burgoon, E.J. Gregg. 1994. Digestible threonine
553 requirements of starter and finisher pigs. Journal of Animal Science 72(1): 144-150.
554 Schulz, C., M. Bohm, M. Wirth, B. Rennert, 2007. Effect of dietary protein on growth, feed
555 conversion, body composition and survival of pike perch fingerlings (*Sander lucioperca*).
556 Aquaculture Nutrition 13(5): 373-380.
557 Schulz, C., S. Günther, M. Wirth, B. Rennert. 2006. Growth performance and body composition
558 of pike perch (*Sander lucioperca*) fed varying formulated and natural diets. Aquaculture
559 International 14(6): 577-586.
560 St-Laurent, M.-H. 2002. Impacts de cinq à sept ans de biomanipulation du meunier noir
561 (*Catostomus commersoni*) sur les communautés piscicoles de cinq lacs du Québec,
562 Université du Québec à Trois-Rivières, pp. 70.
563 Summerfelt, R.C., R.D. Clayton. 2007. Evaluation of open-formula walleye grower diets for
564 juvenile walleyes. North American Journal of Aquaculture 69:53–58.
565 Summerfelt, R.C., J.A. Johnson. 2015. Intensive culture of walleye from egg to juvenile. In:
566 Kestemont, P., Dabrowski, K.et al (Eds.), Biology and culture of percid fishes. Netherlands,
567 Springer Netherlands, pp. XVIII, 901.
568 Summerfelt, S.T., R.C. Summerfelt. 1996. Aquaculture of walleye as a food fish. In: Summerfelt,
569 R.C. (Ed.) Walleye culture manual. Ames, North Central Regional Aquaculture Center
570 Publications Office, Iowa State University, pp. 215-230.

571 Tacon, A.G. J., and M. Metian. 2008. Global overview on the use of fish meal and fish oil in
572 industrially compounded aquafeeds: trends and prospects. Aquaculture 285:146–158.
573 Trippel, E.A., H.H. Harvey. 1987. Abundance, growth, and food supply of white suckers
574 (*Catostomus commersoni*) in relation to lake morphometry and pH. Canadian Journal of
575 Zoology 65(3): 558-564.
576 WBG (World Bank Group). 2013. Fish to 2030: prospects for fisheries and aquaculture. World
577 Bank, Report N-83177-GLB, Washington, D.C.
578 Webster, J. 1978. Historical perspectives of propagation and management of coolwater fishes in
579 the United States. Washington, D.C., American Fisheries Society.
580 Wilson, R.P., W.E. Poe. 1985. Relationship of whole body and egg essential amino acid patterns
581 to amino acid requirement patterns in channel catfish, *Ictalurus punctatus*. Comparative
582 Biochemistry and Physiology- Part B: Biochemistry & Molecular Biology 80(2): 385-388.
583 Yu, H., Q. Zhang, H. Cao, T. Tong, G. Huang, W. Li. 2015. Replacement of fish meal by meat and
584 bone meal in diets for juvenile snakehead *Ophiocephalus argus*. Fisheries Science 81(4):
585 723-729.
586 Yuan, Y. S. Li, K. Mai, W. Zu, Y. Zhang, and Q. Ai. 2015. The effect of dietary arachidonic acid
587 (ARA) on growth performance, fatty acid composition and expression of ARA metabolism-
588 related genes in laral Half-Smooth Tongue Sole (*Cynoglossus semilaevis*). British Journal
589 of Nutrition 113: 1518-1530.
590 Zakes, Z., K. Demska-Zakes. 1996. Effect of diets on growth and reproductive development of
591 juvenile pikeperch, *Stizostedion lucioperca* (L.), reared under intensive culture conditions.
592 Aquaculture Research 27(11): 841-845.

Zapata, D.B., J.P. Lazo, S.Z. Herzka, M.T. Viana. 2016. The effect of substituting fishmeal with poultry by-product meal in diets for *Totoaba macdonaldi* juveniles. Aquaculture Research 47(6): 1778-1789.

## Figure captions

**Fig. 1** Survival of walleye juveniles fed an experimental diet based on the use of white sucker (*Catostomus commersoni*) as fish meal or a commercial diet (EWOS micro; Ewos Canada Ltd) during a six weeks feeding trial.

**Fig.** 2 Ratio of polar fatty acids in walleye (*Sander vitreus*) juveniles to dietary fatty acids. Measurements were made six weeks after juveniles were fed an experimental diet based on the use of white sucker (*Catostomus commersoni*) as fish meal or a commercial diet (EWOS micro; Ewos Canada Ltd). The dashed line indicates equal amounts of fatty acids in the juveniles and in the diet. PUFA: polyunsaturated fatty acid.

Table 1. Composition (%) of experimental (EXP; size = 1.0–1.2 mm) and commercial (COM; EWOS Micro, 1.0–1.2 mm) diets fed to juvenile Walleyes.

| Ingredient or component | EXP diet | COM diet |
|---|---|---|
| White Sucker fish meal | 49.5 | - |
| Fish meal (mix of anchovies, menhaden, pollock, white fish, and herring trimmings from US and Canadian Pacific Coast fisheries) | - | 58.8 |
| Blood meal | 4.8 | 6.7 |
| Soybean meal* | 12 | |
| Corn gluten meal* | 8.3 | |
| Wheat flour* | 12.1 | 11.6 |
| Wheat gluten | - | 2.5 |
| Fish oil | 11.8 | 10 |
| Vitamin mix* | 0.8 | - |
| Ascorbic acid | 0.2 | - |
| Choline chloride | 0.5 | - |
| Yeast-amino acid premixes-vitamin and mineral premix | - | 10.4 |

[a]soybean meal in the EXP diet was obtained from Jefo, St-Hyacinthe, Quebec.

[b]Corn gluten meal in the EXP diet was obtained from Meunerie Gérard Soucy, Inc., Ste-Croix, Québec.

[c]Wheat flour in the EXP diet was obtained from la Seigneurie des Aulnaies, Inc., Saint-Roch-des-Aulnaies, Québec.

[d]Vitamin mix in the EXP diet was obtained from Corey Feed Mills Ltd., Fredericton, New-Brunswick (Vitamin Mix 30): vitamin A, 650; vitamin D3, 1,000; vitamin E, 50 %, vitamin K, MSBC50%, 16.5; vitamin B12, 10%; biotin, 2%, folic acid 20%, niacin 50%; vitamin B6, pyridoxine hydrochloride, 99%; vitamin B2, 96%, BHT-KI, 76%; $FeSO_4$ $7H_2O$ (20% Fe); $MnSO_4$ 7 $H_2O$ (36% Mn); $ZnSO_4$ 7 $H_20$ (40% Zn); $CuSO_4$ $5H_2O$ (25% Cu); $Na_2SeO_3$ (45.6% Se); $CoSO_4$ (21% Co) and starch or cellulose.

Table 2. Growth and condition indices (mean ± nSD) of Walleye juveniles fed a commercial (COM) diet (EWOS Micro; EWOS Canada Ltd.) or an experimental (EXP) diet (containing White Sucker as fish meal) over a six-week study period. Within a given row, means with different letters are significantly different (ANOVA: $P < 0.05$)

| **Growth and condition indices** | **EXP diet** | **COM diet** | **One-way ANOVA (*P*-value)** |
|---|---|---|---|
| Initial weight (g) | 0.03 ± 0.008 | 0.03 ± 0.009 | 0.787 |
| Final weight (g) | 1.12 ± 0.36 $^{z}$ | 0.87 ± 0.35 $^{y}$ | < 0.0001 |
| Weight gain (g) | 1.09 ± 0.06 $^{z}$ | 0.86 ± 0.15 $^{y}$ | 0.042 |
| Final Tl (mm) | 50.92 ± 5.99 | 49.81 ± 6.72 | 0.082 |
| Feed conversion ratio | 2.85 ± 1.12 | 2.21 ± 1.06 | 0.145 |
| Specific growth rate | 8.87 ± 0.16 | 8.58 ± 0.43 | 0.413 |
| Survival (%) | 43.11 ± 10.96 | 46.23 ± 9.34 | 0.727 |
| Condition factor | 0.83 $^{z}$ | 0.67 $^{y}$ | < 0.0001 |
| Moisture (g/kg) | 208.61 ± 2.73 | 203.38 ± 1.75 | 0.150 |
| Ash (g/kg$^{1}$) | 20.27 ± 1.65 | 24.97 ± 2.21 | 0.138 |
| Neutral fatty acids (g/kg) | 5.01 ± 0.45 $^{z}$ | 3.30 ± 0.53 $^{y}$ | 0.013 |
| Polar fatty acids (g/kg) | 2.02 ± 0.47 | 1.27 ± 0.43 | 0.116 |
| Proteins (g/kg) | 115.23 ± 9.99 | 107.17 ± 10.53 | 0.227 |

Table 3. Fatty acid composition (percent of total fatty acids; mean ± SD) of the experimental (EXP) diet (containing White Sucker as fish meal) and the commercial (COM) diet (EWOS Micro; EWOS Canada Ltd) fed to juvenile Walleyes.

| Fatty acid | EXP diet | COM diet |
|---|---|---|
| 14:0 | 2.14 ± 0.40 | 3.84 ± 0.38 |
| 16:0 | 16.82 ± 1.79 | 22.55 ± 1.15 |
| 18:0 | 3.97 ± 0.67 | 5.70 ± 0.90 |
| ∑ SFAα | 25.39 ± 4.46 | 34.56 ± 6.02 |
| 16:1 | 4.80 ± 0.57 | 3.98 ± 0.43 |
| 18:1 n-9 | 8.44 ± 0.29$^{y}$ | 15.64 ± 0.85$^{z}$ |
| 20:1 n-9 | 8.82 ± 2.04$^{z}$ | 4.76 ± 1.58$^{y}$ |
| 22:1 n-9 | 14.62 ± 3.68$^{z}$ | 4.52 ± 1.29$^{y}$ |
| 24:1 n-9 | 0.49 ± 0.09 | 1.02 ± 0.13 |
| ∑ MUFAβ | 37.48 ± 5.48 | 30.43 ± 5.20 |
| 18:2 n-6 | 10.01 ± 0.72 | 7.53 ± 0.31 |
| 18:3 n-3 | 1.64 ± 0.12 | 1.36 ± 0.08 |
| 18:4 n-3 | 0.44 ± 0.03 | 1.53 ± 0.18 |
| 20:4 n-6 | 4.94 ± 0.67$^{z}$ | 1.11 ± 0.32$^{y}$ |
| 20:5 n-3 | 5.98 ± 0.21 | 9.11 ± 0.72 |
| 22:6 n-3 | 13.21 ± 2.10 | 13.65 ± 1.21 |
| ∑ PUFAδ | 37.13 ± 4.61 | 35.01 ± 4.12 |
| ∑ n-3 | 21.33 ± 2.71 | 25.68 ± 4.12 |
| ∑ n-6 | 15.48 ± 4.65 | 9.13 ± 3.52 |

[α]Sum of saturated fatty acids (SFA) includes 11:0, 12:0, 13:0, 15:0, 17:0, 20:0, 21:0, 22:0, 23:0, 24:0, for which the combined percentages are ≤ 0.5% of total fatty acids

[β]Sum of monounsaturated fatty acids (MUFA) includes 14:1 and 17:1, for which the combined percentages are ≤ 0.5% of total fatty acids

[δ]Sum of polyunsaturated fatty acids (PUFA) includes 20:2, 18:3(n-6), 20:3(n-6), 20:3(n-3), for which the combined percentages are ≤ 0.5% of total fatty acids.

Table 4. Amino acid composition (percent of total amino acids; mean ± SD) in the experimental (EXP) diet containing White Sucker as fish meal) and the commercial (COM) diet (EWOS Micro; EWOS Canada Ltd) fed to juvenile Walleyes. Amino acids constituting less than 1% are not listed

| **Amino acid** | **EXP diet** | **COM diet** |
|---|---|---|
| | *Essential amino acids* | |
| Threonine, THR | 15.04 ± 2.05 | 15.54 ± 1.94 |
| Methionine, MET | 3.30 ± 0.19 | 2.79 ± 0.35 |
| All-Leucine type, AILE | 3.49 ± 0.60 | 5.29 ± 0.43 |
| Phenylalanine, PHE | 4.11 ± 0.20 | 3.30 ± 0.26 |
| | *Non-essential amino acids* | |
| Taurine, TAU | 6.41 ± 4.32 | 9.64 ± 7.00 |
| Serine, SER | 21.80 ± 7.84 | 21.04 ± 12.49 |
| Tyrosine, TYR | 4.34 ± 0.27 | 2.01 ± 0.89 |
| Alanine, ALA | 8.59 ± 3.41 | 8.68 ± 5.00 |
| Sarcosine, SAR | 3.64 ± 4.28 | 3.20 ± 3.31 |
| Glycine, GLY | 15.46 ± 4.89 | 14.24 ± 2.41 |
| Hydroxyproline, HYP | 1.04 ± 0.52 | 1.02 ± 0.29 |
| Proline, PRO | 7.71 ± 1.12 | 7.80 ± 1.36 |
| Trymethylglycine, TMG | 3.89 ± 0.36 | 4.52 ± 1.40 |

Table 5. Fatty acid composition of neutral and polar lipids in Walleye juveniles (percent weight of weight of total neutral and polar lipids; mean ± SD) after 6 weeks of feeding with either the experimental (EXP) diet (containing White Sucker as fish meal) or the commercial (COM) diet (EWOS Micro; EWOS Canada Ltd). Different letters indicate significant differences between treatments (ANOVA: $P < 0.05$), with polar and neutral fatty acids being tested separately.

| **Fatty acid** | **Neutral fraction** | | **Polar fraction** | |
|---|---|---|---|---|
| | **EXP diet** | **COM diet** | **EXP diet** | **COM diet** |
| 14:0 | 4.11 ± 0.13 | 4.04 ± 0.96 | 1.92 ± 0.09 | 1.66 ± 0.31 |
| 16:0 | 14.86 ± 2.23 | 15.02 ± 0.65 | 23.08 ± 0.22 | 25.45 ± 0.73 |
| 18:0 | 2.15 ± 0.36 | 3.13 ± 0.79 | 5.66 ± 0.63$^{y}$ | 7.96 ± 0.60$^{z}$ |
| ∑ SFAα | 22.65 ± 3.98 | 24.14 ± 4.02 | 32.92 ± 6.15 | 38.32 ± 6.85 |
| 16:1 | 10.61 ± 0.42 | 7.73 ± 0.53 | 4.78 ± 0.34$^{z}$ | 2.76 ± 0.25$^{y}$ |
| 18:1 n-9 | 16.76 ± 0.92$^{y}$ | 24.19 ± 2.19$^{z}$ | 16.52 ± 1.13 | 14.97 ± 0.33 |
| 20:1 n-9 | 12.62 ± 0.29$^{z}$ | 5.62 ± 2.06$^{y}$ | 6.27 ± 0.35$^{z}$ | 2.19 ± 0.50$^{y}$ |
| 22:1 n-9 | 16.05 ± 0.60$^{z}$ | 4.19 ± 1.65$^{y}$ | 3.91 ± 0.26$^{z}$ | 1.14 ± 0.22$^{y}$ |
| 24:1 n-9 | 0.63 ± 0.05 | 0.94 ± 0.14 | 0.79 ± 0.10 | 0.97 ± 0.20 |
| ∑ MUFAβ | 56.84 ± 7.62$^{z}$ | 43.23 ± 8.11$^{y}$ | 33.01 ± 5.54$^{z}$ | 23.15 ± 4.96$^{y}$ |
| 18:2 n-6 | 5.97 ± 1.98 | 7.34 ± 1.40 | 3.06 ± 0.29 | 2.79 ± 0.39 |
| 18:3 n-3 | 1.04 ± 0.11 | 1.50 ± 0.18 | 0.53 ± 0.04 | 0.69 ± 0.08 |
| 18:4 n-3 | 0.69 ± 0.06 | 1.42 ± 0.14 | 0.37 ± 0.04 | 0.59 ± 0.05 |
| 20:4 n-6 | 1.33 ± 0.12$^{z}$ | 0.73 ± 0.24$^{y}$ | 3.64 ± 0.24$^{z}$ | 1.76 ± 0.22$^{y}$ |
| 20:5 n-3 | 5.17 ± 0.39 | 7.12 ± 1.66 | 7.39 ± 0.37 | 8.80 ± 0.89 |
| 22:6 n-3 | 5.57 ± 0.87$^{y}$ | 13.39 ± 1.53$^{z}$ | 18.09 ± 1.00$^{y}$ | 22.78 ± 1.28$^{z}$ |
| ∑ PUFAδ | 20.50 ± 2.42$^{y}$ | 32.62 ± 4.39$^{z}$ | 34.06 ± 5.48 | 38.53 ± 6.88 |
| ∑ n-3 | 12.47 ± 2.34$^{y}$ | 23.48 ± 3.14$^{z}$ | 26.40 ± 3.55 | 32.87 ± 4.20 |
| ∑ n-6 | 7.82 ± 2.73 | 8.82 ± 3.43 | 7.40 ± 1.75$^{z}$ | 5.26 ± 1.20$^{y}$ |

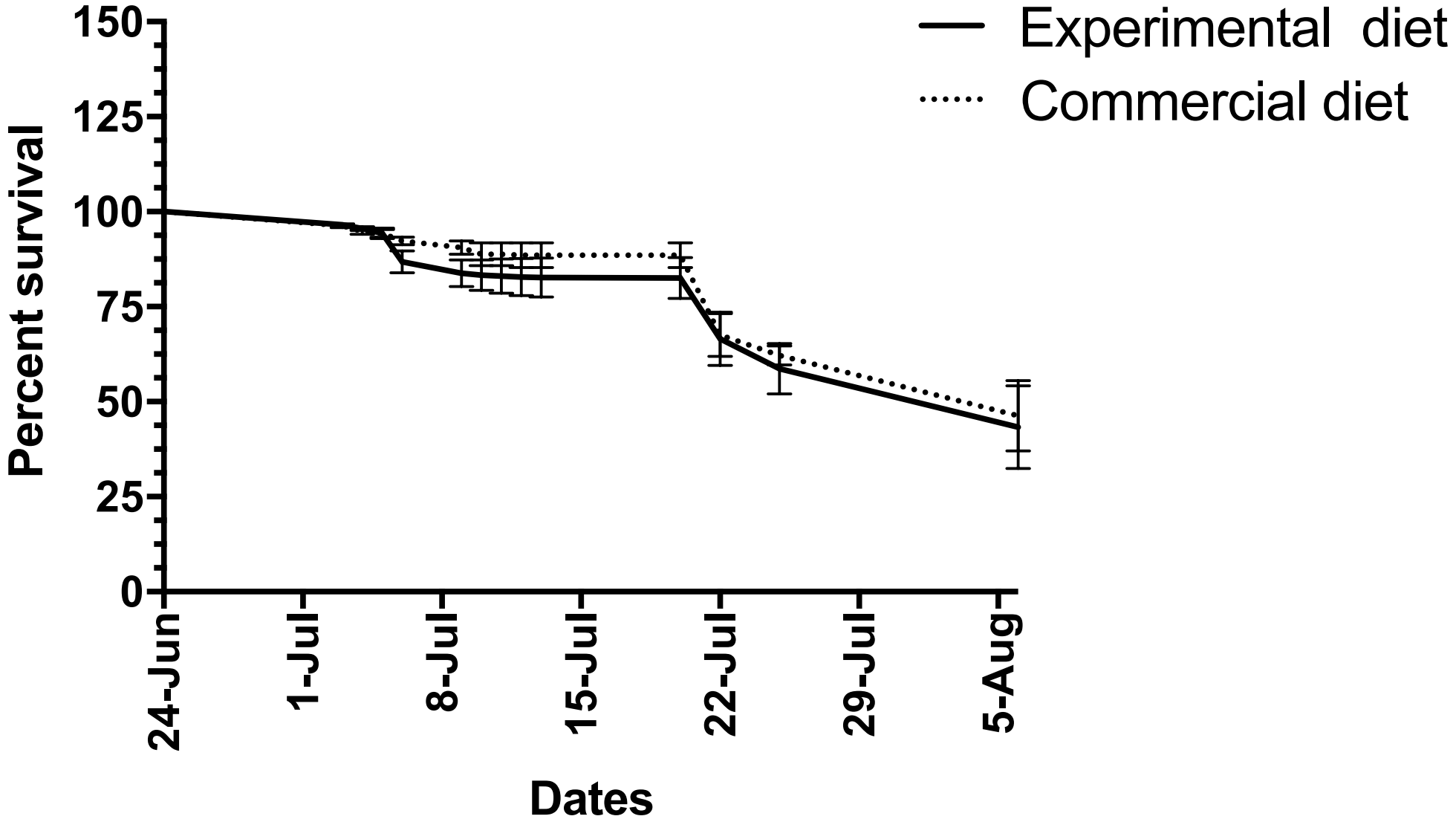
$^{\alpha}$Sum of saturated fatty acids (SFA) includes 11:0, 12:0, 13:0, 15:0, 17:0, 20:0, 22:0, 24:0, for which the combined percentages are ≤ 0.5% of total fatty acids.

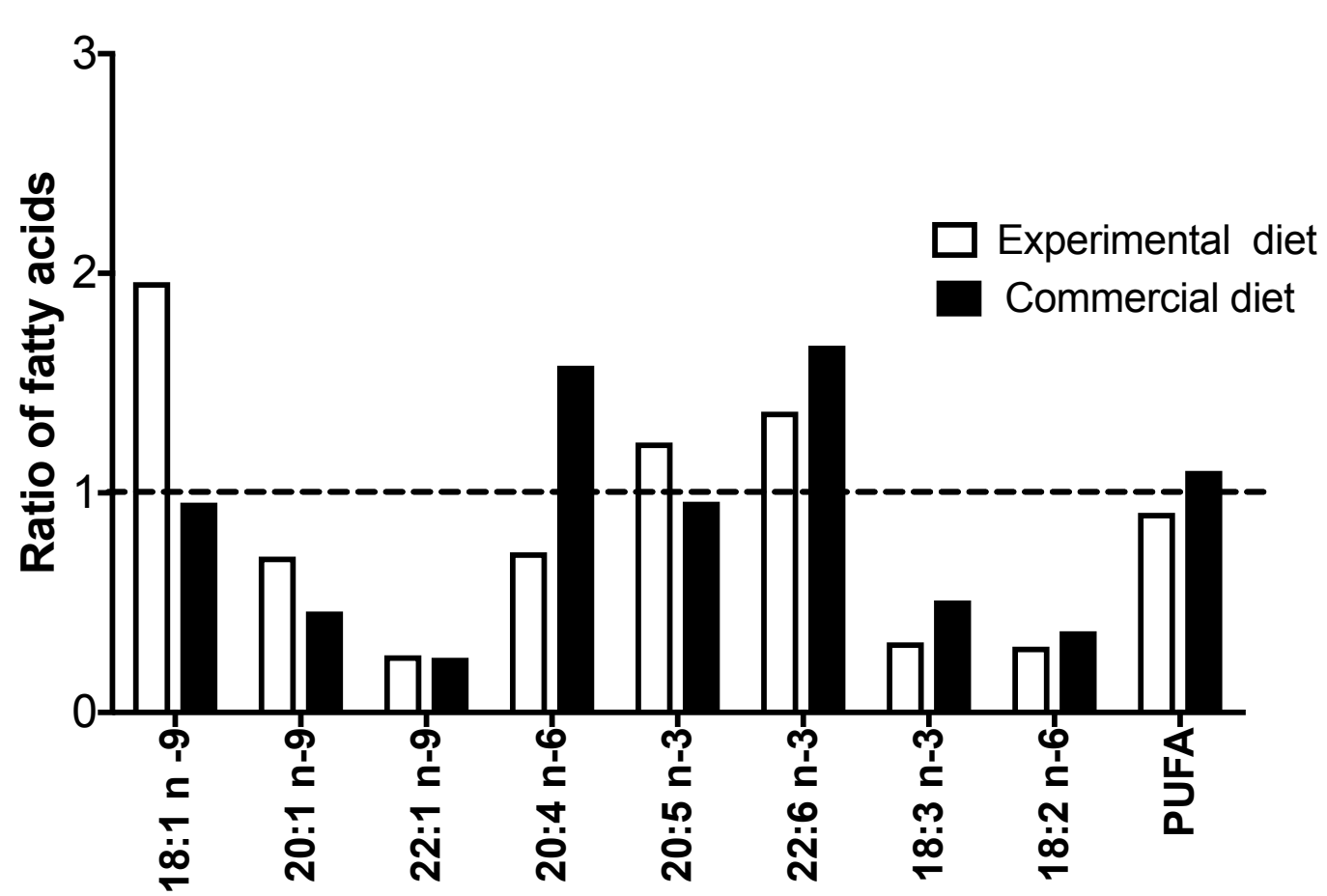
$^{\beta}$Sum of monounsaturated fatty acids (MUFA) includes 14:1 and 17:1, for which the combined percentages are ≤ 0.5% of total fatty acids.

$^{\delta}$Sum of polyunsaturated fatty acids (PUFA) includes 20:2, 18:3(n-6), and 20:3(n-6), for which the combined percentages are ≤ 0.5% of total fatty acids

Table 6. Amino acid composition (percent of total amino acids; mean ± SD) of Walleye juveniles at the end of the 6-week experiment during which they were fed the experimental (EXP) diet (containing White Sucker as fish meal) or the commercial (COM) diet (EWOS Micro; EWOS Canada Ltd). Amino acids constituting less than 1% are not listed. Amino acid codes are defined in Table 4.

| Amino acid | EXP diet | COM diet |
|---|---|---|
| | *Essential amino acids* | |
| THR | 18.97 ± 2.49 | 19.76 ± 2.52 |
| MET | 2.41 ± 0.60 | 3.18 ± 0.21 |
| AILE | 7.17 ± 1.12 | 5.55 ± 0.94 |
| PHE | 7.14 ± 0.82 | 4.18 ± 0.28 |
| | *Non-essential amino acids* | |
| TAU | 4.82 ± 3.39 | 11.07 ± 3.81 |
| SER | 34.08 ± 9.82 | 31.94 ± 4.46 |
| TYR | 4.25 ± 0.85 | 2.18 ± 2.09 |
| ALA | 1.95 ± 0.25 | 3.04 ± 0.23 |
| SAR | 2.11 ± 0.27 | 3.28 ± 0.25 |
| GLY | 9.30 ± 4.48 | 8.55 ± 2.03 |
| PRO | 4.35 ± 2.96 | 3.21 ± 1.16 |
| TMG | 2.02 ± 0.26 | 2.57 ± 0.36 |


Experimental diet
Commercial diet
Percent survival
150
125
100
75
50
25
0
24-Jun
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
Dates


Ratio of fatty acids
3
2
1
0
Experimental diet
Commercial diet
18:1 n -9
20:1 n-9
22:1 n-9
20:4 n-6
20:5 n-3
22:6 n-3
18:3 n-3
18:2 n-6
PUFA