Diet Development and Evaluation for Selected Coolwater Fishes

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Illinois Department of Conservation
Division of Fisheries
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EXECUTIVE SUMMARY

We evaluated commercial and prepared diet suitability for three fishes: muskellunge (*Esox masquinongy*) tiger muskellunge (*E. masquinongy x E. lucius*) and largemouth bass (*Micropterus salmoides*). A variety of commercial feeds are used for raising these fishes but no data are available that compare growth and survival on these diets. Further, aquaculturists many times intensively culture a species before knowing which nutrient requirements are incorporated into a diet or knowing which commercially available diet maximizes growth and survival for the species. Nutritional requirements of many coolwater fish are poorly understood and optimum dietary protein levels necessary to sustain acceptable growth and survival are largely unknown. As protein is a major component and expense of prepared feeds, knowing optimum dietary protein levels of selected fish species would help minimize the cost of producing fish. Not only is protein level important in fish diets, but interaction between protein and energy levels has been shown for many species including walleye (*Stizostedion vitreum*; Barrows et al. 1988), hybrid tilapia (*Oreochromis niloticus x O. aureus*; Shiau and Huang 1990), rabbitfish (*Siganus guttatus*; Parazo 1990) and red drum (*Sciaenops ocellatus*; Daniels and Robinson 1986).

We first compared growth and survival of muskellunge, tiger muskellunge and largemouth bass fed different commercially
available diets. With information gathered from the commercial diet comparison in the second phase of this study we developed prepared diets with different protein levels to determine the optimum dietary protein level for each of the test species. Lastly, we examined the optimum protein and energy ratio for tiger muskellunge, largemouth bass and muskellunge.

Growth and survival was evaluated over an eight week period for both muskellunge (initial mean length = 6.8 in) and tiger muskellunge (initial mean length = 7.4 in) fed four commercially available feeds (Biodry 1000; Biodiet Grower; Abernathy S8-2 (84); W-16). Across all diets, tiger muskellunge grew over 1.5 times as fast as muskellunge. Muskellunge and tiger muskellunge both grew faster on three diets developed for coldwater species (Biodiet, Biodry and Abernathy), than on one developed for coolwater species (W-16). Muskellunge also grew faster when fed Biodiet or Biodry than when fed Abernathy. Differences in growth may be related to dietary protein levels. Body composition was affected by diet; percent fat was highest for both fishes fed Biodry, and protein levels were higher for tiger muskellunge fed Biodiet or Abernathy. Survival was high and not affected by diet type for either fish. Based on growth rates, body composition and feed cost, we recommend Biodiet or Biodry for rearing muskellunge and Biodry or Abernathy for tiger muskellunge.

We evaluated growth rate, survival and body composition over a 56 day period for largemouth bass (initial length = 3.9 in) fed six commercial diets (Abernathy S8-2 (84); Biodiet Grower; Biodry
Largemouth bass fed W-16 and Biodiet Grower had faster growth rates than those fed Black Magic Bass food, Biodry 1000 and Biosponge Bass Grower. Largemouth bass whole body protein, lipid moisture and ash was affected by commercial diet. Lipid levels were higher for fish fed Biodiet Grower than for fish fed all other diets. Based on this evaluation, we recommend either W-16 or Biodiet Grower for rearing largemouth bass.

Growth rate, survival, and body composition for muskellunge and tiger muskellunge fed semi-purified diets differing in protein level were evaluated over an 8 week period. Diets ranged in protein from 31-40% for muskellunge (initial mean total length = 4.9 in) and 34-45% for tiger muskellunge (initial mean total length = 4.5 in). For both taxa, weight gain increased linearly with dietary protein. The optimal dietary protein level for muskellunge was 37%, whereas tiger muskellunge fed the 45% protein diet had greater growth than fish fed all other diets. Condition factors for both taxa increased with dietary protein. Survival of muskellunge (73%) and tiger muskellunge (97%) was not affected by diet type. Fat, protein and moisture, but not ash content, was affected by the diet fed. For both taxa, body protein increased and fat content decreased when fed diets higher in dietary protein. Our results suggest both taxa respond to dietary changes in similar ways. However, differences between muskellunge and tiger muskellunge optimal protein level suggests nutritional requirements vary and should be considered when
developing practical feeds.

We evaluated growth rate, survival and body composition over a 51 day period for largemouth bass (initial length = 4.3 in) fed four diets ranging in protein concentration from 31-40%. Growth varied with protein level. Largemouth bass fed the two diets highest in protein had faster growth than fish fed the two lowest protein diets. Weight gains were greatest for largemouth bass fed the 37% protein diet. Largemouth bass lipid and moisture, but not protein and ash, was affected by diet type. Lipid content decreased and moisture content increased as dietary protein increased.

We fed tiger muskellunge (initial mean total length = 7.3 in), muskellunge (initial mean total length = 3.6 in) and largemouth bass (initial mean total length = 3.4 in) six diets with different protein/energy levels and monitored fish growth and survival for eight weeks. Diets included two protein levels (40% and 48%) and three energy levels (3,000, 3,375 and 3,750 Kcal DE/kg). Tiger muskellunge and largemouth bass grew on all diets. We found no effect of the protein/energy levels tested on the growth of tiger muskellunge and largemouth bass. Though not statistically significant, largemouth bass tended to grow slower when fed the lowest energy level feed across both protein levels.

Muskellunge trials were shorter because of poor feeding and excessive cannibalism. After four weeks muskellunge growth was unaffected by the dietary protein/energy levels tested. Mortality was high (averaged 31% per tank after four weeks) and
may have affected results. Survival of all taxa was independent of dietary protein/energy levels.

We found no effect of the dietary protein/energy levels tested on the growth and survival of tiger muskellunge, largemouth bass and muskellunge. Trials longer than eight weeks may be required to produce growth differences given the protein/energy levels tested. Alternatively a broader range protein/energy ratios may be required to affect growth and survival of muskellunge, tiger muskellunge, and largemouth bass. We recommend further nutritional research be conducted to aid in the formulation of diets which optimizes growth, survival and body composition of these species.
Job 1. Acquire fish trained to accept pelleted diets from Illinois Department of Conservation's hatchery system for use in experimental trials.

OBJECTIVE: To acquire fish trained to accept pelleted diets from Illinois Department of Conservation's hatchery system as they become available and transport them to the Sam Parr Biological Station.

PROCEDURES:

A. Commercial Diet Comparison

In 1990, 405 tiger muskellunge (mean weight of 0.3 oz and mean length of 7.4 in), 480 largemouth bass (mean weight of 0.5 oz, mean length of 4.0 in) and 240 muskellunge (mean weight of 0.6 oz and mean length of 6.8 in) were transported from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Conservation, to Sam Parr Biological Station. All fish were trained to accept pelleted diets.

B. Optimum Dietary Protein Evaluation

In 1991 and 1992, 925 tiger muskellunge (mean weight of 0.2 oz and mean length of 4.0 in), 500 muskellunge (mean weight 0.6 oz and mean length of 6.2 in) and 430 largemouth bass (mean weight of 0.4 oz and mean length of 3.9 in) trained to accept pellet feed were transported to Sam Parr Biological Station from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Conservation.
C. Effect of Dietary Protein/Energy Ratios

Tiger muskellunge are from the same batch of fish as those used in the optimum protein evaluation study (see B above). In 1992, 600 muskellunge and 600 largemouth bass were transported from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Conservation. The muskellunge had a mean weight of 0.1 oz and a mean length of 3.6 in and the largemouth bass had a mean weight of 0.3 oz and mean length of 3.4 in. Again, these fish were trained to accepted pelleted feed.
Job 2. Compare commercial diets for use in rearing largemouth bass, muskellunge, and tiger muskellunge.

OBJECTIVE: The objectives of the commercial diet study were (1) to evaluate commercial diets based on growth rate and survival for each species, (2) conduct a cost/benefit analysis for each diet and species, and (3) make diet recommendations to hatcheries based on fastest growth rate, highest survival and lowest feed cost.

PROCEDURES AND FINDINGS:
Procedures and findings for this job are found in Appendix A, "Comparison of growth, survival, and body composition of muskellunge and tiger muskellunge fed four commercial diets" by Brecka, B.J., M.L. Hooe, and D.H. Wahl, a manuscript which is in press with The Progressive Fish Culturist and in Appendix C, "Effects of growth, survival, and body composition of largemouth bass fed six commercial diets and four diets varying in protein concentration" by Brecka, B.J., M.L. Hooe, and D.H. Wahl, a manuscript to be submitted to The Progressive Fish Culturist.
Formulate more efficient and less expensive diets containing the appropriate levels of protein and micronutrients for selected coolwater fishes.

OBJECTIVE: To formulate more efficient and less expensive diets containing the appropriate levels of protein and micronutrients for selected coolwater fishes.

PROCEDURES:

Test diets for the optimum protein evaluation are found in Appendix B, "Effects of dietary protein concentration on growth, survival, and body composition of muskellunge and tiger muskellunge fingerlings" a thesis by Brian Brecka submitted in partial fulfillment for a Masters degree and Appendix C, "Effects of growth, survival, and body composition of largemouth bass fed six commercial diets and four diets varying in protein concentration" by Brecka, B.J., M.L. Hooe, and D.H. Wahl, a manuscript to be submitted to The Progressive Fish Culturist.

In addition to procedures described in these appendices, we also evaluated the effects of different protein and energy levels on growth and survival of tiger muskellunge, largemouth bass and muskellunge. We formulated six diets with various protein and digestible energy levels (DE). These formulations provided three levels of dietary energy (3,000, 3,375, or 3,750 kcal DE/kg diet) and two levels of dietary protein (40 and 48%, Table 1). The diets were kept isocaloric for each energy level by replacing the
herring meal and wheat shorts with cod liver oil, dextrin and cellulose. Formulations remained isocaloric for each level of energy to ensure equal food uptake, as most animals eat to meet their energy requirements. Additional dietary components included carboxymethyl cellulose as a pellet binder, a vitamin and mineral premix, and supplemental ascorbic acid.

FINDINGS:

All formulated diets were made and successfully fed to tiger muskellunge, largemouth bass and muskellunge (see Job 4).
Job 4. Compare growth and survival of coolwater fish fed newly formulated and commercial diets.

OBJECTIVE: To feed newly developed diet formulations to selected coolwater fishes and determine resulting growth and survival.

PROCEDURES:

Procedures for evaluation of optimum protein levels are found in Appendix B, "Effects of dietary protein concentration on growth, survival, and body composition of muskellunge and tiger muskellunge fingerlings" a thesis submitted by Brian Brecka as partial fulfillment for a Masters degree and Appendix C, "Effects of growth, survival, and body composition of largemouth bass fed six commercial diets and four diets varying in protein concentration" by Brecka, B.J., M.L. Hcoe, and D.H. Wahl, a manuscript to be submitted to The Progressive Fish Culturist.

In addition, experiments evaluating optimum protein/energy levels were conducted at the Sam Parr Biological Station using methods similar to those described in Appendix B. We monitored the growth and survival of tiger muskellunge (initial mean length = 7.3 in), muskellunge (mean length = 3.6 in) and largemouth bass (mean length = 3.4 in) in response to the six prepared diets described in Job 3. We first completed trials with tiger muskellunge, followed by muskellunge and largemouth bass. Diet evaluations were conducted in a recirculating system consisting of 24 fiberglass circular tanks (36 in diameter by 36 in tall)
with common primary and secondary settling tanks, floss filter, and biofilter. Each circular tank was maintained at depth of 26 inches and had a turnover rate of approximately 12 times per day. Photoperiod was controlled to 15L:9D and average water temperature ranged from 64 to 70 F. Feces and excess feed were siphoned daily. Water temperature, dissolved oxygen, ammonia and fish mortalities were also monitored daily. Water quality parameters remained within acceptable ranges (Table 2).

One week before trials were begun, test species were stocked into tanks at a density of 14 fish per tank for tiger muskellunge, 13 fish per tank for muskellunge and 20 fish per tank for largemouth bass. Numbers varied depending upon fish availability. To ensure fish would not acclimate to a test diet, we used an equal mixture of the six feeds during acclimation. After acclimation, each diet was randomly assigned to four of the twenty four tanks. Fish in each tank were individually weighed and measured and the daily feeding rate was set at 10% of the total fish biomass. Feed was dispensed fifteen times daily from 0600 to 2000 using Sweeney model AF6 vibratory feeders. The fish in each tank were weighed and measured and the feed rations adjusted at two-week intervals.

We continued trials for tiger muskellunge and largemouth bass for eight weeks. The muskellunge trials, however, were terminated after six weeks due to poor feeding and excessive cannibalism.

Statistical analyses were similar for the protein/energy
level data for tiger muskellunge and largemouth bass, but different for muskellunge. Tank means were used as experimental units in all analyses to avoid problems associated with pseudoreplication (Hurlbert 1984). We used one-factor analysis of variance (ANOVA) to test for uniformity among initial lengths and weights of fish (ALPHA = 0.05). Repeated measures analysis of variance (RM ANOVA) was used to determine overall differences in growth among diets (ALPHA = 0.05) using the general linear model procedure (SAS 1982). We also used two-factor analysis of variance (two-way ANOVA) to detect differences in weight gain and to test for differences in tiger muskellunge survival at the end of the experiment (ALPHA = 0.05).

As muskellunge trials were terminated after six weeks and mortality was high, we did not analyze the data as described above. These data were analyzed using a one-factor analysis of variance (ANOVA) on initial mean lengths and weights, on lengths and weights after 2 weeks and again after 4 weeks to determine overall differences in growth among diets (ALPHA = 0.05).

FINDINGS:

The majority of the findings for this job are found in Appendix B, "Effects of dietary protein concentration on growth, survival, and body composition of muskellunge and tiger muskellunge fingerlings" a thesis submitted by Brian Brecka in partial fulfillment for a Masters degree and Appendix C, "Effects of growth, survival, and body composition of largemouth bass fed
six commercial diets and four diets varying in protein concentration" by Brecka, B.J., M.L. Hooe, and D.H. Wahl, a manuscript to be submitted to The Progressive Fish Culturist.

In the optimum protein/energy level study, the initial lengths and weights of tiger muskellunge were similar among tanks (ANOVA; $F = 0.56, P = 0.73; F = 0.17, P = 0.97$). Tiger muskellunge increased in length and weight on all diets during the study (Figs. 1 and 2). Throughout the experiment, length and weight of tiger muskellunge did not differ with protein content of the diet (RM ANOVA; $F = 0.18, P = 0.68; F = 0.04, P = 0.84$) or energy level (RM ANOVA; $F = 0.29; P = 0.87; F = 0.10, P = 0.90$). Protein and energy also did not interact significantly in determining the length or weight (RM ANOVA; $F = 0.14, P = 0.87; F = 0.71; P = 0.50$). There was, however, significant interaction between energy level and sampling period on both the length and weight of the fish (RM ANOVA; Wilks' lambda; $F = 3.197, P = 0.010; F = 3.589; P = 0.005$). Because mean lengths and weights of fish fed a given energy level were not consistently higher or lower than another, the interaction further indicates that there was no effect of dietary protein or energy level on tiger muskellunge growth. At the end of the evaluation, there was no effect of protein/energy ratios on the weight gain of tiger muskellunge (two-way ANOVA; $F = 1.85, P = 0.15$). In addition, tiger muskellunge mortality was not affected by protein/energy levels (two way ANOVA; $F = 0.89, P = 0.51$). Mortality ranged from 0-29% and averaged 6% for all tanks. Eighteen of the 21
mortalities were attributed to escapement from tanks.

Largemouth bass also began the experiment with statistically similar lengths and weights (ANOVA; $F = 1.45; P = 0.26; F = 1.22, P = 0.34$) and grew on all diets during the study (Figs. 3 and 4). Neither the length nor the weight of largemouth bass differed with protein content of the diet throughout the study (RM ANOVA; $F = 0.22, P = 0.64; F = 0.31, P = 0.58$). Although the effect of energy level on largemouth bass growth was not quite statistically significant (RM ANOVA; length, $F = 3.19, P = 0.07$; weight, $F = 3.16, P = 0.07$), largemouth bass fed the low energy diet (3,000 Kcal DE/kg) has slightly lower mean lengths and weights than those fed the higher energy diets across both protein levels (Figs. 3 and 4). Again, while there was no interaction between protein and energy (RM ANOVA; $F = 0.18, P = 0.83; F = 0.06, P = 0.94$), interactions between time and energy level on lengths and weights were significant ($F = 2.55, P = 0.030; F = 6.20, P = 0.004$). As for tiger muskellunge, a comparison of weight gain across protein/energy levels at the end of the study resulted in no significant difference between diets (two-way ANOVA; $F = 1.87, P = 0.15$). There was no mortality of largemouth bass during the eight week study, thus indicating survival was unaffected by the protein/energy ratios tested.

The muskellunge trials were terminated after six weeks because of poor feeding and excessive cannibalism. Mean total lengths and weights through this time are found in Tables 3 and 4. Of the 312 fish originally stocked (13/tank), only 100
remained after six weeks. Mortality ranged from 23-100% and averaged 68% for all tanks. Over 90% of the mortalities were attributable to cannibalism. The remaining 10% died from disease, emaciation and tank escapement. Because of the high mortality, the length and weight data were analyzed only through four weeks.

The initial lengths and weights of muskellunge did not differ (ANOVA; F = 1.58, P = 0.22; F = 1.27, P = 0.32, respectively). After two weeks, tank mortality ranged from 0% to 36% and averaged 8% throughout. Dietary protein and energy content had no effect on mean length or weight of muskellunge (two-way ANOVA; F = 2.25, P = 0.09; F = 1.74, P = 0.18). After four weeks, mortality ranged from 8% to 50% per tank and averaged 31% throughout. Again, protein/energy level had no effect on muskellunge length or weight (ANOVA; F = 1.10, P = 0.39; F = 1.36, P = 0.29). Mortality did not differ among diets (two-way ANOVA; F = 0.88, P = 0.52).

We found no effect of the dietary protein/energy levels tested on the growth and survival of tiger muskellunge, largemouth bass and muskellunge. Trials longer than eight weeks may be required to produce growth differences given the protein/energy levels tested. Alternatively a broader range protein/energy ratios tested may be required to affect growth and survival of muskellunge, tiger muskellunge, and largemouth bass. We recommend further nutritional research be conducted to aid in the formulation of diets which optimizes growth, survival and
body composition of these species.
Job 5. Analysis and reporting of data.

Data analyzed throughout the course of this study were presented in part at the following meetings:


Information from this project is included in several manuscripts including:

Effects of dietary protein concentration on growth, survival, and body composition of muskellunge and tiger muskellunge fingerlings. Thesis submitted by Brian Brecka as partial fulfillment for Masters degree (See Appendix B).

RECOMMENDATIONS

The choice regarding which commercial feed to use will be based on growth rates, body composition, and feed costs; survival was not affected by diet type and will not influence diet selection. For both tiger muskellunge and muskellunge, no commercial feed was superior based on all three criteria; however, we recommend Biodiet or Biodry for muskellunge and Biodry or Abernathy when rearing tiger muskellunge. For muskellunge, Biodiet and Biodry provided the fastest growth, Biodry was the least expensive, and these two diets yielded the highest percent whole body fat. For tiger muskellunge, both Biodry and Abernathy provided adequate growth and were the two least expensive of the diets evaluated. Tiger muskellunge fed Biodry had the highest percent whole body fat. Growth and body composition of largemouth bass were affected by diet type. Although W-16 and Biodiet were the most expensive diets tested, both provided faster growth than Black Magic Bass Food and Biosponge Bass Grower, while Biodiet fed largemouth bass exhibited the highest energy reserves. We therefore recommend either W-16 or Biodiet for rearing largemouth bass. Final selection of a diet may depend upon other considerations than growth, body composition and feed costs. Availability of hatchery space, feed storage costs, feed conversion rates, and post-stocking survival of the fish produced may need to be incorporated into any final comparison of cost effectiveness.

Growth and body composition of tiger muskellunge,
muskellunge, and largemouth bass were affected by dietary protein level. The optimum dietary protein level for tiger muskellunge was 45% protein, whereas muskellunge fed the 37% protein diet had greater growth than fish fed all other diets. Condition factors for both taxa increased with dietary protein. Previous dietary formulations evaluated by the U.S. Fish and Wildlife Service have treated both taxa as being nutritionally equal (Orme 1978). Our results suggest that both taxa respond to dietary changes similarly, but that their nutritional requirements are not identical. The optimum protein level tested was 37% for largemouth bass. Largemouth bass lipid and moisture content was affected by diet type, whereas protein and ash was not affected.

The growth and survival of tiger muskellunge, largemouth bass and muskellunge were unaffected by the protein/energy levels tested. Largemouth bass did show a trend toward slower growth when fed the diet with the lowest energy level (3,000 Kcal DE/kg) suggesting energy levels can be important in these species. The lack of growth differences may have been because the range of protein/energy levels tested were not great enough to produce effects. Optimum protein/energy levels for coolwater fish remain largely unknown. The results of these studies suggest the need for further nutritional research on coolwater fish species which will maximize benefits and minimize feed cost.
ACKNOWLEDGEMENTS

We thank K. Schilling, J. Fossom, and P. Hays for assistance in fish care and laboratory analyses. We are grateful to K. Cottrell and S. Stuewe of the Illinois Department of Conservation for their support and cooperation throughout this study, and to L. Willis of the Jake Wolf Memorial Fish Hatchery for rearing fish. We especially thank R. Barrows for his valuable insight throughout all phases of the study. The Statistical Consulting Service at the University of Illinois provided assistance with analyses. C. Kolar analyzed data from the optimum protein/energy level study. Dr. C. Parsons at the University of Illinois, conducted the amino acid profiles. Laboratory facilities at Southern Illinois University at Carbondale were used for proximate analyses work.
REFERENCES


Table 1. Composition of formulated diets (% by weight) fed to tiger muskellunge, muskellunge and largemouth bass adjusted to various protein and digestible energy (DE; kcal/kg diet) levels.

<table>
<thead>
<tr>
<th>Ingredient (% of diet)</th>
<th>% protein</th>
<th>Herring meal</th>
<th>Wheat shorts</th>
<th>Cod liver oil</th>
<th>Dextrin</th>
<th>Cellulose</th>
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* Each diet also contained ascorbyl palmitate (0.5%).

* Provides the following in IU or mg/kg of diet: vitamin A, 10,000 IU; vitamin D₃, 4,000 IU; vitamin E, 75 IU; vitamin K, 22; thiamine, 40; riboflavin, 30; D-calcium pantothenate, 150; niacin, 300; pyridoxine, 20; folic acid, 15; vitamin B₁₂, 0.3; inositol, 500; biotin, 1; vitamin C, 200; choline, 3,000.

* Provides the following amounts in mg/kg of diet: aluminum, 7; calcium, 8,140; chloride, 6,008; cobalt, 12; copper, 8; iron, 104; iodine, 4; magnesium, 421; manganese, 10; phosphorous, 5,250; potassium, 3,474; sodium, 1,932; selenium, 1; zinc, 40.
Table 2. Biweekly range and mean values for temperature, dissolved oxygen and ammonia recorded daily for tiger muskellunge, muskellunge and largemouth bass during protein/energy evaluation.

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<th>Temperature (F)</th>
<th>Dissolved oxygen (ppm)</th>
<th>Ammonia (NH3; ppm)</th>
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</tr>
<tr>
<td>4-6</td>
<td>66-68</td>
<td>8.6</td>
<td>7.5</td>
</tr>
<tr>
<td>6-8</td>
<td></td>
<td></td>
<td>7.2</td>
</tr>
</tbody>
</table>

Tiger Muskellunge
Muskellunge
Largemouth Bass
Table 3. Mean total lengths (inches) of muskellunge fed six formulated diets of various protein and digestible energy levels during 8 week experiments. Standard errors are in parentheses.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>3000 kcal</th>
<th>3375 kcal</th>
<th>3750 kcal</th>
<th>3000 kcal</th>
<th>3375 kcal</th>
<th>3750 kcal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40% protein</td>
<td></td>
<td>48% protein</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5.53 (0.08)</td>
<td>5.37 (0.07)</td>
<td>5.51 (0.08)</td>
<td>5.55 (0.08)</td>
<td>5.26 (0.06)</td>
<td>5.50 (0.07)</td>
</tr>
<tr>
<td>4</td>
<td>5.67 (0.09)</td>
<td>5.43 (0.08)</td>
<td>5.72 (0.08)</td>
<td>5.68 (0.09)</td>
<td>5.30 (0.06)</td>
<td>5.57 (0.07)</td>
</tr>
<tr>
<td>6</td>
<td>5.80 (0.10)</td>
<td>5.59 (0.10)</td>
<td>5.84 (0.09)</td>
<td>5.82 (0.10)</td>
<td>5.41 (0.07)</td>
<td>5.71 (0.08)</td>
</tr>
</tbody>
</table>
Table 4. Mean weights (ounces) of muskellunge fed six formulated diets of various protein and digestible energy levels during 8 week experiments. Standard errors are in parentheses.

<table>
<thead>
<tr>
<th>Weeks</th>
<th>3000 kcal/kg</th>
<th>3375 kcal/kg</th>
<th>3750 kcal/kg</th>
<th>3000 kcal/kg</th>
<th>3375 kcal/kg</th>
<th>3750 kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.32 (0.02)</td>
<td>0.29 (0.02)</td>
<td>0.32 (0.02)</td>
<td>0.33 (0.02)</td>
<td>0.27 (0.01)</td>
<td>0.31 (0.02)</td>
</tr>
<tr>
<td>4</td>
<td>0.31 (0.02)</td>
<td>0.27 (0.02)</td>
<td>0.33 (0.02)</td>
<td>0.31 (0.02)</td>
<td>0.24 (0.01)</td>
<td>0.29 (0.01)</td>
</tr>
<tr>
<td>6</td>
<td>0.31 (0.02)</td>
<td>0.27 (0.02)</td>
<td>0.33 (0.02)</td>
<td>0.33 (0.03)</td>
<td>0.24 (0.01)</td>
<td>0.29 (0.02)</td>
</tr>
</tbody>
</table>
Figure 1. Mean lengths and weights of tiger muskellunge fed a diet of 40% protein and one of three energy levels (3000, 3375, 3750 kcal DE/kg).
Figure 2. Mean lengths and weights of tiger muskellunge fed a diet of 48% protein and one of three energy levels (3000, 3375, 3750 Kcal DE/kg).
Figure 3. Mean lengths and weights of largemouth bass fed a diet of 40% protein and one of three energy levels (3000, 3375, 3750 Kcal DE/kg).
Figure 4. Mean lengths and weights of large-mouth bass fed a diet of 48% protein and one of three energy levels (3000, 3375, 3750 Kcal DE/kg).
Appendix A

Comparison of growth, survival, and body composition of muskellunge and tiger muskellunge fed four commercial diets.

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Progressive Fish-Culturist (Manuscript in press)
Abstract. - Feeds are one of the largest annual costs in fish production. A variety of commercial feeds are used for muskellunge (Esox masquinongy) and tiger muskellunge (E. masquinongy × E. lucius), but no data are available that compared growth and survival of these two fishes on these diets. Growth and survival was evaluated over an eight week period for both muskellunge (initial mean length = 172 mm) and tiger muskellunge (initial mean length = 187 mm) fed four commercially available feeds (Biodry 1000; Biodiet Grower; Abernathy S8-2 (84); W-16). Across all diets, tiger muskellunge grew over 1.5 times as fast as muskellunge. Muskellunge and tiger muskellunge both grew faster on three diets developed for coldwater species (Biodiet, Biodry and Abernathy), than on one developed for coolwater species (W-16). Muskellunge also grew faster when fed Biodiet or Biodry than when fed Abernathy. Differences in growth may be related to dietary protein levels. Body composition was affected by diet; percent fat was highest for both fishes fed Biodry, and protein levels were higher for tiger muskellunge fed Biodiet or Abernathy. Survival was high and not affected by diet type for either fish. Based on growth rates, body composition and feed cost, we recommend Biodiet or Biodry for rearing muskellunge and Biodry or Abernathy for tiger muskellunge.
Commercial intensive culture of fish depends upon the availability of diets which provide maximum growth and survival while minimizing cost. Larger body size at stocking has been shown to result in increased survival. Experiments with muskellunge (*Esox masquinongy*) (Serns and Andrews 1986; Wahl and Stein 1989) and tiger muskellunge (*muskellunge x northern pike* *E. lucius*) (Stein et al. 1981; Carline et al. 1986; Wahl and Stein 1989) fingerlings have shown increases in predatory mortality and reduced survival at smaller stocking sizes. Overwinter mortality, related to metabolism and energy reserves, has also been shown to be greater at smaller sizes for yellow perch (*Perca flavescens*) (Post and Evans 1989; Johnson and Evans 1991), white perch (*Morone americana*) (Johnson and Evans 1991), and smallmouth bass (*Micropterus dolomieu*) (Oliver et al. 1979). It is often desirable, therefore, that hatcheries produce larger fingerlings to reduce predatory mortality and with adequate energy reserves to reduce overwinter mortality. To obtain this goal, hatcheries need a diet which maximizes the size and number of fish at stocking while maintaining cost effectiveness.

Commercial diets are currently available for many species, including trout, salmon and catfish. Diets for coolwater species are limited to W-16, a diet formulated by the U.S. Fish and Wildlife Service. Hatcheries which use pelleted diets to rear coolwater fishes, including muskellunge and tiger muskellunge, use either commercial feeds made for other species or W-16. Unfortunately, since comparisons between commercially available
diets have not been conducted, information is lacking on which diets promote maximum growth and survival for esocids.

Although muskellunge and tiger muskellunge are closely related, different methods are used to rear both fishes. Within hatcheries, intensive culture of tiger muskellunge currently predominates, whereas muskellunge are most often reared extensively. Tiger muskellunge are more amenable to intensive rearing conditions as they readily accept dry food and are more disease resistant (Hesser 1978). However, intensive culture of muskellunge may become more practical as knowledge of which diets maximize growth and survival increases.

The objectives of this study were (1) to evaluate commercial diets based on growth rate, survival and body composition of muskellunge and tiger muskellunge, and (2) make diet recommendations to hatcheries based on fastest growth rates, highest survival, greatest energy reserves, and feed costs.

Methods

Feeding regime.- Diet evaluations for muskellunge and tiger muskellunge were conducted in a recirculating system consisting of 24 circular fiberglass tanks (92 cm diameter x 92 cm tall) with common settling tanks and biofilter. Each circular tank was maintained at a depth of 66 cm (430 L) and had a turnover rate of approximately 12 times per day. Photoperiod was controlled to 15L:9D. Feces and excess feed were removed daily. Water temperature (average $\pm$ 95% CI, 19 $\pm$ 0.2°C), dissolved oxygen (6.6 $\pm$ 0.3 mg/l), nitrogen (0.003 $\pm$ 0.0003 mg/l NH$_3$), and fish
mortalities were also monitored daily. Although temperatures were lower than those for optimal growth of tiger muskellunge (20-23°C) and muskellunge (22.5°C) (Meade et al. 1983; Bevelhimer et al. 1985; Lemm and Rottiers 1986), they were within the range commonly used for rearing these fish as they improve disease control.

Tiger muskellunge (initial mean total length and weight ± 95% CI, 187 ± 2 mm, 28 ± 1 g, respectively) and muskellunge (172 ± 2 mm, 21 ± 1 g, respectively) fingerlings were obtained from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Conservation, Manito. Esocids were stocked at a density of 20 fish per tank and acclimated for at least one week. During acclimation, both fishes were fed a diet other than those used in the trials (Black Magic Bass Food, Mesa Feed and Farm Supply, Grand Junction, CO) to assure they would not become accustomed to a test diet. The feeds evaluated were commonly used for esocid culture and included three salmonid diets, Biodiet Grower (Biodiet, Bioproducts Inc., Warrenton, OR), Biodry 1000 (Biodry, Bioproducts, Inc.), Abernathy S8-2 (84) (Abernathy) and one diet formulated specifically for coolwater species, W-16. Abernathy and W-16 are open-formula diets which were produced by Zeigler Brothers, Gardeners, PA. Nutrient information for the diets were obtained from each manufacturer and represent minimum guaranteed levels. Diet prices were also obtained from each feed manufacturer (1991 US $) and were lowest for Biodry ($0.90 / kg) followed by Abernathy ($0.95 / kg), W-16 ($1.21 / kg) and Biodiet
($1.41 / kg). Diets were assigned randomly to triplicate tanks for muskellunge and tiger muskellunge. Fish were each weighed (g) and measured (mm TL), and feed rates set at 10% of the total fish biomass per day. High feeding rates were chosen to assure ad libitum consumption. Feed was dispensed using automatic feeders eight times daily at two-hour intervals from 0600-2000 hours. During trials, individual fish in each tank were weighed and measured and feed rations adjusted at two-week intervals. Trials lasted 56 days for tiger muskellunge and were conducted between late-July and late-September, whereas trials for muskellunge lasted 51 days and were conducted between late-August and mid-October.

**Proximate analysis.**- Pre-treatment (N = 20) and post-treatment (N = 10 per diet) muskellunge and tiger muskellunge were chosen randomly and frozen for individual whole body proximate analysis. Fish were dried at 60°C for a minimum of seven days to determine moisture content. Crude protein was determined using the Hach (1990) modification of AOAC (1975) standard, whereas total fat was determined using AOAC (1975) Goldfisch extraction method. Ash was determined by the residue remaining after oxidation of a sample at 610°C for two hours.

**Statistical procedures.**- Repeated measures analysis of variance (RM ANOVA) was used to determine differences in growth among diets during the experiment (ALPHA = 0.05). Tank means were used as experimental units in all analyses to avoid problems associated with pseudoreplication (Hurlbert 1984). General
linear models procedure (SAS 1982) was used to detect overall differences, whereas linear polynomials were used to detect differences between diets across time (Bonferroni, \( \text{ALPHA} = 0.008 \)). One-way analysis of variance (ANOVA) was used to determine differences (\( \text{ALPHA} = 0.05 \)) in survival and body composition. These methods were also used to examine differences in weight gain at the end of the experiment; initial fish weights, although not significantly different, were used as covariates. Two-way analysis of variance (ANOVA) was used to determine differences (\( \text{ALPHA} = 0.05 \)) in specific growth rate (SGR) between muskellunge and tiger muskellunge (SGR = \([(\log_{10} \text{final wt}-\log_{10} \text{initial wt})/\text{days}] \times 100 \). The general linear models procedure (SAS 1982) was used to detect overall differences, whereas Tukey's HSD was used to detect differences between treatments.

Results

Growth and Survival.— Figures 1 and 2 show the weight of muskellunge and tiger muskellunge fed each of the diets during the study. Specific growth rate was higher for tiger muskellunge (1.92-2.25) than for muskellunge (0.96-1.61) (ANOVA; \( P < 0.05 \)).

Among diets, both fishes grew faster throughout the evaluation on Biodiet, Biodry and Abernathy than when fed W-16 (RM ANOVA; \( P < 0.005 \)). Muskellunge also grew faster when fed Biodiet and Biodry than when fed Abernathy (RM ANOVA; \( P < 0.005 \)). Similar patterns were observed for total weight gains at the end of the evaluation; muskellunge and tiger muskellunge fed Biodiet
and Biodry had greater weight gains than those fed W-16 (ANOVA; P < 0.05). Survival of both muskellunge (mean ± 95% CI; 83% ± 8%) and tiger muskellunge (94% ± 4%) was high throughout the evaluation; survival was not affected by diet type (ANOVA; P > 0.12).

**Body composition.** The four commercial diets ranged in digestible energy from 3205 to 3786 kcal/kg. Variations in energy among diets were caused by differences in protein (43-53%), fat (14.5-17%) and carbohydrates (7-14%; Table 1). Diets also varied in amount of ash, fiber and moisture (Table 1).

Body composition of muskellunge and tiger muskellunge was affected by diet (Table 2). For both fishes, percent protein and fat increased during the experiment. Among diets, protein and fat content varied for tiger muskellunge, whereas only fat content varied for muskellunge. Tiger muskellunge fed Biodiet and Abernathy had higher percent protein than fish fed Biodry, whereas fat content was higher for tiger muskellunge fed Biodry than for fish fed W-16 and Abernathy (ANOVA; P < 0.05). Fat content was higher for muskellunge fed Biodry than for those fed Abernathy and W-16. Muskellunge fed Biodiet also had a higher percent fat than when fed W-16 (ANOVA; P < 0.05).

**Discussion**

The tested feeds affected growth of muskellunge and tiger muskellunge. Both fishes obtained the fastest growth when fed Biodiet, followed by Biodry, Abernathy, and W-16. Because Biodiet and Biodry are closed formulations, ingredients can vary
depending on availability and cost, and resulting growth may also vary somewhat. However, growth was fastest on three coldwater fish feeds as compared to W-16, one formulated specifically for coolwater fish species. Similar situations have also occurred with striped bass fingerlings, with three coldwater fish feeds producing greater growth than a modified catfish diet or a fish by-products diet (Klar and Parker 1989). Results of this research suggest the need for additional nutritional research for both esocids to develop diets which will optimize growth.

Protein is one of the primary and most costly nutrients in fish feeds. Protein levels in the commercial diets evaluated ranged from 43-53%. Growth was maximized at the lowest protein level (43%) for both muskellunge and tiger muskellunge, decreasing with protein levels up to 53%. Previous studies examining optimum protein for tiger muskellunge determined levels of about 50% for fish up to 50 mm TL (Lemm and Rottiers 1986). Larger tiger muskellunge fingerlings (up to 130 mm) had optimum protein levels of about 45% (Meade and Lemm 1986). Because optimum protein levels generally decline with fish size, we would expect tiger muskellunge of the size used in our experiment (187-264 mm) to have an optimum protein level of less than 45%. Although growth varies due to many factors besides protein level, such as nutrient source, energy level and diet composition (Dupree 1976), our results suggest that the optimum protein level for larger fingerlings may be lower than 45%. Evaluations of optimum protein levels in larger fingerlings are required before
these recommendations can be made to commercial feed manufacturers.

Tiger muskellunge have faster growth rates compared to muskellunge at temperatures between 5 and 22.5°C (Bevelhimer et al. 1985). This results in faster growth for tiger muskellunge in hatcheries and after stocking in lakes and reservoirs (Bevelhimer et al. 1985; Wahl and Stein 1989). However, limited data is available comparing the two fishes in controlled studies. During our evaluation, specific growth rates of tiger muskellunge were over 1.5 times as fast as for muskellunge. Although trials were not conducted simultaneously, they were conducted within the same rearing system with similar water quality, fish size, and fish densities. Seasonal changes in physiological parameters occur in fish and can affect growth (Evans 1984). However, our experiments were conducted over a relatively narrow time period and likely reflect actual differences in growth between these two fishes.

Many factors influence post-stocking survival of hatchery fish with the majority of studies examining the effects of fish size. Studies with tiger muskellunge (Johnson 1978; Stein et al. 1981; Carline et al. 1986; Wahl and Stein 1989) and muskellunge (Johnson 1978; Serns and Andrews 1986; Wahl and Stein 1989) fingerlings has shown lower survival at smaller stocking sizes, attributing much of the difference to higher predatory mortality. Body composition, however, may also play an important role in post-stocking survival. Overwinter mortality, due to low energy
reserves and small sizes, has been documented in smallmouth bass (MacLeod 1975; Oliver et al. 1979; Shutter et al. 1980), largemouth bass (*Micropterus salmoides*) (Adams et al. 1982), brook trout (*Salvelinus fontinalis*) (Hunt 1969), and tiger muskellunge (Carline et al. 1986). Fat reserves have been suggested as important in determining overwinter mortality in tiger muskellunge (Carline et al. 1986). During our evaluation, fat content varied for muskellunge and tiger muskellunge depending on the commercial diet, being highest for fish fed Biodry. These differences in energy reserves should be considered when determining which diet to feed.

**Recommendations to culturist.**—The choice regarding which commercial feed to use will be based on growth rates, body composition, and feed costs; survival was not affected by diet type and will not influence diet selection. For both fishes, no commercial feed was superior based on all three criteria; however, we recommend Biodiet or Biodry for muskellunge and Biodry or Abernathy when rearing tiger muskellunge. For muskellunge, Biodiet and Biodry provided the fastest growth, Biodry was the least expensive, and these two diets yielded the highest percent whole body fat. For tiger muskellunge, both Biodry and Abernathy provided adequate growth and were the two least expensive of the diets evaluated. Tiger muskellunge fed Biodry had the highest percent whole body fat. Final selection of a diet may depend upon other considerations then growth, body composition and feed costs. Availability of hatchery space, feed
storage costs, feed conversion rates, and post-stocking survival of the fish produced may need to be incorporated into any final comparison of cost effectiveness.

Acknowledgments

We thank K. Schilling, Sam Parr Biological Station, for fish care. We are grateful to K. Cottrell and S. Stuewe of the Illinois Department of Conservation for their support and cooperation throughout this evaluation, and to L. Willis of the Jake Wolf Memorial Fish Hatchery for rearing fish used in this study. We especially thank R. Barrows for his valuable insight throughout all phases of the study. The Statistical Consulting Service at the University of Illinois provided assistance with analyses. This project was supported in part by funds from the Federal Aid in Sport Fish Restoration Act under Project F-1113-R.
References


Table 1.- Proximate analysis (% by weight) from data supplied by manufacturers of four commercial diets fed to muskellunge and tiger muskellunge. NFE represents nitrogen-free extract. Digestible energy calculations were based upon the average carbohydrate (NFE), lipid and protein digestibility (2.25, 8.25 and 4.2 kcal/g, respectively) of Pacific salmon and channel catfish (Piper et al. 1982).

<table>
<thead>
<tr>
<th>Feed</th>
<th>Protein</th>
<th>Fat</th>
<th>Moisture</th>
<th>Ash</th>
<th>Fiber</th>
<th>NFE</th>
<th>Digestible Energy (kcal/kg)</th>
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<tr>
<td>Abernathy S8-2(84)</td>
<td>48</td>
<td>17.0</td>
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<td>15.0</td>
<td>2</td>
<td>8.0</td>
<td>3599</td>
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<tr>
<td>Biodiet Grower</td>
<td>43</td>
<td>14.5</td>
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<td>10.5</td>
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<td>9.0</td>
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<tr>
<td>Biodry 1000</td>
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<td>12</td>
<td>9.0</td>
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<td>W-16</td>
<td>53</td>
<td>17.0</td>
<td>10</td>
<td>11.0</td>
<td>2</td>
<td>7.0</td>
<td>3786</td>
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Table 2.- Whole body composition (percent wet weight) of muskellunge and tiger muskellunge at the beginning and end of the commercial diet evaluation. Values within parentheses represent 95% confidence intervals. Values within a row with the same letter are not different (ANOVA; P > 0.05).

<table>
<thead>
<tr>
<th>Body composition</th>
<th>Initial</th>
<th>Abernathy</th>
<th>Biodiet Grower</th>
<th>Biodry 1000</th>
<th>W-16</th>
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<td><strong>Tiger muskellunge</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Protein</td>
<td>18.1(0.9)</td>
<td>20.6(1.1)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.8(1.5)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.0(1.7)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.5(1.2)&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat</td>
<td>2.5(0.3)</td>
<td>3.7(0.5)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.3(0.5)&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>4.6(0.5)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.8(0.3)&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moisture</td>
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<td>71.2(1.3)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>69.3(1.5)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72.4(1.0)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.4(0.8)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ash</td>
<td>3.2(0.1)</td>
<td>3.8(0.3)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.0(0.2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7(0.2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.2(0.3)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Muskellunge</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protein</td>
<td>17.8(0.9)</td>
<td>21.5(1.7)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>21.2(1.6)&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>20.9(0.7)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
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<td>Fat</td>
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<td>1.3(0.4)&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>1.7(0.5)&lt;sup&gt;ac&lt;/sup&gt;</td>
<td>2.1(0.4)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.9(0.3)&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>Moisture</td>
<td>77.6(0.9)</td>
<td>72.4(1.4)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.0(1.9)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.3(1.2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.7(0.7)&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ash</td>
<td>3.0(0.2)</td>
<td>3.9(0.2)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.8(0.3)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7(0.1)&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>3.5(0.2)&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>
Figure Captions

Figure 1.- Mean weights (g) at two week intervals for muskellunge fed four commercial feeds over a 51 day period. Diets compared were W-16, Abernathy S8-2 (84) (AB), Biodry 1000 (BD) and Biodiet Grower (BG). Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05).

Figure 2.- Mean weights (g) at two week intervals for tiger muskellunge fed four commercial feeds over a 56 day period. Diets compared were W-16, Abernathy S8-2 (84) (AB), Biodry 1000 (BD) and Biodiet Grower (BG). Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05).
Figure 2.

[Chart showing weight (g) over days 0, 14, 28, 42, and 56 for different groups labeled W-16, AB, BD, and BG.]
Appendix B

Effects of dietary protein concentration on growth, survival, and body composition of muskellunge and tiger muskellunge fingerlings.

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B.S. University of Wisconsin - Stevens Point, 1990

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of Master of Science

Department of Zoology in the Graduate School
Southern Illinois University at Carbondale
January 1994
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Growth rate, survival, and body composition for muskellunge *Esox masquinongy* and tiger muskellunge *E. masquinongy x E. lucius* fed semi-purified diets differing in protein level were evaluated over an 8 week period. Diets ranged in protein from 31-40% for muskellunge (initial mean total length = 125 mm) and 34-45% for tiger muskellunge (initial mean total length = 115 mm). For both taxa, weight gain increased linearly with dietary protein. The optimal dietary protein level for muskellunge was 37%, whereas tiger muskellunge fed the 45% protein diet had greater growth than fish fed all other diets. Condition factors for both taxa increased with dietary protein. Survival of muskellunge (73%) and tiger muskellunge (97%) was not affected by diet type. Fat, protein and moisture, but not ash content, was affected by the diet fed. For both taxa, body protein increased and fat content decreased when fed diets higher in dietary protein. Our results suggest both taxa respond to dietary changes in similar ways. However, differences between muskellunge and tiger muskellunge optimal protein level suggests nutritional requirements vary and should be considered when developing practical feeds.
ACKNOWLEDGMENTS

This research was conducted under the direction of Dr. Chris Kohler and Dr. David H. Wahl. Both provided great insight and guidance into the scientific method and encouraged me to set goals and develop strategies to achieve these goals. I was also given the opportunity to develop and refine skills not learned in the classroom. These abilities will be used throughout my life, and I will always be appreciative I was given this chance. Dr. Robert D. Arthur served as a committee member and provided valuable information and critical review of the thesis.

I am also grateful to the Illinois Natural History Survey for use of laboratory and field facilities at Sam Parr Biological Station. Mike Hooe provided constructive suggestions over the course of the study and facilitated staff time at Sam Parr. I was assisted in fish care and laboratory analyses by John Fossom and Pat Hayes. Rick Barrows gave many helpful suggestions during project design. I thank the Illinois Department of Conservation (IDOC) and specifically Kirby Cottrell and Scott Stuewe for their support and cooperation throughout all phases of the study. Fish were provided by Larry Willis and his staff at Jake Wolf Memorial Fish Hatchery (IDOC). Dr. Carl Parsons at the University of Illinois, Champaign-Urbana, conducted the amino acid profiles. Laboratory facilities at Southern
Illinois University at Carbondale were used for proximate analyses work. This project was supported in part by funds from the Federal Aid in Sport Fish Restoration Act under Project F-118-R.
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<td>Effects of dietary protein level on weight gain, condition factor (K, Piper et al. 1982) and survival of muskellunge and tiger muskellunge at the end of the 9-week evaluation. Values within parentheses represent 95% confidence intervals. Values within a column with the same letter are not significantly different (ANOVA; P &gt; 0.05)</td>
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Figure 1. Mean weights (g) at two week intervals for muskellunge fed four diets differing in protein level over a fifty-six day period. Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05) . 19

Figure 2. Mean weights (g) at two week intervals for tiger muskellunge fed four diets differing in protein level over a fifty-six day period. Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05) . 20
INTRODUCTION

The muskellunge *Esox masquinongy*, northern pike *E. lucius*, and their hybrid (muskellunge female × northern pike male) are stocked to provide recreational fishing or to control stunted or undesirable fishes (Graff 1978). Both taxa have different characteristics that make them preferable to either hatchery or fishery managers. Hatchery managers find tiger muskellunge much easier and more cost effective to rear compared to muskellunge; tiger muskellunge are also more adaptable to intensive rearing (Hesser 1978). Muskellunge, however, are oftentimes more desirable to sportsmen as a trophy species, and managers may prefer muskellunge because of both higher survival and angler catch rates (Casselman and Crossman 1986; Wahl and Stein 1989; Wahl and Stein 1993). Accordingly, the decision to stock either taxa varies among individual lakes and management plans.

Self-sustaining muskellunge populations are non-existent in many areas, whereas tiger muskellunge are considered sterile and rarely occur naturally in the wild (Scott and Crossman 1973). Hatcheries, therefore, perform an essential role of maintaining esocid populations. Since the late 1960s, esocid propagation has shifted away from extensive pond culture to intensive tank or raceway culture. The transition to intensive culture has occurred because esocids can be reared on prepared "dry" diets (Graff and
Sorenson 1970). Other species, such as rainbow trout *Oncorhyncus mykiss* and channel catfish *Ictalurus punctatus* have been raised on prepared feeds for many years. Nutritional requirements for these species are well-established and are incorporated into specific prepared feed (NRC 1981; NRC 1983).

Aquaculturists first attempted to use commercially available trout or catfish feeds in raising esocids and obtained poor results. Bender and Graff (1986) showed these diets to be inadequate for tiger muskellunge, which is considered the most adaptable esocid to prepared feeds. The diets have proven unsatisfactory for esocids because of poor acceptance, growth and survival. Progress has been slow in producing specific diets for esocids. In 1970, the U.S. Fish and Wildlife Service began formulating diets for coolwater species (Orme 1978). The early formulation has since been improved and a refined version, W-16, is currently available (Bender and Graff 1986). However, both muskellunge and tiger muskellunge exhibited better growth on three commercially available coldwater fish feeds when compared to W-16 (Brecka et al. 1994). These results indicate the need for additional nutritional research for individual esocid taxa in order to develop a diet that improves growth and survival.

The nutritional requirements of muskellunge and tiger muskellunge are poorly understood. Basic information, such
as optimum protein requirements, is known only for tiger muskellunge up to 130 mm TL (Lemm and Rottiers 1986; Meade and Lemm 1986), but not for larger fingerlings of either taxa. Further advances in intensive culture of esocids are limited by the paucity of nutritional data necessary to develop specific feeds. Basic nutritional requirements of both taxa must be determined if their culture is to become efficient and economical.

Optimum protein levels for other fish species generally range from 30-50%, depending on a variety of factors. Fish size, protein source, and dietary energy level can all influence the protein requirement of a particular species (Dupree 1976). The determination of optimum protein levels is important because protein is a major component and expense of prepared feeds. It would be economically advantageous to the culturist to have minimum protein while maintaining maximum growth, as fish more efficiently build and repair tissues when fed an optimum protein level (NRC 1983). The objectives of this study were to compare growth rate, survival and body composition of muskellunge and tiger muskellunge fingerlings fed semi-purified diets differing in protein level in order to provide a baseline for developing practical diets.
MATERIALS AND METHODS

Test diets were formulated to contain 31%, 34%, 37%, 40% or 45% crude protein. Of the five protein formulations, muskellunge were fed the four lowest, whereas tiger muskellunge were fed the four highest levels. A higher protein level was fed to tiger muskellunge because preliminary experiments indicated a relatively higher protein requirement. Protein sources within each diet included casein, herring meal, gelatin and wheat shorts (<7% fiber) with each providing 43.2%, 40.5%, 11.3% and 5% of the protein, respectively (Table 1). These protein sources have been used in previous protein requirement studies for other fish species (Anderson et al. 1981; Daniels and Robinson 1986; Lemm and Rottiers 1986; Parazo 1990). Additional dietary components included dextrin (range = 0-20%) as a carbohydrate source, cod liver oil (4.6-14.1%) as a lipid source, cellulose (3.5-10.1%) as a filler, carboxymethyl cellulose as a pellet binder (2%), a vitamin premix (1%) (NRC 1973), a mineral premix (4%) (Lovell 1989), and ascorbic acid (0.5%) (Table 1).

The digestible energy (DE) in each of the diets (327 kcal/100 g) were held constant by adjustment of the carbohydrate and lipid. These DE values were selected to allow comparison with other studies (Lemm and Rottiers 1986). Carbohydrate, lipid and protein digestibility (2.25,
8.25, 4.2 kcal/gram) was based upon the average digestibility for salmonids and catfish (Piper et al. 1982). Each species was acclimated to a recirculating water system consisting of 24 fiberglass circular tanks with common primary and secondary settling tanks, primary and secondary biofilter, floss filter, and water chiller. Each circular tank (92 cm in diameter by 92 cm tall) was maintained at a water depth of 66 cm and had a turnover rate of approximately 12 times per day. Water temperature was maintained at 21° C which is within the range for optimal growth of tiger muskellunge and muskellunge (Meade et al. 1983; Bevelhimer et al. 1985; Lemm and Rottiers 1986).

Muskellunge (initial mean total length = 125 mm) and tiger muskellunge (initial mean total length = 115 mm), trained to accept pelleted feeds, were obtained from the Jake Wolf Memorial Fish Hatchery, IL. Esocids were stocked at a density of 20 fish per tank and acclimated to the system for at least one week. To ensure fish would not acclimate to a given test diet, an equal mixture of all test diets was fed at a rate of 5% body weight per day. During this period, any mortalities were replaced by fish of similar size.

Following acclimation, each of the test diets were assigned randomly to one of the 24 tanks (four replicates per diet). Fish in each tank were individually weighed and measured, and initial feed rations assigned at 10% of the
total fish biomass per day. This high feeding rate was chosen to ensure feeding to satiation. Feed was dispensed 15 times daily from 0600-2000 using Sweeney model AF6 vibratory feeders. Photoperiod was controlled to 15L:9D. Fish from each tank were weighed and measured and feed rations were adjusted at two-week intervals for eight weeks. Water temperature (21.0 ± 0.7°C), dissolved oxygen (7.7 ± 0.6 ppm) and ammonia (NH₃; 0.01 ± 0.007 ppm) were monitored daily and remained within acceptable ranges.

Pre-treatment muskellunge and tiger muskellunge (N = 10, 20, respectively) and post-treatment fish (N = 10, 20, respectively) were randomly chosen and frozen for whole body proximate analysis. Fish were dried at 60°C for a minimum of seven days to determine moisture content. Protein was determined using the Hach (1990) modification of AOAC (1975) standards, whereas fat was determined using AOAC (1975) standards. Ash was determined by the residue remaining after the oxidation of a sample at 610°C for 2 h. If individual fish were not large enough to provide an adequate amount of sample for fat analysis, fish from a particular treatment were randomly combined. Proximate analysis was conducted on each formulated test diet.

Repeated measures analysis of variance (RM ANOVA) was used to determine overall differences in growth among diets (ALPHA = 0.05) using the general linear models procedure (SAS 1982). Linear polynomials were used to detect
differences among diets across time (Bonferroni, $\alpha = 0.013$). Curvilinear regression analysis was used to determine the protein level which produced the optimum growth of fish fed different diets. One-way analysis of variance (ANOVA) was used to determine differences ($\alpha = 0.05$) in growth, survival, condition, and body composition at the end of the experiment. Initial fish weights, although not significantly different, were used as covariates. The general linear models procedure (SAS 1982) was used to detect overall differences, whereas Tukey's HSD was used to detect differences in treatment means.
RESULTS

Muskellunge and tiger muskellunge growth was affected by dietary protein level. For both taxa, weight gain increased linearly with dietary protein ($P < 0.01$; Table 2). After 4 weeks of the evaluation, growth of muskellunge and tiger muskellunge fed lower protein diets ceased, while those fish decreased in weight (Figures 1 and 2). Comparing weights over the course of the evaluation at 2 wk intervals, both muskellunge and tiger muskellunge growth varied with protein level (Figures 1 and 2; RM ANOVA; $P < 0.01$). Muskellunge fed the highest protein diet had greater growth than fish fed the two lowest protein diets. Tiger muskellunge fed the diet highest in dietary protein had greater growth than fish fed all other diets. At the end of the evaluation, similar patterns were observed in weight gains; muskellunge fed the highest protein diet had greater weight gains than fish fed the lowest protein diet (Table 2; ANOVA; $P = 0.001$), and tiger muskellunge fed the two highest protein levels had greater weight gains than fish fed the two lower protein levels (ANOVA; $P < 0.01$).

Condition factors, but not survival, varied with dietary protein for both muskellunge and tiger muskellunge (Table 2). Muskellunge fed the two diets highest in protein had higher condition factors than fish fed the lowest protein diet (ANOVA; $P < 0.05$). Tiger muskellunge fed the two highest protein diets had higher condition factors than
fish fed the two lowest protein diets (ANOVA; P < 0.05). Survival of both muskellunge (73%) and tiger muskellunge (97%) was consistently high, and for both taxa was not affected by diet type (Table 2; ANOVA; P > 0.24).

Muskellunge whole body protein and moisture, but not ash and fat content, was affected by diet type (Table 3). In general, muskellunge fed higher protein diets also had higher levels of body protein. Muskellunge fed the highest protein diet had higher body protein content than fish fed the two lower protein diets (P < 0.05; Table 3). Moisture content increased for muskellunge fed diets lower in protein (P < 0.05).

Tiger muskellunge body composition differed when compared to muskellunge. Fat content for tiger muskellunge was twice that of muskellunge, while muskellunge ash tended to be higher than that of tiger muskellunge. In contrast, protein and moisture levels were similar to those for muskellunge (Table 3). Tiger muskellunge protein, lipid and moisture content, but not ash, was affected by diet type (Table 3). Tiger muskellunge fed the two higher protein diets had higher body protein content than fish fed the two lower protein diets (ANOVA; P < 0.05). Conversely, lipid content was higher for tiger muskellunge fed the two diets lowest in dietary protein (ANOVA; P < 0.05). Tiger muskellunge fed the highest protein diet had higher moisture
content than fish fed a diet containing 37% dietary protein (ANOVA; P < 0.05).
DISCUSSION

The study was designed to identify the optimum protein level that would maximize growth, survival and fish condition for muskellunge and tiger muskellunge. For muskellunge, the optimum protein level was 37%, as growth did not increase for fish fed a higher protein diet, however we did not feed a diet higher in protein where growth decreased. The optimal protein level for tiger muskellunge was not fully established. Tiger muskellunge fed the highest protein level (45%) exhibited the fastest growth, but growth may or may not have been greater if fish had been fed diets with higher protein levels. Similar to growth, both taxa had higher condition factors when fed higher protein diets. Survival, however, was not affected by dietary protein. Previous studies on smaller sizes of tiger muskellunge determined optimum protein levels of 50% for 50 mm TL fish (Lemm and Rottiers 1986) and 45% for fingerlings up to 130 mm TL (Meade and Lemm 1986). Because protein requirements decline for larger fish (Dupree 1976), we would not expect the optimum protein value to be substantially higher than 45% for the larger tiger muskellunge used in our study (115-147 mm TL).

The formulation of the test diets was kept as semi-purified as possible. An attempt to use protein from only highly purified sources (e.g. casein and gelatin) was made, but these test diets failed because of poor palatability.
Similar results were observed when walleye were fed diets containing protein only from purified sources (personal communication; Barrows, F. T.; Fish Technology Center, Bozeman, Montana). After reformulating the diet by adding herring meal (40.5% of the protein), palatability increased. Both muskellunge and tiger muskellunge exhibited good growth on the higher protein diets and high survival on all diets, however the two lower protein diets were inadequate for growth. Although fish fed all the diets were still consuming feed after four weeks, growth ceased for fish fed the lower protein diets. Overall there was a general decrease in growth rate for fish fed all diets. Tanks were siphoned daily, however we did not notice an increase in uneaten feed as the evaluation progressed. It is plausible that the fish adjusted their feed intake to the corresponding energy level of the diets because animals in general eat to meet their energy requirements. We also considered that the diets may have been deficient in one or more amino acids, however the amino acid composition satisfies the nutritional needs of salmonids (NRC 1981).

The method used to determine optimum protein levels was similar to other studies; as protein levels were reduced, carbohydrate and lipid levels were increased to keep diets isocaloric (Barrows et al. 1988; Clark et al. 1990; Shiau and Huang 1990). Protein, lipid and carbohydrate levels varied in all diets. Because diets were isocaloric, those
with lower protein had higher levels of lipids. Muskellunge and tiger muskellunge responded to these differences and affected their body composition. Body protein increased with dietary protein similar to evaluations with walleye *Stizostedion vitreum* and Nile tilapia *Oreochromis niloticus* (Barrows et al. 1988; Siddiqui et al. 1988). An inverse relationship was found between body fat and dietary protein; the percentage of body fat for muskellunge and tiger muskellunge generally decreased as dietary protein increased. Similar relationships have been observed in channel catfish *Ictalurus punctatus* (Reis et al. 1989), striped bass *Morone saxatilis* (Millikin 1982), walleye (Barrows et al. 1988), and Nile tilapia (Siddiqui 1988).

Differences in body fat content between treatment fish may have implications in part on how fish should be reared to maximize survival. Reviews by Peters (1983), Calder (1984), and Schmidt-Nielsen (1984) found for many animals weight-specific rates of energy use decrease as size increases, and therefore a smaller fish's energy reserves, usually in the form of fats, may be depleted faster than those of a larger fish. Laboratory experiments by Toney and Coble (1980) showed yellow perch *Perca flavescens* to have lower body fat and higher mortality at smaller sizes. In both field and laboratory experiments, a strong correlation has been found between smaller fish size and over winter mortality. Size-selective mortality during winter conditions has been seen
in brooktrout *Salvelinus fontinalis* (Hunt 1969), smallmouth bass *Micropterus dolomieu* (Shuter et al. 1980), and yellow perch (Post and Evans 1989).

As observed previously for several species, dietary protein had no affect on body ash levels for muskellunge and tiger muskellunge (Millikin 1982; Lemm and Rottiers 1986; Barrows et al. 1988; Clark et al. 1990). Muskellunge moisture content, however, decreased as dietary protein increased, whereas tiger muskellunge moisture content increased with protein level. These differences between taxa have been observed before as striped bass (Millikin 1982) and walleye (Barrows et al. 1988) body moisture increased, whereas hybrid tilapia *O. niloticus* × *O. aureus* body moisture decreased as dietary protein increased (Shiau and Huang 1990).

Muskellunge and tiger muskellunge are closely related taxa, however, each may have different nutritional requirements. Although the muskellunge and tiger muskellunge evaluations were independent of each other, the feeding regime, rearing environment, water quality, fish size, and diets were all kept similar. Substantially different optimum protein levels for muskellunge (37%) and tiger muskellunge (≥ 45%) were found suggesting these closely related taxa have different nutritional requirements. Previous diet formulations evaluated by the U.S. Fish and Wildlife Service have treated both taxa as
being nutritionally equal and have been traditionally used to rear coolwater taxa (Orme 1978). This study demonstrates the fallacy of assuming that all coolwater species have similar nutritional requirements. Considerably more nutritional work is needed for esocids and other coolwater species.
Table 1. Composition of formulated muskellunge and tiger muskellunge diets (% as fed) adjusted to various protein levels. The 31% formulation was fed only to muskellunge, whereas the 45% formulation was fed only to tiger muskellunge.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>31%</th>
<th>34%</th>
<th>37%</th>
<th>40%</th>
<th>45%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring meal</td>
<td>18.00</td>
<td>20.25</td>
<td>27.00</td>
<td>29.25</td>
<td>31.50</td>
</tr>
<tr>
<td>Wheat shorts</td>
<td>9.70</td>
<td>10.91</td>
<td>14.55</td>
<td>15.76</td>
<td>16.97</td>
</tr>
<tr>
<td>Casein</td>
<td>16.48</td>
<td>18.53</td>
<td>24.71</td>
<td>26.77</td>
<td>28.80</td>
</tr>
<tr>
<td>Gelatin</td>
<td>4.12</td>
<td>4.63</td>
<td>6.17</td>
<td>6.69</td>
<td>7.23</td>
</tr>
<tr>
<td>Dextrin</td>
<td>20.00</td>
<td>16.00</td>
<td>8.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cod liver oil</td>
<td>14.13</td>
<td>12.72</td>
<td>10.78</td>
<td>7.06</td>
<td>4.55</td>
</tr>
<tr>
<td>Cellulose</td>
<td>10.07</td>
<td>9.46</td>
<td>7.29</td>
<td>6.97</td>
<td>3.45</td>
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<tr>
<td>CMC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Mineral premix&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
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<sup>a</sup>Carboxymethyl cellulose  
<sup>b</sup>Vitamin premix: NRC 1973 (U.S. Biochemical, Cleveland, OH)  
<sup>c</sup>Mineral premix: Lovell 1989 (U.S. Biochemical, Cleveland, OH)
Table 2. Effects of dietary protein level on weight gain, condition factor (K, Piper et al. 1982) and survival of muskellunge and tiger muskellunge at the end of the 8-week evaluation. Values within parentheses represent 95% confidence intervals. Values within a column with the same letter are not significantly different (ANOVA; P > 0.05).

<table>
<thead>
<tr>
<th>Protein (%)</th>
<th>Weight gain (%)</th>
<th>Condition factor</th>
<th>Survival (%)</th>
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</thead>
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<td>Tiger Muskellunge</td>
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<tr>
<td>34</td>
<td>65 (9)</td>
<td>0.365 (0.011)</td>
<td>100 (0)</td>
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<tr>
<td>37</td>
<td>75 (12)</td>
<td>0.368 (0.003)</td>
<td>91 (10)</td>
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<tr>
<td>40</td>
<td>134 (5)</td>
<td>0.395 (0.006)</td>
<td>98 (4)</td>
</tr>
<tr>
<td>45</td>
<td>202 (5)</td>
<td>0.395 (0.009)</td>
<td>100 (0)</td>
</tr>
<tr>
<td>Muskellunge</td>
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<tr>
<td>31</td>
<td>43 (4)</td>
<td>0.285 (0.003)</td>
<td>75 (12)</td>
</tr>
<tr>
<td>34</td>
<td>61 (15)</td>
<td>0.299 (0.008)</td>
<td>65 (16)</td>
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<tr>
<td>37</td>
<td>75 (11)</td>
<td>0.315 (0.006)</td>
<td>79 (12)</td>
</tr>
<tr>
<td>40</td>
<td>90 (23)</td>
<td>0.319 (0.017)</td>
<td>73 (8)</td>
</tr>
</tbody>
</table>
Table 3. Whole body composition (percent wet weight) of muskellunge and tiger muskellunge at the beginning and end of the protein evaluation. Values within parentheses represent 95% confidence intervals. Values for a taxa within a column with the same letter are not significantly different (ANOVA; \( P > 0.05 \)).

<table>
<thead>
<tr>
<th>Diet [% protein]</th>
<th>Body composition</th>
</tr>
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<tr>
<td></td>
<td>Protein</td>
</tr>
<tr>
<td>Muskellunge</td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>15.9(0.8)</td>
</tr>
<tr>
<td>31</td>
<td>15.8(0.7)(^{ab})</td>
</tr>
<tr>
<td>34</td>
<td>15.5(0.7)(^{b})</td>
</tr>
<tr>
<td>37</td>
<td>16.8(1.4)(^{ac})</td>
</tr>
<tr>
<td>40</td>
<td>17.1(1.1)(^{c})</td>
</tr>
<tr>
<td>Tiger Muskellunge</td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>16.1(0.9)</td>
</tr>
<tr>
<td>34</td>
<td>15.4(1.0)(^{a})</td>
</tr>
<tr>
<td>37</td>
<td>16.0(0.9)(^{a})</td>
</tr>
<tr>
<td>40</td>
<td>16.8(0.7)(^{b})</td>
</tr>
<tr>
<td>45</td>
<td>17.0(0.7)(^{b})</td>
</tr>
</tbody>
</table>
LITERATURE CITED


Appendix C

Effects of growth, survival, and body composition of largemouth bass fed six commercial diets and four diets varying in protein concentration.

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Progressive Fish-Culturist (Manuscript in review)
Abstract.- Aquaculturists many times intensively culture a species before nutrient requirements are incorporated into a diet or knowing which commercially available diet maximizes growth and survival. Largemouth bass (Micropterus salmoides) have been cultured on pelleted diets since the 1960's, however growth and survival of fish on these diets has not been evaluated, and nutritional research has not been conducted to formulate specific diets. Growth rate, survival and body composition was evaluated over a 56 day period for largemouth bass (initial length = 98 mm) fed six commercial diets (Abernathy S8-2 (84); Biodiet Grower; Biodry 1000; Biosponge Bass Grower; Black Magic Bass Food; W-16). In a separate study, growth rate, survival and body composition was evaluated over a 51 day period for largemouth bass (initial length = 110 mm) fed four diets ranging in protein concentration from 31-40%. Largemouth bass fed W-16 and Biodiet Grower had faster growth rates than those fed Black Magic Bass Food, Biodry 1000 and Biosponge Bass Grower. Largemouth bass whole body protein, lipid, moisture and ash was affected by commercial diet. Lipid levels were higher for fish fed Biodiet Grower than for fish fed all other diets. Based on this evaluation, we recommend either W-16 or Biodiet Grower for rearing largemouth bass. During the optimum protein evaluation, growth varied with protein level. Largemouth bass fed the two diets highest in protein had faster growth than fish fed the two lowest protein diets. Weight gains were greatest for largemouth bass fed the 37% protein diet. Largemouth bass lipid and moisture, but not protein and ash, was
affected by diet type. Lipid content decreased and moisture content increased as dietary protein increased. In both evaluations we found largemouth bass respond to changes in diet. We therefore recommend further nutritional research be conducted to aid in the formulation of a diet which optimizes growth, survival and body composition for largemouth bass.
Many intensively cultured fish are reared on nutritionally complete pelleted diets. However, aquaculturists have often discovered species which accept pelleted diets before nutritional requirements are known. When this occurs, the culturist can use different methods to rear the species. He may feed a diet which has been formulated for another species, formulate and evaluate a series of test diets against one another for effectiveness, or conduct nutritional research to determine requirements and formulate a diet based on the results.

The methods described above have both benefits and drawbacks. Feeding a diet already commercially available would be the easiest way to rear the species, however it is unknown whether the diet will provide maximum growth and survival while minimizing cost. Evaluating a series of test diets is more expensive and time consuming, and the end result may not be a diet providing maximum benefits. The most expensive and time consuming method would be to conduct nutritional research and determine requirements, however the final formulated diet should be one with maximum benefits.

The intensive culture of largemouth bass (Micropterus salmoides) began in the 1960's. Artificial feeds used during the earliest trials included frozen tadpoles, ground fish, a modified Purina Trout Chow, and the Oregon Moist Pellet (Hublou 1963; Snow 1968; Lewis et al. 1969; Snow and Maxwell 1970). Using the Oregon Moist Pellet, Snow and Maxwell (1970) were able to produce largemouth bass 6-9 inches in length. Feed producers have since
produced dry pelleted diets with longer shelf-lives, less expensive delivery and storage costs, and easier methods of feeding. Some producers even include "bass" within their product name (e.g. Black Magic Bass Food, Mesa Feed and Farm Supply, Grand Junction, CO and Biosponge Bass Grower, Biosponge, Sheridan, WY). However, these and other commercially available diets have not been evaluated to determine which will provide maximum growth and survival for largemouth bass. Information is also lacking on the nutritional requirements of largemouth bass with only limited information available concerning protein levels (Anderson et al. 1981).

It is inevitable that species will be intensively reared without nutritional requirements known. When this occurs, we believe trials must be conducted to evaluate which commercial diet promotes maximum growth and survival while minimizing cost. The use of this optimum diet should only be used on an interim basis. Specific nutritional requirements must be studied and incorporated into diets which give maximum benefits.

This study consisted of two evaluations. The objectives during the commercial diet evaluation were to evaluate commercial diets based on growth rate, survival and body composition of largemouth bass, and make diet recommendations to hatcheries based on fastest growth rates, highest survival, and energy reserves. The objective for the optimum protein evaluation were to compare growth rate, survival and body composition of
largemouth bass fed diets differing in protein level in order to provide a baseline for developing practical diets.

Methods

Feeding regime.- Six commercial diets were evaluated which included three salmonid diets, Biodiet Grower (Biodiet, Bioproducts Inc., Warrenton, OR), Biodry 1000 (Biodry, Bioproducts, Inc.), and Abernathy S8-2 (84) (Abernathy), two diets formulated specifically for bass, Black Magic Bass Food (Black Magic, Mesa Feed and Farm Supply, Grand Junction, CO) and Biosponge Bass Grower (Biosponge, Biosponge, Sheridan, WY), and one diet formulated specifically for coolwater species, W-16. Abernathy and W-16 are open-formula diets which were produced by Zeigler Brothers, Gardeners, PA. Nutrient information for the diets were obtained from each manufacturer and represent minimum guaranteed levels. Diet prices were also obtained from each feed manufacturer (1991 US $) and were lowest for Biosponge ($0.64 / kg), followed by Biodry ($0.90 / kg), Abernathy ($0.95 / kg), W-16 ($1.21 / kg), Black Magic ($1.25 / kg), and Biodiet ($1.41 / kg).

Diets for the optimum protein evaluation were formulated to contain 31%, 34%, 37% or 40% crude protein. Protein sources within each diet included casein, herring meal, gelatin and wheat shorts (<7% fiber) with each providing 43.2%, 40.5%, 11.3% and 5% of the protein, respectively (Table 1). These protein sources have been used in previous protein requirement studies for other fish species (Anderson et al. 1981; Daniels and Robinson 1986;
Lemm and Rottiers 1986; Parazo 1990; Brecka et al. 1994).
Additional dietary components included dextrin (range = 0-20%) as a carbohydrate source, cod liver oil (7.1-14.1%) as a lipid source, cellulose (7.0-10.1%) as a filler, carboxymethyl cellulose as a pellet binder (2%), a vitamin premix (1%) (NRC 1973), a mineral premix (4%) (Lovell 1989), and ascorbic acid (0.5%) (Table 1).

The digestible energy (DE) in each of the formulated diets (327 kcal/100 g) was held constant by adjustment of the carbohydrate and lipid. These DE values were selected to allow comparison with other studies (Lemm and Rottiers 1986; Brecka et al. 1994). Carbohydrate, lipid and protein digestibility (2.25, 8.25, 4.2 kcal/gram) was based upon the average digestibility for Pacific salmon and channel catfish (Piper et al. 1982).

The commercial diet and optimum protein evaluations were not conducted concurrently, however both evaluations were conducted within a similar recirculating water system. The system consisted of 24 fiberglass circular tanks with common primary and secondary settling tanks, primary and secondary biofilter, floss filter, and water chiller. Each circular tank (92 cm in diameter by 92 cm tall) was maintained at a water depth of 66 cm and had a turnover rate of approximately 12 times per day. Photoperiod was controlled to 15L:9D. Feces and excess feed were removed daily.

Largemouth bass for both evaluations (initial mean total length and weight ± 95% CI for commercial diet and optimum protein evaluation, 98 ± 1 mm, 12.2 ± 0.4 g and 110 ± 1 mm, 16.0


± 0.4 g, respectively) were trained to accept pelleted feeds when obtained from the Jake Wolf Memorial Fish Hatchery, Illinois Department of Conservation, Manito. Largemouth bass were stocked at a density of 20 fish per tank and acclimated to the system for at least one week. To ensure fish would not acclimate to a given test diet, an equal mixture of all test diets was fed at a rate of 5% body weight per day. During this period, any mortalities were replaced by fish of similar size.

Following acclimation, each of the test diets were assigned randomly to one of the 24 tanks (four replicates per diet). Fish in each tank were individually weighed (g) and measured (TL mm), and feed rations assigned at 10% of the total fish biomass per day. This high feeding rate was chosen to ensure feeding to satiation. During the commercial diet evaluation feed was dispensed 8 times daily from 0600-2000 using Sweeney model AF6 vibratory feeders, whereas feed was dispensed 15 times daily during the optimum protein diet evaluation. Fish from each tank were weighed and measured and feed rations were adjusted at two-week intervals. Water temperature (mean ± 95% CI for commercial diet and optimum protein evaluations, 18.0 ± 0.2°C and 21.4 ± 0.4°C, respectively), dissolved oxygen (7.7 ± 0.2 ppm and 7.3 ± 0.2 ppm, respectively) and ammonia (NH₃; 0.005 ± 0.0007 ppm and 0.012 ± 0.002, respectively) were monitored daily and remained within acceptable ranges.

**Proximate analysis.** Pre-treatment (N = 10) and post treatment (N = 10) largemouth bass for each evaluation were
randomly chosen and frozen for whole body proximate analysis. Fish were dried at 60° C for a minimum of seven days to determine moisture content. Crude protein was determined using the Hach (1990) modification of AOAC (1975) standards, whereas total fat was determined using AOAC (1975) Goldfisch ether extraction method. Ash was determined by the residue remaining after the oxidation of a sample at 610° C for 2 h. If individual fish were not large enough to provide an adequate amount of sample for fat analysis, fish from a particular treatment were randomly combined. Proximate analysis was conducted on each formulated test diet.

**Statistical analysis.** Similar statistical analyses were used for both evaluations. Tank means were used as experimental units in all analyses to avoid problems associated with psuedoreplication (Hurlbert 1984). Repeated measures analysis of variance (RM ANOVA) was used to determine overall differences in growth among diets (ALPHA = 0.05) using the general linear models procedure (SAS 1982). Linear polynomials were used to detect differences among diets across time (Bonferonni, ALPHA = 0.008 for commercial diet evaluation; ALPHA = 0.013 for optimum protein evaluation). One-way analysis of variance (ANOVA) was used to determine differences (ALPHA = 0.05) in weight gain, survival, condition, and body composition at the end of the experiment. Initial fish weights, although not significantly different, were used as covariates. The general linear models procedure (SAS 1982) was used to detect overall differences, whereas Tukey's HSD
was used to detect differences in treatment means. For the optimum protein evaluation, curvilinear regression analysis was used to determine the protein level which produced the optimum growth of fish fed different diets.

Results

Commercial diet evaluation

Growth and Survival.- Largemouth bass gained weight on all diets during the study (Figure 1). Largemouth bass grew fastest when fed W-16 than when fed Abernathy, Black Magic, Biodry and Biosponge (RM ANOVA; $P < 0.001$). Largemouth bass fed Biodiet also had faster growth than those fed Black Magic, Biodry and Biosponge (RM ANOVA; $P < 0.001$). Similar patterns were observed in total weight gain at the end of the evaluation. Weight gains ranged from 57-91% and were highest for largemouth bass fed W-16, followed by Biodiet, Abernathy, Black Magic, Biodry, and Biosponge (Table 2). Largemouth bass fed W-16 had greater weight gains compared to fish fed Abernathy, Black Magic, Biodry and Biosponge (ANOVA; $P < 0.05$). Largemouth bass condition factors ranged from 1.24-1.28 and were highest for fish fed Biodiet but were not affected by diet type (Table 2; ANOVA; $P = 0.06$). There were no mortalities during the evaluation.

Body composition.- The six commercial diets evaluated ranged in digestible energy from 3045-3786 kcal / kg. Variations in energy among diets were caused by differences in protein (43-53%), fat (8-17%) and carbohydrate (7-23.8%) levels (Table 3).
Diets also varied in the amount of moisture, ash and fiber (Table 3).

Largemouth bass whole body protein, lipid, moisture and ash was affected by commercial diet. Protein and ash decreased, whereas moisture increased during the evaluation (Table 4). Among commercial diets, percent protein was higher for fish fed Biodry and W-16 than for fish fed Abernathy, Biosponge and Black Magic (ANOVA; P < 0.05). Largemouth bass fed Abernathy, Biosponge, Black Magic and W-16 had higher moisture levels than fish fed Biodiet and Biodry (ANOVA; P < 0.05). Lipid levels were higher for fish fed Biodiet than for fish fed all other diets, whereas Biosponge fed largemouth bass had higher percent ash than fish fed W-16 (ANOVA; P < 0.05).

Optimum protein evaluation

Growth and Survival.- Largemouth bass gained weight on all diets over the course of the evaluation, while growth was affected by protein level. Largemouth bass weight gain increased linearly with dietary protein (P < 0.01; Table 2). Comparing weights over the course of the evaluation, largemouth bass growth varied with protein level (Figure 2; RM ANOVA; P < 0.01). Largemouth bass fed the two diets highest in dietary protein had faster growth than fish fed the two lowest protein diets. At the end of the evaluation, similar patterns were observed in weight gains. Weight gains ranged from 99-155% and were higher for largemouth bass fed the two highest protein diets than for fish fed the two diets lowest in dietary protein (Table 2; ANOVA; P <
Largemouth bass condition factors ranged from 1.29-1.36 and were affected by dietary protein (Table 2). Fish fed 37 and 40% protein diets had higher condition factors than fish fed the 34% protein diet (ANOVA; \( P < 0.05 \)). There were no mortalities during the evaluation.

**Body composition.** Largemouth bass lipid and moisture, but not protein and ash content, was affected by diet type (Table 4). Total body lipid was highest for largemouth bass fed the two lowest protein diets compared to lipid levels in fish fed the highest protein diet (Table 4; ANOVA \( P < 0.05 \)). Moisture content was higher for largemouth bass fed the 37 and 40% protein diets than for fish fed the 34% protein diet (ANOVA; \( P < 0.05 \)).

**Discussion**

**Commercial diet evaluation**

Largemouth bass growth was affected by commercial diet. The fastest growth was obtained when fish were fed W-16, followed by Biodiet, Abernathy, Black Magic, Biodry and Biosponge. Largemouth bass fed W-16, a diet formulated for coolwater fishes such as muskellunge (Esox masquinongy) and tiger muskellunge \( \times E. \) lucius), had greater growth than fish fed Black Magic Bass Food and Biosponge Bass Grower, two diets formulated for bass. Variations in growth for fish fed different commercial diets have been documented for other species. Striped bass (Marone saxatilis) fingerlings obtained greater growth when fed three coldwater fish feeds than when fed a modified catfish diet or a fish by-products diet (Klar and Parker 1989). We previously
evaluated growth of muskellunge and tiger muskellunge fed Abernathy, Biodiet, Biodry and W-16 and found both fishes having greater growth on the three coldwater fish feeds compared to W-16 (Brecka et al. 1994). The results of these studies suggest fish respond to changes in dietary formulations, and commercial diets formulated specifically for a species may or may not promote maximum growth.

Whole body composition of largemouth bass was also affected by commercial diet. Similar results were found when muskellunge and tiger muskellunge were fed different commercial diets (Brecka et al. 1994). Largemouth bass protein and moisture content tended to be lower for largemouth bass, while percent lipid and ash tended to be higher compared to muskellunge and tiger muskellunge (see Brecka et al. 1994 for muskellunge and tiger muskellunge results). These differences in body composition among species are most likely due to variability in species response. The more closely related species, muskellunge and tiger muskellunge, had a similar response in body composition than when the two esocids were compared to largemouth bass.

After our commercial diet evaluation for muskellunge and tiger muskellunge, we suggested lipid levels may have ramifications in commercial diet recommendations and should be used as criteria when recommending a commercial diet if lipid levels appear low (Brecka et al. 1994). Although largemouth bass lipid levels in the present evaluation were two times higher than tiger muskellunge and six times higher compared to muskellunge
fed similar commercial diets, lipid levels may still be useful criteria when selecting a diet. Energy reserves, fish size, temperature and prey availability may all affect over-winter survival and have been documented for many species including smallmouth bass (Micropterus dolomieu) (MacLeod 1975; Oliver et al. 1979; Shutter et al. 1980), brook trout (Salvelinus fontinalis) (Hunt 1969), tiger muskellunge (Carline et al. 1986), and largemouth bass (Adams et al. 1982). Adams et al. (1982) evaluated over-winter survival for largemouth bass and found they need to attain $250 \pm 50$ mm before annulus I formation, or they will not survive. Their conclusions were based upon prey availability and the inability of small bass to store sufficient energy reserves.

Growth rate and body composition will be used when recommending which commercial diet to feed; survival was not affected by diet type and will not influence diet selection. Feed cost was highly variable and ranged from $0.64-1.41 / \text{kg}$. Fish were fed ad libitum, and we therefore do not have feed conversion rates for each of the diets. If these rates were known, an analysis of cost-effectiveness could be calculated among diets. No diet was superior based on growth rate and body composition. W-16 and Biodiet provided the fastest growth, whereas Biodiet provided the highest percent lipid content. Based on growth rate and body composition, we recommend Biodiet and W-16, however culturists must recognize they are the two most expensive diets tested. Individual culturists must include other
considerations, such as rearing space, feed storage costs and feed conversion rates, when making their final diet selection.

**Optimum protein evaluation**

The optimum protein level for largemouth bass was 37%, however growth did not significantly decrease for fish fed a higher protein diet. A decrease in growth is expected when fish are fed protein in excess of their optimum amount. This has been shown for many species including channel catfish (*Ictalurus punctatus*) (Reis et al. 1989), walleye (*Stizostedion vitreum*) (Barrows et al. 1988), and Nile tilapia (*Oreochromis niloticus*) (Siddiqui et al. 1988). A decrease in growth would be expected if a diet higher in protein was fed in our study. A previous study of protein requirements for largemouth bass found minimum protein requirements were not greater than 39.9 and 40.8% for age 0 and age 1 fish (Anderson et al. 1981). Both age 0 and 1 fish were much smaller than fish used in our evaluation, with the age 0 and 1 fish approximately one-sixth and one-half times our initial weight, respectively. It should be expected that the larger fish used in our evaluation have a lower optimum protein level. Although this did occur, there are other factors besides fish size which affect optimum protein levels including water temperature, dietary energy and protein source.

The formulations used in the largemouth bass evaluation were similar to diets used to determine optimum protein levels for muskellunge and tiger muskellunge (Brecka 1994). For muskellunge, the optimum protein level was also 37%, however was
not fully established for tiger muskellunge. Tiger muskellunge fed a higher protein level (45%) exhibited the fastest growth, but growth may or may have been greater if fish had been fed diets with higher protein levels. Largemouth bass maintained their weight gains throughout the evaluation, whereas muskellunge and tiger muskellunge growth ceased for fish fed the lower protein diets and slowed for fish fed diets higher in protein.

The diets used in the evaluation were kept isocaloric to assure differences in growth were due to changes in dietary protein. Isocaloric diets are necessary because most animals can modify their feed intake to satisfy their daily energy requirements. Other optimum protein studies have also used this method (Brecka 1994; Barrows et al. 1988; Clark et al. 1990) in which diets are kept isocaloric by decreasing lipid and carbohydrate levels as protein is increased. Largemouth bass responded to these dietary changes as it affected their body composition. Lipid levels generally decreased, whereas moisture level tended to increase with dietary protein. This is similar to other optimum protein studies with striped bass (Millikin 1982), walleye (Barrows et al. 1988), channel catfish (Reis et al. 1989), and tiger muskellunge (Brecka 1994). Dietary protein did not affect percent protein or ash content for largemouth bass. Percent ash has been shown to be unaffected by dietary protein for fish including muskellunge and tiger muskellunge (Brecka 1994; Lemm and Rottiers 1986) and Florida red tilapia (Oreochromis urolepis hornorum x O. mossambicus) (Clark et al.
The results of many protein evaluations have shown body protein to be directly proportional to dietary protein (Brecka 1994; Barrows et al. 1988; Siddiqui et al. 1988). Other studies, however, have shown body protein content is not greatly affected by dietary protein (Clark et al. 1990; Reis et al. 1989; Millikin 1982; Winfree and Stickney 1981). These discrepancies may be due to a short evaluation period or variations in response between species.

Conclusions

Largemouth bass during both the commercial diet and optimum protein evaluations showed their growth and body composition are affected by diet type. Although W-16 and Biodiet were the most expensive diets tested, both provided faster growth than Black Magic Bass Food and Biosponge Bass Grower, while Biodiet fed largemouth bass exhibited the highest energy reserves. We therefore recommend either W-16 or Biodiet for rearing largemouth bass. The optimum protein level in the evaluation was 37% for largemouth bass. Largemouth bass lipid and moisture content was affected by diet type, whereas protein and ash was not affected. The results of both studies suggest further nutritional research be conducted for largemouth bass which will maximize benefits and minimize feed cost.

Acknowledgments

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References


Snow, J. R. 1968. Production of six- to eight-inch largemouth bass for special purposes. The Progressive Fish-Culturist 30:144-152.

Table 1.- Composition of formulated largemouth bass diets (% as fed) adjusted to various protein levels.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>31%</th>
<th>34%</th>
<th>37%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herring meal</td>
<td>18.00</td>
<td>20.25</td>
<td>27.00</td>
<td>29.25</td>
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<tr>
<td>Wheat shorts</td>
<td>9.70</td>
<td>10.91</td>
<td>14.55</td>
<td>15.76</td>
</tr>
<tr>
<td>Casein</td>
<td>16.48</td>
<td>18.53</td>
<td>24.71</td>
<td>26.77</td>
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<tr>
<td>Gelatin</td>
<td>4.12</td>
<td>4.63</td>
<td>6.17</td>
<td>6.69</td>
</tr>
<tr>
<td>Dextrin</td>
<td>20.00</td>
<td>16.00</td>
<td>4.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cod liver oil</td>
<td>14.13</td>
<td>12.72</td>
<td>8.78</td>
<td>7.06</td>
</tr>
<tr>
<td>Cellulose</td>
<td>10.07</td>
<td>9.46</td>
<td>7.29</td>
<td>6.97</td>
</tr>
<tr>
<td>CMC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
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<tr>
<td>Mineral premix&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>Ascorbic acid</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
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</tbody>
</table>

<sup>a</sup> Carboxymethyl cellulose

<sup>b</sup>Vitamin premix: NRC 1973 (U.S. Biochemical, Cleveland, OH)

<sup>c</sup>Mineral premix: Lovell 1989 (U.S. Biochemical, Cleveland, OH)
Table 2.- Weight gain (%) and condition factor (K, Piper et al. 1982) of largemouth bass at the end of the optimum protein and commercial diet evaluations. Values within parentheses represent 95% confidence intervals. Values for an evaluation within a column with the same letter are not significantly different (ANOVA; P > 0.05).

<table>
<thead>
<tr>
<th>Diet</th>
<th>Weight gain (%)</th>
<th>Condition factor</th>
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</thead>
<tbody>
<tr>
<td></td>
<td><strong>Commercial Diet Evaluation</strong></td>
<td></td>
</tr>
<tr>
<td>Abernathy</td>
<td>73(11)_b</td>
<td>1.24(0.01)_a</td>
</tr>
<tr>
<td>Biodiet Grower</td>
<td>86(13)_ab</td>
<td>1.28(0.02)_a</td>
</tr>
<tr>
<td>Biodry 1000</td>
<td>71(13)_bc</td>
<td>1.26(0.04)_a</td>
</tr>
<tr>
<td>Biosponge Bass Grower</td>
<td>57(12)_c</td>
<td>1.26(0.03)_a</td>
</tr>
<tr>
<td>Black Magic Bass Food</td>
<td>72(7)_b</td>
<td>1.25(0.04)_a</td>
</tr>
<tr>
<td>W-16</td>
<td>91(18)_a</td>
<td>1.26(0.03)_a</td>
</tr>
<tr>
<td></td>
<td><strong>Optimum Protein Evaluation</strong></td>
<td></td>
</tr>
<tr>
<td>31%</td>
<td>99(19)_b</td>
<td>1.33(0.07)_ab</td>
</tr>
<tr>
<td>34%</td>
<td>112(12)_b</td>
<td>1.29(0.04)_b</td>
</tr>
<tr>
<td>37%</td>
<td>155(23)_a</td>
<td>1.36(0.06)_a</td>
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<tr>
<td>40%</td>
<td>145(17)_a</td>
<td>1.36(0.04)_a</td>
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Table 3.- Estimated proximate analysis (% by weight) from data supplied by manufacturers of six commercial diets fed to largemouth bass. NFE represents nitrogen-free extract. Digestible energy calculations were based upon the average carbohydrate (NFE), lipid and protein digestibility (2.25, 8.25 and 4.2 kcal/g, respectively) of Pacific salmon and channel catfish (Piper et al. 1982).

<table>
<thead>
<tr>
<th>Feed</th>
<th>Protein</th>
<th>Fat</th>
<th>Moisture</th>
<th>Ash</th>
<th>Fiber</th>
<th>NFE</th>
<th>Digestible Energy (kcal/kg)</th>
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<tr>
<td>Abernathy S8-2(84)</td>
<td>48</td>
<td>17.0</td>
<td>10</td>
<td>15.0</td>
<td>2</td>
<td>8.0</td>
<td>3599</td>
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<td>Biodiet Grower</td>
<td>43</td>
<td>14.5</td>
<td>20</td>
<td>10.5</td>
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<tr>
<td>Biodry 1000</td>
<td>47</td>
<td>16.0</td>
<td>12</td>
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<tr>
<td>Biosponge Bass Grower</td>
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<td>8.0</td>
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<tr>
<td>Black Magic Bass Food</td>
<td>45</td>
<td>8.0</td>
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<td>4</td>
<td>22.0</td>
<td>3045</td>
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<tr>
<td>W-16</td>
<td>53</td>
<td>17.0</td>
<td>10</td>
<td>11.0</td>
<td>2</td>
<td>7.0</td>
<td>3786</td>
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Table 4. Whole body composition (percent wet weight) of largemouth bass at the beginning and end of the optimum protein and commercial diet evaluations. Values within parentheses represent 95% confidence intervals. Values for an evaluation within a column with the same letter are not significantly different (ANOVA; P > 0.05).

<table>
<thead>
<tr>
<th>Diet</th>
<th>Body composition</th>
<th>Protein</th>
<th>Lipid</th>
<th>Moisture</th>
<th>Ash</th>
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<td>Commercial Diet Evaluation</td>
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<td>Initial</td>
<td>19.5(0.5)</td>
<td>9.1(0.7)</td>
<td>65.3(1.7)</td>
<td>4.4(0.4)</td>
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<td>Abernathy</td>
<td>17.2(1.1)</td>
<td>8.8(0.7)bc</td>
<td>69.0(1.0)a</td>
<td>4.0(0.2)ab</td>
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<td>Biodiet Grower</td>
<td>18.0(0.8)ab</td>
<td>10.3(0.7)a</td>
<td>67.2(1.0)b</td>
<td>4.0(0.2)ab</td>
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<td>Biodry 1000</td>
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<td>9.3(0.6)b</td>
<td>66.8(0.7)b</td>
<td>4.0(0.2)ab</td>
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<td>8.2(0.4)cd</td>
<td>68.6(0.6)a</td>
<td>4.2(0.2)b</td>
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<td>Black Magic Bass Food</td>
<td>17.7(0.8)b</td>
<td>7.7(0.5)d</td>
<td>69.2(0.6)a</td>
<td>3.9(0.2)ab</td>
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<td>W-16</td>
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<td>8.1(0.3)cd</td>
<td>68.7(0.6)a</td>
<td>3.8(0.3)a</td>
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<td>Optimum Protein Evaluation</td>
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<td>Initial</td>
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<td>7.2(0.2)</td>
<td>70.8(0.4)</td>
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<td>31%</td>
<td>16.9(0.6)a</td>
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<tr>
<td>34%</td>
<td>17.8(1.3)a</td>
<td>7.8(0.6)a</td>
<td>70.0(0.6)b</td>
<td>3.7(0.3)a</td>
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<td>37%</td>
<td>17.3(0.6)a</td>
<td>7.0(0.4)b</td>
<td>70.8(0.4)a</td>
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<td>40%</td>
<td>17.7(0.8)a</td>
<td>6.2(0.5)c</td>
<td>70.9(0.5)a</td>
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</table>
Figure Captions

Figure 1.- Mean weights (g) at two week intervals for largemouth bass fed six commercial feeds over a 56 day period. Diets compared were Biosponge Bass Grower (BS), Biodry 1000 (BD), Black Magic Bass Food (BM), Abernathy S8-2 (84) (AB), Biodiet Grower (BG), and W-16. Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05).

Figure 2.- Mean weights (g) at two week intervals for largemouth bass fed four diets differing in protein level over a 51 day period. Vertical lines represent 95% confidence intervals. For diets with common underline, weights were not different during the evaluation (Repeated measures ANOVA; P > 0.05).
Fig. 2

Weight (g)

Days

0 14 28 42 51

35 30 25 20 15 10 5 0

- 31% 34% 37% 40%