

BIOENERGETICS OF SMALLMOUTH BASS

MICROPTERUS DOLOMIEU IN

OKLAHOMA HATCHERIES

AND STREAMS

By

GREG ROBEL

Bachelor of Science

University of California


San Diego, California

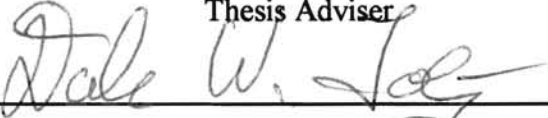
1979

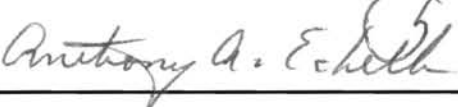
Submitted to the Faculty of the
Graduated College of the
Oklahoma State University
in partial fulfillment of
the requirements of
the Degree of
MASTER OF SCIENCE
December 1996


BIOENERGETICS OF SMALLMOUTH BASS
MICROPTERUS DOLOMIEU IN
OKLAHOMA HATCHERIES
AND STREAMS

Thesis Approved:



Thesis Adviser






Dean of the Graduate College

ACKNOWLEDGEMENTS

A number of people deserve my gratitude for having helped make this research possible. I deeply thank my graduate advisor Dr. William L. Fisher for generously making a place for me in the Oklahoma Cooperative Fish and Wildlife Research Unit and in the field of fisheries research and management; his suggestions, support, and invaluable editorial expertise made the professional difference. Other especially helpful members of the Research Unit include Paul Balkenbush, who was always quick to volunteer helpful advice, Judy Gray, who always got things to work out, Dr. David Leslie, who led us all, and Craig Martin. I thank Dr. Robert L. Lochmiller of the Department of Zoology, with whom it was a privilege to work, and to share a byline in a published article on wildlife research. I thank my graduate committee members Dr. Anthony Echelle and Dr. Dale Toetz, who spoke not often, but always wisely. I thank Dr. William Ward and Dr. Carla Goad for their generous statistical treatments.

I also thank Cary Graves of Tishomingo National Fish Hatchery and Gordon Schomer of Durant State Fish Hatchery for their cooperation and assistance, and Oklahoma Department of Wildlife Conservation for their interest in and support of the project.

I thank my family, for being behind me no matter where I ventured, and my wife Tomoko--camp cook, data recorder, and fellow seiner in waders.

TABLE OF CONTENTS

Chapter	Page
I. INTRODUCTION.....	1
II. A BIOENERGETICS ESTIMATE OF THE POTENTIAL EFFECTS OF DIFFERENT STOCKING DENSITIES UPON PRODUCTION OF SMALLMOUTH BASS <u>MICROPTERUS DOLOMIEU</u> FINGERLINGS RAISED IN OKLAHOMA HATCHERIES.....	2
Abstract.....	3
Introduction.....	4
Methods.....	5
Results and Discussion.....	10
Bibliography.....	18
Appendices.....	30
III. A BIOENERGETICS ESTIMATE OF THE POTENTIAL EFFECTS OF IMPOSING A FISHING REGULATION ON THE GROWTH OF SMALLMOUTH BASS <u>MICROPTERUS DOLOMIEU</u> IN EASTERN OKLAHOMA STREAMS.....	35
Abstract.....	36
Introduction.....	37
Methods.....	38
Results and Discussion.....	42
Bibliography.....	48

LIST OF TABLES

Table	Page
Chapter II	
1. Data of computer file representing the proportion of prey items in the diet of smallmouth bass sampled at Tishomingo National Fish hatchery and Durant State Hatchery, OK from 16 May--24 June, 1996. File was for use in Fish Bioenergetics Model II (Hewett and Johnson 1992).....	23
2. Values of p , fraction of maximum consumption, computed by Fish Bioenergetics Model II using actual growth data for cohorts of smallmouth bass fry and fingerlings grown during 1996 at Tishomingo National Fish Hatchery and Durant State Fish Hatchery in OK. These values represent the baseline stocking densities of 23,800 for Tishomingo pond and 20,800 for Durant pond. Day 1 was May 16. The model's default value of 0.009 for RA, the respiratory maintenance rate measured on juvenile bass, was used. Values of p resulting when using default values for CA and CB are shown in parentheses, whereas the other p values resulted when using altered values of CA=0.35 and CB=-0.5.....	24
3. Comparison of actual production of smallmouth bass fingerlings at two hatcheries in Oklahoma with two different estimates generated by Fish Bioenergetics Model II (Hewett and Johnson 1992). One production estimate was the sum of production data based on weights measured each week during the study period (SWEP). The other production estimate was based on weight data measured at the start and finish of the study period (IFEP).....	25
4. Effects of prey availability p on food conversion efficiency of smallmouth bass fingerlings raised at Tishomingo National Fish Hatchery and Durant State Fish Hatchery in Oklahoma in 1996.....	26
Chapter III	
1. Data on smallmouth bass populations sampled in two eastern Oklahoma streams in a previous study.....	51

2. Effects of various fractions of prey availability on growth of smallmouth bass individuals and cohorts in Barren Fork Creek, Oklahoma.....	52
3. Effects of various fractions of prey availability upon the growth of smallmouth bass individuals in Glover River, Oklahoma.....	53

LIST OF FIGURES

Figure		Page
	Chapter II	
1. Measured vs. estimated growth of smallmouth bass raised at Tishomingo National Fish Hatchery and State Fish Hatchery in Oklahoma. Estimates were by Fish Bioenergetics Model II, using its default values of physiological parameters in one case and adjusted values for CA and CB in another. Day 1 of sampling period was 16 May, 1996. Beginning and end weights input into the model were for the first and last days of the sampling period.....		28
2. Effects of simulated stocking density on production and consumption of smallmouth bass fingerlings raised at Tishomingo National Fish Hatchery and Durant State Fish Hatchery in 1996.....		29
	Chapter III	
1. Weekly mean temperatures of water vs. proximal air for Glover River and Barren Fork Creek, Oklahoma.....		55
2. Estimated weekly water temperatures in Glover River and Barren Fork Creek during period of recorded growth of smallmouth bass.....		56
3. Differential effects of a reduction in prey availability on the simulated growth of smallmouth bass individuals of different size in Glover River, Oklahoma....		57

CHAPTER I

INTRODUCTION

The two following chapters of this thesis are written in the format required of manuscripts submitted to the American Fisheries Society publications Progressive Fish Culturist and North American Journal of Fisheries Management. This Chapter I introduces Chapter II, entitled “A bioenergetics estimate of the potential effects of different stocking densities on production of smallmouth bass Micropterus dolomieu fingerlings raised in Oklahoma hatcheries” and Chapter III, entitled “A bioenergetics estimate of the potential effects of imposing a fishing regulation on the growth of smallmouth bass Micropterus dolomieu in eastern Oklahoma streams.”

CHAPTER II.
A BIOENERGETICS ESTIMATE OF THE POTENTIAL EFFECTS OF
DIFFERENT STOCKING DENSITIES UPON PRODUCTION OF SMALLMOUTH
BASS MICROPTERUS DOLOMIEU FINGERLINGS RAISED IN OKLAHOMA
HATCHERIES

Greg Robel

Oklahoma Cooperative Fish and Wildlife Research Unit

Department of Zoology, Oklahoma State University

Stillwater, Oklahoma 74078

Abstract.--Consumption and production rates of hatchery-reared smallmouth bass Micropterus dolomieu fry and fingerlings at various simulated stocking densities were estimated with a bioenergetics model. Fish growth rates and pond water temperatures during the 1996 growing season at two hatcheries in Oklahoma were input into the model. After testing the suitability of using literature-reported values for respiration and consumption, we found a set of consumption values that improved accuracy of growth rate estimates. Consumption and production differed greatly between the two hatcheries, probably because of differences in pond fertilization programs and mortality rates. Our results suggest that appropriate stocking density depends largely upon prey availability as affected by fertilization program and fingerling mortality rates.

Bioenergetics modeling is increasingly used in both aquaculture production planning and fisheries management (Jobling 1994). Such modeling can provide an accounting of the effects of abiotic factors (temperature, photoperiod, dissolved oxygen, ammonia, etc.) and biotic factors (fish size, competition for food as affected by stocking density and prey availability, exercise, hormonal exposure, etc.) on fish growth and production. For example, a model for channel catfish Ictalurus punctatus (Cuenco et al. 1985a, 1985b, 1985c) predicted: the particular stocking density that would maximize growth; that feeding fish to satiety with artificial feed would result in a yield ten times that of natural feeding; that an increased feeding rate should be accompanied by a dissolved oxygen level high enough to support the increased metabolic activity and optimum growth; and that, compared to larger fish, smaller fish need more oxygen to accommodate their higher metabolic rates and are more sensitive to temperature changes.

The bioenergetics model Fish Bioenergetics Model II (Hewett and Johnson 1992) has been routinely applied to a variety of fisheries management scenarios (Kitchell and Breck 1980; Rice et al. 1983; Hill and Magnuson 1990; Perry et al. 1995; Negus 1995). Most of these studies have been performed on juvenile or adult fish for which physiological parameter values have already been measured. To enhance the usefulness of this model for hatcheries, it is necessary to evaluate the appropriateness of parameter values for modeling young-of-year (YOY) fish, since such values can change with age (Hewett 1989; Post 1990; Hewett and Johnson 1992).

Parameter values for YOY of walleye Stizostedion vitreum (Madon and Culver 1993), striped bass Morone saxatilis (Hartman and Brandt 1993), rainbow smelt Osmerus

mordax (Lantry and Stewart 1993), and smallmouth bass Micropterus dolomieu (Shuter et al. 1980, 1989; Shuter and Post 1990; DeAngelis et al. 1993) should enhance the utility of bioenergetics modeling for hatcheries that routinely raise fish up to the fingerling stage for stocking. Other refinements such as treating activity metabolism as a variable that is dependent on prey availability (Madon and Culver 1993) instead of as a constant (Hewett and Johnson 1992) promise to further enhance the accuracy of bioenergetics modeling.

We evaluated the use of YOY parameter values for smallmouth bass (Shuter and Post 1990) to model the consumption and production of smallmouth bass fry and fingerlings raised in two Oklahoma hatcheries. We then used this model to predict the effects of manipulating stocking density upon consumption and production.

Methods

Study Ponds.---- We evaluated fish growth in a rearing pond at Durant State Fish Hatchery near Durant, Oklahoma. The pond was 225 x 18 m in area with a surface area of 0.42 ha, volume of 486.69 m³, and maximum depth of about 2.4 m. It was filled on 9 May 1996 with water from a hatchery reservoir fed by Blue River. Before being filled, the pond was fertilized along shore from the deep end to mid-pond with 113 kg of cottonseed meal, 113 kg of alfalfa, and 23 kg of triple super phosphate on 1 May 1996, and after being filled, with 45 kg of cottonseed meal and 45 kg of alfalfa pellets on 20 June 1996. In our seine hauls, there was an abundance of crayfish, which may have contributed to the high

fish mortality observed in this pond. Although crayfish feed primarily on detritus and aquatic vegetation, they are also omnivorous, opportunistic predators of invertebrates and vertebrates (Hobbs 1991).

The rearing pond used at Tishomingo National Fish Hatchery near Tishomingo, Oklahoma was 114 m x 35 m with a surface area of 0.405 ha, volume of 374.4 m³, mean depth of 0.91 m, and maximum depth of 2.4 m. The clay-bottomed pond was last drained in August 1995 and refilled on 9 April 1996. Fairy shrimp (Anostraca), tadpole shrimp (Notostraca), and clam shrimp (Conchostraca) were abundant in seine hauls made 16 May 1996. In subsequent hauls, fairy shrimp and, later, tadpole shrimp declined, until only clam shrimp were evident. Alfalfa meal was applied evenly around the pond in amounts of 45 kg on 16 and 19 April 1996, and 23 kg on 23 and 30 April 1996 and 7 and 9 May 1996; 2.2 kg of meat and bone meal were applied twice daily from 10 May-19 June 1996 along the pond's windward side.

Culture Techniques.---- At both hatcheries, eggs were produced on spawning mats by brood stock of the "Tennessee strain" of smallmouth bass, which was originally obtained in 1985 from J. Percy Priest Reservoir, Tennessee. At the Durant hatchery, hatchling fry remained in the breeding pond until after reaching the swim-up stage. On 9 May 1996, an estimated 20,800 swim-up fry that were first observed on 15 April 1996 were stocked, along with a 5-day younger spawn, in the deep and shallow zones of the pond, respectively.

To avoid fungal parasitism, all spawning mats with eggs at the Tishomingo

hatchery were removed from the breeding pond on the same day, the eggs were disassociated and placed in indoor hatching jars where a steady water current was maintained. Fry hatched on 26 April 1996. On 3 May, an estimated 23,800 of these fry were stocked into the deep end of the rearing pond.

Zooplankton.----At Tishomingo hatchery, vertical plankton sampling on 23 April 1996 showed the cladoceran Moina spp. to be abundant, with many adult females containing eggs and a large percentage of juveniles; several calanoid copepods (Diaptomus spp.) were also present. On 3 May 1996, plankton abundance was judged by hatchery personnel to be ample to support the fish stock. All adult female Moina had eggs, and there was a high percentage of juveniles. Plankton were abundant on 7 May 1996, consisting mainly of Moina, and an increased number of Diaptomus, especially juveniles and nauplii. (Kerry Graves, Tishomingo National Fish Hatchery, personal communication). Information on plankton at Durant hatchery was not available.

Modeling.---- The Fish Bioenergetics Model II program (Hewett and Johnson, 1992) was used to conduct the bioenergetics analysis. Equation sets used in the analysis were those recommended in the program user's manual for smallmouth bass. Physiological parameter values were set to those used by Shuter and Post (1990) for 1 g smallmouth bass. The only parameter in Shuter and Post (1990) that differed from the program default values (Hewett and Johnson 1992) was respiratory maintenance rate or specific standard metabolism (RA) in the respiration equation, which was set at $0.03 \text{ g O}_2 \text{ g}^{-1} \text{ day}^{-1}$ (the

program default value is $0.009 \text{ O}_2 \text{ g}^{-1} \text{ day}^{-1}$; Hewett and Johnson 1992). We used stocking rates of 20,800 fish for the Durant pond and 23,800 fish for the Tishomingo pond along with respective mortality rates to compute the population size at the start of the sampling period.

The caloric densities for two types of prey were used. We set the caloric density for copepods and cladocerans at 634 cal/gram, which is the mean of the means of the ranges for these taxa in Hewett and Johnson (1992). These organisms are reportedly the main dietary items for smallmouth bass fry and fingerlings in culture ponds (Robertson 1953; Farquhar and Guest 1991). The energy density of insect larvae, another prey item, was set at 700 cal/g, which is mid-range between the values of 600 cal/g used by Post (1988) and 830 cal/g used by Perry et al. (1995). To confirm the diets of the fry and fingerling smallmouth bass, we examined the gut contents of fish ($N > 5$) that we kept from each weekly sample and preserved in 70% ethanol. Because data on the energy density of smallmouth bass fry and fingerlings were unavailable, we used a value of 700 cal/g of wet weight. This value is similar to the values of 700 cal/g of wet weight developed for striped bass fingerlings (Hartman and Brandt 1993), 600-1,000 cal/g for alewife larvae (Hewett and Stewart 1989), 600 cal/g for yellow perch larvae (Post 1990), and 800 cal/g for walleye larvae (Madon and Culver 1993). Mortality rates (0.32 for Tishomingo and 0.7 for Durant) were computed by hatchery personnel from population sizes at stocking and harvest as estimated by multiplying the number of individuals per unit weight times the total weight harvested; instantaneous mortality rates were computed automatically by the model. Water temperature was measured every two hours throughout the study period

with an automatic temperature logger (Onset Computer Corporation, Massachusetts, USA) submerged in approximately 1 m of water at each study pond; the daily temperature data used in the model is shown in Appendix B.

Analyses. ----To avoid sampling site bias within the pond, each pond was divided across its length into four equal-sized areas. We sampled three randomly-chosen areas in the littoral zone of each pond weekly with a 3 x 1.2 m x 0.32 cm-mesh seine. Prior to weighing, each fish was blotted free of excess water and then weighed to the nearest 0.01 g in a tared, water-filled weighing dish on a portable balance (model CT200-12U, Ohaus Corporation, New Jersey). The total length of each fish was measured to the nearest mm. Means and standard deviations of weights and lengths for pooled samples of fish from each pond on each sampling day were computed. Initially, mean weights measured on consecutive days of the sampling period were input as the beginning and end weights in the bioenergetics model; model estimates for each weekly period were summed to yield totals for the entire sampling period. We later found that using weights measured only at the beginning and end of the study period did not compromise the accuracy of the model estimates, so we used this latter method in the analysis. Daily mean temperatures were computed from temperature readings taken every two hours. To derive regression equations relating length and weight, data from all sampling days were pooled for each pond.

Results and Discussion

Gut contents

Inspection of gut contents of fish sampled at both Tishomingo and Durant revealed a diet of mainly ostracods and copepods from day 1 (16 May 1996) through day 14 (30 May 1996). From day 21--28, the diet included zooplankton, insect larvae, and other unidentifiable arthropods. Only insect larvae were observed in guts from day 35--40. These findings are consistent with those of previous studies on the diet of smallmouth bass in hatchery ponds (Robertson 1953; Farquhar and Guest 1991). Identical data files representing the proportional change in prey items by number during the study period were constructed for Tishomingo and Durant hatchery ponds (Table 1).

Fish growth

Both measured and estimated growth rates of bass differed significantly between the two hatcheries ($t=14.8$, $p<0.01$; Figure 1). This was presumed to be caused by differences in prey availability as influenced by the different pond fertilization programs, which are known to affect fish growth rates in hatchery ponds (Snow 1975).

Equations for regression lines relating total length (L) and weight (W) measured on each fish are:

$$\text{Log } W = -3.833 + 2.327 (\text{log } L), \text{ with } r^2 = 0.8869 \text{ for Tishomingo hatchery}$$

$\text{Log } W = -4.289 + 2.625 (\log L)$, with $r^2 = 0.9530$ for Durant hatchery.

Consumption parameter optimization

Shuter and Posts's (1990) recommended value of 0.03 for the parameter RA proved to be unsuitable for use with our smallmouth bass fry and fingerlings when used with our growth and temperature data and the default settings provided with Fish Bioenergetics Model II. When we used this relatively high value of RA (compared to the program default value of 0.009), the model computed the value of p , the fraction of maximum consumption at which the fish is feeding, to be 0.0, whereby the model informs the user that the fish are starving. Further investigation of this matter revealed that the model could not accept values of p that exceeded 2.0. Conceivably, the 0.03 value for RA necessitates a correspondingly high value of consumption that exceeds the model's default value of maximum consumption such that p exceeds 2.0. A credible value of p must instead be within the range of 0 through 1.

Shuter and Post's (1990) RA value of 0.03 was based on laboratory measurements (Shuter et al. 1989) of the size-dependent weight loss by active, starving YOY smallmouth bass over temperatures ranging from 6-23° C. This range included YOY fish collected from wild populations in south-central Ontario and starved at temperatures 17 and 23° C, plus fish obtained from hatcheries in Ontario and New York and starved at temperatures less than 17°C. However, it is uncertain whether or not the bioenergetic characteristics of wild fish are similar to those of hatchery fish. Because the hatchery environment

(including production management aims and methods) differs from that of the wild, perhaps artificial propagation through generations of populations has caused hatchery fish to differ from wild fish on the physiological level that bioenergetic parameter values reflect. There is evidence that hatchery and wild fish of the same species can be significantly different on the genetic level (Cross and King 1983; Edds and Echelle 1989). Genetic differences among individuals of the same species of fish have been found to be associated with physiological differences such as rates of growth, metabolism, and development (Danzmann et al. 1987), hatching times of eggs (Dimichele and Powers 1982), and fry deformation and survival (Agnese et al. 1995). There is also evidence that a captive environment can rapidly affect the physiology of even a wild-caught organism, such as the cotton rat, *Sigmodon hispidus* (Robel et al. 1996).

Even after reverting to the default RA value of 0.009, p values computed to fit growth rates in each of the first two weeks of the study still exceeded one (Table 2, referring to values in parentheses), meaning that the consumption rate was exceeding its maximum. One possible explanation for this is that the model's value for maximum consumption rate for the smallmouth bass fry and fingerlings of this study is too low for our hatchery populations. In other words, hatchery-reared smallmouth bass of this size might be eating more than is assumed in the model.

Shuter and Post's (1990) data are also the basis for some of the default values for smallmouth bass in Fish Bioenergetics Model II. The values of maximum consumption rate (CA), a parameter which determines how consumption increases with temperature for temperatures below optimal temperature (CQ), optimal temperatures for consumption

(CTO) and respiration (RTO), and maximum temperature for consumption (CMT) were derived using data reported by Peek (1964) on actual rates of growth in length of smallmouth bass fry and fingerlings grown ad libitum in the laboratory at different temperatures. These fish were collected in Arkansas, far south of Ontario. The assumption that the physiology of the Ontario fish and Arkansas fish do not significantly differ, such that respiration rates from Ontario fish and consumption rates from Arkansas fish can be used in combination, remains unverified. Growth rates and efficiency of food utilization are known to differ between the Northern Smallmouth Bass (*M. d. dolomieu*), the range of which does not extend into Arkansas (Stark 1995), where Peek collected his fish, and the Neosho Smallmouth Bass (*M. d. velox*) of Arkansas (Coble 1975).

Peek (1964) was unsure of the genetic background of his fish. The eggs producing his fish came from a pond at Centerton Hatchery in Arkansas that contained a hatchery stock plus fifty wild-caught, breeding size smallmouth bass that were taken from Crooked Creek in Boone County, Arkansas and stocked into the hatchery pond one week before the eggs were collected. Peek believed that the wild-caught fish were the parents of the fish used in his experiments because the hatchery stock had apparently finished spawning before the wild stock was introduced into the pond. If the fish Peek used were wild fish, we would again have to assume that their physiology does not significantly differ from that of hatchery fish if using parameter values based on Peek's experiments in order to model the growth of hatchery fish.

To obtain a model estimate of p that did not exceed 1.0, different values of consumption parameters CA and CB (weight dependence coefficient) were tested. Raising

the default value of CA from 0.25 to 0.35 and lowering that of CB from -0.31 to -0.5 not only reduced the associated p values to below one (Table 2), but also enhanced the accuracy of growth rate estimates (Figure 1).

Actual production estimates by hatchery personnel compared with those estimated by the model using weights from the start and finish of the study period were similar; however, production estimates computed by summing production estimates based on weekly weight changes during the study period were slightly greater (Table 3). Hence, modeling proceeded with the settings of CA=0.35 and CB=-0.5, and the use of actual initial and final weights only.

Effects of stocking density on consumption, production, and food use efficiency

Stocking density was inversely related to production and consumption as estimated by the model (Figure 2). Equations of fitted curves are: $P=3.77 \times 10^{11} (X^{-1.58})$ at Tishomingo and $P=6.51 \times 10^{11} (X^{-1.59})$ at Durant, where P=production in grams and X=stocking density in fish/acre; $C=3.09 \times 10^8 (X^{-0.75})$ at Tishomingo and $C=1.46 \times 10^8 (X^{-0.80})$ at Durant, where C=consumption in grams and X=stocking density in fish/acre.

The higher consumption and production rates at Tishomingo compared with those at Durant were expected because the actual growth rates were much higher and mortality much lower at Tishomingo. The increase in consumption and production rates with a decrease in stocking density reflects the positive effect of increased prey availability on

consumption (Hewett and Johnson 1992). With an increase in consumption, body weight also rises. Although not directly affected by prey availability, weight-specific metabolic rate decreases exponentially as body weight increases. Consumption rate also decreases exponentially with increasing body weight, but less so than does metabolic rate; the net result is that the fish devote less of their energy budget to weight-specific metabolism and more to growth and production.

Food conversion efficiency (consumption:production) was slightly higher for fish in the Durant pond than for those in the Tishomingo pond (Table 4). Food conversion efficiency depends on p , baseline values of which were higher at Tishomingo (0.71) than at Durant (0.44). The higher prey availability at Tishomingo promoted more consumption and growth. The better-fed, larger fish at Tishomingo were able to devote less of their energy budget to weight-specific metabolism and more to growth and production than the less well-fed, smaller fish at Durant. This suggests that a decrease in stocking density, by increasing p , leads to a decrease in conversion efficiency.

The choice of appropriate stocking density should be made with consideration of the particular pond in which the fish are to be stocked. The results of this study suggest that the effect of a change in stocking density on production and consumption can depend to a large degree on prey availability, which is largely a function of pond fertilization program. A more heavily fertilized pond such as the one at Tishomingo hatchery has the potential to produce more biomass more quickly when stocking density is reduced; the reduction in the number of fish harvested might be offset by the increased likelihood that these larger individuals would survive their first winter, a critical period in cohort success

(Shuter and Post 1990). A similar decrease in stocking density in a less fertilized pond with low prey availability and slower growth rates as was seen at the Durant hatchery would offer comparatively less of an advantage or an impact upon production.

The importance of pond fertility and stocking density on production are well-documented (Snow 1975; Fuarquhar and Guest 1991), but there is a shortage of information that explicitly considers the bioenergetic mechanism that relates these factors to body weight, growth, and weight-specific rates of consumption and metabolism. This study represents an attempt to point out that bioenergetic mechanism and demonstrate its implications for fish hatchery management.

Research in fish bioenergetics has accelerated since the debut of Fish Bioenergetics Model I in 1987, but application of the modeling approach to hatchery management has not kept pace. This study demonstrates the applicability of bioenergetics modeling as an economical, convenient research tool for exploring and more deeply understanding the effects of different production strategies on fish production. As interest in bioenergetics modeling rises with time, perhaps too will efforts to determine more specific and accurate values of bioenergetic parameters for smallmouth bass fry and fingerlings.

Acknowledgements

This study was supported by Oklahoma Department of Wildlife Conservation and Oklahoma Cooperative Fish and Wildlife Research Unit. We thank Cary Graves of Tishomingo National Fish Hatchery and Gordon Schomer of Durant State Fish Hatchery

for their cooperation and assistance. Tomoko Robel diligently helped in collecting field data.

References

- Agnese, J., Z. J. Oteme, and S. Gilles. 1995. Effects of domestication on genetic variability, fertility, survival, and growth rate in a tropical siluriform: Heterobranchus longifilis Valenciennes 1840. *Aquaculture* 131:197-204.
- Coble, D. W. Smallmouth Bass. Pages 21-33 in R. H. Stroud and H. Clepper, editors. *Black Bass Biology and Management*. National symposium on the biology and management of the centrarchid basses, Tulsa.
- Cross, T. F., and J. King. 1983. Genetic effects of hatchery rearing in Atlantic salmon. *Aquaculture* 33:33-40.
- Cuenca, M. L., R. R. Stickney, and W. E. Graves. 1985a. Fish bioenergetics and growth in aquaculture ponds: I. Individual fish model development. *Ecological Modeling* 27:169-190.
- Cuenca, M. L., R. R. Stickney, and W. E. Graves. 1985b. Fish bioenergetics and growth in aquaculture ponds: II. Effects of interactions among size, temperature, dissolved oxygen, unionized ammonia, and food on growth of individual fish. *Ecological Modeling* 27:191-206.
- Cuenca, M. L., R. R. Stickney, and W. E. Graves. 1985c. Fish bioenergetics and growth in aquaculture ponds: III. Effects of intraspecific competition, stocking rate, stocking size, and feeding rate on fish productivity. *Ecological Modeling* 28:73-95
- Danzmann, R. G., M. M. Ferguson, and F. W. Allendorf. 1987. Heterozygosity and oxygen consumption rate as predictors of growth and developmental rate in

- rainbow trout. *Physiological zoology* 60:211-220.
- DeAngelis, D. L., Shuter, B. J., Ridgway, M. S., and M. Scheffer. 1993. Modeling growth and survival in an age-0 fish cohort. *Transactions of the American Fisheries Society* 122:927-941.
- Dimichele, L., and D. A. Powers. 1982. LDH-B genotype specific hatching times of Fundulus heteroclitus embryos. *Nature* 196:563-564.
- Edds, D. R., and A. A. Echelle. 1989. Genetic comparisons of hatchery and natural stocks of small endangered fishes: Leon Springs Pupfish, Comanche Springs Pupfish, and Pecos Gambusia. *Transactions of the American Fisheries Society* 118:441-446.
- Fuarquhar, B. W., and W. C. Guest. 1991. Food habits and feeding selectivity of smallmouth bass in culture ponds. Pages 24-26 in D. C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agricultural and Forestry Experiment Station, Mississippi State University, Mississippi State.
- Hartman, K. J., and S. B. Brandt. 1993. Systematic sources of bias in a bioenergetics model: examples for age-0 striped bass. *Transactions of the American Fisheries Society* 122:912-926.
- Hewett, S. W. 1989. Ecological applications of bioenergetics models. *American Fisheries Society Symposium* 6:113-120.
- Hewett, S. W., and D. J. Stewart. 1989. Zooplanktivory by alewives in Lake Michigan: ontogenic, seasonal, and historical patterns. *Transactions of the American Fisheries Society* 118:581-596.
- Hewett, S. W., and B. L. Johnson. 1992. *Fish Bioenergetics Model II*. University of

- Wisconsin Sea Grant Institute. WIS-SG-91-250. Madison.
- Hill, D. K., and J. J. Magnuson. 1990. Potential effects of global climate warming on the growth and prey consumption of Great Lakes fish. *Transactions of the American Fisheries Society* 119:265-275.
- Hobbs, H. H. III. 1991. Decapoda. Pages 823-858 in J. H. Thorp, and A. P. Covich, editors. *Ecology and classification of North American freshwater invertebrates*. Academic Press, San Diego.
- Jobling, M. 1994. *Fish bioenergetics*. Chapman and Hall, London.
- Kitchell, J. E., and J. E. Breck. 1980. Bioenergetics model and foraging hypothesis for sea lamprey *Petromyzon marinus*). *Canadian Journal of Fisheries and Aquatic Science* 37:2159-2168.
- Lantry, B. F., and D. J. Stewart. 1993. Ecological energetics of rainbow smelt in the Laurentian Great Lakes: an interlake comparison. *Transactions of the American Fisheries Society* 122:951-976.
- Madon, S. P., and D. A. Culver. 1993. Bioenergetics model for larval and juvenile walleye: an in situ approach with experimental ponds. *Transactions of the American Fisheries Society* 122:797-813.
- Negus, M. T. 1995. Bioenergetics modeling as a salmonine management tool applied to Minnesota waters of Lake Superior. *North American Journal of Fisheries Management* 15:60-78.
- Pennington, C. H., and K Strawn. Stocking density: its effect on caged-channel catfish production. *Proceedings of the Annual Conference of the Association of Fish and*

- Wildlife Agencies 31:514-518.
- Perry, W. B., W. A. Janowsky, and F. J. Margraf. 1995 A bioenergetics simulation of the potential effects of angler harvest on growth of largemouth bass in a catch-and-release fishery. *North American Journal of Fisheries Management* 15:705-712.
- Post, J. R. 1990. Metabolic allometry of larval and juvenile yellow perch (Perca flavescens): *in situ* estimates and bioenergetic models. *Canadian Journal of Fisheries and Aquatic Science* 47:554-560.
- Robel, G. L., R. L. Lochmiller, S. T. McMurry, and C. W. Qualls, Jr. 1996. Environmental, age, and sex effects on cotton rat Sigmodon hispidus hematology. *Journal of Wildlife Diseases* 32:390-394.
- Robertson, R. K. 1953. Food of young smallmouth black bass, Micropterus dolomieu Lacapède, in a hatchery pond. Master's thesis. University of Arkansas
- Rice, J. A., J. E. Breck, S. M. Bartell, and J. F. Kitchell. 1983. Evaluating the constraints of temperature, activity, and consumption on growth of largemouth bass. *Environmental Biology of Fish* 9:263-275.
- Shuter, B. J., MacLean, J. A., Fry, F. E. J., and H. A. Regier. 1980. Stochastic simulation of temperature effects on first-year survival of smallmouth bass. *Transactions of the American Fisheries Society* 109:1-34.
- Shuter, B. J., Ihssen, P. E., Wales, D. L., and E. J. Snucins. 1989. The effects of Temperature, pH and water hardness on winter starvation of young-of-year smallmouth bass, Micropterus dolomieu Lacapède. *Journal of Fish Biology* 35:765-780.

- Shuter, B. J., and J. R. Post. 1990. Climate, population, viability, and the zoogeography of temperate fishes. *Transactions of the American Fisheries Society* 119:314-336.
- Snow, J. R. 1975. Hatchery propagation of black basses. In *Black bass biology and management*. R. H. Stroud and H. Clepper, ed. pp 344-356.
- Snow, J. R. 1978. Increasing the yield of channel catfish rearing ponds by periodic division of the stock. *Proceedings of the Annual Conference of the Association of Fish and Wildlife Agencies* 32:239-245.
- Stark, W. J. 1995. Genetic structure and systematics of smallmouth bass: zoogeography and implications for conservation. Doctoral dissertation. Oklahoma State University.

Table 1. Proportion of prey items by number in the diet of smallmouth bass sampled at Tishomingo National Fish hatchery and Durant State Hatchery, OK from 16 May--24 June, 1996. Day 1 is 16 May. These data were input in Fish Bioenergetics Model II (Hewett and Johnson 1992).

Prey item	Day						
	1	7	14	21	28	35	40
Zooplankton	1.0	1.0	1.0	0.5	0.5	0.0	0.0
Insects	0.0	0.0	0.0	0.5	0.5	1.0	1.0

Table 2. Values of p , fraction of maximum consumption, computed by Fish Bioenergetics Model II using actual growth data of cohorts of smallmouth bass fry and fingerlings grown during April-June, 1996 at Tishomingo National Fish Hatchery and Durant State Fish Hatchery in Oklahoma. These values represent the baseline stocking densities of 23,800 for Tishomingo pond and 20,800 for Durant pond. Day 1 was May 16. The model's default value of 0.009 for RA, the respiratory maintenance rate measured on juvenile bass, was used. p values were estimated using altered values of CA=0.35 and CB=-0.5. Values of p resulting when using default values of 0.25 for CA and -0.31 for CB are shown in parentheses.

Hatchery	Days					
	1-7	7-14	14-21	21-28	28-35	35-40
Tishomingo	0.77 (1.28)	0.92 (1.30)	0.71 (0.90)	0.50 (0.61)	0.61 (0.74)	----
Durant	0.78 (1.32)	0.45 (0.67)	0.30 (0.44)	0.39 (0.53)	0.37 (0.67)	0.46 (0.65)

Table 3.----Comparison of actual production of smallmouth bass fingerlings at two hatcheries in Oklahoma with two different estimates generated by Fish Bioenergetics Model II. One production estimate was the sum of production data based on weights measured each week during the study period (SWEP). The other production estimate was based on weight data measured at the start and finish of the study period (IFEP).

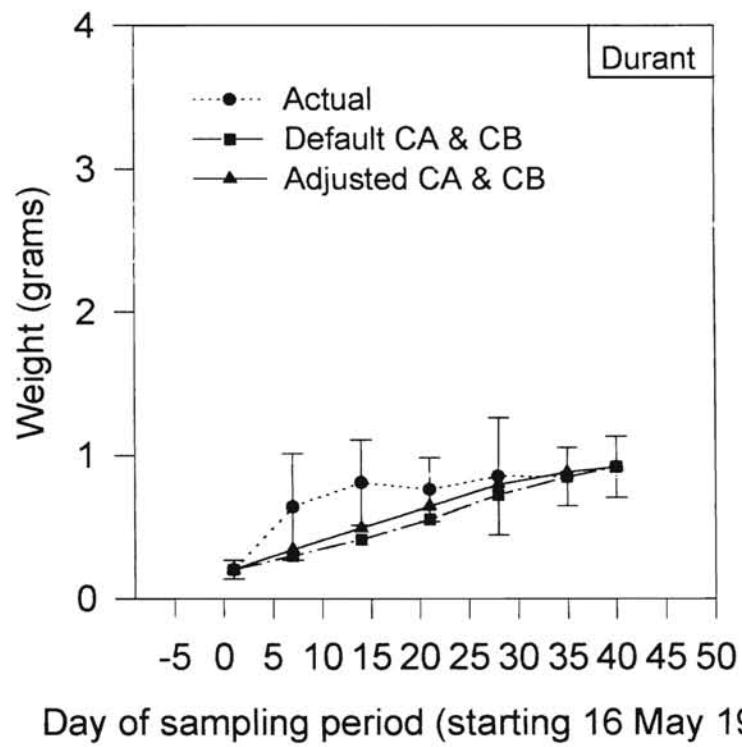
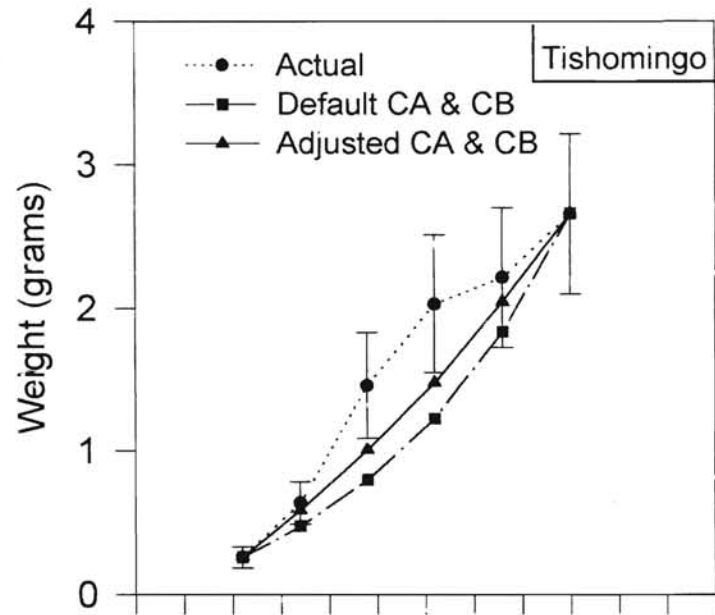
Hatchery	Actual production (g)	IFEP (g)	SWEP (g)
Tishomingo	41,178	43,584	44,946
Durant	7,264	7,945	9,534

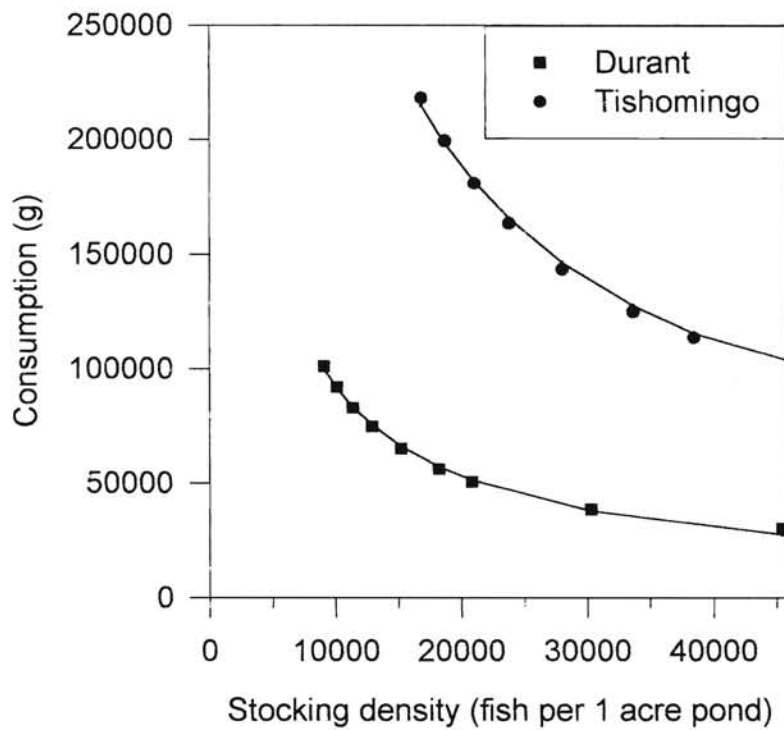
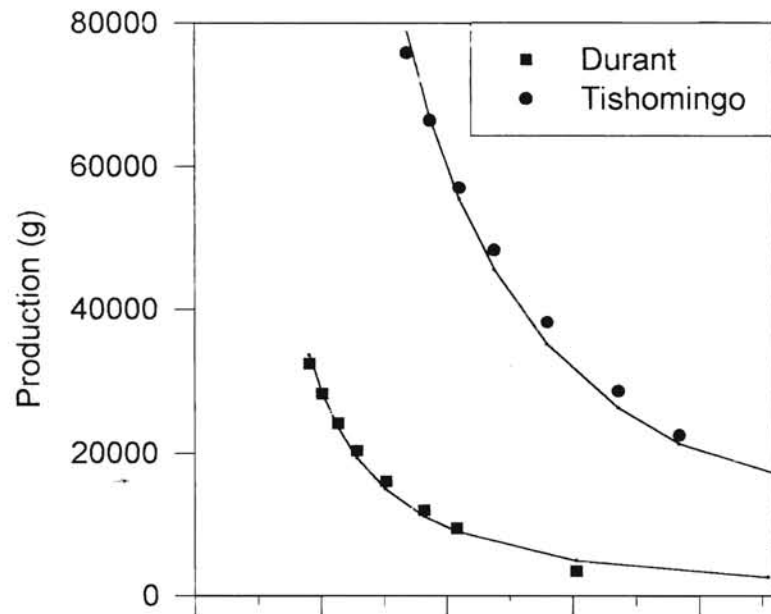
Table 4. Effect of prey availability, p , on food conversion of smallmouth bass fingerlings raised at Tishomingo National Fish Hatchery and Durant State Fish Hatchery from May-June 1996. Baseline p values were 0.71 at Tishomingo and 0.44 at Durant.

p	Consumption:production	
	Tishomingo	Durant
0.2	-15.3	-16.0
0.3	11.2	11.1
0.44	5.0	5.4
0.5	4.4	4.7
0.6	3.8	4.0
0.71	3.4	3.7
0.8	3.2	3.4
0.9	3.0	3.2
1.0	2.9	3.1

Figure Captions

1. Measured vs. estimated growth of smallmouth bass raised at Tishomingo National Fish Hatchery and State Fish Hatchery in Oklahoma. Estimates were by Fish Bioenergetics Model II, using its default values ($CA=0.25$, $CB=-0.31$) and adjusted values ($CA=0.35$, $CB=-0.5$) of physiological parameters. Day 1 of sampling period was 16 May 1996. Beginning and end weights input into the model were for the first and last days of the sampling period.
2. Effects of simulated stocking density on production and consumption of smallmouth bass fingerlings raised at Tishomingo National Fish Hatchery and Durant State Fish Hatchery in 1996.





Appendices

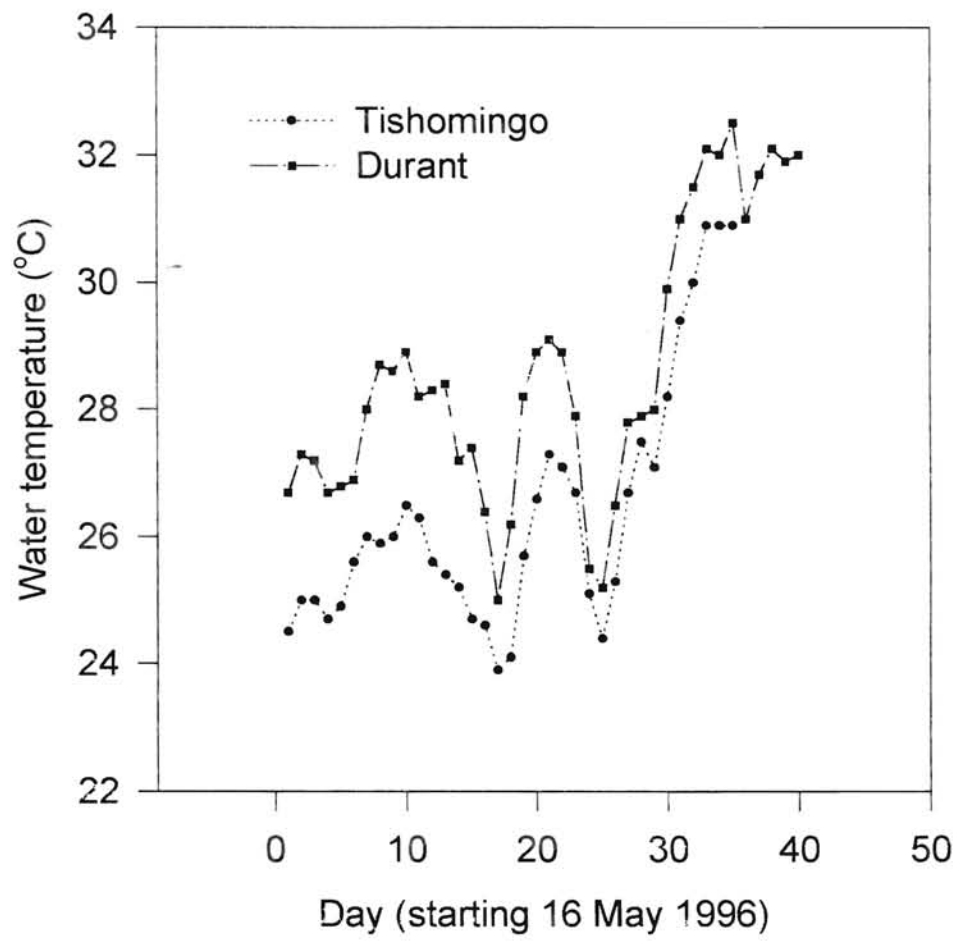
Appendix A

Mean (\pm standard deviation) weights and lengths of smallmouth bass sampled weekly at two fish hatcheries in Oklahoma.

Date	Mean weight±SD (g)	Mean length±SD (mm)
Durant State Fish Hatchery		
16 May 1996	0.2617±0.649	25.15±1.8579
22 May 1996	0.6395±0.3719	37.1311±6.0260
29 May 1996	0.8106±0.2998	43.0462±5.3922
5 June 1996	0.7608±0.2212	43.3333±3.9560
12 June 1996	0.8554±0.4108	43.8980±5.1092
19 June 1996	0.8512±0.2057	44.0862±3.8946
24 June 1996	0.9198±0.2161	45.7719±4.5655
Tishomingo National Fish Hatchery		
16 May 1996	0.2617±0.0730	25.8276±3.2180
22 May 1996	0.6396±0.1497	38.3600±2.9813
29 May 1996	1.4622±0.3722	50.6000±3.7241
5 June 1996	2.0178±0.4826	57.0877±4.7745
12 June 1996	2.2177±0.4853	59.8500±5.0984
19 June 1996	2.6632±0.5501	63.7586±4.5279

Appendix B

Mean daily water temperatures of study ponds at Tishomingo National Fish Hatchery and Durant State Fish Hatchery, Oklahoma.



CHAPTER III

A BIOENERGETICS ESTIMATE OF THE POTENTIAL EFFECTS OF IMPOSING
A FISHING REGULATION ON THE GROWTH OF SMALLMOUTH BASS
MICROPTERUS DOLOMIEU IN EASTERN OKLAHOMA STREAMS

Greg Robel

Oklahoma Cooperative Fish and Wildlife Research Unit

Department of Zoology, Oklahoma State University

Stillwater, Oklahoma 74078

Abstract.--We investigated the potential effects of prey availability altered by the imposition of fishing regulations on the growth of smallmouth bass *Micropterus dolomieu* in two eastern Oklahoma streams with bioenergetic modeling. Prey availability was assumed to vary inversely with population size which would be affected by the imposition of the fishing regulation. Baseline values of prey availability were derived for individuals and cohorts of smallmouth bass whose actual growth rates were obtained in previous studies in Glover-River in southeastern Oklahoma and Barren Fork Creek in northeastern Oklahoma. Water temperature in these streams for the period of growth was estimated after developing a model relating water and proximal air temperature. Simulated alterations in prey availability reflecting population size changes were based on recommended fishing regulations for each river. Our results showed that managing for increased population size and catch rates in Glover River, thereby reducing prey availability, would reduce growth rates and possibly survival rates more in smaller-sized fish than in larger-sized fish. In contrast, managing for decreased population size and enhanced growth rates in Barren Fork Creek, thereby increasing prey availability, would increase growth rates more in larger or older fish than in smaller or younger fish. These results suggest that a change in prey availability could potentially affect the size and survival of a cohort, the structure, size, and survival of a population, and perhaps the geographic distribution of the species through a bioenergetic mechanism.

Length limit regulations are routinely imposed on a fishery to enhance fishing. Before deciding on the implementation of a length limit regulation, fisheries managers judge its potential to achieve its aim. Reported effects of length limits on population size and growth have varied considerably from a positive to null to negative effect (Van Horn et al. 1981; Eder 1984; Summers 1988; Dean et al. 1991; Smith and Kauffman 1991). Hence, it is presumptuous to assume that a specific population size will result from a certain length limit regulation without first testing this assumption. Bioenergetics modeling is a tool that can be used to evaluate such assumptions (Hewett and Johnson 1992).

Based on an assessment of smallmouth bass Micropterus dolomieu populations in eastern Oklahoma streams, Stark and Zale (1991) recommended a slot limit regulation for several northeastern Oklahoma streams. They found smallmouth bass densities in Barren Fork Creek, a representative stream, to be among the highest on record for North America; however, lengths of fish older than age 2 were less than both national and regional averages. The recommended slot limit regulation was aimed at producing fewer, larger fish of higher quality by promoting the harvest of smaller fish, protecting mid-sized fish in the 110 to 304 mm slot so they could keep growing, and allowing the harvest of large fish. Such a slot limit regulation fulfilled a similar aim in a largemouth bass Micropterus salmoides fishery where population densities of fish were similarly high and growth rates were low (Eder 1984).

For southeastern Oklahoma streams, Stark and Zale (1991) recommended a minimum length limit for smallmouth bass. Compared to the smallmouth bass fisheries in northeastern Oklahoma, the representative Glover River fishery was characterized as

having relatively low numbers of fast growing fish with a greater fraction of larger individuals in the total population. A 384-mm minimum length and a daily creel of one fish was proposed to protect the most productive and fastest growing members of the smallmouth bass population in order to boost their numbers and increase catch rates.

Subsequent studies on the smallmouth bass fishery in eastern Oklahoma have produced additional information on fish population densities, growth rates, fishing pressure, and recreational use and value of the fishery (Martin 1995; Balkenbush 1996). We used a bioenergetics model (Fish Bioenergetics Model II; Hewett and Johnson 1992) and findings from Martin (1995) and Balkenbush (1996) to estimate the potential effects of length and creel limit regulations at Barren Fork Creek and Glover River on smallmouth bass growth. Our approach resembled that of Perry et al. (1995) who simulated the potential effects of harvest on largemouth bass growth in a catch-and-release fishery using the same model.

Methods

Study sites----Barren Fork Creek originates in northwestern Arkansas and flows into the Illinois River about 5.6 km southeast of Tahlequah in Cherokee County in northeastern Oklahoma. This Ozark Mountain stream is underlain by the Keokuk and Reeds Spring formations, which are composed of chert and limestone, and pre-Mississippian formations of shale, sandstone, and limestone (Marcher 1988). The streambed is alluvial, with much gravel. Water in the region is hard, with a range of 20-

1,172 ppm and a median of 1,262 ppm of CaCO_3 for 1948-1969. A few springs in the region are reported to yield several hundred gallons of water per minute. For 1994 and 1995, annual discharge rates on Barren Fork Creek averaged 126 m^3/s and ranged from an annual average of 12 to 2009 m^3/s (Blazs et al. 1996a).

In southeastern Oklahoma, Glover River flows into Little River about 19.3 km west of Broken Bow in McCurtain County. It is underlain by Arkansas Novaculite (includes fine-grained chert) and Bigfoot Chert with some interbedded shale and limestone (Marcher and Bergman 1983). The streambed is alluvial, with much Collier shale. Water hardness in Glover River is lower than at Barren Fork Creek, ranging from 12 to 38 ppm of CaCO_3 during 1949-1963. Precipitation in this region is historically the highest in Oklahoma (1.07-1.42 meters per year; Marcher and Bergman 1983). For 1994 and 1995, annual discharge rates on Glover River averaged 166 m^3/s and ranged from an annual average of 0.83 to 3509 m^3/s (Blazs et al. 1996b).

Model input simulating a no-regulation scenario.—We used Fish Bioenergetics Model II (Hewett and Johnson 1992) to model smallmouth bass growth. For this study, we used the preset values for all physiological parameters and the equation sets for smallmouth bass that were provided in the model (Hewett and Johnson 1992). Only adult bass >180mm in length were considered. Based on diet studies of stream-dwelling smallmouth bass (Doan 1940; Probst et al. 1984; Rabeni 1992), the diet file was set to represent a diet of 60% crayfish and 40% fish (by wet weight). Metabolizable energy densities of 2,449 cal/g dry weight for crayfish (Probst et al. 1984; Rabeni 1992) and 5498

cal/g dry weight for fish (Probst et al. 1984; Rabeni 1992) were converted into corresponding wet weight values using mean dry weight:wet weight conversion factors of 17.5% for larger aquatic invertebrates and 27.5% for fish (Hewett and Johnson 1993) and set at 612 cal/g wet weight and 1,520 cal/g wet weight, respectively, in the data file for prey caloric density. Using annual mortality rates reported by Martin (1995), instantaneous fishing mortality rate was set at the model's estimate of 0.00019882 and instantaneous natural mortality rate at the model's estimate of 0.00312174 for Barren Fork Creek. Mean weights of age 2 and age 3 cohorts sampled in Barren Fork Creek from August-September in 1994 and 1995 (Table 1) were input into the model as beginning and end weights, along with initial population size (abundance) for each cohort (Balkenbush 1996). Weights of individual fish weighed once when tagged in May 1994 and when recaptured in May 1995 by Martin (1995) in Barren Fork Creek (Table 2) and Glover River (Table 3) were also used; mortality rates for these individual fish were set at zero.

To generate water temperature data for the modeled period of fish growth, we related ambient air temperatures to stream temperatures for both streams with regression analysis (Stefan and Preud'homme 1993). Stream temperatures were measured every two hours using an electronic temperature data logger (Stowaway_{TM} XTI, Onset Computer Corporation, Pocasset, MA). One logger was submerged from January-November 1996 at about 45 cm in Barren Fork Creek at a site located less than 16 km northeast of Tahlequah, Oklahoma where the air temperature was routinely measured at a weather station of National Oceanic and Atmospheric Administration (NOAA). Another temperature logger was submerged from September 1995 to September 1996 at about 45

cm in Glover River at a site less than 24 km east of Broken Bow Dam, Oklahoma, where air temperatures were routinely measured by NOAA. Weekly means of air and water temperatures were computed and correlated with regression analysis. Weekly air temperature data acquired from NOAA for 1994 and 1995 from the Tahlequah and Broken Bow weather stations were input into the air-water temperature models to predict weekly mean temperatures of the stream water in which the smallmouth bass had grown. These weekly mean temperatures were input into the temperature data file in the bioenergetics model.

The input values described above were processed by the model to generate p values that represent the fraction of maximum consumption and are regarded as prey availability (Hewett and Johnson 1992). These p values were regarded as baseline values for the fishery as it exists now without fishing regulations.

Model input simulating a regulation scenario.----The value of p was adjusted to reflect changes in fish population size and prey availability (which p represents: Hewett and Johnson 1992) likely to result from the imposition of a fishing regulation. We chose fractions of the population size that were either more or less (e.g. $1.1p$ or $0.9p$) than the baseline fraction ($1.0p$) depending on the aim of the regulation concerned. The proposed regulations were aimed at enhancing growth rates by reducing the overall smallmouth bass population on Barren Fork Creek and at enhancing catch rates by increasing the population at Glover River. Population size was assumed to be inversely proportional to prey availability, p (Perry et al. 1995). For example, a population increased to 1.053 times

its baseline level corresponds to a reduction of p to 0.95 (1/1.053) of its baseline value. This allowed the computation of a new value of p from the population size presumed to result after the imposition of the fishing regulation. This new value of p was next input into the model to compute corresponding fish growth.

Results and Discussion

Air temperature-stream temperature model.----The regression equations relating air and stream temperatures were $W=1.9114+0.9346A$, for Glover River; and $W=4.5579+0.6890A$, for Barren Fork Creek, where W =water temperature and A =air temperature (both in °C). Correlation coefficients were $r^2=0.9596$ for Glover River and $r^2=0.9076$ for Barren Fork Creek (Figure 1). Unlike a similar model which excludes winter data for the iced-over periods of northern latitudes (Stefan and Preud'homme 1993), this “southern” model includes some winter data since there was no ice-over period. These models were used to estimate mean weekly water temperatures of each river the individual fish or cohorts experienced during their observed growth period (Figure 2).

Baseline p values----Baseline p values (“prey availability”) estimated using actual fish growth and water temperature data from Barren Fork Creek were 0.74 for an individual that grew from 580 g to 675 g, 0.93 for an individual that grew from 150 g to 374 g, 0.87 for an individual that grew from 160 g to 345 g, 1.0 for an age 2 cohort that grew from a mean weight of 127 g to 406 g, and 0.88 for an age 3 cohort that grew from

a mean weight of 332 g to 542 g. On Glover River, baseline p values were 0.77 for an individual that grew from 1048 g to 1305 g, and 0.66 for an individual that grew from 470 to 519 g. All of these values are within the range of 0.6 to 1.0 reported for adult smallmouth bass (Shuter and Post 1990).

Effect of fishing regulation on growth.----In Barren Fork Creek, the modeled reduction in population size, as indicated by the increase in prey availability, p , had a greater positive effect on the growth of larger individuals than smaller individuals. This is indicated by the higher ratio of relative growth under the fishing regulation to baseline relative growth under no fishing regulation for the larger individual (starting weight=580 g) compared with the two smaller individuals (starting weights of 150 g and 160 g; Table 2). This difference is attributable to the fact that increased prey availability increases consumption, which increases body weight, which has a negative exponential effect on consumption and metabolism (Kitchell et al. 1977; Hewett and Johnson 1992). Thus, the larger fish with its lower weight-specific metabolic rate was able to devote more energy to growth than the smaller fish with their higher weight-specific metabolic rates.

The age 2 cohort in the baseline scenario with no fishing regulation was feeding at maximum capacity ($p=1.0$); therefore, the increase in prey availability did not increase the growth rate (Table 2). Age 3 fish, however, did have the potential to grow faster ($p=0.88$). As with the individual fish, we expected the increase in prey availability to enhance the growth of age 3 cohort with greater mean weight (starting weight=332 g) more than it would enhance the growth of age 2 cohort with lesser mean weight (starting

weight=127 g), and their ratios of relative growth to baseline relative growth confirmed this.

In Glover River, a 10% reduction in p ($0.90p$) from the baseline level ($1.0p$) resulted in opposite effects on the growth of fish of different size. The larger individual went from a starting weight of 1048 g to 1080 g, a slight gain, whereas the smaller individual lost weight from 470 g to 421 g (Table 3, Figure 3). A comparison of ratios of relative weight change to baseline relative weight change showed that the reduction of p below baseline had a greater negative effect on the growth of the smaller individual (starting weight=470 g) vs. the larger individual (starting weight=1048 g). Simulated weights of fish using a 5% reduction in p were intermediate between the baseline and 10% reduction. Annual growth data on cohorts in Glover River were unavailable, but the same principle should apply: the reduction of p would have a greater negative impact on the growth of a younger cohort of lesser mean weight than on the growth of a cohort of greater mean weight.

Implications for fisheries management.----In using actual field data combined with a bioenergetics model, this study demonstrates that a change in prey availability, resulting from a change in fish population size due to the imposition of a fishing regulation designed to enhance either growth or catch rates, can have different effects on the growth of fish of different size. This influence of body weight on metabolic rate can be expanded to the population level under the reasonable assumption that body weight is correlated with age. A reduction of prey availability would have less of a negative impact on the growth (and

perhaps survival) of older versus younger cohorts as well as on larger versus smaller individuals within each of those cohorts. An increase in prey availability would favor older cohorts over younger cohorts as well as the larger versus younger individuals within each of those cohorts. Thus, a fishing regulation designed to alter the age structure and length frequency distribution of a fish population, by affecting prey availability, has different bioenergetic effects on fish of different size. The potential effects upon prey availability and the fish's energy budget should, therefore, be considered when judging the goals of a particular fishing regulation and its potential effects on the growth and survival of the managed species.

Considering the case of Barren Fork Creek, a regulation designed to enhance growth rates by decreasing overall population size and subsequently increasing prey availability would increase growth rates, albeit at a cost in population size and catch rates. With higher prey availability, the growth rate of larger or older individuals would be enhanced more than would that of smaller or younger individuals, thereby achieving the management aim of the regulation.

In the case of the Glover River, however, a fishing regulation designed to enhance catch rates by increasing population size might reduce prey availability and could potentially lead to the loss of smaller individuals (or younger cohorts) from the population. Considering the small individual, the minimum value of p required for annual maintenance lies somewhere between $0.95p$ (0.59) at which the fish lost weight and $1.0p$ (0.66) where the fish gained weight. In other words, prey availability is currently near the minimal level required for survival. A further reduction of prey availability resulting from the proposed

regulation would seem unwise, since the population size of smallmouth bass in Glover River would decline if smaller fish starved. This population decline would be contrary to the regulation's aim to increase the population for higher catch rates.

The effects of size limit regulations on growth rates, catch rates, population size and structure are well-documented (Eder 1984; Summers 1988; Smith and Kauffman 1991; Dean et al. 1991). Size limits are known to act partly by affecting prey availability (Timmons 1985; Brousseau and Armstrong 1987), but there is a lack of information on the weight-dependent, bioenergetic effects of changes in prey availability on growth rates, catch rates, and population size and structure. There is a need for more studies like Timmons' (1985), in which prey availability data were collected and considered in judging which type of regulation to apply on a black bass fishery in Kentucky Lake; and Perry's (1995), in which prey availability was estimated and then manipulated using a bioenergetics model (Hewett and Johnson 1992) to forecast the potential effects of imposing harvest upon a catch-and-release fishery. By enabling the estimation of baseline prey availability from readily measurable field data on growth rates and water temperature and allowing manipulations of prey availability to estimate its effects, bioenergetics modeling has the potential to facilitate such investigations. For example, the model could be applied to estimate existing prey availability in a fishery under consideration for a regulation aimed at enhancing catch rates; an estimate of prey availability, p , near 0.6 would suggest that the regulation could starve smaller fish despite to the regulation's objective. Another application would be to estimate prey availability and actual population size on a fishery, actually impose a fishing regulation, and then re-estimate prey availability

to assess how the regulation actually affected prey availability, actual growth rates, and population size, thus clarifying their interrelationships. Research on the effects of fluctuations in prey availability due to natural causes might also shed light on how such causes affect population size, structure, survival, and geographical distribution.

Acknowledgements

Mr. Zeek Rozelle generously provided access across his land to tend the temperature data logger. Tomoko Robel assisted with logger retrieval and disaster avoidance.

References

- Austen, D. J., and D. J. Orth. 1988. Evaluation of a 305-mm minimum-length limit for smallmouth bass in the New River, Virginia and West Virginia. *North American Journal of Fisheries Management* 8:231-239.
- Balkenbush, P. E. 1996. Population biology and management of centrarchids in Baron Fork Creek and Glover River, Oklahoma. Master's thesis. Oklahoma State University, Stillwater.
- Blazs, R. L., D. M. Walters, T. E. Coffey, D. K. White, D. L. Boyle, and J. F. Kerestes. 1996a. Water resources data, Oklahoma, water year 1995. U. S. Geological Survey Water-Data Report OK-95-1, Oklahoma City.
- Blazs, R. L., D. M. Walters, T. E. Coffey, D. K. White, D. L. Boyle, and J. F. Kerestes. 1996b. Water resources data, Oklahoma, water year 1995. U. S. Geological Survey Water-Data Report OK-95-2, Oklahoma City.
- Brousseau, C. S., and E. R. Armstrong. 1987. The role of size limits in walleye management. *Fisheries*. 12:2-5.
- Dean, W. J, Terre, D. R., Dolman, W. B., and T. W. Schlagenhaft. 1991. Largemouth bass population structure changes and harvest under a slot length limit. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 45:261-269.
- Doan, K. H. 1940. Studies of the smallmouth bass. *The Journal of Wildlife Management* 4:241-265.
- Eder, S. 1984. Effectiveness of an imposed slot length limit of 12-14.9 inches on

- largemouth bass. *North American Journal of Fisheries Management* 4:469-478.
- Hewett, S. W., and B. L. Johnson. 1992. Fish Bioenergetics Model II. University of Wisconsin Sea Grant Institute. WIS-SG-91-250. Madison.
- Kitchell, J. F., D. J. Stewart, and D. Weininger. 1977. Applications of a bioenergetics model to yellow perch *Perca flavescens* and walleye *Stizostedion vitreum vitreum*. *Journal of the Fisheries Research Board of Canada* 34: 1922-1935.
- Marcher, M. V.; and D. L. Bergman. 1983. Reconnaissance of the water resources of the McAlester and Texarcana Quadrangles, southeastern Oklahoma. Map HA-9. Oklahoma Geological Survey. Norman, Oklahoma.
- Marcher, M. V. 1988. Reconnaissance of the water resources of the Fort Smith Quadrangle, east-central Oklahoma. Map HA-1. Oklahoma Geological Survey. Norman, Oklahoma.
- Martin, C.D. 1995. Comparisons between Ozark and Ouachita stream fisheries in eastern Oklahoma. Master's thesis. Oklahoma State University, Stillwater.
- Perry, W. B., Janowsky, W. A., and F. J. Margraf. 1995. A bioenergetics simulation of the potential effects of angler harvest on growth of largemouth bass in a catch-and-release fishery. *North American Journal of Fisheries Management* 15:705-712.
- Probst, W. E., Rabeni, C. F., Covington, W. G., and R. E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. *Transactions of the American Fisheries Society* 113:283-294.
- Rabeni, C. F. 1992. Trophic linkage between stream centrarchids and their crayfish prey. *Canadian Journal of Fisheries and Aquatic Science* 49:1714-1721.

- SAS Institute, Inc. 1985. SAS users guide. Version 5 edition. Cary, N. C. 373 pp.
- Shuter, B. J., and J. R. Post. 1990. Climate, population, viability, and the zoogeography of temperate fishes. *Transactions of the American Fisheries Society* 119:314-336.
- Smith, P. P., and J. W. Kauffman. 1991. The effects of a slot size limit regulation on smallmouth bass in the Shenandoah River, Virginia. *In* First International Smallmouth Bass Symposium. D. C. Jackson, ed. pp.112-117.
- Stark, W. J, and A. V. Zale. 1991. Status of smallmouth bass populations in eastern Oklahoma. Oklahoma Department of Wildlife Conservation. Final Report. Federal Aid Project F-41-R, Job 14. Oklahoma City.
- Stefan, H. G, and E. B. Preud'homme. 1993. Stream temperature estimation from air temperature. *Water Resources Bulletin* 29 (1): 27-45.
- Summers, G. L. 1988. Largemouth bass population changes following implementation of a slot length limit. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 42:209-217.
- Timmons, T. J. 1985. Possible effects of changes in fishing regulations on the black bass population in the Kentucky section of Kentucky Lake. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 39:176-184.
- Van Horn, S. L., Chapman, W. R., and F. A. Harris. 1981. Results of a 45 cm (18 in) minimum size regulation on largemouth bass populations. *Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies* 35:424-429.

Table 1. Some statistics for smallmouth bass populations sampled in Barren Fork Creek, Oklahoma. Mean weights (in grams) and abundances (# of individuals) were used as input parameters in Fish Bioenergetics Model II (Hewett and Johnson 1992).

Age	Mean weight±SD				Abundance
	1994	N	1995	N	
2	126.9±71.8	15	406.3±78.7	8	393
3	332.3±66.2	12	541.7±30.6	6	787

Table 2. Simulated effects of various fractions of p , interpreted as prey availability, upon the weight after one year's growth of smallmouth bass individuals and cohorts in Barren Fork Creek, Oklahoma. Numbers in parentheses show the ratio of relative weight change to baseline relative weight change. Actual starting weight=SW. Actual ending weights are shown in the baseline situation represented by 1.00 p . Other ending weights are estimates using Fish Bioenergetics Model II (Hewett and Johnson 1992). Individuals were tagged and weighed in May 1994 and reweighed in May 1995. Cohorts were weighed first in August 1994 and later in August 1995.

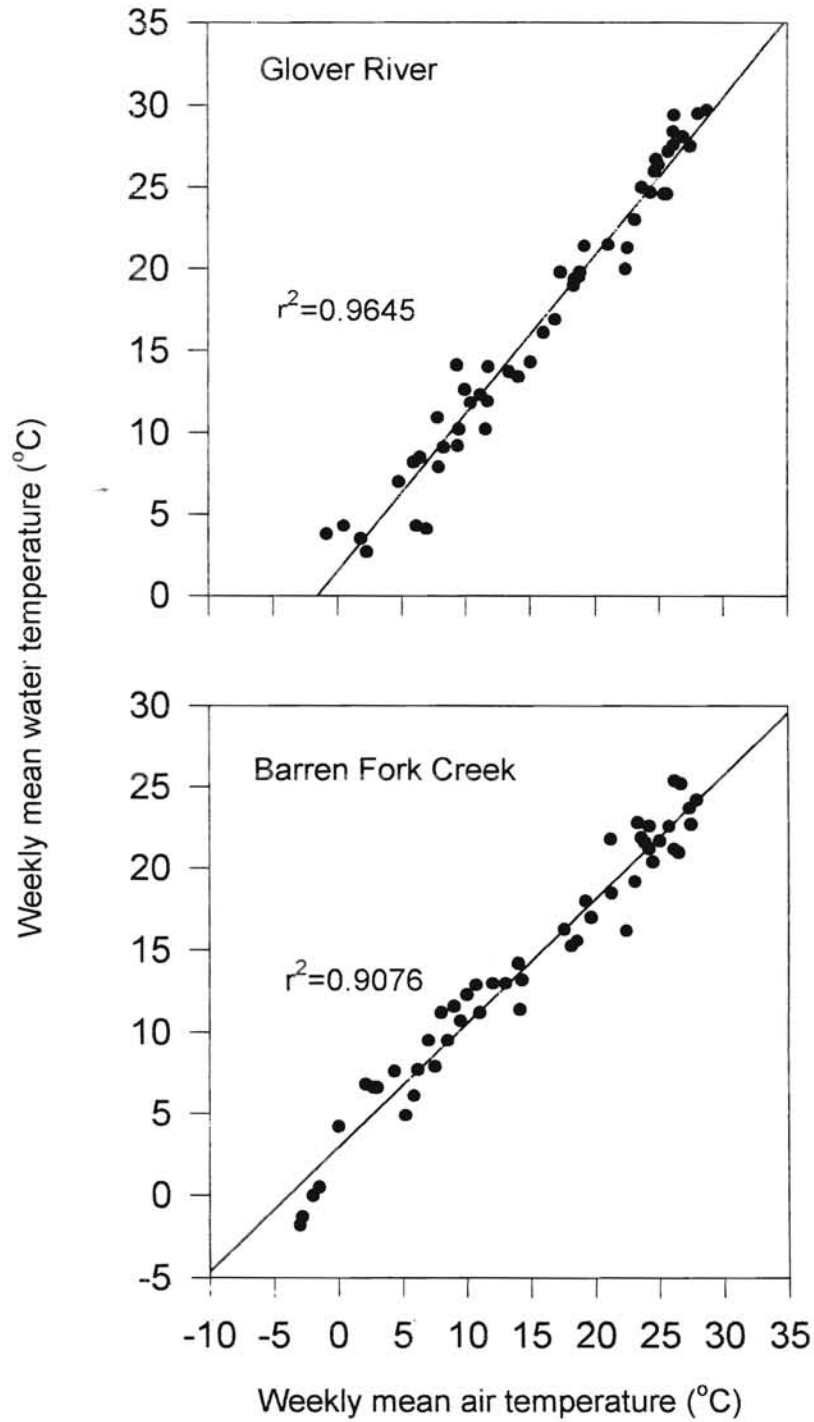
Consumption fraction	Individual fish weight			Mean cohort weight	
	g (ratio)	g (ratio)	g (ratio)	Age 2 g (ratio)	Age 3 g (ratio)
SW	150	160	580	127	332
1.00 p	374 (1.0)	345 (1.0)	675 (1.0)	406 (1.0)	542 (1.0)
1.05 p	419 (1.2)	384 (1.2)	728 (1.63)	406 (1.0)	588 (1.2)
1.10 p	442 (1.3)	432 (1.5)	858 (3.0)	-----	----

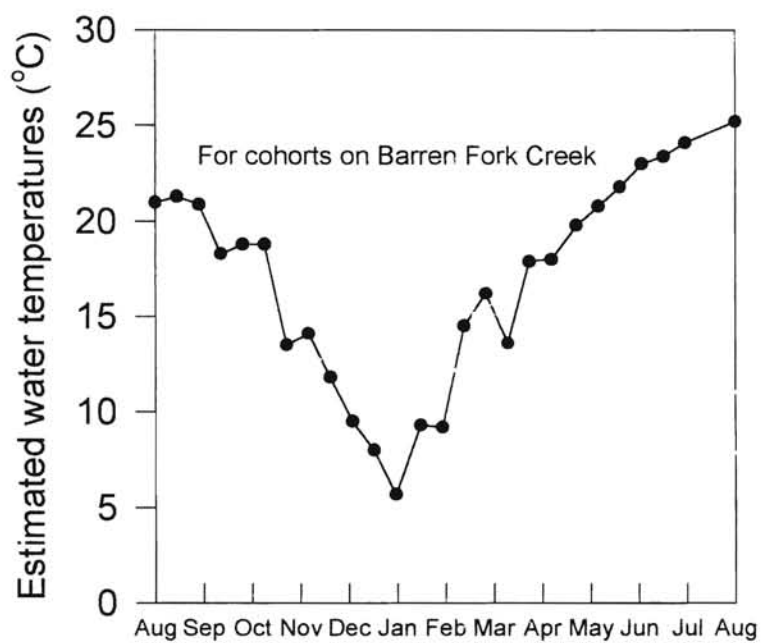
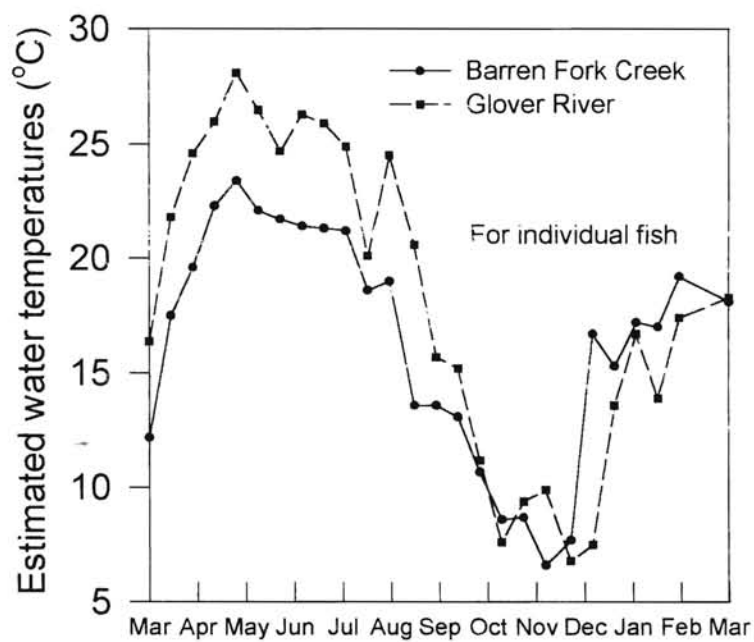
Table 3. Simulated effects of various fractions of p , interpreted as prey availability, upon the weight after one year's growth of smallmouth bass individuals in Glover River, Oklahoma. Numbers in parentheses show the ratio of relative weight change to baseline relative weight change. Weights are in grams. Actual starting weight=SW. Actual ending weights are shown in the baseline situation represented by 1.00 p . Other ending weights are estimates using Fish Bioenergetics Model II (Hewett and Johnson 1992). Individuals were tagged and weighed in May 1994 and reweighed in May 1995.

Consumption fraction	Fish weight	
	g (ratio)	g (ratio)
SW	470	1048
0.90 p	421 (-1.0)	1080 (0.124)
0.95 p	468 (-0.043)	1189 (0.52)
1.00 p	519 (1.0)	1305 (1.0)

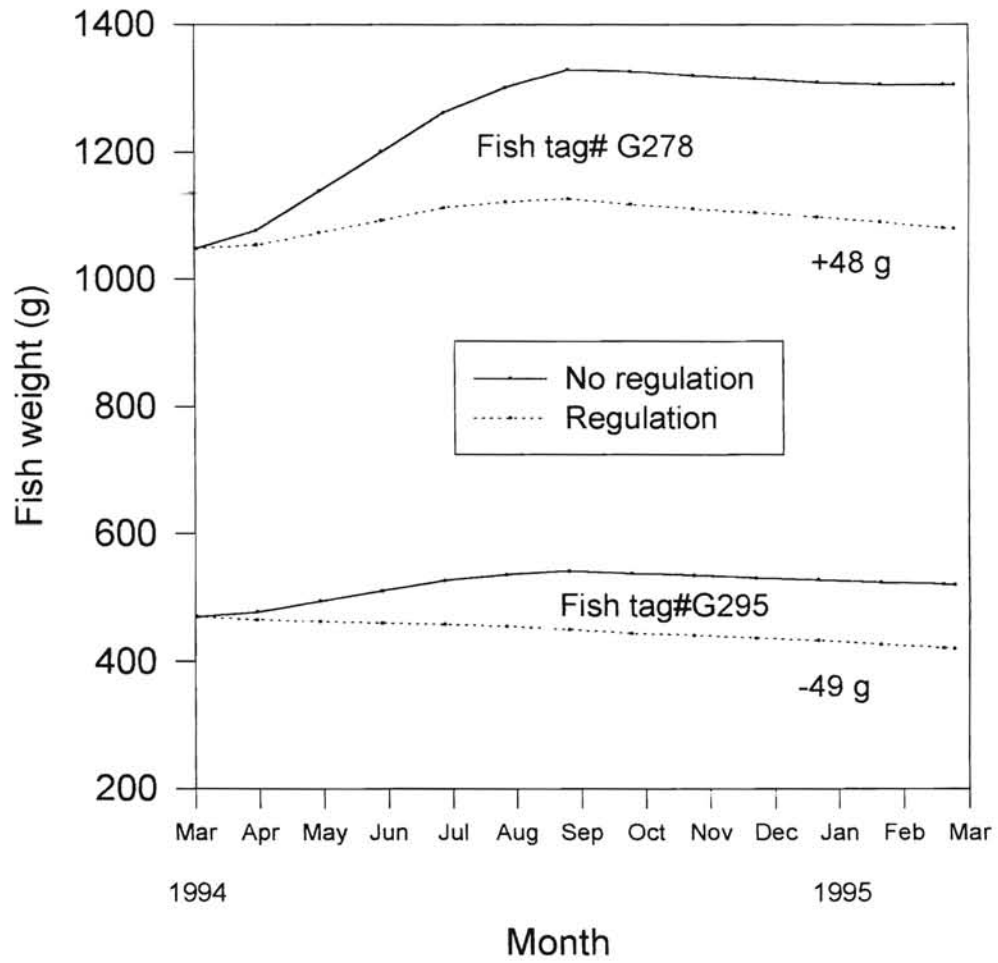
Figure Captions

1. Weekly mean temperatures of water vs. proximal air for Glover River and Barren Fork Creek, Oklahoma.
2. Estimated weekly water temperatures in Glover River and Barren Fork Creek during period of recorded growth of smallmouth bass individuals and cohorts.
3. Differential effect of a reduction in prey availability on the simulated growth of smallmouth bass individuals of different size in Glover River, Oklahoma. Fish were weighed when tagged in May 1994 and when recaptured in May 1995.





Month (starting in 1994)



VITA

Gregory Lee Robel

Candidate for the Degree of Master of Science

Thesis: Bioenergetics of Smallmouth Bass Micropterus dolomieu in Oklahoma hatcheries and streams

Major field: Wildlife and Fisheries Ecology

Biographical:

Education: Received Bachelor of Science Degree in Biology from University of California, San Diego, in March 1979; completed the Requirements for the Master of Science Degree at Oklahoma State University in December 1996.

Professional experience: Research assistant at Scripps Clinic in San Diego, 1982-1986; self-employed as translator/copywriter in Nagoya, Japan, 1986-1992; graduate research assistant for the Department of Zoology and Oklahoma Cooperative Fish and Wildlife Research Unit, May 1994-December 1996.

Organizational Memberships: Student sub-chapter of the Oklahoma Chapter of the American Fisheries Society, National Writers Club, Nature Conservancy, World Wildlife Fund.