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An evaluation of total body electrical conductivity to estimate body composition of largemouth bass, *Micropterus salmoides*

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Abstract − Measurement of total body electrical conductivity (TOBEC) recently has been used to estimate the body composition of several fish species in a noninvasive manner. The present study was conducted to evaluate the use of TOBEC in estimating body composition of largemouth bass (*Micropterus salmoides*). A total of 85 largemouth bass weighing 154 to 3 245 g were measured for electrical conductivity after which their proximate composition was determined by chemical means. Significant linear relationships existed between the natural logarithm of whole-body ash, lean body mass, lipid, protein, and water content and the natural logarithm of length and/or weight with r^2 values ranging from 0.860 to 0.999. Inclusion of the TOBEC value did not significantly improve the prediction accuracy of these models. Equations were developed to allow the prediction of body composition of largemouth bass based on length and weight measurements. Prediction models including only length and weight as variables provided estimates of body components of an independent set of fish that were not significantly different from chemically derived measurements of these components. These models should allow the rapid, nondestructive estimation of body composition of largemouth bass varying in size and condition without the added cost and processing time associated with measurement of TOBEC, although large prediction errors might prevent the detection of ecologically significant differences in body composition. However, with additional data involving narrower fish-size ranges and constant temperatures for the development of prediction equations, TOBEC may improve the prediction accuracy of body composition estimates for largemouth bass. © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

***Micropterus salmoides* / body composition / TOBEC**

Résumé − Évaluation de la conductivité électrique du corps entier pour estimer la composition corporelle de *Micropterus salmoides.* Des mesures de conductivité électrique totale (TOBEC) ont été utilisées récemment pour estimer la composition corporelle de plusieurs espèces de poissons sans dommage corporel. Cette étude a été conduite pour évaluer l'utilisation de TOBEC dans l'estimation de la composition corporelle de *Micropterus salmoides.* La conductivité électrique de 85 poissons de 154 à 3 245 g a été mesurée après que leur composition ait été déterminée par des moyens chimiques. Des relations linéaires significatives existent entre le logarithme de la composition en cendres, lipides, protéines, eau, la masse corporelle et le logarithme de la taille et/ou le poids avec des valeurs de r^2 comprises entre 0,860 et 0,999. L'introduction de valeurs obtenues par TOBEC n'améliore pas de façon significative la précision de prédiction de ces modèles. Des équations sont développées pour permettre la prédiction de la composition corporelle de ce poisson basée sur des mesures de taille et de poids. Des modèles de prédiction contenant seulement la taille et le poids comme variables fournissent des estimations des composants d'un groupe indépendant de poissons qui n'étaient pas significativement différents à partir des mesures dérivées de l'analyse biochimique. Ces modèles permettent l'estimation rapide et de façon non destructive de *Micropterus salmoides* de différentes tailles et de condition sans coût, ni temps de traitement supplémentaire, bien que des erreurs de prédiction puissent empêcher la détection de différences écologiques significatives dans la composition biochimique. Cependant, avec des données supplémentaires mettant en jeu des gammes de taille plus étroites et à des températures constantes pour établir des équations prédictives, TOBEC pourrait améliorer la précision de prédiction des estimations de la composition biochimique de *Micropterus salmoides.* © 2000 Ifremer/CNRS/INRA/IRD/Cemagref/Éditions scientifiques et médicales Elsevier SAS

***Micropterus salmoides* / composition corporelle / TOBEC**

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1. INTRODUCTION

An important aspect in the management of largemouth bass (*Micropterus salmoides*) and its prey is the assessment of body composition as it reflects the recent nutritional history of the fish and may indicate qualitative or quantitative value of prey species. The most common method of assessing body composition of fish is chemical proximate analysis. This method, however, is expensive, time-intensive, and requires the sacrificing of subject animals. Thus, several other means of estimating body composition have been established. McComish et al. (1974) accurately predicted percent lipid, protein, ash, and dry weight of bluegill (*Lepomis macrochirus*) using regression models based on length and live weight of the fish; whereas, Brown and Murphy (1991) found proximate components of juvenile striped bass (*Morone saxatilis*) and palmetto bass (*M. saxatilis* × *M. chrysops*) to be correlated with relative weight (*Wr*) which compares the weight of fish of a given length with a standard weight for fish of that length. Similarly, Rose (1989) determined that *Wr* may be used to estimate body composition of immature walleye (*Stizostedion vitreum vitreum*).

Total body electrical conductivity (TOBEC) is another non-destructive and reliable means of estimating a variety of body composition parameters in humans (Presta et al., 1983), small mammals (Keim et al., 1988; Walsburg, 1988) and birds (Castro et al., 1990; Walsburg, 1988). This technology also has been used to estimate body composition parameters of several species of fish including bluegill (Fischer et al., 1996), channel catfish (*Ictalurus punctatus*) (Jaramillo et al., 1994), red drum (*Sciaenops ocellatus*) (Bai et al., 1994), and sunshine bass (*Morone chrysops* × *M. saxatilis*) (Brown et al., 1993). In these previous studies with fish, the relatively small size of the detection chamber limited measurements to those from smaller specimens. In contrast, other researchers have recently reported that TOBEC did not significantly improve the prediction accuracy for lipid content in brook trout (*Salvelinus fontinalis*) (Novinger and Del Rio, 1999) or whole-body water content in yellow perch (*Perca flavescens*) and alewife (*Alosa psuedoharengus*) (Lantry et al., 1999).

In TOBEC measurement, the subject is introduced into a chamber containing a solenoidal coil which generates a low-frequency (10 MHz), oscillating magnetic field. The conductive and dielectric properties of the whole body due to the ionic (i.e., sodium and potassium ions) content of hydrated tissues cause a change in the impedance of the coil. This change in impedance is measured after the subject's body is inserted into the chamber. Because the capacitance of the body is partly determined by its geometry, the TOBEC value combined with relevant morphometric measurements can be used to predict lean body mass and percentage body fat (Fiorotto et al., 1987). However, the equations developed using TOBEC to predict body composition are species-specific and validation of the technique for individual species is recommended (Asch and Roby, 1995).

The objective of the present study was to evaluate the use of TOBEC to estimate whole-body composition of largemouth bass and to develop equations whereby the body composition of largemouth bass could be predicted based upon TOBEC and/or morphometric measurements. In this study, the detection chamber of the TOBEC unit was larger than the chamber used in previous studies with other fish species, thus potentially allowing assessment over a broad size range of largemouth bass.

2. METHODS

2.1. Experimental animals

A total of 85 largemouth bass with total lengths ranging from 23.5 to 56.6 cm and weights ranging from 154 to 3 245 g were collected for this study (*table I*). Of these, 69 were wild fish collected by hook-and-line sampling of several reservoirs within the state of Texas from 12 March 1997 to 23 April 1998. Fish were collected during various seasons of the year during this 57-week period, and the reservoirs varied in size, structure, and in the quality and quantity of prey species. Therefore, the sampled fish were expected to represent a wide range of nutritional states. The remaining 16 fish were cultured in a flow-through concrete raceway with prepared diets and were provided by Simaron Freshwater Fish, Inc., Hempstead, TX.

Upon collection, the stomach contents of the fish were removed by injecting a 3% solution of H_2O_2 into the stomach to induce regurgitation (Miranda, 1986). Stomach contents were removed to reduce the effect of recently ingested meals on body composition estimates, although the composition of gastrointestinal contents were read by TOBEC in a manner indistinguishable from other body components (Voltura and Wunder, 1998). Once regurgitation appeared complete, the fish were anesthetized with a 15 $mg \cdot L^{-1}$ solution of MS-222 (tricaine methanesulfonate) until a complete loss of equilibrium occurred. Water temperature was recorded and assumed to equal the body temperature of the fish. The fish were then measured for total length (cm) before being inserted into a model SA-3203 detection chamber connected to a model SA-3000 detector (EM-SCAN, Inc., Springfield, IL) for measurement of TOBEC. Fish were measured immediately after induction of anesthesia in order to prevent any possible effects due to the duration of anesthesia (Tobin and Finegood, 1995). The carrier sled used to introduce the fish into the detection chamber was created from a piece of 12.5-cm polyvinylchloride (PVC) pipe the length of the detection chamber and cut along the diameter. Individual fish were blotted dry and placed on the carrier sled lying on their left side. Blotting the fish and using the same orientation prior

Table I. Length, weight, sex, percent body composition, and total body electrical conductivity (TOBEC) values of all largemouth bass included in the model building and validation set*.

Length (cm)	Weight (g)	Sex	% Ash (CV)	% lean body mass (CV)	% Lipid (CV)	% Protein (CV)	% Water (CV)	TOBEC (CV)
23.5	204.1	m	2.7 (0.9)	93.7 (1.4)	6.3 (4.5)	18.2 (0.3)	72.7 (1.0)	22.4 (3.9)
23.8	187.9	f	3.2 (6.7)	94.9 (1.6)	5.1 (7.6)	18.9 (1.9)	71.4 (1.8)	23.4 (9.8)
24.0	153.9	f	5.5 (19.3)	97.5 (2.5)	2.5 (23.8)	20.1 (3.6)	73.1 (1.9)	15.8 (8.2)
24.1	225.6	m	3.5 (20.0)	93.6 (3.8)	6.4 (13.1)	17.7 (3.7)	71.3 (1.8)	27.8 (3.9)
24.5	222.6	m	3.8 (19.4)	93.4 (2.7)	6.6 (9.1)	18.0 (2.5)	71.4 (1.1)	25.4 (3.2)
24.6	194.9	m	3.2 (16.4)	92.1 (2.4)	7.9 (5.9)	17.2 (0.9)	72.6 (0.6)	24.8 (3.3)
24.9	233.0	m	3.8 (7.3)	91.2 (9.3)	8.8 (23.3)	17.7 (0.2)	68.9 (1.6)	25.4 (2.1)
25.3	250.0	f	4.1 (19.1)	93.1 (2.0)	6.9 (6.8)	18.1 (2.5)	69.4 (1.2)	25.0 (4.0)
25.3	275.1	f	3.2 (5.9)	92.9 (1.0)	7.1 (2.9)	18.1 (0.3)	71.4 (0.6)	27.4 (2.0)
25.8	231.3	m	4.2 (18.0)	93.9 (4.3)	6.1 (17.1)	18.3 (1.0)	70.0 (1.4)	27.4 (7.5)
25.8	263.5	f	5.0 (30.6)	90.6 (4.9)	9.4 (11.7)	18.1 (2.6)	68.2 (2.9)	28.4 (5.9)
27.1	302.2	f	3.6 (20.8)	92.6 (1.5)	7.4 (4.5)	18.4 (0.9)	70.5 (1.5)	32.2 (2.6)
27.3	380.3	f	3.3 (17.2)	92.1 (3.4)	7.9 (10.4)	18.2 (1.8)	68.1 (0.9)	33.8 (2.4)
27.7	323.1	f	3.2 (8.8)	91.1 (7.0)	8.9 (17.1)	18.2 (1.3)	69.5 (1.4)	35.4 (3.2)
29.0	297.0	m	5.2 (18.5)	93.6 (6.4)	6.4 (23.6)	17.2 (5.3)	70.0 (2.1)	31.8 (8.1)
29.0	429.0	m	4.9 (9.9)	94.1 (0.7)	5.9 (2.9)	18.9 (0.9)	69.7 (1.6)	50.0 (3.4)
29.4	364.9	f	3.8 (17.0)	91.2 (0.1)	8.8 (0.3)	18.0 (3.8)	68.1 (1.0)	44.2 (3.4)
29.5	293.8	m	4.3 (23.7)	94.6 (0.9)	5.4 (4.6)	17.7 (3.2)	67.7 (6.9)	28.8 (12.3)
31.9	464.0	f	3.5 (39.9)	89.6 (8.0)	10.4 (16.0)	18.3 (0.2)	68.9 (3.7)	50.2 (2.9)
32.0	363.6	m	5.2 (39.2)	94.7 (0.6)	5.3 (2.8)	16.8 (6.9)	69.9 (3.4)	36.0 (4.1)
32.4	388.5	m	5.8 (15.3)	96.6 (1.7)	3.4 (12.8)	17.8 (4.4)	71.4 (1.3)	41.8 (11.4)
32.5	416.1	m	6.3 (73.0)	95.7 (0.8)	4.3 (4.7)	17.8 (7.7)	69.4 (7.1)	45.2 (3.9)
32.7	427.7	m	4.8 (45.4)	98.3 (0.9)	1.7 (11.8)	18.4 (1.0)	74.7 (3.2)	40.0 (5.9)
32.9	493.9	m	4.1 (7.0)	95.1 (1.7)	4.9 (7.1)	18.3 (1.1)	74.6 (4.9)	55.2 (4.1)
33.0	411.1	m	5.3 (24.4)	94.2 (4.1)	5.8 (18.3)	19.1 (0.9)	68.6 (2.8)	42.8 (3.8)
33.3	481.9	f	4.0 (23.0)	94.7 (1.6)	5.3 (6.5)	19.2 (3.9)	73.1 (2.1)	48.2 (3.9)
33.5	388.8	m	4.3 (9.7)	95.1 (6.0)	4.9 (30.5)	18.0 (1.5)	70.1 (2.0)	46.2 (4.2)
33.7	548.5	m	5.7 (17.4)	91.4 (0.8)	8.6 (2.2)	18.6 (0.5)	67.3 (2.5)	60.4 (4.5)
34.5	546.0	m	4.1 (34.9)	91.5 (0.2)	8.5 (0.4)	17.9 (5.8)	69.1 (3.0)	55.8 (2.9)
35.0	592.3	m	3.7 (7.5)	88.9 (4.7)	11.1 (8.8)	18.8 (3.1)	68.3 (1.4)	57.6 (4.1)
35.3	638.8	m	4.8 (35.4)	91.7 (4.3)	8.3 (11.2)	15.1 (2.4)	70.2 (4.4)	65.8 (4.1)
35.4	513.5	m	5.6 (32.8)	88.8 (7.9)	11.2 (14.6)	18.2 (2.6)	68.3 (2.0)	53.8 (3.3)
35.5	603.1	f	2.9 (11.8)	92.9 (1.0)	7.1 (3.1)	17.9 (5.5)	71.0 (1.3)	62.0 (4.7)
35.5	676.0	m	4.8 (21.0)	91.0 (4.0)	9.0 (11.0)	18.5 (0.2)	66.3 (1.1)	84.8 (1.9)
35.7	543.5	m	3.9 (15.0)	95.1 (1.0)	4.9 (4.9)	19.3 (6.4)	71.5 (2.9)	65.8 (1.2)
35.7	598.0	m	4.5 (64.0)	91.5 (1.5)	8.5 (3.6)	16.8 (3.3)	70.8 (3.5)	64.2 (5.4)
35.7	613.3	m	4.3 (3.0)	93.0 (2.6)	7.0 (8.1)	17.8 (0.7)	71.0 (1.0)	62.8 (2.0)
36.0	628.5	f	3.5 (16.1)	90.5 (9.3)	9.5 (19.8)	17.9 (0.6)	70.1 (1.6)	66.4 (2.9)
36.5	622.0	m	3.7 (28.7)	92.5 (0.7)	7.5 (2.2)	16.9 (1.8)	69.8 (0.5)	69.0 (3.2)
36.7	640.9	m	7.1 (24.6)	93.8 (2.5)	6.2 (10.0)	17.6 (1.1)	69.3 (6.6)	71.2 (2.3)
37.0	547.3	m	4.5 (8.1)	96.9 (0.6)	3.1 (4.3)	17.5 (3.0)	74.9 (0.6)	59.2 (10.2)
37.0	572.4	m	5.2 (28.5)	97.2 (0.5)	2.8 (3.9)	17.8 (3.2)	73.2 (3.6)	63.2 (4.7)
37.0	636.4	f	6.2 (21.7)	93.4 (5.8)	6.6 (22.4)	18.1 (3.2)	68.1 (2.6)	68.2 (3.0)
37.5	737.2	f	4.4 (3.8)	92.9 (0.5)	7.1 (1.6)	17.7 (2.1)	71.0 (0.3)	82.4 (3.6)
37.6	1020.8	m	4.4 (2.5)	89.9 (0.6)	10.1 (1.3)	18.5 (1.5)	67.2 (1.6)	133.8 (0.8)
37.8	636.7	m	4.2 (7.7)	95.9 (0.4)	4.1 (2.3)	18.2 (5.2)	72.0 (1.3)	66.6 (1.7)
37.8	685.8	f	4.8 (22.7)	97.0 (2.3)	3.0 (19.3)	17.6 (6.1)	71.3 (5.6)	72.6 (4.9)
38.0	700.9	m	5.2 (5.7)	95.6 (5.0)	4.4 (25.9)	19.1 (2.9)	72.7 (0.6)	84.2 (2.5)
38.3	707.5	f	4.8 (9.5)	95.1 (2.6)	4.9 (12.4)	18.5 (2.4)	71.8 (1.1)	85.2 (3.0)
38.5	628.6	f	5.6 (12.6)	97.6 (0.4)	2.4 (4.5)	16.9 (0.6)	72.7 (1.1)	78.6 (3.2)
39.0	794.8	m	3.1 (31.8)	94.4 (0.8)	5.6 (3.3)	19.4 (3.2)	70.5 (2.2)	96.8 (3.2)
39.4	691.4	m	4.0 (7.9)	94.0 (1.0)	6.0 (4.1)	18.9 (1.0)	69.9 (3.2)	77.6 (2.5)
39.5	776.8	m	6.8 (15.4)	95.1 (1.4)	4.9 (7.7)	18.6 (0.7)	67.6 (5.4)	94.2 (2.4)
41.0	700.9	f	5.6 (15.0)	98.2 (0.9)	1.8 (12.8)	16.1 (0.9)	73.6 (2.6)	92.4 (4.9)
41.0	775.5	f	7.8 (44.4)	94.7 (1.7)	5.3 (8.5)	18.6 (1.4)	67.3 (6.8)	100.4 (4.7)
42.0	799.4	f	7.0 (14.5)	97.2 (2.1)	2.8 (19.9)	15.4 (9.9)	70.8 (3.3)	84.8 (6.6)
42.7	952.6	f	5.1 (25.4)	97.8 (0.1)	2.2 (0.7)	18.6 (0.4)	75.4 (2.1)	110.4 (4.3)
43.0	862.8	f	3.9 (14.2)	98.6 (0.1)	1.4 (2.3)	14.5 (0.8)	77.9 (1.0)	121.2 (3.6)
43.5	989.4	f	5.0 (5.5)	96.6 (0.6)	3.4 (4.0)	18.4 (0.8)	74.3 (0.8)	120.8 (3.3)

Length (cm)	Weight (g)	Sex	% Ash (CV)	% lean body mass (CV)	% Lipid (CV)	% Protein (CV)	% Water (CV)	TOBEC (CV)
44.1	1111.1	f	5.6 (7.3)	97.0 (0.3)	3.0 (2.8)	19.1 (1.7)	72.9 (1.7)	133.2 (4.6)
44.1	1635.0	m	3.6 (38.1)	88.9 (14.9)	11.1 (30.6)	16.7 (0.0)	66.1 (2.9)	275.4 (1.4)
45.8	1544.5	f	3.5 (13.3)	93.9 (6.1)	6.1 (24.6)	17.6 (4.0)	69.4 (4.6)	243.0 (1.1)
46.0	1143.4	f	5.7 (14.3)	95.3 (0.7)	4.7 (3.8)	17.4 (0.7)	70.6 (2.3)	143.4 (2.2)
46.0	1666.6	m	3.3 (16.6)	91.2 (8.5)	8.8 (23.6)	16.7 (1.1)	66.6 (2.8)	224.2 (1.6)
46.1	1746.9	f	3.4 (36.0)	93.3 (2.7)	6.7 (11.4)	18.6 (2.3)	64.9 (1.8)	285.0 (1.0)
46.4	1548.9	m	5.4 (33.0)	91.1 (6.9)	8.9 (19.0)	17.6 (3.4)	66.9 (4.8)	207.8 (2.5)
46.9	1923.8	f	4.5 (13.6)	91.0 (5.7)	9.0 (16.2)	17.9 (1.7)	65.4 (3.9)	351.0 (0.7)
47.0	1695.2	f	3.1 (28.0)	93.5 (0.4)	6.5 (1.5)	18.5 (1.6)	70.3 (2.9)	271.0 (1.0)
47.7	1762.1	f	4.0 (34.3)	92.0 (5.1)	8.0 (14.8)	18.3 (5.8)	69.0 (5.1)	286.6 (1.6)
47.7	1768.2	m	3.5 (8.4)	91.0 (2.4)	9.0 (6.2)	17.3 (1.0)	67.8 (2.3)	263.6 (2.3)
47.9	1687.1	f	3.8 (14.8)	95.2 (5.0)	4.8 (21.7)	17.7 (0.7)	74.6 (5.5)	263.4 (1.5)
49.4	2239.0	f	2.8 (23.5)	91.8 (8.3)	8.2 (21.1)	17.2 (4.2)	70.9 (0.6)	396.2 (4.6)
49.9	2418.9	f	3.7 (20.2)	87.6 (0.0)	12.4 (0.0)	16.7 (2.9)	64.2 (1.7)	439.6 (0.6)
51.9	2270.0	f	3.5 (19.1)	89.8 (7.1)	10.2 (14.3)	16.5 (5.0)	69.2 (1.9)	374.2 (1.0)
52.0	2064.9	f	3.3 (23.3)	96.0 (1.3)	4.0 (7.0)	19.1 (1.5)	74.1 (1.8)	304.4 (3.6)
52.0	2370.8	f	3.7 (59.7)	91.6 (0.6)	8.4 (1.6)	17.8 (0.5)	67.5 (3.5)	370.8 (5.2)
52.0	2538.1	f	4.3 (30.5)	90.2 (11.0)	9.8 (25.1)	18.1 (4.5)	67.9 (1.1)	519.8 (4.1)
52.1	2311.2	f	4.8 (46.4)	89.7 (4.5)	10.3 (9.5)	17.8 (2.6)	67.8 (1.8)	371.4 (0.8)
53.0	2750.9	f	2.4 (17.0)	85.1 (15.0)	14.9 (16.8)	16.9 (0.3)	68.4 (1.5)	516.8 (1.9)
53.4	2354.0	f	4.3 (10.8)	84.8 (5.6)	15.2 (6.3)	17.7 (1.5)	67.6 (1.3)	445.2 (4.3)
53.6	2474.1	f	3.3 (16.9)	93.4 (1.0)	6.6 (3.5)	16.7 (1.2)	70.5 (0.4)	555.8 (3.2)
54.1	2585.1	f	4.1 (8.0)	97.9 (1.6)	2.1 (21.4)	17.7 (6.0)	70.4 (1.6)	581.2 (4.3)
56.6	2360.3	m	6.1 (13.4)	92.1 (1.0)	7.9 (3.1)	17.6 (2.4)	67.6 (1.2)	429.2 (4.1)
56.6	3141.4	f	5.3 (15.1)	89.6 (5.9)	10.4 (13.4)	17.7 (3.9)	66.2 (2.5)	651.0 (9.4)
56.6	3245.3	f	4.2 (4.7)	88.6 (2.6)	11.4 (5.1)	16.6 (6.3)	66.0 (1.7)	799.8 (9.8)

* Values for ash and water are means of triplicate determinations from individual fish, while values for lean body mass, lipid and protein are means of duplicate analyses. TOBEC values are means of five separate readings. Coefficient of variation (CV = 100 SD/mean) values are included parenthetically.

to scanning reduced the potential variability due to conductivity of non-body water and body orientation, respectively. The fish were inserted on the carrier head first and centered in the detection chamber. Individual fish were repeatedly inserted into the chamber and scanned five times to obtain a mean TOBEC reading. As the non-destructive nature of this method for fish already has been established (Bai et al., 1994; Brown et al., 1993; Jaramillo et al., 1994), fish were immediately placed on ice and subsequently frozen pending analysis without first being allowed to recover. Once in the laboratory, the total weight (g) of individual fish was measured. Sex of the fish was noted to determine potential gender differences that may have affected model development.

The total length measurement of a portion of the sampled fish was not obtained until after the fish had been chilled on ice. This resulted in contraction of the body, and a reduction of the total length measurement. To compensate for this effect, the total lengths of a subset of 14 fish with lengths from 28.5 to 43.0 cm were measured in a live and chilled state. The following regression equation was then developed by which live length could be estimated from the chilled length:

$$\text{Live length} = -0.483 + 1.029 \text{ chilled length}$$

Length was expressed in centimeters. The r^2 coefficient for this equation was 0.997, and thus the adjusted fish length was used in the analysis of all fish that were chilled prior to being measured for total length.

2.2. Proximate analysis

Individual whole fish were homogenized prior to proximate analysis by dicing with a cleaver and passing them through a meat grinder with a 3-mm diameter die. Moisture content was measured in homogenized samples as weight loss after oven-drying at 125 °C for 3 h (AOAC, 1984). Subsequently, samples were placed in a muffle furnace at 650 °C for 3 h for ash determination (AOAC, 1984). Analyses for dry matter and ash were performed in triplicate for individual fish. Total lipid content was determined by chloroform–methanol extraction (Folch et al., 1957), and lean body mass (LBM) was calculated as total weight minus lipid weight. Determination of nitrogen was accomplished by the macro-Kjeldahl procedure (AOAC, 1984), and crude protein was calculated as nitrogen × 6.25. Duplicate samples for individual fish were used in the analysis of protein and lipid. Means of replicate samples for individual fish were used in all statistical analyses.

Table II. Means (± SD) of length, weight, and proximate body composition (percent wet basis) of male and female fish used in development of predictive equations for estimating body composition of largemouth bass.

Sex	*n*	Length (cm)	Weight (g)	Ash	Lean body mass	Lipid	Protein	Water
Male	40	34.9 (± 7.0)	661.8 (± 482.0)	4.6 (± 1.0)	93.3 (± 2.3)	6.7 (± 2.3)	17.9 (± 0.9)	69.9 (± 2.3)
Female	45	41.6 (± 10.0)	1300.7 (± 916.9)	4.3 (± 1.1)	93.1 (± 3.4)	6.9 (± 3.4)	17.8 (± 1.0)	70.1 (± 2.9)
Both	85	38.5 (± 9.22)	1000.1 (± 806.9)	4.4 (± 1.1)	93.2 (± 2.9)	6.8 (± 2.9)	17.9 (± 0.9)	70.0 (± 2.6)
Results of ANOVA comparison of male and female largemouth bass								
ANOVA Pr > F		0.0004	0.0001	0.2077	0.7611	0.7611	0.5554	0.6984

2.3. Statistical modeling and analyses

Prior to statistical analysis of the data, ten fish from the data set were randomly selected to serve as an independent validation group to test the prediction accuracy of the developed models. Predictive modeling and statistical analyses were conducted using established procedures (i.e., MEANS, ANOVA, REG, RSQUARE, STEPWISE) (SAS, 1988), and significance was set at $P < 0.05$ for all tests. Due to the high repeatability among the five TOBEC readings per fish and the success with other fish species (Bai et al., 1994; Brown et al., 1993; Jaramillo et al., 1994), a multiple regression model was used for the development of calibration equations in this study with TOBEC value, length, and weight assigned as independent variables. Whole-body ash, lipid, protein, water, and LBM were used as response variables. Models that best predicted body composition of largemouth bass were based on TOBEC value (T), total length (L), and weight (W) (or logarithmic or higher order transformations thereof) as independent variables. Subsets of independent variables were selected for further analysis based on higher coefficient of determination (r^2) and adjusted r^2 values, C_p statistic, lower mean square error (MSE), and the minimum number of significant variables (Ott, 1988). Plots of residual versus predicted values were examined to ensure constant variance, and the p-value for each variable within a model was examined to ensure its significance to the model.

Once the equations were developed, the body composition of each fish in the independent test group was estimated using the calibration equations. The prediction accuracy of the models was determined by comparing these estimated values with the values obtained by proximate analysis as previously described. The paired t-test was used to determine differences between actual and predicted values for the test group.

3. RESULTS

The collection of fish from various reservoirs, culture systems, and in various seasons provided a broad range of fish sizes and body compositions (*table I*). The mean length, weight, and body composition of largemouth bass collected for this study are shown in *table II*.

Although sampling of largemouth bass was performed in a random manner, dissection of the sampled fish revealed that a roughly equal number of males and females (40 males; 45 females) had been collected. Mean total length and total weight were significantly ($P < 0.05$) larger for female than for male largemouth bass collected in this study (*table II*). However, no significant differences between male and female bass existed in any of the proximate body composition components when expressed as a percentage of total body weight. Although it is likely that differences exist in body composition between male and female largemouth bass, particularly during the spawning season, these differences were likely masked by the collection of samples at various times of the year and from habitats that varied in prey quality and availability. Therefore, no distinctions were made between male and female bass for the development of the calibration equations.

All body components were significantly correlated with TOBEC value, with r^2 values ranging from 0.790 for lipid to 0.948 for lean body mass (LBM). However stronger correlation (r^2 from 0.792 to 0.996) existed with weight for all body components except ash which was most strongly correlated with length ($r^2 = 0.869$). Additionally, TOBEC values were very highly correlated with weight ($r^2 = 0.956$). Models that best predicted LBM, water, ash, protein, and lipid from length, weight and TOBEC value (or higher order transformations thereof) had high r^2 values (0.867 for lipid to 0.997 for LBM and water). Relative weight (Wr), condition factor ($W{\cdot}L^{-3}$), temperature, and length correction factor $(\text{TOBEC} \times L)^{1/2}$ (Jaramillo et al., 1994) also were tested as predictor variables but did not significantly contribute to the models. However, plots of residual versus predicted values indicated unequal variances for all models. Because unequal variances violate one of the necessary assumptions of parametric regression, logarithmic transformation of the response variables was performed to equalize variances. Natural logarithms were used for all log transformations in this study. Logarithmic transformation of the response variables resulted in a decrease in the r^2 values, and residual plots indicated that a linear fit was not appropriate for all of the predictive models. Logarithmic transformation of the predictor variables increased r^2 values and provided accurate models.

Table III. Least-squares regression equations for estimating the natural logarithm of body components (g) of largemouth bass based on the natural logarithms of total length (L) and total body weight (W) measurements ($P < 0.0001$).

Predictive models	β_0 se	β_1 se	β_2 se	r^2	Dependent mean	Mean square error
ln (*Ash*) = – 8.206 + 3.226 ln (*L*)	0.332	0.091	–	0.994	3.458	0.038
ln (*LBM*[a]) = – 0.571 + 0.357 ln (*L*) + 0.879 ln (*W*)	0.093	0.055	0.017	0.999	6.525	0.001
ln (*Lipid*) = 6.570 – 6.293 ln (*L*) + 3.033 ln (*W*)	1.51	0.892	0.274	0.860	3.801	0.160
ln (*Protein*) = – 1.621 + 0.984 ln (*W*)	0.051	0.008	–	0.996	4.871	0.002
ln (*Water*) = – 0.820 + 0.346 ln (*L*) + 0.880 ln (*W*)	0.119	0.071	0.021	0.999	6.238	0.001

[a] Lean body mass.

However, transformation of the predictor variables resulted in the TOBEC value no longer being a significant predictor in the models for any of the response variables. Although the original models required higher order transformation of the L and W variables, these also became unnecessary upon logarithmic transformation as higher order transformations become perfectly linear functions of their respective variables when taken as a logarithm. Selection procedures performed using logarithmic transformed response and predictor variables confirmed the appropriateness of the models, and plots of residual versus predicted values indicated equal variances for all models. Regression equations, coefficient standard errors, r^2 coefficients, dependent means, and MSE values for predicting logarithmically transformed body components are provided in *table III*.

Body weight proved to be the only significant variable for predicting protein in largemouth bass. Transformation of the equation for direct prediction of protein from weight resulted in:

$$\text{protein (g)} = 0.198 \times W^{0.984}$$

Similarly, the model for best predicting ash only required the use of length:

$$\text{ash (g)} = 0.000272 \times L^{3.223}$$

Length was an important variable in this model because a majority of the minerals are incorporated in the skeletal tissue. Models for all other body components necessitated the inclusion of both L and W as variables. Transformation of these equations for direct calculation resulted in:

$$\text{water (g)} = 0.440 \times W^{0.880} \times L^{0.346}$$
$$\text{lipid (g)} = 713.4 \times W^{3.033} \times L^{-6.293}$$

and

$$\text{LBM (g)} = 0.565 \times W^{0.879} \times L^{0.358}$$

For all equations, length was measured as total length in centimeters, and weight was expressed in grams.

These five regression equations were used to estimate the body composition of an independent test group of fish and predicted values were compared to those obtained by chemical proximate analysis (*table IV*). Paired *t*-tests were applied to the measured and predicted values of body components for this independent group to confirm the validity of the models. These tests indicated there were no significant differences between observed and predicted values (*table V*). However, water was overestimated for 8 of the 10 test fish, and ash was underestimated for 7 of the fish. This led to large mean differences for these two variables and resulted in p values that were considerably closer to the significance level than those obtained for the other variables. Similarly, although not significantly different, predicted lipid values had a mean prediction error of over 22%.

4. DISCUSSION

The fish used for the development of calibration equations in this study represent a much broader range in size and body composition than those used previously for other fish species. This was designed to allow the development of more general prediction equations that can be used to estimate composition of largemouth bass of various sizes and in various states of condition. However, this large size range resulted in the presence of unequal variances when predicting body composition components using TOBEC measurements, as large fish exhibited larger residual values than smaller fish, although percentage errors were likely similar. Logarithmic transformation of both response and predictor variables was required to equalize variances. Although transformation of the response and predictor variables resulted in the TOBEC value no longer being a significant predictor of body components, there appeared to be no loss of correlation in the transformed models as r^2 coefficients either increased or remained constant for all transformed models except for lipid which decreased by only 0.003 when compared to the untransformed model. These r^2 values are within the ranges obtained for models including TOBEC to predict body composition of other fish species (Bai et al., 1994; Brown et al., 1993; Fischer et al., 1996; Jaramillo et al., 1994).

Previous studies which reported the importance of TOBEC in estimating body composition of other fish

Table IV. Individual body measurements, and observed (O) and predicted (P) composition data, and mean prediction error for largemouth bass from the validation set used to evaluate the predictive equations developed in the present study. Statistical results are provided in *table V*.

Fish measurement		Ash (g)		LBM (g)		Lipid (g)		Protein (g)		Water (g)	
Weight (g)	Length (cm)	O	P	O	P	O	P	O	P	O	P
707.5	38.3	34.2	33.6	672.9	668.7	34.6	39.0	131.2	125.9	507.8	498.4
794.8	39.0	24.7	35.8	750.0	745.6	44.8	41.1	154.3	141.2	560.4	555.6
636.4	37.0	39.5	29.7	594.7	601.8	41.7	34.7	115.4	113.5	433.3	448.7
493.9	32.9	20.4	20.9	469.5	461.7	24.4	34.6	90.3	88.4	368.3	344.7
628.5	36.0	22.0	27.5	568.5	589.4	59.9	38.1	112.5	112.1	440.3	439.6
1111.1	44.1	62.0	52.3	1078.0	1046.2	33.0	47.8	212.7	196.3	810.1	778.5
2270.1	52.0	79.5	92.9	2038.3	2080.9	231.6	209.9	374.7	396.6	1570.2	1545.3
2474.1	53.5	82.1	105.1	2311.3	2267.4	162.8	178.9	413.2	431.6	1745.1	1683.2
204.1	23.8	5.5	7.7	191.2	189.0	12.9	12.0	37.2	37.1	148.3	141.7
388.8	33.5	16.9	21.6	369.7	376.4	19.1	26.1	70.0	69.9	272.6	281.0
Mean prediction error		22.7%		1.8%		22.4%		3.5%		2.9%	

species used small ranges of fish sizes for model development. The large size range used in the present study resulted in TOBEC values being more strongly correlated with body weight than with the various body components. Bell et al. (1994) found that TOBEC could not accurately predict lean mass due to a stronger correlation between TOBEC and body weight than between TOBEC and lean mass. In the previous studies with fish, TOBEC may have been more strongly correlated with the body composition as differences in the values for length and weight were not as large. Variability of the conductivity measurements also may have contributed to the low association between conductance and proximate measurements for largemouth bass. Coefficients of variation for conductivity measurements in the present study were larger than those obtained for bluegill (Fischer et al., 1996), brook trout (Novinger and Del Rio, 1999), channel catfish (Jaramillo et al., 1994), and red drum (Bai et al., 1994). However, coefficients of variation for the conductivity measurements were similar to those obtained by Brown et al. (1993) for sunshine bass.

Precision of body composition estimates using TOBEC is very sensitive to subject size in relation to the size of the detection chamber, with precision being greatest for those subjects which more completely fill the chamber (Asch and Roby, 1995). In this study, a large chamber was necessary to encompass the full range of fish sizes. The wide size range resulted in considerable variation in fish size relative to chamber size, and this may have led to a lack of precision for smaller subjects.

Another possible complication in using such a broad size range is due to the allometric growth of largemouth bass in which the overall body geometry of the fish changes as the fish grows (W and $L^{x \neq 3}$). Because the TOBEC signal is affected by the subject's body geometry as well as body composition (Fiorotto et al. 1987), models based on TOBEC which are developed using a broad size range may give erroneous results or result in unequal variances. Bellinger and Williams (1993) concluded that results from TOBEC may not be valid across size ranges, and more than one measurement equation may be necessary for various sizes. However, attempts to develop models using subsets of largemouth bass of smaller size ranges in the present study resulted in more complex prediction equations with considerably lower r^2 values, possibly due to the small sample size in each subset.

Measurement of TOBEC also is affected by the body temperature of the subject (Bai et al., 1994; De Bruin et al., 1994). Due to their poikilothermic nature, fish are considerably more variable in body temperature than homeothermic mammals or birds. In previous studies with fish, body temperature was constant across all subjects as they came from the same experimental system. Therefore, there was no need for a temperature correction of the TOBEC value. However, in the present study, largemouth bass were collected in various environments and seasons. This resulted in a body temperature range from 10.2 to 28.8 °C. In a previous study, TOBEC value was corrected for temperature using an estimate of a 2% change in TOBEC value for each 1 °C (De Bruin et al.,

Table V. Results of paired *t*-test analysis of observed and predicted body components (g) for largemouth bass in the validation set.

Statistic parameters	Ash	Lean body mass	Lipid	Protein	Water
Mean difference	–4.01	1.71	0.26	–0.12	13.96
SE	3.19	7.71	4.30	3.79	7.09
T	–1.26	0.22	0.57	–0.03	1.97
P value	0.24	0.83	0.96	0.98	0.08

1994). Correction of TOBEC value for temperature in the present study did not result in TOBEC becoming a significant predictor of body composition. This is likely due to the fact that although the overall temperature range was very broad, most of the subjects in this study were within a range of 4 °C. Walsburg (1988) estimated that a range of 4 °C would represent only a 5% error in TOBEC, although the estimations of De Bruin et al. (1994) would predict higher error from this temperature range. Roby (1991) found no correlation between residuals and body temperature within a range of 4 °C. In the present study, relationships between TOBEC and body temperature could not be assessed, as TOBEC measurements were not repeated on individual fish at different temperatures. However, there was no noticeable trend when residuals were plotted against body temperature. In future model development with fish, care should be taken to equalize temperatures among all subjects or to develop specific equations by which TOBEC value can be adjusted for the temperature of the subject.

Other researchers also have found that inclusion of TOBEC value did not significantly improve the prediction accuracy of models based upon morphometric measurements. Novinger and Del Rio (1999) reported that TOBEC did not add significant explanatory power for predicting lipid mass of brown trout. TOBEC also did not add significant predictive capability for whole-body water content of yellow perch and alewife over a model containing only wet weight (Lantry et al., 1999). These studies also report that further analysis of models including TOBEC to predict body composition of hybrid striped bass, channel catfish, and red drum provides only minor improvements over models using morphometric measurements alone (Lantry et al., 1999; Novinger and Del Rio, 1999). Burger (1997) found that TOBEC did not significantly enhance the accuracy of estimates for Northern cardinals and may not justify the purchasing of expensive TOBEC equipment. Similarly, Lyons and Haig (1995) found that TOBEC only slightly improved body composition estimates for shorebirds.

Relative weight (*Wr*) which compares the weight of a fish of given length to a standard weight also has been successfully used to predict body composition of striped bass and hybrid striped bass (Brown and Murphy, 1991) and juvenile walleye (Rose, 1989). However, attempts to develop predictive equations for largemouth bass body composition on a percent basis using *Wr* in the present study were not successful. Although all of the proximate components had a highly significant ($P < 0.001$) relationship to *Wr*, the r^2 values for the equations were low and only ranged from 0.13 for protein to 0.47 for ash.

McComish et al. (1974) developed models that accurately predicted body composition of bluegill based only on non-destructive length and weight measurements. However, all models developed for bluegill had considerably lower r^2 coefficients than the respective models developed for largemouth bass in the present study. In addition, models for predicting water, protein, and lipid of bluegill all included a coefficient of condition that was not shown to be a significant predictor for largemouth bass. However, the model developed by McComish et al. (1974) for prediction of ash in bluegill was similar to the one developed for largemouth bass in this study as both models required the use of the natural logarithm of length to predict the natural logarithm of ash. However, the intercept and slope coefficients were not similar between the two equations, possibly due to the differences in body shape between these two species. Similarly, length also was shown to be the only variable necessary to accurately predict ash for red drum, although logarithmic transformations were not required for that species (Bai et al., 1994).

Although TOBEC was not found to be a significant predictor of body composition of largemouth bass, models were developed whereby length and weight measurements can be used to estimate body composition of this species. These measurements are commonly collected by fisheries managers and might provide reliable estimates of body composition without the increase in cost and processing time associated with TOBEC measurement. Comparison of r^2 values indicates that predictive power is similar for the two methods. However, the prediction error for these models, particularly for lipid and ash, were relatively large. Lipid is a proportionally small, but very important, component of body composition, and even small prediction errors when expressed in grams may result in large percentage errors when compared to the total body lipid content. Although relatively small changes in lipid content may not significantly affect the total weight of the fish, they could represent a significant change in the whole-body energy content. Therefore, models predicting lipid based on length and weight alone may not adequately capture these small but ecologically significant differences, and caution should be used when interpreting the results of these predictions for individual fish.

Further refinement of the TOBEC method for largemouth bass involving the use of smaller size ranges and attempts to minimize differences in body temperature may result in the development of more specific predictive equations using TOBEC to further improve the prediction accuracy of body composition estimates.

5. CONCLUSION

The body composition of largemouth bass can be predicted by models containing only nondestructive length and/or weight measurements, and the inclusion of the TOBEC value does not significantly improve the prediction accuracy of these models. These models should allow the rapid, nondestructive estimation of body composition of largemouth bass varying in size and condition without the added cost and processing time associated with measurement of TOBEC, al though large prediction errors might prevent the detection of ecologically significant differences in body composition. However, with additional data involving narrower fish-size ranges and constant temperatures for the development of prediction equations, TOBEC may improve the prediction accuracy of body composition estimates for largemouth bass.

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