ELSEVIER

0308-8146(95)00092-5

*Food Chemistry*, Vol. 54, No. 4, pp. 409–418, 1995

0308-8146/95 $9.50

# Comparison of chemical composition of striped bass (*Morone saxatilis*) from three Chesapeake Bay tributaries with those of two aquaculture hybrid striped bass types

**Carol Karahadian,[a]* Kelly P. Fowler[b] & Dyveke H. Cox[c]**

[a]*Firmenich, Inc. Princeton, NJ 08543, USA*
[b]*Department of Nutrition and Food Science, University of Maryland-College Park, College Park, MD 20742, USA*
[c]*Department of Foods and Nutrition, Purdue University, West Lafayette, IN 47907, USA*

(Received 8 November 1994; accepted 2 May 1995)

Striped bass (*Morone saxatilis*) from three tributaries of the Chesapeake Bay (Potomac, Choptank and Upper Bay regions) and two commercial hybrid striped bass species (*M. saxatilis* x *M. chrysops* and *M. chrysops* x *M. saxatilis*) were evaluated for chemical composition. Fatty acid and proximate compositions of edible tissue from wild catches were very similar within a sampling season. Generally, fish sampled during spring spawning were higher in moisture and lower protein, lipid, ash, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) contents compared to their winter counterparts. Observed differences were influenced by seasonal factors including, water temperature, feed, and physiological changes. Both hybrid striped bass crosses had substantially higher *n*-6 and lower *n*-3 contents compared to wild-captured fish. This was a reflection of their diets.

## INTRODUCTION

Over the past several years, consumer demand for fish and seafood has been steadily increasing. Consumption of fish in the United States reached 7.2 kg per capita in 1990 and is expected to increase in the coming years (USDC, 1990; Haumann, 1989*a*; Haumann, 1989*b*; Redmayne, 1989). While demand for fish and seafood has increased, stocks of wild shellfish and fish including Atlantic striped bass (*Morone saxatilis*) have declined (Pigott & Tucker, 1990; Redmayne, 1989; Boreman & Austin, 1985; Goodyear *et al.*, 1985). Although federal and state agencies have successfully prevented extinction of striped bass in Atlantic regions by imposing moratoriums and fishing restrictions (Anonymous, 1989; Anonymous, 1990; Fincham, 1990; Diamond, 1990), it is unlikely that commercial catches will be able to fully supply consumer demands (Keiger, 1991). Therefore, in response to limited supplies of wild-captured striped bass, a renewed interest in aquaculture farming of striped bass and its hybrids has emerged (Redmayne, 1989; Haumann, 1989*b*; Smith, 1990; Greer, 1994).

Although aquaculture farming is not new to worldwide production of fish and seafood (Redmayne, 1989; Lovell, 1991; Hempel, 1993), producers have continued to explore cost-effective production practices that provide consumer-acceptable products (Hauck, 1989; Haumann, 1989*b*; Ling, 1989). Much of the research on the culture of striped bass has focused on nutritional (Eldridge *et al.*, 1981; Millikin, 1982; Geiger *et al.*, 1985; Martin *et al.*, 1985; Brown *et al.*, 1992; Nematipour *et al.*, 1992; Brown *et al.*, 1993; Nematipour & Gatlin, 1993) and other environmental requirements (Eldridge *et al.*, 1982; Tuncer *et al.*, 1990; Woods *et al.*, 1985; Houde & Lubbers, 1986) necessary for successful production. However, attention must also be given to end-product quality that result when fish are grown under the recommended conditions.

Changes in feed composition, seasons, and environment can alter the chemical and sensory properties of wild (Josephson *et al.*, 1991; Josephson *et al.*, 1984; Gallagher *et al.*, 1989; Coutant, 1986; Farkas *et al.*, 1980; Reiser *et al.*, 1963) and farm-raised fish (Fowler *et al.*, 1994; Polvi & Ackman, 1992; Maligalig *et al.*, 1983; Gibson *et al.*, 1977; Snow & Lovell, 1974).

Other than limited compositional data on wild-captured striped bass (Exler & Weihrauch, 1976; Smith, 1982; USDA, 1987), little is known about variations

*To whom correspondence should be addressed.

**Table 1. Sample description and environmental conditions of wild-captured striped bass and aquaculture hybrid striped bass**

| Sample description | Location of capture/harvest | Environmental conditions[a] | | |
|---|---|---|---|---|
| | | Temperature (°C) | | Salinity (parts/thousand) |
| Wild-captured | | | | |
| Potomac | Potomac River, near Quantico, VA | Spring (1990 and 1991) | | |
| | | 4/30/90 | 20.0°C | 0 |
| | | 5/4/90 | 19.5°C | 0 |
| | | 5/6/90 | 19.0°C | 0 |
| | | 5/9/91 | 20.2°C | 0 |
| | | Winter (1990) | | |
| | | 11/14/90 | 8.0°C | 0 |
| | | 11/19/90 | 8.0°C | 0 |
| Choptank | Choptank River, near Dover Bridge, Easton, MD | Spring (1990 and 1991) | | |
| | | 5/2/90 | 20.0°C | 0 |
| | | 5/3/91 | 20.0°C | 0 |
| | | Winter (1991) | | |
| | | 1/26/91 | 5.0°C | 0 |
| Upper Bay | Near Elk Neck State Park, MD and Aberdeen Proving Ground south of Sepsutie Point, MD | Spring (1990 and 1991) | | |
| | | 5/3/90 | 17.0°C | 0 |
| | | 5/30/90 | 18.0°C | 0 |
| | | 4/30/91 | 14.0°C | 0 |
| | | 5/30/91 | 21.0°C | 0 |
| | | Winter (1990) | | |
| | | 10/17/90 | 16.5°C | 0 |
| Liberty Reservoir | Liberty Reservoir, north of Patapsco Valley State Park, Oakland, MD | Spring (1991) | | |
| | | 5/21/91 | | 0 |
| Aquaculture | | | | |
| Original cross hybrid (*Morone saxatilis x M. chrysops*) | Eagle Farms (Cambridge, MD) | Brackish water | | |
| Reciprocal cross hybrid (*M. saxatilis x M. chrysops*) | Walnut Point Farms (Chestertown, MD) | Fresh (well) water | | |

[a]Conditions for wild-captured fish were provided by the Maryland Department of Natural Resources (Markham & Hornick, 1991; Schaefer & Hornick, 1991). Conditions for aquaculture fish were provided by the respective farms.

within subpopulations of wild striped bass and how they compare to aquaculture hybrid striped bass species. Therefore, the objective of this study was to compare chemical composition of wild-captured striped bass obtained from three tributaries of the Chesapeake Bay, a freshwater reservoir (Liberty Reservoir, Oakland, MD), and commercial aquaculture hybrid striped bass to determine how genetics, environmental, and seasonal conditions influence variations between populations.

## MATERIALS AND METHODS

### Capture/harvest and processing of striped bass

Samples of male wild-captured striped bass (*Morone saxatilis*) were obtained from the Maryland Department of Natural Resources (DNR) during the spring (April/May, 1990 and 1991) and winter (October/November, 1990) Chesapeake Bay tributaries sampling program (Table 1). Fish from the Upper Bay, Choptank River and Potomac River were captured using experimental drift gill nets. Samples were placed on ice and transported to the University of Maryland at College Park within 12 h of capture. Additionally, winter fish (January, 1991) from the Choptank River were purchased from a commercial fisherman. These fish were held on ice for 18 h prior to transport. Striped bass from a closed freshwater reservoir (Liberty Reservoir, Oakland, MD) were also obtained for the study (spring; May, 1991) and were transported on ice within 12 h of capture. Water temperatures and salinity values were measured and recorded by the Maryland DNR (Table 1).

Reciprocal cross hybrid striped bass (*Morone chrysops* × *M. saxatilis*) grown in fresh well waters (Walnut Point Farm; Chestertown, MD) and original cross hybrids (*M. saxatilis* × *M. chrysops*) grown in brackish waters (Eagle Farm; Cambridge, MD) were harvested from aquaculture ponds. Fish were cultured at these commercial farms according to general aquaculture practices described by Harrell *et al.* (1990) using commercial diets formulated for trout (38% protein, 8% fat; Ziegler Brothers, Gardners, PA).

Upon arrival, all fish were skinned and filleted, vacuum packaged in oxygen-barrier pouches (Winpack Vak 3-R, 0.80 mil Nylon/2.4 mil EVA copolymer, 3.2 $cm^3$ × mil/100 $in^2$ × 24 h × atm at 23°C; Holly Sales and Service, Inc., Elkridge, MD) at a minimum of 77 mm Hg (Multivac A300 Vacuum Packager, Wolfertschwenden, Germany) and frozen at -20°C (±2°C) until analyzed. No special care was taken to remove belly flaps from fillets. Fillets were ground in a food processor (Model KFP 400, Hobart Corp., Kitchen Aid Div., Troy, OH) to provide a homogeneous sample prior to analysis.

### Chemical analysis

Four replicate samples of edible muscle tissue from each fish group were analyzed for moisture, protein and ash. Moisture was analyzed using the AOAC vacuum oven method (AOAC, 1980). Replicates were dried for 5 h at 100°C and 77 mm Hg in a vacuum oven (Scientific Products, Columbia, MD). Protein content was determined using the Kjeldahl method (AOAC, 1980). After digestion, quantification of nitrogen was determined automatically using the Buchi distillation and titration system (Buchi, Flawil, Switzerland). Protein content was determined by multiplying nitrogen by 6.25 (AOAC, 1980). Ash was determined using the AOAC muffle furnace method (AOAC, 1980). Replicates consisting of about 2 g dehydrated sample were heated in a muffle furnace (Lindberg, Model 51894, Watertown, WI) for at least 2 h at 600°C. Calculations for percent ash were adjusted to account for hydration of original samples.

Samples of edible muscle tissue from three fish within each treatment group were analyzed to determine total lipid content. Analyses were carried out on homogenized (Model KFP 400, Hobart Corp., Kitchen Aid Div., Troy, OH) edible fish muscle tissue using the $CHCl_3$-MeOH solvent system of Bligh & Dyer (1957). Solvent was removed from the lipids using a vacuum evaporator (Rotovapor Model RE-111; Buchi, Flawil, Switzerland) at 45°C to constant weight. A modification of this method (Smith *et al.*, 1964) was employed for extraction of lipids from fish feeds. Diatomaceous earth (Sigma Chemical Co., St. Louis, MO) and anhydrous sodium sulfate (J.T. Baker, Inc. Phillipsburg, NJ) were incorporated into the solvent/feed slurries to prevent emulsification and to aid in filtration. Lipids were weighed to determine percent total lipid and were then vacuum packaged and frozen (−20 ± 2°C) for fatty acid analysis at a later date.

Fatty acid profiles of lipid extracts from three fish sampled at each sampling day (Table 1) were determined as methyl esters of fatty acids from saponified lipid (Metcalf & Schmitz, 1966). Approximately 150 mg of lipid were saponified using 5 ml of anhydrous 0.5 N methanolic sodium hydroxide (J. T. Baker, Phillipsburg, NJ) and heated in a 100°C waterbath for 3 min. The mixture was esterified using a $BF_3$ in methanol solution (approx. 50% by wt; Aldrich Chemical, Co., Milwaukee, WI).

Methyl esters of fatty acids were separated using a gas chromatograph (Hewlett Packard 5890 Series II, Hewlett Packard, Inc., Avondale, PA) fitted with a permanently bonded polyethylene glycol-fused silica capillary column (SUPELCOWAX-10; 30 m x 0.25 mm i.d.; 0.25 μm film thickness; Supelco, Inc., Bellefonte, PA). A program rate of 195°C (8 min hold) to 240°C at 3°C/min was employed. Identification of fatty acid methyl esters was achieved using published retention times (Anonymous, 1984) and position of eluting methyl esters of standard fatty acid methyl esters (FAME; Supelco, Inc., Bellefonte, PA) from the same SUPELCOWAX-10 column used for sample analysis. Peak areas were integrated using a Hewlett Packard computing integrator (HP 3396A, Hewlett Packard, Inc., Avondale, PA) and concentrations (area %) of each methyl

ester identified were calculated from all such fatty acids of each lipid sample.

Replicates of fatty acid analyses between sampling days and years within each subpopulation for a given season were not significantly different. Therefore, fatty acid data reported for each subpopulation (sampling region) within a season (winter and spring) reflects the mean of multiple analyses from all sampling days and years within a treatment group.

### Statistical analysis

Proximate and fatty acid data were analyzed by one-way analysis of variance (ANOVA) using the GLM procedure (SAS Institute, 1990). Least significant difference (LSD) tests at the 0.05 level of significance were used to separate means when significant differences were found.

## RESULTS AND DISCUSSION

### Comparison of wild-captured striped bass from three Chesapeake Bay tributaries

Mean weights and lengths of fish sampled from the Chesapeake Bay tributaries ranged from 0.73 to 3.45 kg and 32.3 to 57.6 cm, respectively (Table 2). All fish sampled were considered marketable size. Proximate analysis and fatty acid compositions of edible muscle tissue from regionally-sampled striped bass are reported in Table 3 and Table 4, respectively.

No significant difference in moisture, lipid or protein content were observed for non-hybrid fish sampled from Potomac River or Upper Bay regions within a sampling season (Table 3). However, fish from the Choptank River in spring and winter had significantly lower lipid

**Table 2. Mean values (SE) of weights and lengths of wild-captured striped bass and aquaculture hybrid striped bass samples.**

| Sample description | Weight (kg) | Length (cm) | Estimated age[a] (years) | $n^b$ |
|---|---|---|---|---|
| Wild-captured Spring samples | | | | |
| Potomac | 2.22 (0.20)[c] | 48.6 (1.6) | 4 | 15 |
| Choptank | 3.45 (0.17) | 57.6 (1.0) | 4–5 | 18 |
| Upper Bay | 2.00 (0.16) | 47.2 (1.5) | 4 | 18 |
| Upper Bay hybrid | 3.04 (0.35) | 48.3 (1.3) | 4 | 6 |
| Liberty Reservoir | 2.12 (0.22) | 45.7 (1.6) | 4 | 10 |
| Wild-captured Winter samples | | | | |
| Potomac | 1.50 (0.11) | 41.0 (1.2) | 3–4 | 25 |
| Choptank | 2.30 (0.22) | 48.0 (1.6) | 4 | 10 |
| Upper Bay | 0.73 (0.03) | 32.3 (0.6) | 2 | 22 |
| Aquaculture samples | | | | |
| Original cross hybrid | 0.44 (0.01) | 26.1 (0.2) | 1 | 91 |
| Reciprocal cross hybrid | 0.30 (0.01) | 22.1 (0.3) | 1 | 33 |

[a]Estimated age of wild-captured fish based on fish length as described by Setzler *et al.* (1980). Estimated age of aquaculture fish based on growing time from fingerlings to harvest. [b]$n$ = number of fish sampled. [c]Standard error of the mean in parentheses.

**Table 3. Proximate analysis of wild-captured striped bass and aquaculture hybrid striped bass**

| Sample description | Proximate analysis | | | |
|---|---|---|---|---|
| | Moisture | Lipid | Protein | Ash |
| | % Composition[1] | | | |
| Wild-captured Spring | | | | |
| Potomac | 78.86$^b$ | 2.63$^c$ | 19.6$^c$ | 1.22$^a$ |
| Upper Bay | 79.36$^b$ | 2.55$^c$ | 19.0$^{bc}$ | 1.56$^b$ |
| Choptank | 79.71$^b$ | 1.82$^b$ | 18.1$^b$ | 1.09$^a$ |
| Upper Bay hybrid | 79.76$^b$ | 3.25$^d$ | 16.4$^a$ | 0.95$^a$ |
| Liberty Reservoir | 79.06$^b$ | 1.01$^a$ | 19.2$^{bc}$ | 1.07$^a$ |
| Wild-captured Winter | | | | |
| Potomac | 78.86$^b$ | 3.25$^d$ | 21.8$^d$ | 1.15$^a$ |
| Upper Bay | 77.88$^b$ | 3.51$^d$ | 20.4$^{cd}$ | 1.64$^b$ |
| Choptank | 74.70$^a$ | 2.65$^c$ | 21.9$^d$ | 1.20$^a$ |
| Aquaculture | | | | |
| Original cross hybrid | 72.69$^a$ | 2.84$^c$ | 24.8$^e$ | 1.59$^{bc}$ |
| Reciprocal cross hybrid | 78.22$^b$ | 2.63$^c$ | 18.9$^{bc}$ | 1.17$^a$ |

[1] Values reflect means of four replications. [a,b,c,d,e]Mean values in the same column with different superscripts are significantly different ($P < 0.05$).

**Table 4. Total fatty acid composition of raw edible muscle tissue from wild-captured striped bass and aquaculture hybrid striped bass**

| Fatty acid | Spring samples | | | | | Winter samples | | |
|---|---|---|---|---|---|---|---|---|
| | Potomac[1] | Choptank[1] | Upper Bay[1] | Upper Bay Hybrid[1] | Liberty Reservoir[2] | Potomac[1] | Choptank[1] | Upper Bay[1] |
| | % of total lipids[3] | | | | | | | |
| C14 | | | | | | | | |
| 14:0 | 11.68$^{a}$ | 12.68$^{a}$ | 12.44$^{a}$ | 9.79$^{ab}$ | 5.65 | 6.29$^{b}$ | 10.39$^{a}$ | 9.81$^{ab}$ |
| C16 | | | | | | | | |
| 16:0 | 32.44$^{a}$ | 28.27$^{a}$ | 32.02$^{a}$ | 26.38$^{a}$ | 25.84 | 28.17$^{a}$ | 30.13$^{a}$ | 28.16$^{a}$ |
| 16:1*n*7 | 16.42$^{b}$ | 17.61$^{ab}$ | 16.33$^{b}$ | 17.73$^{ab}$ | 15.79 | 13.49$^{b}$ | 15.29$^{b}$ | 21.61$^{a}$ |
| C18 | | | | | | | | |
| 18:0 | 3.40$^{b}$ | 3.15$^{b}$ | 3.23$^{b}$ | 3.13$^{b}$ | 4.12 | 5.16$^{a}$ | 3.53$^{b}$ | 3.13$^{b}$ |
| 18:1*n*9 | 12.42$^{a}$ | 13.95$^{a}$ | 12.61$^{a}$ | 12.85$^{a}$ | 17.29 | 12.56$^{a}$ | 10.88$^{a}$ | 10.02$^{a}$ |
| 18:1*n*7 | 2.90$^{ab}$ | 1.08$^{b}$ | 1.82$^{ab}$ | 4.75$^{ab}$ | 5.60 | 3.02$^{ab}$ | 4.71$^{a}$ | 5.30$^{a}$ |
| 18:1*n*5 | 0.10$^{a}$ | 0.20$^{a}$ | 0.14$^{a}$ | 0.12$^{a}$ | 0.26 | 0.12$^{a}$ | 0.00$^{a}$ | 0.10$^{a}$ |
| 18:2*n*6 | 1.44$^{b}$ | 1.49$^{b}$ | 1.62$^{b}$ | 1.91$^{ab}$ | 3.35 | 2.41$^{a}$ | 1.34$^{b}$ | 2.09$^{ab}$ |
| 18:3*n*3 | 1.14$^{b}$ | 1.09$^{b}$ | 1.37$^{b}$ | 2.15$^{a}$ | 2.40 | 2.27$^{a}$ | 1.70$^{ab}$ | 2.28$^{a}$ |
| 18:4*n*3 | 1.69$^{ab}$ | 2.04$^{ab}$ | 2.45$^{a}$ | 2.75$^{a}$ | 2.55 | 0.97$^{b}$ | 1.81$^{ab}$ | 1.83$^{ab}$ |
| C20 | | | | | | | | |
| 20:1*n*9 | 1.31$^{ab}$ | 1.23$^{ab}$ | 0.85$^{b}$ | 1.37$^{ab}$ | 2.01 | 1.49$^{a}$ | 1.29$^{ab}$ | 0.84$^{ab}$ |
| 20:1*n*7 | 0.37$^{a}$ | 0.25$^{a}$ | 1.06$^{a}$ | 0.33$^{a}$ | 0.44 | 0.73$^{a}$ | 0.37$^{a}$ | 0.33$^{a}$ |
| 20:2*n*6 | 0.32$^{a}$ | 0.43$^{a}$ | 0.26$^{a}$ | 0.33$^{a}$ | 0.34 | 0.37$^{a}$ | 0.26$^{a}$ | 0.13$^{a}$ |
| 20:3*n*6 | 0.15$^{a}$ | 0.42$^{a}$ | 0.18$^{a}$ | 0.23$^{a}$ | 0.43 | 0.37$^{a}$ | 0.21$^{a}$ | 0.27$^{a}$ |
| 20:4*n*6 | 1.43$^{b}$ | 1.34$^{b}$ | 1.12$^{b}$ | 1.48$^{b}$ | 2.48 | 4.12$^{a}$ | 1.67$^{b}$ | 1.81$^{b}$ |
| 20:3*n*3 | 0.16$^{a}$ | 0.17$^{a}$ | 0.34$^{a}$ | 0.27$^{a}$ | 0.37 | 0.25$^{a}$ | 0.20$^{a}$ | 0.17$^{a}$ |
| 20:4*n*3 | 0.59$^{a}$ | 0.94$^{a}$ | 0.72$^{a}$ | 0.96$^{a}$ | 1.18 | 0.77$^{a}$ | 0.73$^{a}$ | 0.75$^{a}$ |
| 20:5*n*3 | 4.69$^{a}$ | 7.03$^{a}$ | 5.23$^{a}$ | 5.31$^{a}$ | 3.79 | 5.84$^{a}$ | 6.46$^{a}$ | 6.19$^{a}$ |
| C22 | | | | | | | | |
| 22:5*n*3 | 0.87$^{b}$ | 0.89$^{b}$ | 0.66$^{b}$ | 1.35$^{ab}$ | 1.20 | 1.86$^{a}$ | 1.53$^{a}$ | 1.40$^{ab}$ |
| 22:6*n*3 | 5.96$^{b}$ | 5.92$^{ab}$ | 5.71$^{b}$ | 7.00$^{ab}$ | 4.93 | 8.97$^{a}$ | 6.93$^{ab}$ | 3.80$^{b}$ |
| Total *n*-3 | 15.10 | 18.08 | 16.48 | 19.79 | 16.42 | 20.93 | 19.36 | 16.42 |
| Total *n*-6 | 3.34 | 3.68 | 2.91 | 3.95 | 6.60 | 6.90 | 3.48 | 4.30 |
| *n*-3:*n*-6 | 4.5:1 | 4.9:1 | 5.7:1 | 5.0:1 | 2.5:1 | 3.0:1 | 5.6:1 | 3.8:1 |
| Saturated | 47.52 | 44.10 | 47.69 | 39.30 | 35.61 | 39.62 | 44.05 | 41.10 |
| Monounsat. | 33.52 | 34.32 | 32.81 | 37.15 | 41.39 | 31.41 | 32.54 | 38.20 |
| Polyunsat. | 18.44 | 21.76 | 19.67 | 23.74 | 23.02 | 28.20 | 22.84 | 20.72 |

[1]Values represent means of at least six extractions from six fish sampled from spring 1990/1991 and winter 1990/1991 seasons; See Table 1. [2] Values represent duplicate analysis of a three fish composite sample and are within 10% variation.No statistical analyses were performed on these samples. [3]Percent total lipids were calculated from the total area of identified fatty acids.

contents compared to Potomac and non-hybrid Upper Bay fish (Table 3). Although slight variations were observed in protein content of fish muscle when sampled within a season, an increase in tissue protein was generally observed in winter-captured fish compared to fish sampled in the spring (Table 3). These findings were in agreement with those reported earlier for Atlantic cod (Botta *et al.*, 1987). Ash contents for Upper Bay fish were significantly higher than either Potomac or Choptank fish when sampled in spring and winter (Table 3).

Fatty acid compositions from each subpopulation showed more variation among winter- compared to spring-captured fish (Table 4). Concentrations of all identified fatty acids from spring-captured Potomac, Choptank, and Upper Bay (non-hybrid) striped bass were not significantly different from each other (Table 4). Spring-captured Choptank fish had a combined eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) content of 12.95% whereas fish from the Potomac and Upper Bay regions had a combined EPA and DHA contents of 10.65% and 10.94%, respectively (Table 4). Regionally-sampled winter fish showed significant differences in $C_{14:0}$, $C_{16:1n7}$, $C_{18:0}$, $C_{18:2n6}$, $C_{20:4n6}$, and $C_{22:6n3}$ (Table 4). Concentrations of EPA and DHA in winter-captured Potomac and Choptank fish were found to be slightly higher overall compared to their spring counterparts (14.81 and 13.39%, respectively; Table 4) whereas Upper Bay fish showed a substantially lower combined EPA and DHA concentration (9.99%; Table 4). In general, regionally-sampled spring fish had higher concentrations of saturated and monosaturated fatty acids and lower concentrations of polyunsaturated fatty acids (PUFA) compared to their winter counterparts (Table 4).

Compositional differences observed for wild-captured striped bass can be attributed to a variety of factors which include differences in growing environments, genetic variations within subpopulations, and sexual maturation that is influenced by age and season (Halver, 1989; Armstrong *et al.*, 1994; Reiser *et al.*, 1963; Sinclair *et al.*, 1986; Ackman, 1980; Evans *et al.*, 1986). Results obtained often represent the combined affect of one or more of these factors.

Feed sources within various tributaries of the bay can account for some of the compositional differences among regionally-sampled striped bass. Striped bass are primarily piscivorous and survive on schooling fish which are available in the environment (Scofield, 1928; Setzler *et al.*, 1980). Selection and abundance of each species varies substantially depending upon location, time of year and water conditions including temperature, oxygen content and salinity (Setzler *et al.*, 1980). Since spawning fish typically cease or limit their food intake, feed supply would be expected to influence fatty acid compositions of non-spawning winter fish to a greater extent than spring spawners (Halver, 1989; Setzler *et al.*, 1980; Hollis, 1952). Non-spawning fish have been shown to readily assimilate preformed fatty acids from the diet into tissue triglycerides (Sargent *et al.*, 1989). In studies using rainbow trout, uptake and storage of fatty acids originated from either dietary sources or *de novo* biosynthesis in the liver (Henderson & Sargent, 1981). Hybrid striped bass have been shown to readily incorporate dietary fatty acids into their tissue triglycerides (Nematipour & Gatlin, 1993; Fowler *et al.*, 1994).

Hollis (1952) determined that prey of Chesapeake Bay striped bass reflected seasonal populations of food organisms found in the bay. He noted that bay anchovy (*Anchoa mitchilli*) and menhaden (*Brevoorta tyrannus*) were the predominant prey of late summer and early fall, larval and juvenile spot (*Leiostomus xanthurus*) and croaker (*Micropogonias undulatus*) were predominant in winter, white perch (*Morone americanus*) in early spring and alewives (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*) in late spring and early summer. Winter-captured Potomac fish (October and November) feeding on *n*-3-rich menhaden and anchovies prior to their capture, contained high concentrations of EPA and DHA as well as other PUFA (Table 4). Lower concentrations of PUFA in fish captured from the Choptank River in January (Table 4) reflected to fatty acid content of croaker (Kinsella, 1987), a likely prey of winter striped bass (Hollis, 1952). Fatty acid profiles of winter-captured Upper Bay fish showed a substantial increase in monounsaturated fatty acids and low contents of PUFA which would appear to be contradictory. However, feed sources in the Upper Bay region may be substantially different from prey residing closer to the mouth of the bay.

*n*-6 Fatty acid concentrations in wild-captured winter fish were observed to be slightly higher than their spring counterparts. This was primarily caused by the increased concentrations of linoleic and arachidonic acids (Table 4). Although linoleic and arachidonic acid concentrations are not typically high in fall or winter prey (i.e. anchovy, menhaden and croaker), consumption of other aquatic algae, cyanobacteria, plankton, or aquatic plants rich in *n*-6 fatty acids (Sargent *et al.*, 1989) that are native to freshwater environments inhabited by striped bass during winter months may contribute to increase concentrations of these fatty acids in striped bass from all three sampling sites. Additionally, larval and juvenile spot which are known planktivorus feeders that scoop and strain bottom invertebrates (Homer & Mihursky, 1991), could accumulate *n*-6 fatty acids from their feed source and thus contribute to the final *n*-6 fatty acid content of winter-captured striped bass as well (Table 4).

Striped bass are anadromous fish that spawn in tidal freshwater zones of Chesapeake Bay tributaries and the main stem of the Upper Bay during April and May (Merriman, 1941; Raney, 1957). Unlike salmon, they can spawn many times throughout their lifetime (Jackson & Tiller, 1952; Setzler *et al.*, 1980). Their homing instincts direct them to their original spawning grounds each year (Setzler *et al.*, 1980). Studies using morphometric characters (Lund, 1957) as well as electrophoresis (Morgan *et al.*, 1973) have shown that subpopulations of striped bass exist within bay tributaries. Fish from Upper Bay regions including the Choptank, Nanticoke, Patuxent and Potomac Rivers have been characterized into different subpopulations (Morgan *et al.*, 1973). Although subpopulation distinctions have been made, a high degree of similarity has been observed between fish residing in eastern shore tributaries (Choptank and Nanticoke Rivers) and the western shore (Potomac and Patuxent Rivers) regions of the bay (Morgan *et al.*, 1973). Variations within subpopulations may account for some of the observed compositional differences in the edible muscle tissue.

Life cycle changes in spawning fish are known to modify fish muscle tissue (Halver, 1989). In this study, 4–5-year-old male fish inhabiting spawning tributaries of the Chesapeake Bay (Table 2) had reached sexual maturity (Jackson & Tiller, 1952; Setzler *et al.*, 1980). Studies with spawning salmon have shown that lipid, protein and carotenoids are mobilized into gonads and skin (Halver, 1989). Since many anadromous fish cease feeding during spawning (Setzler *et al.*, 1980), it has been observed that although some mobilized lipid is deposited in the gonads (Shatunavskiy, 1971; Henderson *et al.*, 1984; Idler & Bitners, 1960), catabolism of muscle tissue lipid to provide energy results in increased water content of muscle tissue while depleting lipid stores (Sargent, 1976). Significantly lower concentrations of protein and lipid contents observed in spring-captured fish from all bay tributaries could be attributed in part to mobilization of macronutrients to supply energy as well as gonadal development (Table 3).

Mobilization of lipids can also play a role in observed fatty acid composition of edible tissue in spawning fish. It has been noted that different species of fish preferentially mobilized specific fatty acids to supply energy or to participate in gonadal development (Sargent *et al.*, 1989). Salmon have been shown to preferentially mobilize long-chain monounsaturated fatty acids during gonadal development (Iverson, 1972). When significant differences were observed in monounsaturated fatty acid concentrations of striped bass, spring catches contained lower amounts of these fatty acids compared to their winter counterparts.

Previous studies have noted a correlation between colder water temperatures and increased PUFA in tissue triglycerides in selected fish species (Armstrong *et al.*, 1994; Reiser *et al.*, 1963; Sinclair *et al.*, 1986). When PUFA contents in fish were evaluated in light of water temperature, it was noted that catches from colder waters exhibited higher PUFA concentration compared to catches from warmer temperatures (Winter Potomac and Choptank, Table 1 and Table 4). These findings are in agreement with those previously reported for other species of fish (Armstrong *et al.*, 1994; Reiser *et al.*, 1963 Sinclair *et al.*, 1986).

**Wild-captured striped bass from Liberty Reservoir and Chesapeake Bay tributaries**

Wild striped bass not only reside in oceans, bays and bay tributaries but they also grow and survive in freshwater lakes and reservoirs. Edible muscle tissue of striped bass captured from the Liberty Reservoir were analyzed for proximate composition and sensory attributes and was compared to fish captured from the bay tributaries (Table 3 and Table 4 and Table 5). Comparisons of proximate compositions showed lipid content of Liberty Reservoir fish to be significantly lower compared to other wild-captured fish sampled in spring. Moisture and protein contents were not significantly different from spring-captured fish and ash content was significantly different from Upper Bay fish (Table 3). Since freshwater environments support aquatic life that is different from saltwater environments (Sargent *et al.*, 1989), it was not surprising to see differences in nutrient composition.

In addition to having substantially lower lipid contents, fish captured from the Liberty Reservoir had elevated concentrations of oleic acid and linoleic acids as well as lower concentrations of EPA and DHA compared to their bay tributary counterparts (Table 4). Concentrations of total fatty acids generally paralleled the relative abundance of fatty acids found in the stomach contents of the fish (Table 5). Lower concentrations of EPA and DHA in muscle tissue compared to their bay tributary counterparts (3.79 and 4.93%, respectively; Table 4) reflected the low EPA and DHA contents of the stomach contents (2.35 and 3.55%, respectively; Table 5). Although high concentration of oleic acid present in the stomach contents reflected concentrations observed in edible muscle tissue, high

**Table 5. Total fatty acid composition of lipids from aquaculture hybrid striped bass and feed sources of aquaculture hybrid striped bass and of stomach contents of wild-captured striped bass from Liberty Reservoir**

| Fatty acid | Raw muscle tissue samples[a] | | Feed samples | | |
|---|---|---|---|---|---|
| | Original cross hybrid | Reciprocal cross hybrid | Original cross hybrid | Reciprocal cross hybrid | Stomach contents Liberty Reservoir |
| | | | % of total lipids[b] | | |
| C14 | | | | | |
| 14:0 | 5.02 | 5.23 | 8.50 | 7.81 | 5.90 |
| C16 | | | | | |
| 16:0 | 22.54 | 25.57 | 22.77 | 23.50 | 26.53 |
| 16:1*n*7 | 9.64 | 7.82 | 10.01 | 7.31 | 10.59 |
| C18 | | | | | |
| 18:0 | 2.78 | 3.85 | 3.74 | 3.91 | 3.48 |
| 18:1*n*9 | 24.16 | 24.03 | 15.00 | 15.22 | 21.28 |
| 18:1*n*7 | 4.16 | 2.69 | 3.93 | 4.34 | 3.30 |
| 18:1*n*5 | 0.64 | 0.17 | —[c] | — | 0.38 |
| 18:2*n*6 | 14.57 | 12.73 | 17.45 | 16.07 | 13.84 |
| 18:3*n*3 | 1.54 | 1.53 | 1.74 | 2.12 | 1.97 |
| 18:4*n*3 | 1.11 | 0.95 | 1.66 | 2.04 | 2.10 |
| C20 | | | | | |
| 20:1*n*9 | 1.72 | 2.01 | 1.00 | 1.57 | 1.41 |
| 20:2*n*6 | 0.55 | 0.62 | 0.12 | 0.16 | 0.74 |
| 20:4*n*6 | 0.61 | 1.07 | 0.61 | 0.12 | 0.61 |
| 20:4*n*3 | 0.53 | 0.54 | 1.07 | 1.47 | 1.16 |
| 20:5*n*3 | 5.67 | 5.68 | 7.89 | 6.48 | 2.35 |
| C22 | | | | | |
| 22:5*n*3 | 0.81 | 0.86 | 0.98 | 1.12 | 0.79 |
| 22:6*n*3 | 3.97 | 4.93 | 3.49 | 6.76 | 3.55 |
| Total *n*-3 | 13.63 | 14.49 | 16.38 | 19.99 | 11.92 |
| Total *n*-6 | 15.73 | 14.42 | 18.18 | 16.35 | 15.19 |
| *n*-3:*n*-6 | 0.9:1 | 1.0:1 | 0.9:1 | 1.2:1 | 0.8:1 |
| Saturated | 30.34 | 34.65 | 35.01 | 35.22 | 35.91 |
| Monounsaturated | 40.32 | 36.72 | 29.94 | 28.44 | 36.96 |
| Polyunsaturated | 29.36 | 28.91 | 35.01 | 36.34 | 27.11 |

[a]See Table 1 for complete sample description. [b]Values presented represent duplicate injections of a three fish composite extraction and are within 10% variation. Percent total lipids were calculated from the total area of identified fatty acids. [c]None detected.

concentration of linoleic acid observed in feed source (Table 5) did not parallel that found in edible muscle tissue (Table 4). Since arachidonic acid levels were somewhat elevated in Liberty Reservoir fish, it appeared that linoleic acid was a precursor to the formation of arachidonic acid as well as other physiologically active compounds derived from *n*-6 fatty acids (Sargent *et al.*, 1989).

### Comparison of wild striped bass to wild hybrid striped bass

A small population of wild hybrid striped bass, which are believed to be primarily a cross between female striped bass and male white bass, reside in the Upper Bay region of the Chesapeake Bay. Little is known about their physiology, mode of reproduction, composition, or sensory attributes. Wild hybrid striped bass were identified by body shape and their proximate composition is reported in Table 3. Since these fish were captured in spring, comparisons were made to other spring-captured wild striped bass. Samples of Upper Bay hybrids had significantly more lipid compared to all other spring-captured fish but were not significantly different than their winter counterparts (Table 3). Their protein content was significantly lower than all other fish evaluated (16.32%; Table 3), but moisture content was not significantly different from all other fish sampled except for winter-captured Choptank fish. Assuming that environment and feed source of these wild hybrids were the same as striped bass residing in the Upper Bay region, it could be concluded that observed differences in macronutrient composition reflected genetic traits contributed by the white bass cross. Data provided by Kinsella (1987) showed white bass to have a higher total fat content (4.0%) compared to striped bass. The genetic trait of white bass to be able to accumulate higher concentrations of lipid could be carried through the hybrid cross and thus result in higher lipid contents in muscle tissue (Table 3).

Fatty acid compositions of wild hybrid striped bass are reported in Table 4. All fatty acids identified in wild hybrids and striped bass captured in the spring from the Upper Bay were not significantly different with the exception of linolenic acid (Table 4). Overall, concentrations of polyunsaturated and monounsaturated fatty acids were greater and saturated fatty acids were lower in hybrids compared to spring-captured striped bass in the other regions (Table 4). Although some of these observations reflect the fatty acid profile of white bass (Kinsella, 1987), the high degree of similarity between these two species would suggest that their environment may be more influential than genetic factors.

### Comparison of aquaculture striped bass to wild-captured striped bass

Samples of original and reciprocal cross aquaculture hybrid striped bass grown in brackish and freshwater environments were analyzed for proximate and fatty acid compositions (Table 3 and Table 5). While moisture, protein, and ash contents were significantly different for the two aquaculture hybrids, lipid content was not significantly different (Table 3). Fatty acid profiles were very similar between the two species and distribution of fatty acids closely parallelled that seen in the aquaculture feed (Table 5). Since both hybrid species have previously been shown to accumulate dietary fatty acids into muscle lipids (Fowler *et al.*, 1994), these results would be expected.

Fatty acid profiles of lipids from aquaculture and wild-captured fish indicated that wild-captured fish had substantially higher concentrations of *n*-3 and lower levels of *n*-6 fatty acids compared to the aquaculture fish (Table 4 and Table 5). Commercial feeds used to grow hybrid striped bass are generally supplemented with vegetable oils that contain higher concentrations of *n*-6 fatty acids compared to typical diets of fish found in the wild (Fowler *et al.*, 1994). The accumulation of dietary lipids in the edible muscle tissue would account in part for the observed fatty acid distribution (Table 4 and Table 5). These results are in agreement with other reports of fatty acid compositions of aquaculture species and their wild counterparts (Chanmugam *et al.*, 1986; Jahncke *et al.*, 1988; Nettleton, 1990; Van Vliet & Katan, 1990; Nettleton & Exler, 1992).

## CONCLUSIONS

It was generally observed that the edible muscle tissue of subpopulations of Atlantic striped bass native to sampled Chesapeake Bay tributaries were similar in chemical composition within a sampling season. Spring catches were generally higher in moisture content and lower in protein, lipid and ash compared to their winter counterparts which may be partially attributed to physiological changes resulting from spawning. Although concentrations of many fatty acid from regionally-sampled fish were not significantly different within a season, winter catches in colder water environments exhibited higher PUFA contents compared to spring counterparts. Temperature, feed, and physiological changes resulting from seasonal changes contribute to these differences. Wild-captured hybrid striped bass were closely comparable to the wild striped bass with the exception of significantly higher lipid contents and linolenic acid contents. Wild striped bass from freshwater reservoirs showed substantially lower concentrations of *n*-3 fatty acids which were likely attributed to differences in dietary fatty acids. Aquaculture hybrids were substantially different in their fatty acid composition compared to wild striped bass with lower 3-*n* and higher *n*-6 fatty acid contents.

## ACKNOWLEDGEMENTS

The authors would like to thank H. T. Hornick & W.P. Jensen from the Maryland Department of Natural

Resources for supplying samples of Potomac, Choptank, and Upper Bay fish and E. Enamait for providing samples of Liberty Reservoir fish. Research supported by the Maryland Agricultural Experiment Station and the College of Human Ecology, University of Maryland, College Park.

## REFERENCES

Ackman, R. G. (1980). Fish Lipids. Part I. In *Advances in Fish Science and Technology*, ed. J. J. Connell. Fishing News Books Ltd., Farnham, UK, pp. 86–103.

Anonymous (1984). GC capillary analysis of nonhydrogenated oils as fatty acid methyl esters. *The Supelco Reporter.*, **3**(5), 4.

Anonymous (1989). Chesapeake Bay striped bass management plan. Chesapeake Bay Program. Agreement Commitment Report. Annapolis, MD.

Anonymous (1990). Fisheries management report no. 16 of the Atlantic States Marine Fisheries Commission. Source document for the Supplement to the Striped Bass Fisheries Management Plan — Amendment #4. Columbia, MD.

AOAC (1980). *Official Methods of Analysis*, (13th edn). Association of Official Analytical Chemists, Washington, D.C.

Armstrong, S. G., Wyllie, S. G. & Leach, D. N. (1994). Effects of season and location of catch on fatty acid compositions of some Australian fish species. *Food Chem.*, **51**, 295–305.

Bligh, E. G. & Dyer, W. J. (1957). A rapid method of total lipid extraction and purification. *Can. J. Biochem. Physiol.*, **37**(8), 911–17.

Boreman, J. & Austin, H. M. (1985). Production and harvest of anadromous striped bass stocks along the Atlantic coast. *Trans. Am. Fish. Soc.*, **114**, 3–7.

Botta, J. R., Kennedy, K. & Squires, B. E. (1987). Effect of method of catching and time of season on composition of Atlantic cod (*Gadus morhua*). *J. Food Sci.*, **52**, 922–4.

Brown, P. B., Griffin, M. E. & White, M. R. (1993). Experimental and practical dietary evaluations with juvenile hybrid striped bass. *J. World Aquacult. Soc.*, **24**, 80–9.

Brown, L. M., Nematipour, G. R. & Gatlin, D. M. III. (1992). Dietary protein requirement of juvenile hybrid striped bass at different salinities. *Prog. Fish-Cult.*, **54**, 148–56.

Chanmugam, P., Boudreau, M. & Hwang., D. H. (1986). Differences in the *n*-3 fatty acid contents in pond-reared and wild fish and shellfish. *J. Food Sci.*, **51**(6), 1556–7.

Coutant, C. C. (1986). Thermal niches of striped bass. *Sci. Amer.*, **255**(2), 98–104.

Diamond, G. (1990). *Morone saxatilis* returns! The rock are back. *Maryland Magazine*, **23**(1), 53–5.

Eldridge, M. B., Whipple, J. A., Eng, D. Bowers, M. J. & Jarvis, B. M. (1981). Effects of food and feeding factors on laboratory-reared striped bass larvae. *Trans. Am. Fish. Soc.*, **110**, 111–20.

Eldridge, M. B., Whipple, J. A. & Bowers, M. J. (1982). Bioenergetics and growth of striped bass, *Morone saxitilis*, embroys and larve. *Fish. Bull.*, **80**(3), 461–74.

Evans, A. J., Fogerty, A. C. & Sainsbury, K. J. (1986). The fatty acid composition of fish from the North West Shelf of Australia, CSIRO. *Food Res. Q.*, **46**, 40–5.

Exler, J. & Weihrauch, J. L. (1976). Comprehensive evaluation of fatty acids in foods. *J. Am. Dietetics Assn.*, **69**, 243–8.

Farkas, T., Csenger, I., Majoros, F. & Olah, J. (1980). Metabolism of fatty acids in fish III. Combined effect of environmental temperature and diet on formation and deposition of fatty acids in the carp, *Cyprinus carpio* Linnaeus 1758. *Aquaculture*, **20**, 29–40.

Fincham, M. W. (1990). A season for stripers: The transition of the commons. *Maryland Marine Notes*, **8**(8), 1–3. Sea Grant Program, Patterson Hall, College Park, MD.

Fowler, K. P., Karahadian, C., Greenberg, N. J. & Harrell, R. M. (1994). Composition and quality of aquacultured hybrid striped bass fillets as affected by dietary fatty acids. *J. Food Sci.*, **59**, 70–5.

Gallagher, M. L., McLeod, S. H. & Rulifson, R. (1989). Seasonal variations in fatty acids of striped bass *Morone saxatilis*. *J. World Aquacul. Soc.*, **20**(2), 38–45.

Geiger, J. G., Turner, C. J., Fitzmayer, K. & Nichols, W. C. (1985). Feeding habits of larval and fingerling striped bass and zooplankton dynamics in fertilized rearing ponds. *Prog. Fish-Cult.*, **47**(4), 213–23.

Gibson, T. A., Worthington, R. E., Heaton, E. K. & Beuchat, L. R. (1977). Quality evaluation of frozen stored channel catfish grown by tank culture: effects of dietary fat, freezing method and storage temperature. *J. Food Sci.*, **42**(2), 352–4.

Goodyear, C. P., Cohen, J. E. & Christensen, S. W. (1985). Maryland striped bass: recruitment declining below replacement. *Trans. Am. Fish. Soc.*, **114**, 146–51.

Greer, J. (1994). Raising rockfish: the promise of aquaculture in Maryland. *Maryland Marine Notes*, **12**(5), 1–4. Sea Grant Program, Patterson Hall, College Park, MD.

Halver, J. E. (1989). *Fish Nutrition*,2nd edn. Academic Press, San Diego, CA.

Harrell, R. M., Kerby, J. H. & Minton, R. V. (1990). Culture and propagation of striped bass and its hybrids. Striped Bass Committee, Southern Div., American Fisheries Society, Bethesda, MD.

Hauck, K. (1989). Catfish cradle. *Prepared Foods.*, Nov. pp. 53–6.

Haumann, B. F. (1989*a*). Aquaculture; new markets for meals, fats and oils. *J. Am. Oil Chem. Soc.*, **66**(11), 1531–43.

Haumann, B. F. (1989*b*). Aquaculture helps meet rising demand. *J. Am. Oil Chem. Soc.*, **66**(11), 1544–6.

Hempel, E. (1993). Constraints and possibilities for developing aquaculture. *Aquacult. Int.*, **1**, 2–19.

Henderson, R. J. & Sargent, J. R. (1981). Lipid biosynthesis in rainbow trout, *Salmo gairdner II*, fed diets of differing lipid content. *Comp. Boichem. Physiol.*, **69C**, 31–7.

Henderson, R. J., Sargent, J. R. & Hopkins, C. C. E. (1984). Changes in the content and fatty acid composition of lipids in an isolated population of the capelin *Mallotus villosus* during sexual maturation and spawning. *Mar. Biol.*, **78**, 255–63.

Hollis, E. H. (1952). Variations in the feeding habits of the striped bass, *Roccus saxatilis* (Walbaum), in the Chesapeake Bay. Bull. Bingham Oceanogr. Collect., Yale Univ., **14**(1), 111–31.

Homer, M. L. & Mihursky, J. A. (1991). Spot *Leiostomus xanthurus*. In *Habitat Requirements for Chesapeake Bay Living Resources*, eds S. L. Funderburk, S. J. Jordan, J. A. Mihursky & D. Riley. Chesapeake Research Consortium, Inc., Solomons, MD.

Houde, E. D. & Lubbers, III, L. (1986). Survival and growth of striped bass, *Morone saxatilis*, and *Morone* hybrid larve: laboratory and pond enclosure experiments. *Fish. Bull.*, **84**(4), 905–14.

Idler, D. R. & Bitners, I. (1960). Biochemical studies on sockeye salmon during spawning migration. IX. Fat, protein and water in the major internal organs and cholesterol in the liver and gonads of the standard fish. *J. Fish. Res. Board Can.*, **17**, 113–22.

Iverson, J. L. (1972). Percent fatty acid composition and quality differences of Chinook and Coho salmon. *J. Am. Oil Chem. Soc.*, **55**(6), 1187–90.

Jackson, H. W. & Tiller, R. E. (1952). Preliminary observations on spawaning potentila in the striped bass, *Roccus saxatilis* (Walbaum). Md. Dept. Res. Educ., No. 93.

Jahncke, M., Hale, M. B., Gooch, J. A. & Hopkins, J. S. (1988). Comparison of pond-raised and wild red drum (*Sciaenops ocellatus*) with respect to proximate composition, fatty acid profiles, and sensory evaluation. *J. Food Sci.*, **53**(1), 286–7.

Josephson, D. B., Lindsay, R. C. & Stuiber, D. A. (1984). Variations in the occurrences of enzymically derived volatile aroma compounds in salt- and freshwater fish. *J. Agric. Food Chem.*, **32,** 1344–7.

Josephson, D. B., Lindsay, R. C. & Stuiber, D. A. (1991). Influence of maturity on the volatile aroma compounds from Pacific and Great Lakes salmon. *J. Food Sci.*, **56**(6), 1576–85.

Keiger, D. (1991). Troubled waters. A battle rages over rockfish. *Warfield's.*, Oct. 2, pp. 30–6.

Kinsella, J. E. (1987). *Seafood and Fish Oils in Human Health and Disease*. Marcel Dekker, Inc., New York.

Ling, R. (1989). Catfish culture, southern style. *Prepared Foods*, **Nov.**, 145–51.

Lovell, R. T. (1991). Foods from aquaculture. *Food Technol.*, **45**(9), 87–92.

Lund, W. A. Jr. (1957). Morphometric study of the striped bass, *Roccus saxatilis. U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish.*, 216, 24p.

Maligalig, L. L., Caul, J. F. & Tiemeier, O. W. (1983). Aroma and flavor of farm-raised channel catfish: effects of pond conditions, storage, and diet. *Food Prod. Dev.*, **7**(4), 86.

Morgan, R. P., II, Koo, S. Y. & Krantz, G. E. (1973). Electrophoretic determination of populations of the striped bass, *Morone saxatilis*, in the Upper Chesapeake Bay. *Trans. Am. Fish. Soc.*, **102,** 21–32.

Markham, J. L. & Hornick, H. T. (1991). Fall and winter stock assessment and commercial fishery monitoring. In *Investigation of Striped Bass in the Chesapeake Bay.* USFWS Federal Aid Performance Report. Project No. F-42-R-4. Maryland Department of Natural Resources, Fisheries Div., Annapolis, MD. p. 142.

Martin, F. D., Wright, D. A., Means, J. C. & Setzler-Hamilton, E. M. (1985). Importance of food supply to nutritional state of larval striped bass in the Potomac River estuary. *Trans. Am. Fish. Soc.*, **114,** 137–45.

Merriman, D. (1941). Studies on the striped bass (*Roccus saxatilis*) of the Atlantic Coast. *U.S. Fish Wildl. Serv., Fish Bull.*, **50,** 1–77.

Metcalf, L. D. & Schmitz, A. A. (1966). The rapid preparation of fatty acid esters for gas chromatographic analysis. *Anal. Chem.*, **33,** 363–4.

Millikin, M. R. (1982). Effects of dietary protein concentration on growth, feed efficiency, and body composition of age-0 striped bass. *Trans. Am. Fish. Soc.*, **111,** 373–8.

Nematipour, G. R., Brown, M. L. & Gatlin, D. M. III. (1992). Effects of dietary carbohydrate: lipid ratio on growth and body composition of hybrid striped bass. *J. World Aquacult. Soc.*, **23,** 128–32.

Nematipour, G. R. & Gatlin, D. M. III. (1993). Requirement of hybrid striped bass for dietary (*n*-3) highly unsaturated fatty acids. *J. Nutr.*, **1234,** 744–53.

Nettleton, J. A. (1990). Comparing nutrients in wild and farm fish. *Aquacult. Mag.*, **Jan/Feb**, 34–41.

Nettleton, J. A. & Exler, J. (1992). Nutrients in wild and farmed fish and shellfish. *J. Food Sci.*, **57**(2), 257–60.

Pigott, G. M. & Tucker, B. W. (1990). *Seafood. Effects of Technology on Nutrition.* Marcel Dekker, Inc., New York.

Polvi, S. M. & Ackman, R. G. (1992). Atlantic salmon (*Salmo salar*) muscle lipids and their response to alternative dietary fatty acid sources. *J. Agric. Food Chem.*, **40,** 1001–7.

Raney, E. C. (1957). Subpopulations of the striped bass *Roccus saxatilis* (Walbaum), in tributaries of Chesapeake Bay. In *Contributions to the Study of Subpopulations of Fishes*, ed. J. C. Marr. *U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish.* 208, pp. 85–107.

Redmayne, P. C. (1989). World aquaculture development. *Food Technol.*, **43**(11), 80–1.

Reiser, R., Stevenson, B., Kyama, M., Choulhury, R. B. R. & Hood, D. W. (1963). The infuence of dietary fatty acids and environmental temperature on fatty acid composition of teleost fish. *J. Am. Oil Chem. Soc.*, **40,** 507–13.

Sargent, J. (1976). In *Biochemical Biophysical Perspectives in Marine Biology*, eds D. C. Malins & J. R. Sargent. Vol. 3. Academic Press, New York, pp.149–212.

Sargent, J., Henderson, R. J. & Tocher, D. R. (1989). The lipids. In *Fish Nutrition*, 2nd edn, ed. J. E. Halver. Academic Press, Inc. New York, pp. 153–218.

SAS Institute, Inc. (1990). *SAS Language: Reference, Version 6, 1st edition*, p. 1042, SAS Institute, Inc., Cary, NC.

Schaefer, R. K. & Hornick, H. T. (1991). Characterization of striped bass spawning stocks in Maryland. In *Investigation of Striped Bass in the Chesapeake Bay.* USFWS Federal Aid Performance Report. Project No. F-42-R-4. Maryland Department of Natural Resources, Fisheries Div. Annapolis, MD, p. 142.

Scofield, E. C. (1928). Striped bass studies. *Calif. Fish Game.*, **14,** 29–37.

Setzler, E. M, Boynton, W. R., Wood, K. V., Zion, H. H., Jubbers, L., Mountford, N. K., Frere, P., Tucker, L. & Mihursky, J. A. (1980). Synopsis of biological data on striped bass, *Morone saxatilis* (Walbaum). N)AA Technical Report NMFS Circular 433. US Department of Commerce, NOAA, NMFS, Washington, D.C., pp. 1–69.

Shatunavskiy, I. M. (1971). Alterations in the qualitative composition of lipids in the organs and tissue of Baltic cod [*Gadus morhua callarias* (L.)] as the gonads mature. *J. Ichthyol.*, **11,** 790–8.

Sinclair, A. J., O'Dea, K. & Naughton, J. M. (1986). Polyunsaturated fatty acid types in Australian fish. *Proc. Nutr. Soc. Aust.*, **25,** 81–2.

Smith, Jr., P., Ambrose, M. E. & Knobl, Jr. G. N. (1964). Improved rapid method for determining total lipids in fish meal. *Comm. Fish. Rev.*, **26**(7), 1–5.

Smith, W. G. (1982). In *Fish Distribution*, eds M. Grosslein & T. R. Azarovitz. Mesa, NY. Blight Atlas Monograph 15. NY Sea Grant, Albany, NY, pp. 79–82.

Smith, T. I. J. (1990). Aquaculture of striped bass, *Morone saxatilis*, and its hybrids in North America. Genetics in Aquaculture, NOAA Technical Report NMFS 92, ed. R. S. Svrjcek. US Dept of Commerce, National Marine Fisheries Service, Washington, DC, pp. 53–60.

Snow, J. R. & Lovell, R. T. (1974). Comparison of organoleptic quality of largemouth bass fed natural and artificial diets. *Prog. Fish-Cult.*, **36**(4), 216–18.

Tuncer, H., Harrell, R. M. & Houde, E. D. (1990). Comparative energetics of striped bass (*Morone saxatilis*) and hybrid (*M. saxatilis x M. chrysops*) juveniles. *Aquaculture*, **86,** 387–400.

USDA (1987). US Handbook 8–15, pp. 22 and 22.1.

USDC (1990). Fisheries of the United States, 1989. Current Fisheries Statistics No. 8900, US Dept. of Commerce, Washington, DC.

Van Vliet, T. & Katan, M. B. (1990). Lower ratio of *n*-3 to *n*-6 fatty acids in cultured than wild fish. *Am. J. Clin. Nutr.*, **51,** 1–2.

Woods, III, L. C., Kerby, J. H. & Huish, M. T. (1985). Culture of hybrid striped bass to marketable size in circular tanks. *Prog. Fish. Cult.*, **47**(3), 147–53.