MFR PAPER 1199

Seasonal Variations in Chemical Composition and Protein Quality of Menhaden

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ABSTRACT—Proximate chemical composition of menhaden collected during the course of four different fishing seasons is presented. Atlantic menhaden, Brevoortia tyrannus, *had an abnormally low oil content during the latter half of the 1972 season, probably due to environmental effects of Hurricane Agnes. Fish protein concentrates were prepared from both the Atlantic menhaden and the Gulf menhaden,* B. patronus, *samples collected during 1972 and were evaluated by rat bioassay. Fatty acid compositions of the extracted fish oils were determined by gas-liquid chromatography. No seasonal trend in protein quality was detected, but there was a trend toward a higher proportion of saturated fatty acids during the course of the season.*

INTRODUCTION

Menhaden are the raw material from which most of the fish meal, solubles, and oil are produced in the United States. Approximately half of the total tonnage of finfish landed in the United States is menhaden. During 1974 almost 1.3 billion pounds of Gulf menhaden, *Brevoortia patronus*, were taken from the Gulf of Mexico and 683 million pounds of Atlantic menhaden, *B. tyrannus*, were harvested (National Marine Fisheries Service, 1975). The total value of the combined Atlantic and Gulf menhaden harvests was estimated at $66.4 million. This compares with a value in excess of $71 million for only 247.7 million pounds of yellowfin tuna, *Thunnus albacares*, the tonnage leader among food fish.

Recently, interest has heightened in the potential for utilization of menhaden in higher-valued products. Possible uses which are currently being considered include menhaden hydrolysates for incorporation into milk replacers or microbiological culture media and fish protein concentrates or isolates for use as protein supplements. The human food uses are considered a longer term possibility.

After initial work with red hake, *Urophycis chuss*, the National Marine Fisheries Service (NMFS), then the Bureau of Commercial Fisheries, utilized menhaden in the development of the fish protein concentrate (FPC) process. Produced hygienically by isopropyl alcohol extraction of menhaden, FPC was approved as a food additive by the Food and Drug Administration (Federal Register, 1970).

The purpose of this study was to obtain basic information on the seasonal variations in chemical composition and protein quality of Atlantic and Gulf menhaden for potential FPC production as well as for fish meal and oil production purposes.

MATERIALS AND METHODS

The data obtained consist of two parts. Seasonal data on proximate composition of Atlantic menhaden from the Chesapeake Bay area were collected by Haynie Products, Inc. (now Zapata Haynie Corporation[1]) from 1967 to 1969. During the 1972 fishing season both Atlantic and Gulf menhaden were analyzed at the Southeast Utilization Research Center, NMFS. The FPC's were prepared from the 1972 samples and the extracted fish oils were analyzed for fatty acid patterns.

Menhaden Samples, 1967-69

Whole Atlantic menhaden were sampled directly from the fishing vessel prior to unloading at the dock of the Zapata Haynie plant at Cape Charles, Va. Two boats were inspected to estimate the average size of fish from the day's catch. From the hold of a third vessel, fish of approximately the same average size were selected at random. In most cases the fish were less than 4 hours old when prepared for analysis at the plant. They were cut into smaller pieces and ground through a meat grinder. Each sample was a composite of three whole fish. Sampling frequency varied with fishing activity and ranged from 2 to 15 samples per month.

Menhaden Samples, 1972

Approximately 50-100 pounds of whole menhaden from Chesapeake Bay were selected in the same manner as above from an unloading area at Reedville, Va. The fish were immediately iced and transported to the Southeast Utilization Research Center, College Park Laboratory, College Park, Md. Upon arrival at the laboratory about 40 to 50 fish were randomly sampled for length and weight. The fish were then frozen in polyethylene bags at −20°C

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

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and stored until required. During this sampling period, only one to two samples were obtained monthly.

Fish received from the Gulf of Mexico were obtained by personnel of the NMFS Pascagoula Fishery Products Technology Laboratory, Pascagoula, Miss. The sampled fish were frozen prior to shipping to the College Park Laboratory. These fish, upon arrival, were placed in a refrigerated (5°C) room overnight for partial thawing so as to remove individual fish for length-weight measurements.

Fish Protein Concentrate

Twenty pounds of frozen fish from each 1972 sample were removed from the freezer and processed by isopropyl alcohol extraction into FPC. The extraction process was as described by Dubrow et al. (1970) in which the authors found the process to have no significant effect on the nutritive value of the fish protein. Therefore, the FPC's were submitted to rat-feeding studies to estimate the seasonal variation in the nutritive quality of the menhaden protein.

Analytical Methods

Samples of fish during 1967 to 1969 were analyzed for crude protein by the Kjeldahl technique (Horowitz, 1965), and for moisture and fat content by the methods of Salle (1958).

The 1972 samples of fish and FPC were analyzed for crude protein (Horowitz, 1965). Moisture was determined by drying a 2-g sample in a forced draft oven for 16 hours at 100°C. Samples were ashed overnight in a muffle furnace at 600°C. Fat content was determined using a chloroform:methanol extraction procedure (Smith, Ambrose, and Knobl, 1964).

Protein quality of the FPC produced from the 1972 menhaden was determined in a rat-feeding study. The diets contained 10 percent protein supplied by FPC and the reference diet contained casein. The protein efficiency ratio (PER = wt. gained/wt. protein consumed) was calculated at the end of 4 weeks of feeding. The fatty acid composition of the raw fish oil extracted in the FPC process was determined by gas-liquid chromatography (GLC) of methyl esters prepared as described by Gauglitz and Lehman (1963). A diethylene glycol succinate polyester (DEGS) column was used. Identification of fatty acid esters was as described by Ackman and Burgher (1965).

RESULTS AND DISCUSSION

Analytical: 1967-69 Menhaden Samples

Table 1 shows the proximate composition of Atlantic menhaden sampled during the fishing seasons of 1967-69. The protein content of the raw whole fish ranged between 14.5 and 17.02 percent during these periods. This range is similar to that reported by Thompson (1966) for Gulf menhaden. The oil content showed monthly variations increasing from a low in June to a peak in October. These changes are shown in Figure 1, which shows the average lipid content by month during the three years of sampling. Fish landed during the early part of the season had a lipid content of about 8-10 percent, whereas at the peak month of October, the lipid content was about 20

Table 1.—Proximate composition of Chesapeake Bay Atlantic menhaden sampled during fishing seasons 1967-69.

Date	No. samples	Protein $\bar{x} \pm$ SD (%)	Lipid $\bar{x} \pm$ SD (%)	Moisture $\bar{x} \pm$ SD (%)
1967				
June	2	16.70 ± 0.85	7.87 ± 2.20	69.62 ± 2.03
July	15	17.02 ± 0.92	9.05 ± 3.24	69.40 ± 3.22
Aug.	8	15.67 ± 1.22	13.34 ± 2.46	69.94 ± 2.67
Sept.	2	14.50 ± 0.14	16.55 ± 0.56	65.55 ± 0.78
1968				
July	12	16.45 ± 0.74	8.23 ± 4.65	69.50 ± 4.48
Aug.	10	16.01 ± 1.40	14.36 ± 6.09	64.20 ± 4.75
Sept.	6	14.84 ± 0.93	15.97 ± 4.38	63.60 ± 4.64
Oct.	12	15.10 ± 0.93	20.81 ± 3.89	59.37 ± 2.81
Nov.	6	16.25 ± 0.83	18.24 ± 2.19	60.78 ± 2.54
1969				
June	7	15.76 ± 0.87	10.08 ± 4.18	69.34 ± 4.23
July	8	16.56 ± 3.07	15.13 ± 6.78	65.46 ± 6.17
Aug.	12	16.20 ± 1.31	16.13 ± 4.85	64.87 ± 4.16
Oct.	2	15.75 ± 0.18	20.75 ± 0.39	—

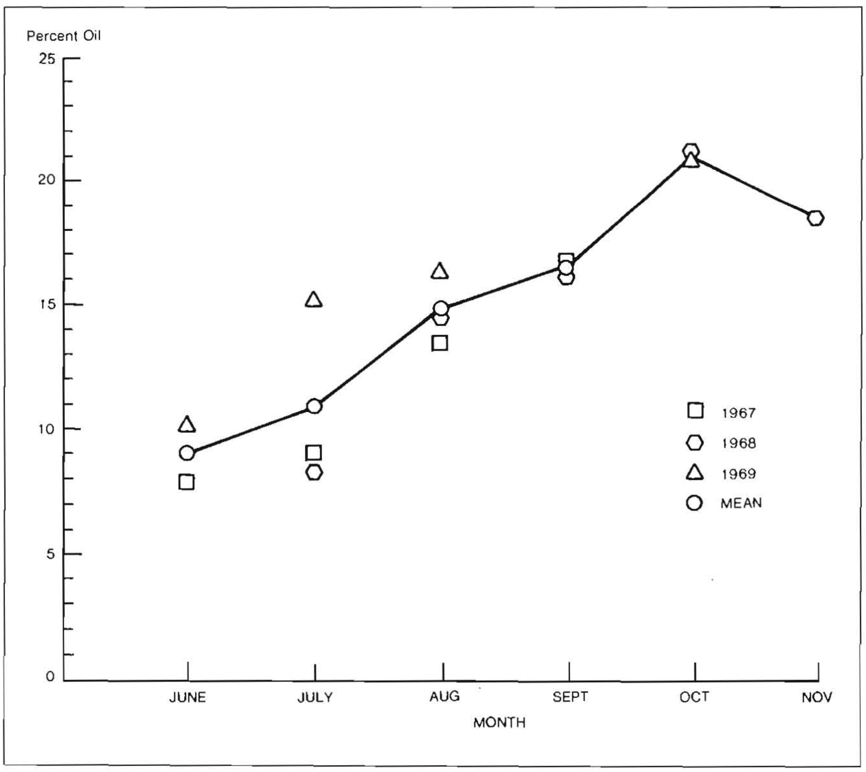

Figure 1.—Average oil content of Atlantic manhaden by month of harvest, 1967-69 fishing seasons.

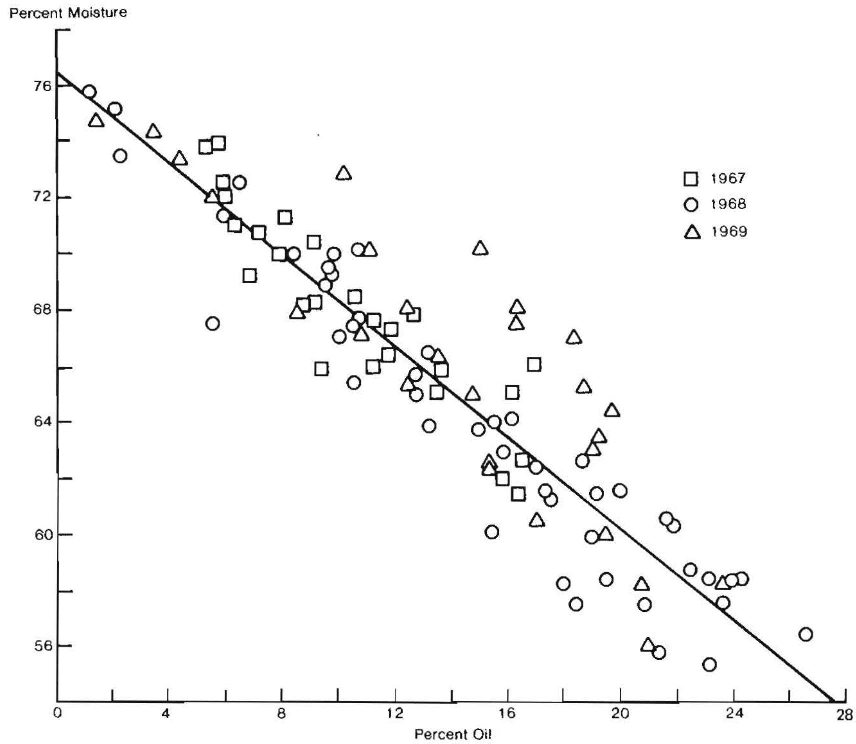

Figure 2.—Moisture content of Atlantic menhaden samples, 1967-69, versus oil content.

Table 2.—Proximate composition and size of Atlantic and Gulf menhaden sampled during 1972 season.

Date	No. sampled	Avg. weight (g)	Avg. length (cm)	Protein (%)	Lipid (%)	Moisture (%)	Ash (%)
B. tyrannus (Chesapeake Bay)							
6/15	52	455.4	29.2	16.78	12.77	66.58	3.84
6/27	33	402.0	28.7	15.70	17.90	62.40	4.20
7/25	40	460.7	30.1	16.42	10.60	66.20	4.90
8/30	86	305.3	27.2	16.75	10.64	69.37	5.46
9/19	51	126.5	19.7	16.88	4.34	74.98	4.42
10/6	51	122.8	18.9	17.14	4.01	72.56	5.68
10/27	50	107.5	18.7	15.91	2.46	77.61	4.42
11/17	50	157.9	20.2	16.19	4.36	75.70	4.67
B. patronus (Gulf of Mexico)							
6/2	50	84.4	15.8	15.05	15.24	65.19	4.27
7/27	32	85.8	—	16.99	17.44	62.40	4.25
9/12	40	136.0	18.1	14.62	23.90	59.45	4.53
10/10	35	72.8	15.6	16.97	12.29	66.55	5.16
11/9	50	78.7	15.6	16.97	13.78	65.68	4.53
12/3	50	117.5	17.5	16.92	10.58	68.01	4.56

percent. Figure 2 is a plot of percent moisture vs. percent oil for all 1967-69 samples. As expected, there was a significant negative correlation ($r =$ -0.9198) between moisture and oil contents. The regression line was calculated as: percent moisture = 76.47 − (0.800) x (percent oil).

Analytical: 1972 Menhaden Samples

During this project in June 1972, the Chesapeake Bay area was hit by Hurricane Agnes. The decrease in salinity in the bay as a result of the storm had a profound effect on the native flora, and normal species of plankton were displaced. This may be the reason for an abnormal seasonal pattern of lipid content in menhaden taken from the bay in 1972. As can be seen in Table 2, the size of the fish caught decreased from August through November and the total lipid content of September-November fish was significantly lower than for the same months in 1967-69. The average size of menhaden sampled from Chesapeake Bay decreased sharply over a 3-month period from a weight of 460.7 g in July to a weight less than one-quarter as great on October 27th. There was a partial recovery in size in the November catch. There is normally a general northward movement of menhaden along the Atlantic Coast during the summer (Dryfoos, Cheek, and Kroger, 1973). There may well have been an abnormal migration of the larger menhaden due to the decrease in salinity in the bay in 1972. The lower oil content found in the fish was evidently a reflection of the smaller menhaden fish left in the harvesting areas around the Chesapeake Bay and perhaps was also due to a change in the food chain (plankton, etc.) caused by the hurricane.

Although the Gulf menhaden were smaller than the Atlantic menhaden sampled, they had a significantly higher oil content. The proximate analyses fell within the ranges reported by Thompson (1966) for Gulf menhaden caught by trawlers of the industrial (pet food) fishing fleet. Thompson did not find a reliable correlation between menhaden size and oil content for the gulf species.

Fish Protein Concentrate

Table 3 shows the proximate composition and protein efficiency ratio (PER) for FPC's made from whole menhaden sampled during the 1972 fishing season. Most of the FPC's produced were either borderline or deficient in terms of the FDA specification of 75 percent minimum protein for fish protein concentrate. Mean protein content for both the Atlantic and Gulf menhaden FPC samples was slightly below the 75 percent specification. This was due primarily to the high bone content of menhaden and for this reason wet deboning machines were included in the process line at the FPC Experiment and Demonstration Plant (Ernst, 1971). For these limited data the correlation between FPC protein and menhaden ash content was not very good ($r = -0.603$). The FPC samples, with an average oil content of about 0.1 percent were considerably below the FDA specification for a maximum of 0.5 percent residual lipids.

Protein Quality

The protein quality of menhaden FPC's as measured by PER did not reveal any particular seasonal trend. In general the PER's were practically

Table 3.—Proximate composition and protein efficiency ratio of menhaden FPC produced from whole fish during fishing season of 1972.

Source and Date	Crude Protein (%)	Residual lipid (%)	Volatiles (%)	Ash (%)	PER	PER relative to casein (%)
B. tyrannus (Chesapeake Bay)						
6/15	74.70	0.12	9.31	18.64	3.53	101
6/27	78.95	0.09	6.90	17.18	3.56	101
7/25	76.12	0.08	7.94	18.67	3.69	103
8/30	70.87	0.07	8.52	23.87	3.53	101
9/19	74.65	0.11	4.83	22.91	n.a.	n.a.
10/6	69.82	0.05	8.40	23.99	3.34	97
10/27	74.31	0.10	8.53	19.70	3.57	103
11/17	73.06	0.02	8.09	20.98	3.69	107
	$\bar{x}$ = 74.06	0.08	7.82	20.74	3.56	101.86
B. patronus (Gulf of Mexico)						
5/26	75.68	0.53	7.34	19.45	3.37	97
7/27	74.04	0.03	7.17	21.44	3.70	105
9/12	73.54	0.03	9.87	20.40	3.63	104
10/10	72.40	0.05	8.72	21.61	3.77	110
11/8	75.17	0.17	8.06	20.13	3.57	103
12/3	75.06	0.02	7.79	18.33	3.43	99
	$\bar{x}$ = 74.31	0.14	8.16	20.23	3.62	103.00

Table 4.—Fatty acid compositions[1] of extracted menhaden oil, 1972 season.

Fatty acids	Atlantic menhaden							Gulf menhaden		
	6/15	6/27	7/25	8/30	9/19	10/6	11/17	9/12	10/10	12/3
Saturated										
14:0	7.00	9.93	7.98	7.02	8.45	8.47	9.73	8.63	6.92	7.92
15:0	0.61	0.79	0.73	0.96	1.18	1.23	1.29	0.68	1.18	0.92
16:0	11.86	12.35	10.73	18.31	14.60	19.45	27.03	11.69	10.20	17.53
17:0	1.35	1.17	1.25	1.98	1.46	2.50	2.00	1.35	1.81	1.26
18:0	3.23	2.93	2.28	5.24	3.34	5.61	6.62	3.41	3.77	5.40
20:0	0.50	0.47	0.44	1.92	0.48	2.29	—	1.46	2.36	—
Total:	24.55	27.64	23.41	35.43	29.51	39.55	46.67	27.22	26.24	33.03
Monounsaturated										
14:1	0.35	0.47	0.40	0.49	0.68	0.70	0.43	0.22	0.29	0.23
15:1	0.16	0.19	0.18	0.26	0.26	0.28	0.19	0.10	0.12	0.13
16:1	9.41	11.19	9.46	9.74	10.63	9.88	8.37	11.41	9.51	10.68
17:1	1.66	1.93	1.88	0.54	1.59	0.57	1.05	0.36	0.35	—
18:1	10.36	9.23	9.15	7.92	5.54	7.10	6.97	8.10	6.34	8.67
20:1	1.90	1.83	2.31	1.47	0.63	1.13	1.31	1.89	1.15	1.87
Total:	23.84	24.84	23.38	20.42	19.33	19.66	18.32	22.08	17.76	21.58
Polyunsaturated										
18:2ω9	1.78	1.63	1.99	1.55	1.74	1.73	0.55	1.45	1.98	0.88
18:2ω6	1.84	1.59	1.77	0.49	0.45	0.40	1.20	0.59	0.70	1.59
18:4ω3	3.40	3.53	4.05	2.11	3.86	2.71	1.99	1.91	2.31	2.23
20:2ω9	0.52	0.39	0.38	0.47	0.60	0.37	—	0.60	0.49	0.27
20:3ω9	0.30	0.28	0.24	0.56	0.30	0.32	0.19	—	—	0.23
20:4ω6	1.28	1.07	1.13	1.48	1.35	1.17	1.18	2.51	2.48	1.92
20:4ω3	2.32	2.05	2.34	1.83	1.77	1.61	1.08	1.80	1.83	1.51
20:5ω3	13.70	12.50	15.24	9.13	10.70	7.21	7.63	15.12	12.96	13.40
22:4ω6	1.22	1.07	1.04	0.94	1.17	1.19	1.05	1.83	1.85	1.46
22:5ω6	1.18	0.92	0.82	1.86	0.71	2.11	1.33	1.54	2.38	1.24
22:5ω3	3.16	2.60	2.86	2.89	2.23	2.28	1.57	5.09	3.95	3.51
22:6ω3	14.49	12.99	17.46	14.17	18.75	13.17	15.22	11.00	16.39	13.48
Total:	45.19	40.62	49.32	37.48	43.63	34.27	32.99	43.44	47.32	41.72

[1]As percent of total fatty acids measured.

Table 5.—Summary of fatty acid compositions[1] by degree of unsaturation, 1972 season.

	Atlantic menhaden							Gulf menhaden		
	6/15	6/27	7/25	8/30	9/19	10/6	11/17	9/12	10/10	12/3
Saturated fatty acids	24.55	27.64	23.41	35.43	29.51	39.55	46.67	27.22	26.24	33.03
Monounsaturated	23.84	24.84	23.38	20.42	19.33	20.65	18.32	22.08	18.64	21.58
Polyunsaturated	45.19	40.62	49.32	37.48	43.63	34.27	32.99	43.44	47.32	41.72
Unidentified	6.42	6.90	3.89	6.67	7.53	5.53	2.02	7.26	7.80	3.67
Total U/S	2.81	2.37	3.11	1.63	2.13	1.39	1.10	2.41	2.51	1.92
Total percent oil	12.77	17.90	10.60	10.64	4.34	4.01	4.36	23.90	12.29	10.58

[1]As percent of total fatty acids measured.

equal to or slightly higher than the reference casein values. The PER's for Atlantic menhaden FPC ranged between 97 and 107 percent, averaging 102 percent, relative to the casein PER value. The Gulf menhaden PER's averaged 103 percent relative to casein and ranged between 97 and 110 percent.

Fatty Acids

The fatty acid patterns of Atlantic and Gulf menhaden, as measured by GLC analysis of the extracted fish oils, are presented in Table 4. Duplicate analyses of each sample were made. These data are grouped on the basis of degree of unsaturation and are summarized in Table 5. For the Atlantic menhaden there was an irregular trend toward more saturated fatty acids during the course of the fishing season and the ratio of unsaturated to saturated fatty acids (U/S ratio) decreased from 2.81 in June to 1.10 in November. Analyses are available on only three Gulf menhaden samples, but the saturated fatty acid content was higher in the December sample relative to the earlier samples.

Data reported by Gruger, Nelson, and Stansby (1964) for an Atlantic menhaden sample taken in December 1959 had 43.3 percent saturated fatty acids and a relatively low U/S ratio of 1.305. The palmitic acid content of the sample was particularly high at 28.9 percent. The later (Aug.-Nov.) 1972 samples of Atlantic menhaden had higher palmitic acid levels than earlier (June-July) samples and the November value reached 27 percent. The November Gulf sample contained only 17.5 percent palmitic acid but was notably higher than the earlier Gulf samples. All of the Atlantic and Gulf samples had a higher palmitoleic content and a lower oleic acid content relative to the data of Gruger et al. (1964) which were 7.9 percent and 13.4 percent, respectively, for the 16:1 and 18:1 fatty acids. The other fatty acids reported generally fell within the same range as our 1972 data. By family groupings, the polyunsaturates within the 1972 data were slightly higher in ω6 fatty acid content, slightly lower in ω9 content, and similar in ω3 content in comparison with the data of Gruger et al. (1964).

Erucic acid (22:1ω9) was measured in only two samples, 0.99 percent in the

10/6 Atlantic menhaden and 0.88 percent in the 10/10 Gulf menhaden. It appeared as a shoulder to the adjacent peak of 20:4ω6 combined with 20:3ω3. Probably erucic acid was present in other samples but was masked by the adjacent fatty acid peak.

SUMMARY AND CONCLUSIONS

Some seasonal data on the proximate composition of Atlantic menhaden (*B. tyrannus*) sampled over the 1967-69 fishing seasons are presented and show a peak in oil content during the month of October. Chemical composition and length-weight data are also presented for samples of Atlantic and Gulf menhaden collected during the 1972 season. The Atlantic menhaden had an abnormal pattern of oil content and size, possibly due to environmental changes caused by Hurricane Agnes which struck the Atlantic coast in June of 1972.

Fish protein concentrates were prepared by isopropanol extraction of the 1972 samples and were evaluated by rat bioassay. No seasonal trends in menhaden protein quality were detected and the PERs averaged slightly higher than those of the reference casein.

The fatty acid patterns of the extracted menhaden oils were analyzed by GLC. There was an apparent trend toward a higher proportion of saturated fatty acids, particularly palmitic acid, as the season progressed from June to December. A comparison between 1972 Atlantic and Gulf samples and an additional Atlantic menhaden analysis from the literature indicates that the observed trend is truly seasonal rather than being directly related to the abnormal pattern of oil content in 1972 samples from the Chesapeake Bay area. Additional data from other years would be required to confirm the trend, however.

There is a need for updating composition data on both the menhaden resource and the fish meal, oil, and solubles products of industry. Industrial practice has changed somewhat in recent years with a greater proportion of "whole" fish meals containing added solubles being produced. The acquisition of appropriate data and the determination of new menhaden products of higher value have been proposed as goals of the NMFS.

ACKNOWLEDGMENTS

We thank the Chemical Analysis Group at the Southeast Utilization Research Center for analyses, particularly Virginia White for the GLC analyses. The PER determinations by Herta Lagally and Donald Briscoe are also appreciated.

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MFR Paper 1199. From Marine Fisheries Review, *Vol. 38, No. 9, September 1976. Copies of this paper, in limited numbers, are available from D825, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235. Copies of* Marine Fisheries Review *are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 for $1.10 each.*