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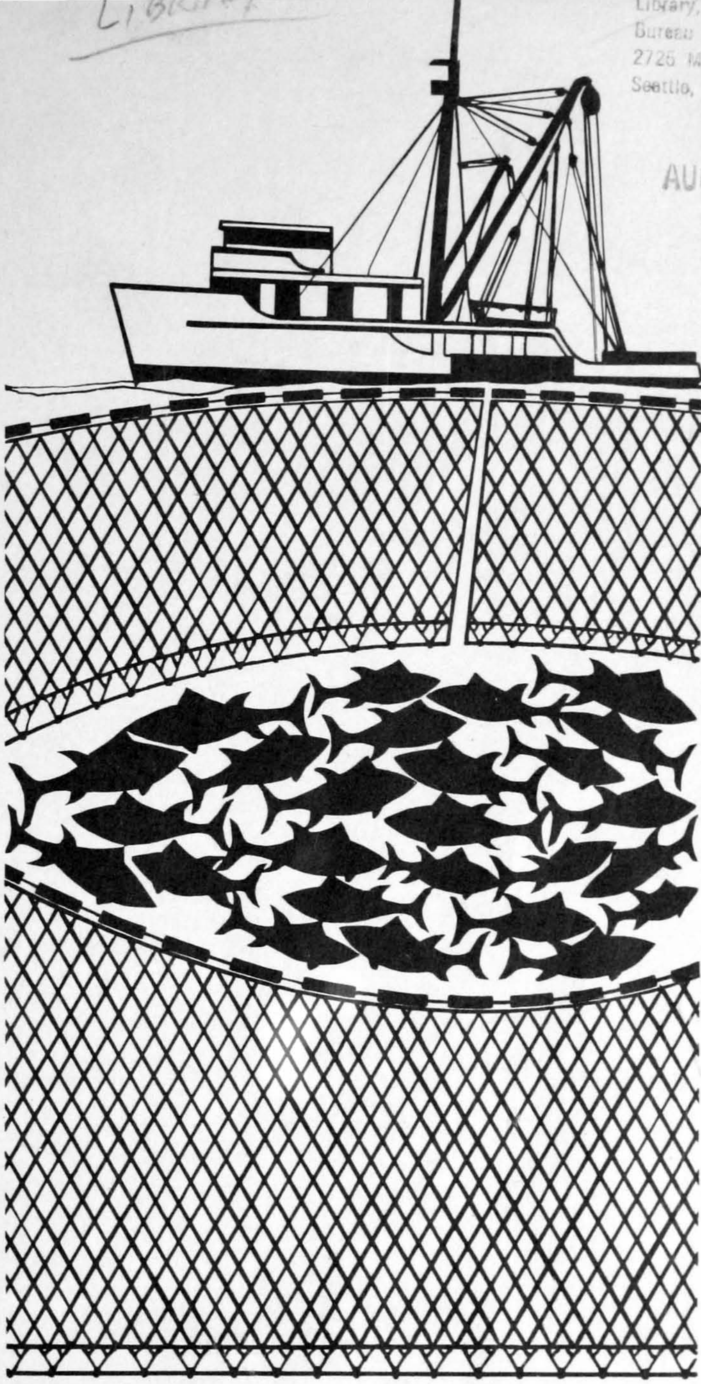

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As the Nation's principal conservation agency, the Department of the Interior has basic responsibilities for water, fish, wildlife, mineral, land, park, and recreational resources. Indian and Territorial affairs are other major concerns of America's "Department of Natural Resources."

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PROXIMATE COMPOSITION OF COMMERCIAL FISHES FROM THE MEDITERRANEAN SEA AND THE RED SEA

by

A. Herzberg and Rachel Pasteur

ABSTRACT

Data are needed on the proximate composition of tropical and semitropical fishes. This paper reports, on a year-round basis, the proportions of protein, oil, ash, and water in 10 commercial species of fishes from the Eastern Mediterranean Sea and the Southern Red Sea. All species were high in protein. The demersal fishes were low in oil, whereas the pelagic fishes were relatively high. Large changes in the concentration of oil observed in the pelagic fishes were probably related to the spawning cycle.

CONTENTS

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INTRODUCTION

Vinogradov (1953), Stansby (1963), and Thompson (1966) have extensively investigated the proximate composition of fishes and have published bibliographies relating to the subject.

Stansby (1962) has emphasized that little is known of basic facts concerning the protein, oil, mineral, and water composition of fishes. He states:

> Even 30 years ago, proximate composition was considered to be such an elementary sort of thing that scientists felt they ought to spend their time on something requiring more skill. Surely, so the argument went, proximate composition of all important commercial species of fish must be known, since it involves only the simplest techniques well understood for over half a century. Despite this argument, I kept finding evidence that the erroneous value for the oil content of mackerel was not an isolated instance; in fact, for some important species, I could find no data on proximate composition at all.

Sometimes one finds extensive qualitative analyses of lipids without any indication of the concentration of the lipids present in the source material. Hence, as Stansby has indicated, exact quantitative information on proximate composition is needed.

The development of fisheries in subtropical and tropical areas has aroused wide interest in species of fishes that, until recently, have not been marketed in large quantity. Some of these species doubtlessly have permanent market value, either as fresh fish or as raw material for canned fish or fish meal. Accordingly, information on the proximate composition of fishes from subtropical and tropical areas is long overdue.

Some of the species analyzed in the present work were investigated by Milone (1896) in his extensive study of the composition of Mediterranean fishes caught during the summer. His work includes three analyses of each species caught, and his results indicate the variations in nutritive value that may occur, especially in those species in which the concentration of oil varies widely.

More recent reports indicate that the concentration of oil in even a single species of subtropical and tropical fishes may vary widely. In 1934, El Saby reported much valuable information on Egyptian food fishes. In 1937, he showed that *Sardinella aurita* (gilt sardine), which in the Israel canning industry is a lean fish, may contain up to 30 percent oil (on a fresh-weight basis) during its feeding season. In contrast, Mainguy and d'Outre (1958) found only up to 9.4 percent of oil in *Sardinella aurita* caught in West Africa.

This variation in concentration of oil is important because, in general, fishes are more suitable for canning and are tastier during their high-oil period, even though they may keep better if they are lean. Because of these fluctuations in composition and because *Sardinella aurita* constitutes almost half of the catch of Israel's fisheries in the Mediterranean, more knowledge of its composition is of interest.

Ben-Tuvia (1963a) reports that several species of commercially important fishes from the Red Sea have recently established themselves in the Mediterranean. Many species are common to both seas; yet the temperature of the Red Sea seldom if ever drops below 21.5° C., whereas the minimum temperature of the Eastern Mediterranean fluctuates between 15° and 17° C. In addition, the salinity of the Southern Red Sea and that of the Eastern Mediterranean differ considerably (Oren, 1957 and 1962). Thus, the possible relation between the chemical composition of fishes and the temperature and salinity of the sea should be studied.

A comprehensive study, however, of any relation between the chemical composition of fishes and the temperature and salinity of their environment was beyond the scope of the present work. Nevertheless, we observed certain broad relations even in our less-than-extensive studies. The purposes of the work reported here were simply to determine the proximate composition of some commercially important fishes of the Mediterranean Sea and the Red Sea and to draw whatever conclusions such determinations would permit. Accordingly, this report is divided into two main parts. The first part presents data on physical characteristics (that is, on the length and weight of the fishes analyzed) and on proximate composition. The second part examines the broad relations among the variables studied.

I. PHYSICAL DATA AND PROXIMATE COMPOSITION

Most fishes from the Mediterranean Sea (Figure 1) were sampled at the dock immediately after they were brought into harbor or were sampled on the trawler (Figure 2) immediately after the net was hoisted aboard (Figure 3) and unloaded. Some samples of fish, however, were bought at the market. These included *Sardinella aurita*, *Scomber japonicus* (Pacific mackerel), and *Euthynnus alletteratus* (little tunny) all of which were caught by purse seines in the Eastern Mediterranean and were bought on the day they were captured.

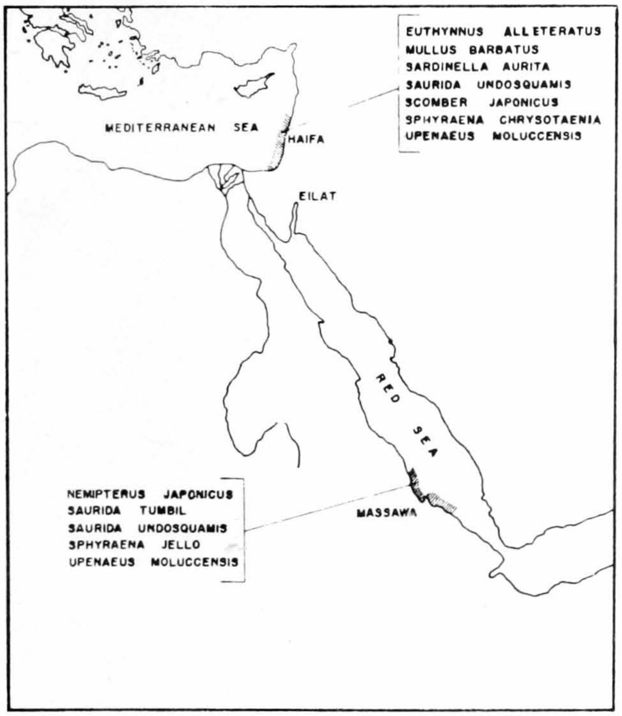

Figure 1.—Fishing areas of the investigated species.

Fishes from the Red Sea were given to us by the fishing company at the wholesale market in Haifa, immediately after they arrived by overland transport from Eilat. Owing to this method of handling, the fishes from the Red Sea were kept for about 10 days on ice before they arrived at the laboratory.

A. PHYSICAL DATA

In this section, we specify the fishes that were sampled and the measurements that were made on them.

1. Fishes Sampled

The fishes analyzed were taken once a month, for as long as they were available, from commercial catches, so they include only the abundant and commercially important species. During peak seasons, *Sardinella aurita*, *Scomber japonicus*, and *Euthynnus alletteratus* were sampled several times a month. They were caught by trawls and purse seines in the Eastern Mediterranean.

The other fishes analyzed were caught mostly by trawls and purse seines. *Mullus barbatus* (red mullet; Figure 4), *Upeneus moluccensis* (golden banded goatfish; Figure 5), *Saurida undosquamis* (Red Sea lizardfish; Figure 6), and *Sphyraena chrysotaenia* (*obtusata*) (blunt jaw barracuda; sea pike; Figure 7) were caught in the Eastern Mediterranean trawl fishery; *Sardinella aurita*, *Scomber* (*Pneumatophorus*) *japonicus*, *Euthynnus alletteratus*, and *Sphyraena chrysotaenia* were caught in the purse seine fishery there. *Saurida tumbil* (Red Sea lizardfish), *Sphyraena jello* (Red Sea barracuda), *Nemipterus japonicus* (threadfin bream), and *Upeneus moluccensis* were caught by trawls in the Southern Red Sea.

Figure 2.—Israel trawler of the type used in the Mediterranean and in the Red Sea.

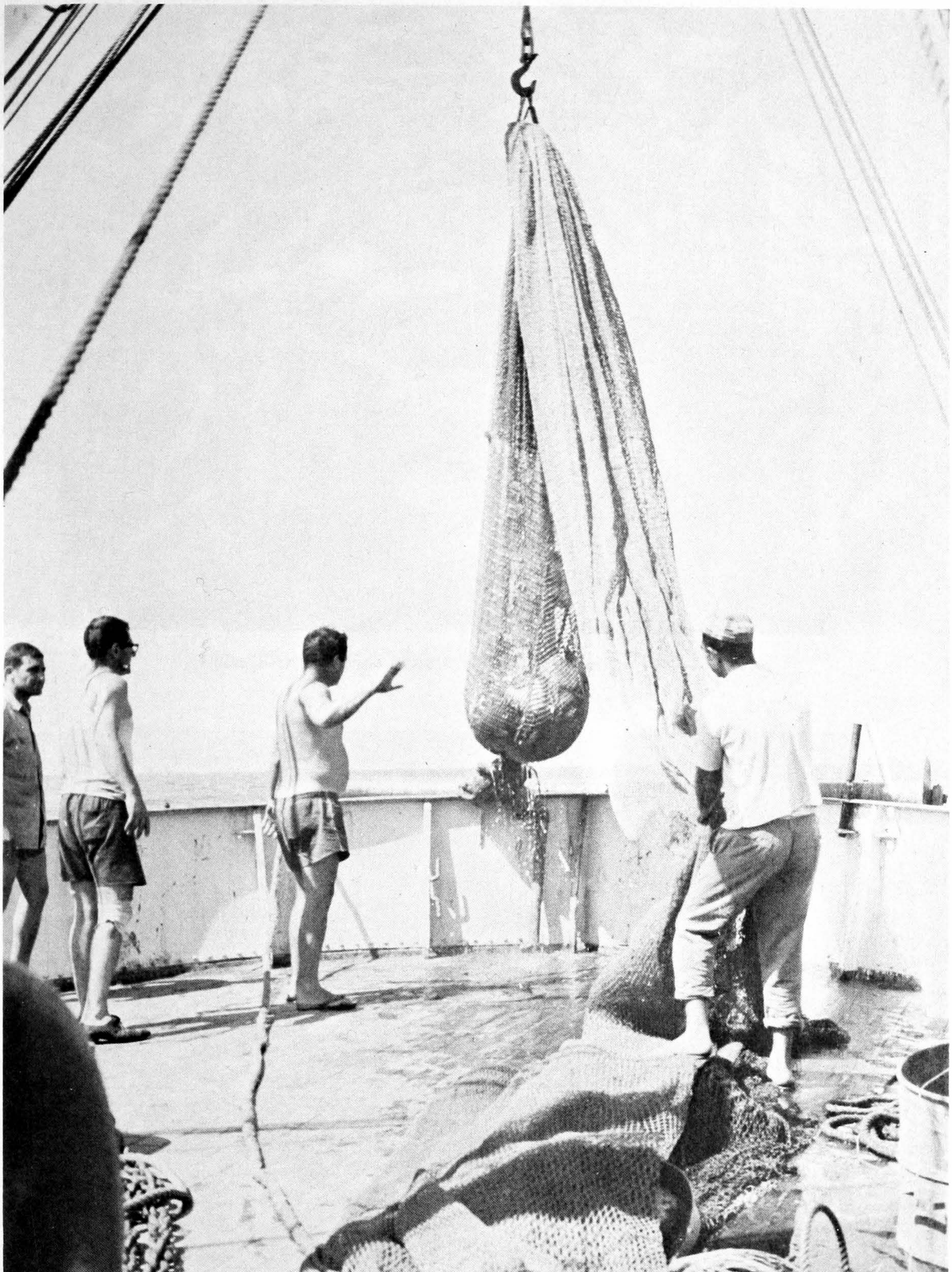

Figure 3.—Hoisting the net.

Figure 4.—Part of the catch, mainly *Mullus barbatus* (red mullet).

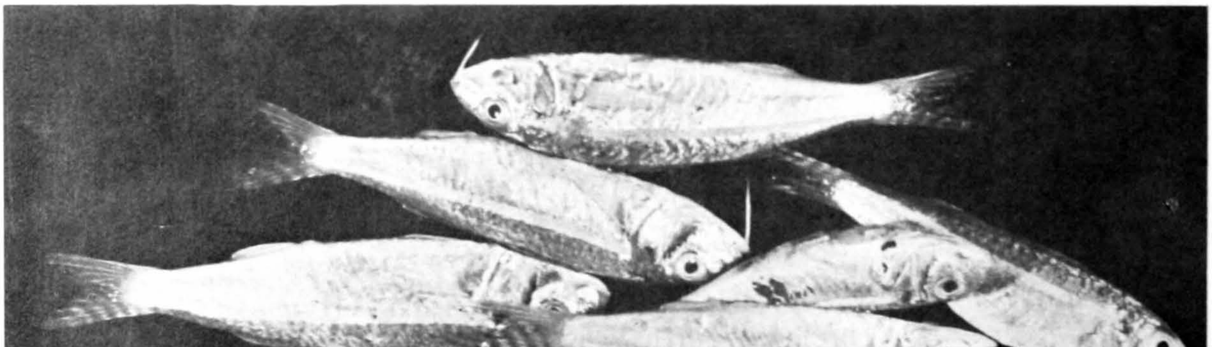

Figure 5.—*Upeneus moluccensis* (golden banded goatfish).

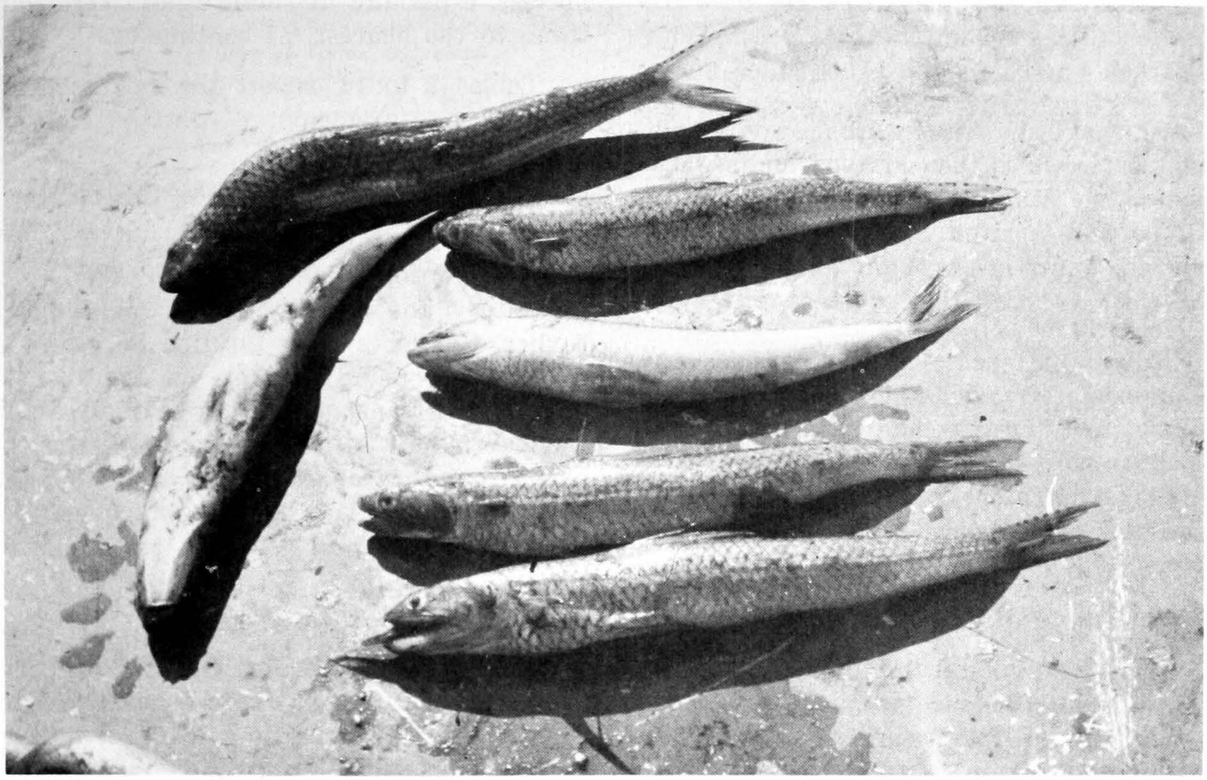

Figure 6.—*Saurida undosquamis* (Red Sea lizardfish). (*S. tumbil* looks very similar.)

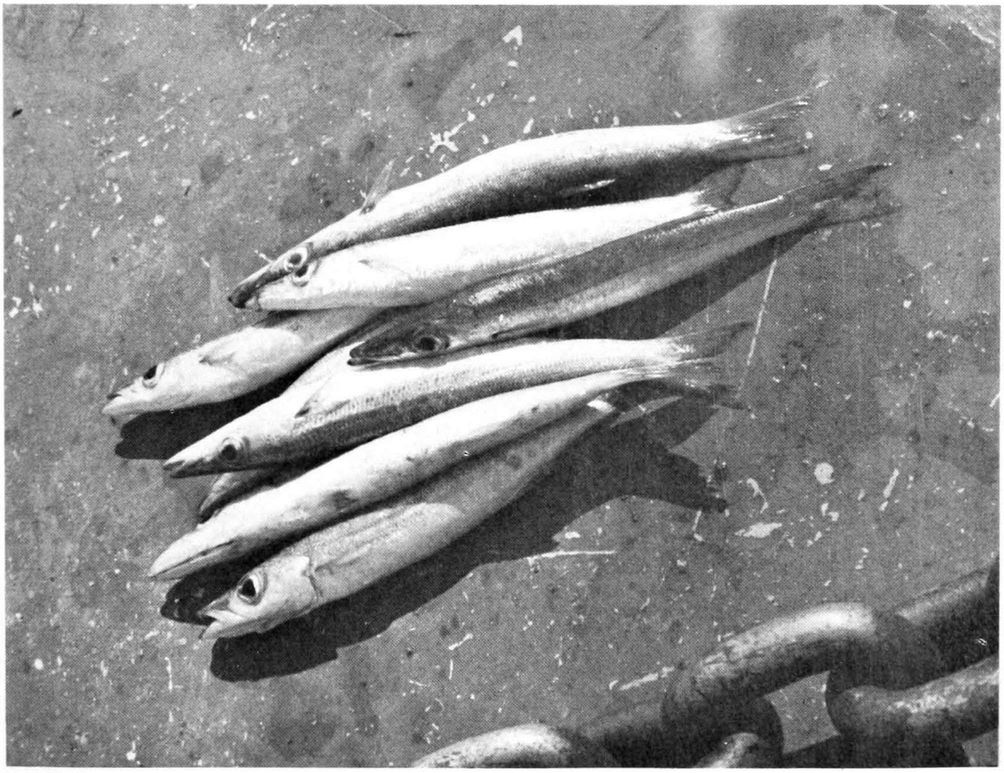

Figure 7.—*Sphyraena chrysotaenia (obtusata)* (blunt jaw barracuda).

Because identical names often are used in different countries for different species of fish, a list of fish names (Table 1) is added here.

All fish caught by trawl were iced on board and kept on ice until they arrived at the laboratory. Fish caught by purse seines were iced when they arrived at the harbor, were kept on ice, and were brought to the laboratory on the day after they were caught.

Analysis of all samples was carried out either immediately after they arrived at the laboratory or after they had been stored for 1 to 2 days in polyethylene bags at −8° to −10° C. (any changes in chemical composition during transport or storage were not measured).

2. Measurements Made

The total length and the standard length (the straight-line distance from the most anterior part of the head backward to the end of the vertebral column) of each fish were generally measured to the nearest 0.5 centimeter. The total weight was determined generally to the nearest 0.1 gram. Very big fish, especially *Euthynnus*, were weighed to the nearest gram or 5 grams. Length measurements of several species, especially of small fishes, were sometimes to the nearest 0.1 centimeter.

Tables 2 to 11 report the results of the physical measurements.

B. PROXIMATE COMPOSITION

Fishes from the Mediterranean were in prime condition when they were taken to the laboratory for analysis. As was indicated earlier, the fishes from the Red Sea were analyzed after being kept on ice for about 10 days during transport. Analysis of all samples was carried out either immediately after they arrived at the laboratory or after they had been stored for 1 to 2 days in polyethylene bags at −8° to −10° C.

1. Methods of Analysis

Small fishes were analyzed in lots of at least five individuals; large fishes were analyzed individually, one to a lot. All determinations were made from the edible parts of gutted, cleaned, and beheaded fishes with skeletal frame and bones retained. Each lot was ground up and mixed as described by the Association of Official Agricultural Chemists (1960, 18.001 et seq.).

Table 1.—Scientific and common names of fishes analyzed in the present work

Scientific name	Arabic (Egyptian)	English	French	Hebrew	Italian	Russian	Spanish
Euthynnus alletteratus	Tunna	Little tuna, Little tunny	Thonine	Palmuda, Tunit	Alletterato	Malyi Tunets	Bacoreta
Mullus barbatus	Barbouni	Red mullet[1] (Europe)	Rouget barbet Rouget de vase	Muleet	Triglia di fango	Sultanka Barabul'ka	Salmonete de fango
Nemipterus japonicus	--	Threadfin bream Red Sea bream	--	--	--	Morskoi Karas' Krasnomorskii Karas'	--
Sardinella aurito	Sardina mabrouma	Gilt sardine	Allache	Tareet	Alaccia (Sardone dorato)	Sardinella	Alacha
Saurida tumbil	--	Red Sea lizardfish	--	Poteet	Pesce ramarro orientale	--	--
Saudida undosquamis	--	Red Sea lizardfish	--	Poteet	Pesce ramarro orientale	--	--
Scomber (Pneumatophorus) japonicus	Scomber	Pacific, chub, or blue mackerel	Maquereau[2] espagnol	Kolias	Lanzardo	Skumbriya	Estornino
Sphyraena chrysotaenia (obtusata)	Moghzal	Blunt jaw barracuda, sea pike	Brochet de mer	Asfirna	Luccio marino orientale	Barakuda	Espeton
Sphyraena jello	--	Red Sea barracuda	--	--	--	Krasnomorskaya Barakuda	--
Upeneus moluccensis	--	Golden banded goatfish	Rouget de roche	Uppon	Triglia dorata	--	--

[1] Not to be confused with *Mugil* species (grey mullet, etc.).
[2] Not to be confused with the Spanish mackerel (*Scomberomorus maculatus*).

Sources: Catalogue 1 Fish names, G.F.C.M., FAO, Rome, 1960.
Fish as food, by G. Borgstrom (editor), volume 1, Academic Press, New York & London, 1961.
Report on the fisheries in Ethiopa, by M. Ben-Yami, Jerusalem, Israel, 1964.

Table 2.—*Sardinella aurita*--from the Eastern Mediterranean, physical measurements and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Replicates	Physical measurements: Total length, Range	Total length, Average	Weight, Range	Weight, Average	Average proximate composition: Protein	Oil, Range	Oil, Average	Ash	Total solids
Date	*No.*	*No.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1964											
9/10	5	1	21.0-22.5	21.5	--	76.5	21.5	--	0.9	1.9	25.1
10/13	5	1	15.5-18.5	17.5	--	50.0	21.4	--	7.1	2.1	30.1
10/14	5	1	16.0-18.0	17.0	--	42.0	--	--	4.7	--	--
10/26	5	1	12.0-13.5	12.7	--	18.5	22.0	--	3.3	2.1	27.1
10/26	5	1	19.0-20.5	20.0	--	74.0	21.7	--	10.6	2.4	34.1
11/2	6	6	18.5-21.0	20.0	48.5-80.4	58.7	--	6.9-11.7	9.3	--	--
11/18	6	6	9.5-10.5	10.0	7.3-10.4	9.5	--	1.4- 3.5	2.1	--	--
1965											
1/3	5	1	--	20.0	--	75.0	--	--	1.0	2.9	25.2
1/12	2	2	27.0-29.0	28.0	227.3-277.0	252.1	--	1.0- 5.7	3.3	--	--
2/18	5	1	15.5-19.0	--	24.0- 50.0	--	18.7	--	0.4	--	--
2/26	5	1	17.0-18.0	--	37.0- 45.0	--	--	--	1.0	--	--
2/28	5	1	18.0-19.5	18.5	--	56.4	--	--	17.9	--	--
3/7	5	1	--	18.0	--	--	--	--	20.0	--	--
3/15	10	10	13.5-18.5	17.5	24.9- 52.3	44.0	--	1.4-19.5	14.2	--	--
3/21	9	9	15.0-16.0	14.5	22.1- 30.2	26.0	--	6.3-12.6	9.3	--	--
3/23	6	6	15.0-17.0	16.0	30.3- 45.6	37.0	--	10.1-16.6	14.3	--	--
3/30	3	3	17.0-18.0	17.5	28.0- 51.6	38.7	--	0.9-10.9	5.1	--	--
4/11	10	10	16.0-19.0	17.0	33.8- 58.2	39.9	--	2.3- 5.2	4.1	--	--
4/22	10	1	17.0-18.0	17.5	--	47.2	--	--	7.7	--	--
5/11	3	3	15.0-18.5	16.8	30.6- 54.0	42.0	--	4.4- 7.3	5.7	--	--
5/26	5	5	19.0-21.0	19.7	53.9- 78.9	67.5	--	4.7-12.1	6.6	--	--
6/3	13	1	--	16.5	--	42.7	--	--	5.3	--	--
6/25	8	1	--	20.0	--	76.1	--	--	1.7	--	--
7/6	25	1	8.8-11.4	10.2	--	8.3	--	--	2.1	--	--
7/18	2	2	17.5-19.0	18.2	--	49.0	--	2.5- 2.7	2.6	--	--
7/19	1	1	--	16.0	--	34.0	--	--	1.6	--	--
7/21	5	1	17.0-19.5	18.5	--	52.5	--	--	2.5	--	--
7/30	12	1	--	18.0	--	47.0	17.0	--	3.3	2.4	24.6
8/3	--	1	--	9.0	--	6.0	--	--	2.2	--	22.7
8/10	1	1	--	9.0	--	9.8	--	--	1.7	--	--
8/15	1	1	--	19.0	--	55.3	--	--	4.2	--	--
8/19	2	2	14.5-18.0	16.5	22.7- 47.5	35.1	--	1.3- 2.2	1.7	--	--
9/2	1	1	--	17.0	--	38.6	--	--	2.0	--	--
9/5	2	2	15.5-18.0	17.0	28.3- 50.2	39.2	--	2.4- 3.0	2.7	--	--
9/15	3	3	12.0-15.5	13.0	13.7- 31.9	21.1	--	2.2- 4.0	3.1	--	--
9/19	3	3	11.0-13.0	12.0	10.3- 18.0	14.1	--	2.4- 3.3	2.7	--	--
10/3	8	1	--	16.0	--	48.4	21.0	--	3.8	1.9	25.3
10/31	12	1	--	15.0	--	27.5	20.9	--	2.4	2.3	24.3
12/6	--	1	10.5-12.0	--	--	12.4	19.9	--	1.4	1.4	23.8
12/8	7	7	14.5-21.0	16.5	24.0- 81.0	40.6	--	1.2- 5.2	3.0	--	--
12/8	3	3	10.0-12.5	10.9	7.8- 14.6	10.0	--	1.0- 1.3	1.2	--	--
12/10	15	15	14.0-16.5	15.7	22.0- 40.8	32.1	--	1.1- 3.4	2.1	--	--
12/31	26	26	18.5-20.5	19.5	48.0- 64.0	60.0	--	0.6-12.1	5.4	--	--
1966											
1/9	7	1	17.5-20.0	18.6	40.0- 51.0	44.8	--	--	3.6	--	--
1/25	5	1	19.1-22.2	20.3	52.5- 92.2	66.9	21.9	--	3.3	2.1	27.7
2/7	16	16	16.5-18.0	17.4	--	42.0	--	1.4-14.4	5.4	--	--
2/8	10	1	15.0-15.5	15.2	26.3- 27.9	27.1	17.3	--	1.5	1.8	21.9
3/2	10	1	--	17.0	34.0- 43.0	37.0	21.8	--	1.3	2.0	24.9
3/22	11	1	15.0-18.5	17.0	28.5- 48.5	40.6	21.1	--	2.5	2.1	24.5
3/27	8	8	16.0-19.5	17.8	--	--	--	1.4- 9.8	3.6	--	--
3/31	4	4	15.4-19.7	18.4	--	--	--	2.3- 4.4.	3.5	--	--
4/1	8	1	18.0-19.0	18.6	43.3- 50.7	47.1	21.4	--	3.1	2.2	25.6
4/3	6	6	15.0-17.0	16.0	--	--	--	1.6- 4.6	2.5	--	--
4/21	7	1	--	17.5	40.0- 48.0	44.7	21.0	--	3.7	1.9	25.6
4/21	5	1	21.0-22.0	21.5	71.0- 85.5	76.3	21.5	--	2.2	1.9	24.8
4/26	10	1	15.5-17.0	16.1	30.0- 42.5	34.2	19.5	--	3.8	1.7	25.4
4/26	8	8	20.0-20.5	20.5	--	--	21.4	1.8-10.7	3.6	--	27.3
5/6	12	1	15.5-17.0	16.1	33.0- 46.5	36.3	20.4	--	2.5	2.1	24.3
5/23	10	1	--	14.5	--	27.2	21.0	--	3.0	2.0	25.9
6/16	12	1	17.0-19.5	18.1	40.0- 59.5	50.8	20.7	--	2.5	2.0	25.0
6/23	8	1	17.3-21.0	19.1	41.5- 77.5	59.8	20.4	--	1.4	1.9	24.0
7/18	17	1	--	9.0	6.0- 7.4	6.8	19.1	--	2.8	1.5	23.5
7/18	11	1	--	11.0	12.0- 13.3	12.6	17.7	--	6.4	1.4	28.0

Table 2.—Continued

Time of catch	Total fish ana-lyzed	Repli-cates	Physical measurements				Average proximate composition				
			Total length		Weight		Protein	Oil		Ash	Total solids
			Range	Average	Range	Average		Range	Average		
Date	*No.*	*No.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1966—Con.											
7/26	14	1	11.0-12.5	12.0	16.8- 20.5	18.2	--	--	9.7	1.5	30.1
7/26	5	5	11.5-12.0	11.7	--	--	--	--	10.5	--	--
8/1	20	1	17.0-17.5	17.2	35.0- 48.0	39.7	20.4	--	3.8	2.2	25.4
8/24	12	1	--	14.0	--	20.1	21.7	--	2.6	1.9	25.4
8/26	8	1	16.8-19.2	17.8	38.5- 58.0	46.9	20.3	--	2.0	2.1	25.3
8/26	15	1	12.5-14.5	13.4	14.5- 24.0	18.9	21.1	--	3.3	2.2	26.5
8/26	15	1	11.0-12.5	11.8	10.0- 16.0	12.9	21.0	--	3.4	2.0	25.3
10/3	--	2	13.5-15.0	--	20.0- 26.5	--	21.2	2.3- 2.9	2.6	1.8	25.4
10/3	--	1	--	11.0	--	10.7	20.4	--	1.5	2.0	24.4
10/11	23	1	--	13.5	--	19.3	20.7	--	1.7	1.8	23.5
10/18	8	8	13.0-15.5	14.4	17.5- 30.5	25.1	--	1.7- 5.2	2.8	--	--
10/24	9	1	20.0-20.5	20.2	69.0- 76.0	72.0	--	--	4.1	--	--
11/7	4	1	19.0-21.0	19.8	58.5- 77.5	66.5	22.2	--	4.3	1.9	27.6
11/7	15	2	15.5-17.5	16.7	29.0- 43.0	37.0	21.0	--	2.8	1.9	25.6
11/16	19	2	14.5-16.5	15.5	27.7- 30.1	28.9	21.0	--	2.6	2.1	25.6
11/21	11	1	--	15.0	--	25.5	21.5	--	2.7	1.8	25.6
11/21	8	1	--	18.0	--	47.2	22.3	--	4.2	2.0	27.7
12/29	10	1	16.0-17.0	16.5	31.0- 38.0	33.6	21.8	0.8- 3.2	2.5	2.3	25.2
12/29	6	6	15.5-17.0	16.1	30.5- 38.0	33.6	--	--	2.0	--	--
1967											
1/9	30	1	--	11.5	9.4- 12.8	11.1	20.7	--	1.2	2.1	21.9
1/9	5	5	13.5-14.9	14.2	17.5- 22.5	20.4	--	0.8- 1.1	1.0	--	--
2/7	5	5	15.5-18.5	17.0	30.5- 44.2	37.4	--	0.7- 3.7	2.2	--	--
2/15	8	8	15.0-18.0	15.9	26.0- 41.5	32.1	--	1.5- 3.8	2.6	--	--
2/19	10	1	13.7-17.5	15.4	22.0- 45.0	29.6	19.1	--	1.8	1.7	21.7
2/27	30	1	9.1-11.2	10.0	--	8.0	20.2	--	2.2	2.6	24.0
3/14	15	1	14.8-15.8	15.4	24.7- 32.5	28.6	20.7	--	3.0	2.1	25.8
3/21	11	2	14.7-17.8	16.1	25.8- 44.5	34.0	20.3	2.3- 2.5	2.4	1.8	23.8
4/2	14	1	--	14.0	--	19.1	19.1	--	2.1	1.9	22.1
4/14	20	1	--	13.0	--	17.8	18.3	--	1.7	1.9	22.1
4/17	11	1	14.0-14.8	14.3	23.5- 29.8	25.7	18.6	--	4.3	1.8	24.2
5/1	16	16	14.0-16.5	14.8	21.0- 35.0	25.2	--	1.1- 6.0	3.2	--	--
5/8	24	24	13.0-16.0	14.0	15.0- 31.0	20.7	--	1.3- 7.7	2.8	--	--
5/9	14	1	14.3-15.4	14.8	22.0- 29.5	25.4	21.1	--	2.7	2.0	24.4
5/16	15	1	--	14.0	--	20.8	--	--	2.2	--	--
6/13	21	21	13.5-17.0	14.6	18.0- 39.0	24.8	--	1.5- 5.2	2.6	--	--
6/13	10	1	14.2-16.5	15.5	25.1-37.6	31.0	20.8	--	3.9	1.6	25.4
7/13	15	1	15.2-14.5	14.3	--	27.3	19.6	--	2.4	2.5	23.2
7/13	10	10	13.0-14.5	13.8	19.2- 26.5	23.0	--	1.1-14.6	3.9	--	--
7/13	3	3	11.8-12.5	12.1	16.2- 21.7	18.9	--	5.5-10.7	8.5	--	--
7/26	15	15	8.5- 9.6	8.9	5.0- 7.2	5.9	--	2.2- 6.5	4.3	--	--
7/26	--	1	9.0- 9.7	--	5.8- 7.7	--	--	--	4.2	--	--
7/30	8	8	9.2- 9.7	9.4	6.8- 8.5	7.7	--	3.3- 7.7	5.6	--	--
7/30	22	1	9.2-10.6	9.7	6.2- 10.5	7.9	--	--	3.4	--	--
8/18	18	18	16.2-21.0	18.2	32.5- 88.5	52.2	--	2.0- 5.7	3.4	--	--
8/20	15	15	9.3-11.8	10.8	6.0- 13.2	10.0	--	1.8- 3.4	2.3	--	--
9/3	45	3	11.0-12.0	11.5	11.6- 15.0	13.3	--	5.3- 6.0	5.7	--	--
9/8	8	1	--	13.5	--	17.8	--	--	1.5	--	--
9/10	10	1	17.2-19.0	18.0	43.8- 57.5	47.8	--	--	1.8	--	--
9/10	7	7	--	20.0	--	68.0	--	1.2- 3.3	2.2	--	--
9/25	20	2	9.5-10.5	10.0	5.9- 8.5	7.2	--	1.8- 2.1	2.0	--	--
9/25	10	1	--	18.0	--	47.5	--	--	2.4	--	--
10/2	10	1	--	11.5	--	12.0	--	--	2.3	--	--
10/13	10	10	--	18.0	--	48.0	--	2.0- 4.4	2.9	--	--
10/17	18	18	18.0-22.0	19.7	48.0- 80.0	63.0	--	1.4- 6.7	3.6	--	--
10/29	6	6	--	11.0	9.5- 11.0	10.1	--	1.3- 3.1	2.4	--	--
10/29	5	5	--	16.0	33.5- 36.5	35.5	--	2.9- 6.5	4.1	--	--
10/29	7	7	16.0-19.5	17.0	30.5- 67.0	37.9	--	2.6- 4.5	3.4	--	--
10/29	6	6	--	11.0	8.0- 9.5	8.9	--	2.0- 4.7	3.0	--	--
10/31	12	1	14.5-15.5	15.0	24.5- 29.6	26.4	--	--	2.5	--	--
10/31	7	1	--	18.0	--	49.6	--	--	3.2	--	--
11/1	10	1	--	16.0	--	32.7	--	--	2.7	--	--
11/7	10	10	18.0-19.0	18.5	42.5- 55.5	48.6	--	1.9- 5.2	3.5	--	--

Nitrogen (crude protein), oil, and ash were determined according to the official methods of the Association, but with the following modifications:

1. Isopropanol was substituted for ethanol in the determination of oil.

2. Porcelain crucibles were used instead of platinum ones. The ash was not moistened, and the sample was not re-ashed (Thompson, 1966).

3. Selenium powder was used as the catalyst in the determination of nitrogen (Thompson, 1966).

We analyzed the samples in duplicate. When, however, the results were questionable, we analyzed them in triplicate.

2. Results

Tables 2 to 12 and Figures 8 to 17 give the data on the concentration of protein, fat, ash, and water in the fishes.

a. Protein.—The concentration of crude protein ranged from about 17 to 24 percent, so all species were classed in the high-protein group (15 to 20 percent) or the very-high-protein group (20 percent and over) specified in Stansby's system of classification (1962). Even the high-oil group (over 15 percent oil) always contained more than 15 percent protein and sometimes more than 20 percent. This group is not included in Stansby's system. The members of this high-oil, high-protein group are *Euthynnus alletteratus*, *Sardinella aurita*, and *Scomber japonicus*. *Euthynnus alletteratus* had particularly high-protein values (Tables 2 to 4).

b. Oil.— Small-to-very-large changes in oil concentration and simultaneous changes in dry matter were observed. We believe that these

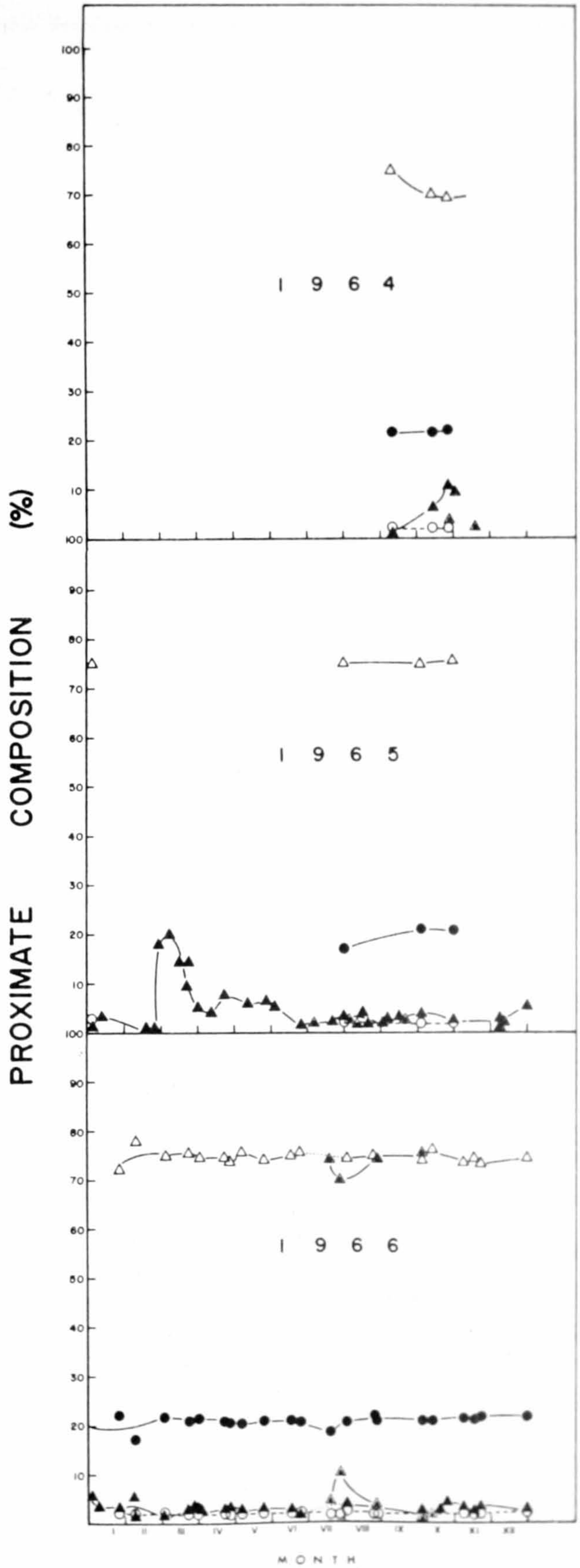

Figure 8.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Sardinella aurita*. [△ = water; ● = protein; ▲ = oil; ○ = ash; ◬ = water or oil values for juvenile fish.]

Table 3.—*Scomber japonicus*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1965											
11/14	5	--	--	22.5-23.5	--	--	155.6	23.0	7.6	1.5	30.5
1966											
4/18	5	--	26.0	--	23.0	149.4-170.4	162.3	20.8	2.6	1.63	25.6
5/11	5	26.0-28.5	26.7	22.5-25.5	23.3	160.5-237.0	181.1	23.0	1.4	1.81	25.2
5/22	5	25.0-27.0	25.7	21.5-23.0	22.0	--	--	22.2	2.3	1.7	26.1
5/29	5	26.0-28.0	27.1	23.5-25.0	24.1	162.0-221.0	186.6	22.5	2.8	1.51	26.4
6/12	5	25.0-26.5	25.4	21.5-23.5	22.3	138.0-177.0	153.6	21.6	2.4	1.70	25.8
8/21	7	12.9-14.9	13.9	11.3-13.1	12.2	20.5- 28.5	24.4	21.8	1.96	2.44	26.2
9/18	7	19.5-21.0	20.1	17.0-18.0	17.2	65.6- 80.5	71.4	22.9	1.95	1.79	25.5
10/17	5	21.5-22.0	21.7	19.0-19.5	19.2	--	97.0	23.2	3.5	1.74	27.3
10/26	5	--	26.0	--	23.0	--	152.0	21.7	5.65	1.82	28.7
11/14	5	23.5-25.0	24.4	20.0-21.5	20.9	119.0-146.0	130.6	22.0	5.69	1.86	28.8
1967											
5/16	4	30.5-33.5	32.0	25.5-28.0	26.7	238.5-337.5	304.0	21.4	2.35	1.9	24.7

changes are due mainly to season. The divergence from individual fish, however, was also noticeable; it tended to increase as the concentration of oil increased. El Saby (1937) also noted this phenomenon in *Sardinella aurita*. Figure 18 shows the relation graphically.

A discussion of oil content can hardly be separated from the relation of oil to protein. Low oil and high protein (15 to 20 percent) were found in both the *Saurida* species (*S. undosquamis* and *S. tumbil*) and in *Nemipterus japonicus* and *Sphyraena jello*. The Red Sea species were generally lower in concentration of oil than were their Mediterranean counterparts. *Nemipterus japonicus* particularly was very lean (Table 11), *Saurida tumbil* contained less oil than did *S. undosquamis*, which inhabits both seas (Tables 8 and 9); *Sphyraena jello* was much leaner than was *S. chrysotaenia* (Tables 4 and 9). *Upeneus moluccensis* from the Red Sea was never as fat as the same fish from the Mediterranean was (Table 7). Yaroslavtseva's (1966) data on the composition of *Nemipterus japonicus*, *Upeneus tragula*, *U. vitatus*, *Saurida gracilis*, and many other species from the Red Sea and Gulf of Aden tend to substantiate our general impression that lean fish (containing 0.25 to 3.2 percent oil with a high protein content of 19 to 23 percent) are common in the Red Sea area.

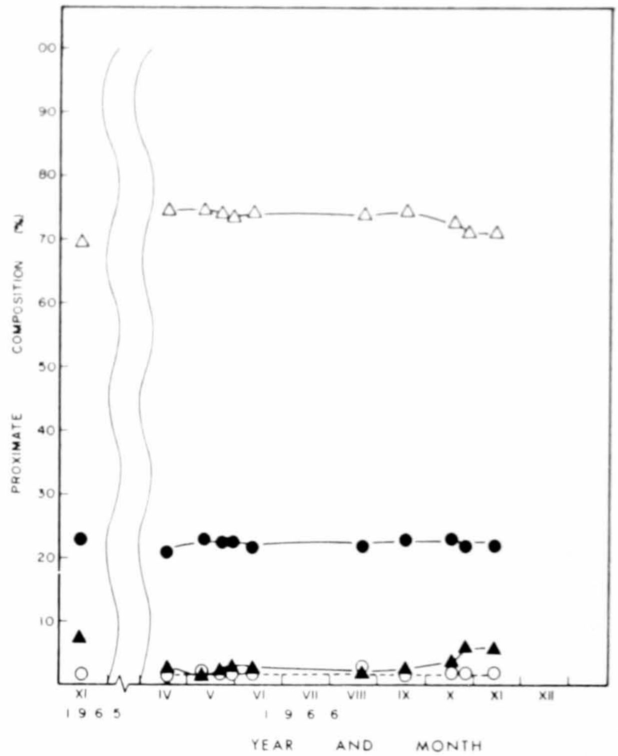

Figure 9.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Scomber japonicus*. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 4.—*Euthynnus alletteratus*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1964											
8/23	1	--	--	--	--	--	--	23.9	0.75	1.3	27.1
9/30	1	--	--	30.0	--	--	--	21.6	3.7	1.5	28.6
11/3	1	--	--	23.5	--	242.0	--	22.1	1.3	1.6	28.1
11/3	1	--	--	25.0	--	346.0	--	21.4	3.2	1.6	28.2
1965											
11/25	1	--	--	33.0	--	696.0	--	21.9	17.6	1.4	40.6
12/1	1	--	--	31.5	--	653.0	--	21.6	17.8	1.4	40.7
12/1	1	--	--	32.5	--	696.0	--	22.1	13.7	1.4	38.7
12/29	1	48.0	--	36.5	--	962.0	--	24.1	13.7	1.36	36.7
1966											
2/7	1	42.5	--	36.5	--	943.0	--	22.5	9.7	1.55	33.4
2/7	1	55.0	--	48.0	--	1850.0	--	22.2	5.0	1.54	31.3
3/15	1	48.0	--	42.0	--	1330.0	--	23.9	5.7	1.54	31.3
3/15	1	41.0	--	36.0	--	820.0	--	23.0	1.6	1.72	26.3
4/28	1	48.5	--	41.0	--	1170.0	--	23.6	1.04	1.77	27.4
5/24	[1]1	75.0	--	65.5	--	5315.0	--	25.0	2.17	1.35	28.8
5/24	[1]1	73.0	--	64.0	--	4325.0	--	24.3	1.1	1.39	27.2
5/25	1	56.0	--	49.0	--	2400.0	--	23.9	2.0	1.51	27.0
5/25	1	56.0	--	49.0	--	2125.0	--	25.1	1.2	1.48	26.6
6/26	1	46.0	--	39.5	--	1230.0	--	23.0	7.67	1.36	32.0
6/26	1	46.0	--	39.0	--	1110.0	--	23.1	3.0	1.53	27.6
6/26	1	44.0	--	38.0	--	1100.0	--	23.0	7.6	1.50	31.5
7/6	1	65.0	--	54.5	--	3420.0	--	24.5	1.96	1.48	--
7/21	1	87.0	--	75.5	--	7950.0	--	21.8	1.2	1.45	--
7/21	1	82.5	--	73.0	--	6760.0	--	22.7	0.72	1.4	27.5
8/3	[1]1	66.0	--	56.5	--	3000.0	--	22.5	1.86	1.44	26.5
8/3	[1]1	70.5	--	61.5	--	4080.0	--	23.0	1.08	1.4	26.1
8/3	1	50.5	--	43.5	--	1480.0	--	22.2	2.38	1.57	27.1
8/21	9	11.5-12.8	12.2	10.5-11.7	11.0	13.5-21.0	17.2	20.8	1.16	1.78	23.0
8/29	[1]1	67.0	--	59.5	--	3710.0	--	23.1	1.79	1.54	27.0
8/29	[1]1	68.0	--	60.0	--	3890.0	--	23.1	1.56	1.41	26.1
8/29	[1]1	65.5	--	56.5	--	3400.0	--	25.4	1.89	1.45	27.2
9/12	5	--	--	--	18.0	--	95.2	22.0	0.83	1.78	25.8
9/22	--	--	20.0	--	--	--	--	23.0	1.32	2.07	26.2
10/10	5	--	26.5	--	--	--	350.0	22.4	2.43	1.76	27.4
10/18	2	27.7-29.0	28.3	24.5-25.2	24.8	230.0-263.0	246.0	23.4	1.20	1.70	26.6
11/15	1	--	--	32.0	--	588.0	--	22.4	7.65	1.60	31.7
11/15	1	--	--	30.0	--	273.0	--	22.7	5.15	1.64	29.4
11/15	1	--	--	28.0	--	407.0	--	23.6	1.86	1.74	27.5
12/5	1	--	--	50.5	--	2150.0	--	21.8	9.9	1.48	33.9
12/5	1	34.0	--	28.5	--	455.0	--	21.6	10.2	1.53	33.9
12/5	1	--	--	51.0	--	2510.0	--	20.8	20.2	1.19	41.0
12/5	1	41.0	--	36.0	--	810.0	--	21.8	16.1	1.46	38.5
12/26	1	38.5	--	32.5	--	705.0	--	21.7	14.1	1.55	37.5
12/26	1	39.0	--	33.0	--	693.5	--	21.8	11.1	1.58	34.1
12/26	1	37.5	--	31.5	--	582.5	--	22.4	12.9	1.58	36.3
1967											
1/5	1	35.5	--	31.0	--	550.0	--	23.5	4.12	1.60	29.1
1/5	1	41.0	--	35.5	--	820.0	--	21.7	6.64	1.58	30.0
1/5	1	43.0	--	37.5	--	900.0	--	23.1	1.6	1.64	25.6

[1] Vertebral column removed.

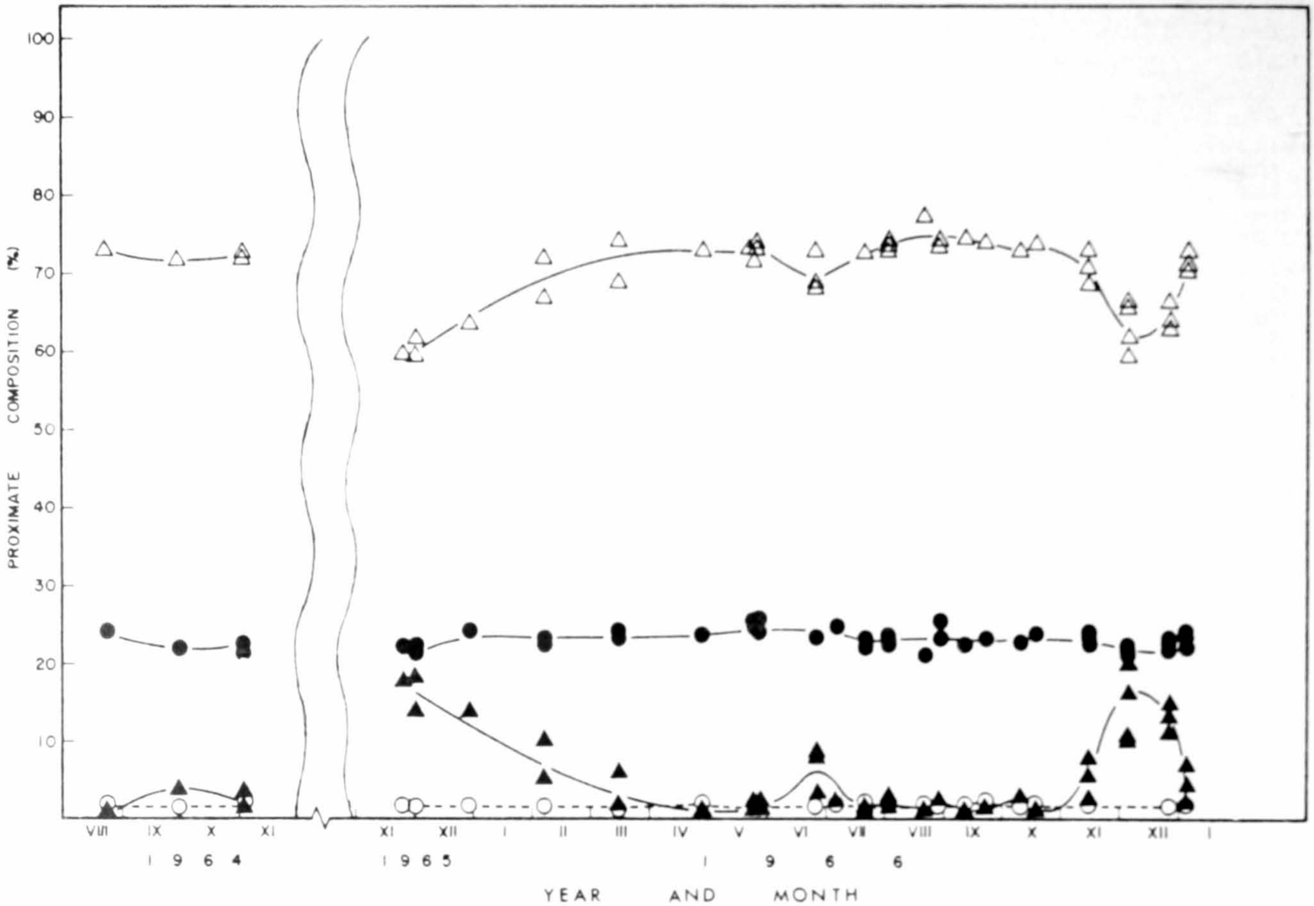

Figure 10.—Seasonal changes in the chemical composition of the edible parts, generally with skeletal frame and bones (see Table 4), of *Euthynnus alletteratus* in the Eastern Mediterranean. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

During part of the year, *Mullus barbatus* and *Upeneus moluccensis* from the Mediterranean belong in Stansby's category of medium-oil, high-protein fish, but during long periods of the year they are extremely lean. They contained up to 10 percent and 7 percent, respectively, of a bright orange oil that becomes colorless when exposed to sunlight.

The three pelagic species--*Euthynnus alletteratus, Scomber japonicus,* and *Sardinella aurita*--varied widely in concentration of oil. They furnish a good example of the rule that isolated analyses do not give a true picture either of composition or of the complex changes that may affect composition.

c. Ash.— We found some variations in the concentration of ash, which ranged from about 1.5 to 2.5 percent in most species, but we could establish no relation between these variations and season, fishing ground, or size of fish. Only *Nemipterus japonicus,* which is a very spiny species, contained as much as 3.5 percent ash (Table 11).

Table 5.—*Sphyraena chrysotaenia (obtusata)*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1965											
7/25	5	--	--	18.0-19.0	--	--	--	21.7	4.5	2.5	26.4
11/29	7	--	--	18.0-19.0	--	--	56.6	21.2	9.6	1.8	30.6
12/8	6	18.2-19.6	18.7	15.5-16.8	15.9	32.7- 44.6	37.7	21.1	2.9	2.3	24.9
1966											
1/6	3	25.3-27.0	25.9	--	--	104.9-122.0	110.7	19.6	10.25	1.67	30.9
2/3	7	19.3-23.2	21.7	16.6-19.8	18.5	39.6- 70.2	55.9	20.2	5.2	1.78	27.0
3/2	5	21.0-24.5	22.9	19.0-22.0	20.5	49.0- 79.0	66.0	20.5	3.5	2.0	24.6
4/17	6	23.0-24.5	23.5	20.0-21.5	20.6	61.3- 90.1	69.2	18.8	2.04	1.94	22.9
4/28	5	23.0-24.0	23.3	20.0-21.0	20.8	68.5- 73.0	71.0	18.9	2.64	1.79	23.3
6/5	5	21.0-22.6	22.1	17.6-19.5	18.9	57.6- 75.9	68.1	20.8	5.0	1.86	27.7
8/2	7	24.0-26.5	25.0	21.5-23.5	22.3	66.0-102.0	89.0	19.4	1.97	1.81	23.7
8/16	6	22.0-23.0	22.5	19.5-21.0	20.1	63.5- 74.5	67.9	19.0	1.70	1.72	23.1
11/11	12	15.5-19.5	17.4	13.0-16.5	15.0	23.5- 40.0	31.6	19.0	3.75	1.67	24.4
11/17	5	22.9-25.7	24.2	21.0-22.5	21.3	78.5-113.5	97.8	18.3	10.25	1.60	30.0
12/27	5	23.3-28.5	25.8	20.3-25.0	22.3	72.0-140.0	105.0	20.1	9.12	1.61	29.3
1967											
2/7	5	22.5-23.5	23.1	19.5-21.5	20.5	65.9- 80.8	71.8	19.7	7.50	1.84	28.2
2/20	7	22.2-25.0	23.3	19.0-21.3	20.1	59.0- 99.0	72.0	19.45	8.0	1.50	27.8

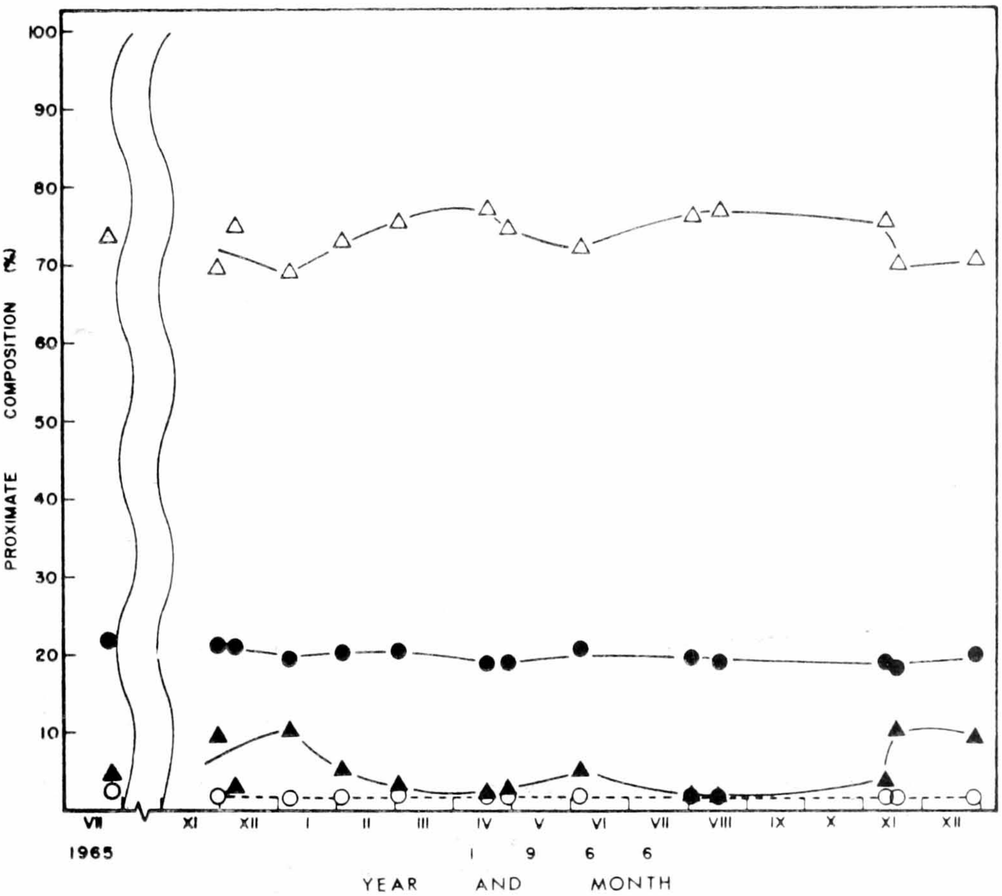

Figure 11.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones of *Sphyraena chrysotaenia (obtusata)* in the Eastern Mediterranean. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 6.—*Sphyraena jello*--total length, standard length, weight and proximate composition edible parts with skeletal frame and bones

Time of catch	Total fish ana-lyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1965											
11/5	5	--	--	--	--	--		21.2	2.2	2.10	24.3
11/20	6	29.0-31.5	30.1	24.5-27.0	25.6	118.0-135.5	126.7	22.1	1.9	1.90	22.1
12/20	4	35.5-38.5	37.1	31.0-33.0	32.0	198.0-239.5	218.8	21.7	--	2.30	23.0
1966											
1/1	4	29.0-32.5	30.7	25.0-27.5	26.2	112.0-140.0	126.0	19.4	1.78	1.92	24.0
2/1	5	--	31.5	--	27.0	--	142.0	21.1	1.35	1.82	23.1
2/25	5	31.5-38.5	35.0	27.0-33.0	30.0	141.0-240.0	195.3	20.2	2.30	2.20	24.1
5/1	5	29.5-32.0	30.5	25.0-26.5	25.5	105.0-144.5	120.5	18.4	0.66	1.43	20.9
5/25	5	30.5-32.0	31.2	25.5-27.5	26.3	121.5-147.5	133.8	18.6	0.75	1.25	20.5
6/28	7	29.5-35.5	31.9	25.0-30.0	27.1	116.5-179.0	142.0	20.3	1.02	1.71	21.9
10/12	7	24.0-27.2	25.5	20.0-22.7	21.3	58.0- 85.0	72.8	19.0	0.70	1.68	21.4
11/14	3	43.5-45.0	44.3	38.0-39.0	38.6	281.0-311.5	296.5	--	1.55	2.06	23.8
11/26	6	25.3-30.0	27.4	21.5-25.5	22.9	72.5-118.5	92.1	19.0	1.06	1.71	21.5

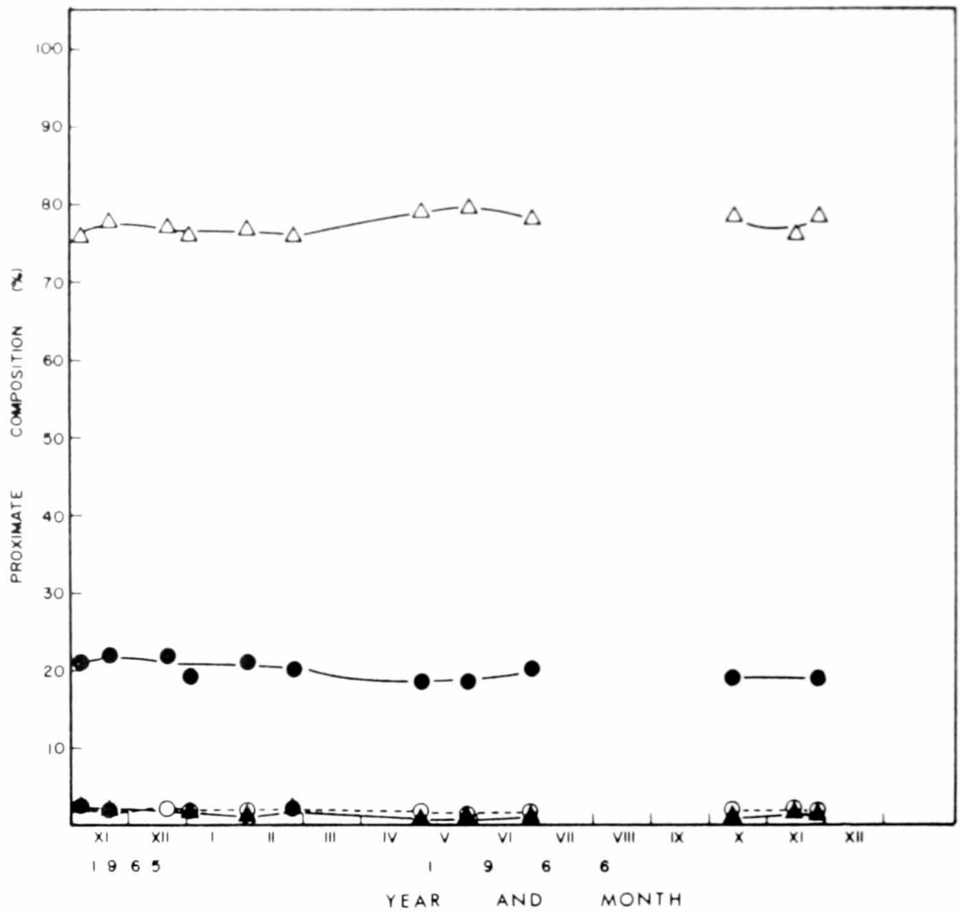

Figure 12.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Sphyraena jello* from the Red Sea. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 7.—*Upeneus moluccensis* --total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
Mediterranean:											
1965											
7/29	4	--	--	--	14.5	--	--	--	4.1	1.88	25.3
12/1	9	--	--	10.0-12.0	--	--	29.5	20.2	6.3	2.5	28.2
1966											
1/5	5	14.5-15.0	14.6	12.0-12.5	12.1	34.9-36.0	35.4	20.0	7.0	1.9	28.3
2/5	18	12.0-14.5	12.7	10.0-12.0	10.4	21.0-36.0	21.7	18.9	4.6	1.88	24.4
3/13	11	13.5-15.5	14.4	11.0-12.5	11.8	26.0-41.5	34.3	21.5	6.6	1.8	28.0
6/5	7	12.5-15.8	13.8	10.0-13.0	11.2	22.0-43.5	30.8	20.0	6.17	1.63	27.2
6/29	11	12.0-14.5	13.0	9.5-12.0	10.5	18.5-35.5	25.0	19.0	2.77	1.77	23.3
7/27	8	13.0-16.0	14.2	11.0-13.0	11.8	30.5-58.0	40.3	20.4	2.95	1.49	25.3
8/5	9	13.0-15.5	14.7	11.0-13.0	12.2	26.5-46.5	41.7	19.6	2.04	1.8	23.4
9/23	9	12.6-15.9	14.6	10.2-13.0	11.9	24.0-49.0	36.9	20.3	2.48	1.78	24.2
11/12	15	14.0-17.3	15.6	11.3-14.0	12.6	31.5-56.0	43.4	19.0	3.61	1.93	24.2
Red Sea: approximate											
5/1	7	12.5-13.0	12.7	10.0-10.5	10.5	19.0-26.5	22.9	20.6	3.7	1.59	24.5
5/25	16	12.5-15.0	13.2	10.0-12.0	10.4	18.5-37.0	27.6	19.5	1.9	1.72	22.0
6/28	14	14.5-15.5	15.2	12.0-12.5	12.4	38.5-53.5	45.6	19.8	--	1.7	22.6
9/8	15	13.0-16.0	16.0	10.5-13.0	11.7	25.5-45.0	34.7	18.7	1.59	1.6	21.6

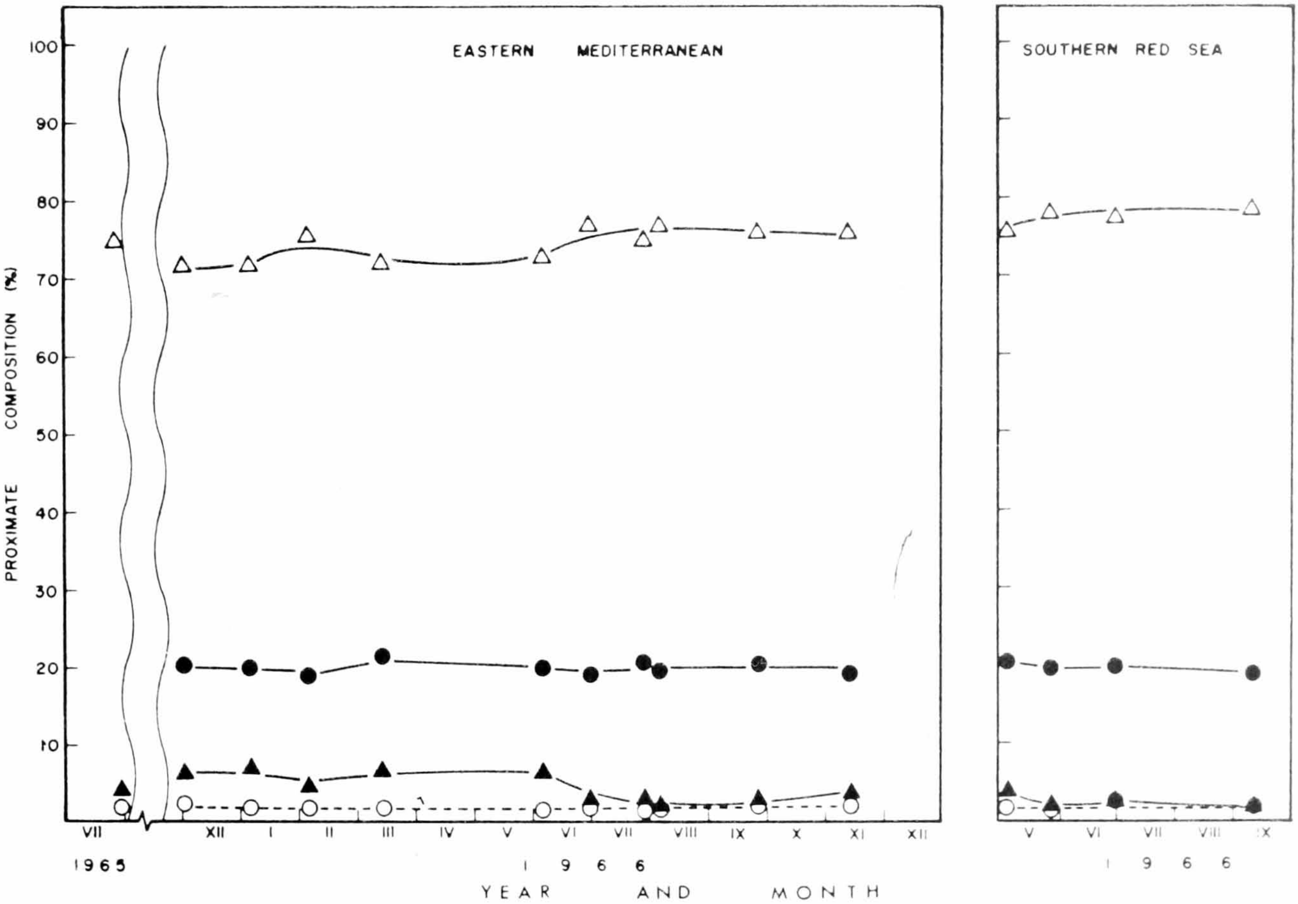

Figure 13.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of Figure13.— *Upeneus moluccensis*. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 8.—*Saurida undosquamis*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1965											
2/14	5	--	--	24.5-26.5	--	--	160.0	19.4	2.0	--	23.2
10/25	5	--	--	--	--	--	56.0	18.9	2.0	1.8	22.0
12/10	5	23.5-27.5	25.4	20.5-23.5	21.9	97.7-144.2	120.6	20.4	2.5	1.8	22.5
1966											
1/11	18	14.0-19.0	16.3	12.0-16.5	14.0	23.0- 41.0	27.3	18.4	2.05	2.21	22.5
2/10	8	23.0-32.5	26.6	19.5-28.0	22.8	77.5-215.0	128.0	20.2	2.53	1.92	23.8
3/8	10	20.5-23.5	21.9	18.0-20.0	18.9	59.5- 92.5	72.1	20.9	3.4	1.78	24.1
4/17	6	23.5-28.0	25.5	20.0-24.0	21.9	82.8-155.3	112.1	18.5	2.6	1.71	23.6
6/5	3	29.5-31.0	30.3	26.0-27.0	26.3	198.5-246.0	226.3	20.0	2.8	1.6	24.4
7/27	5	25.0-27.0	26.0	22.0-23.5	22.7	118.0-145.0	132.6	20.2	1.77	1.89	23.3
9/23	5	30.5-32.0	30.8	26.0-27.0	26.4	193.0-244.0	205.9	18.5	1.67	1.72	22.3
11/12	9	18.5-22.0	20.1	16.0-19.5	17.3	46.0- 73.0	57.6	19.1	3.44	1.8	23.9
12/1	8	21.3-23.5	22.1	18.5-20.5	19.1	67.5- 89.5	76.8	18.6	2.87	1.49	23.0

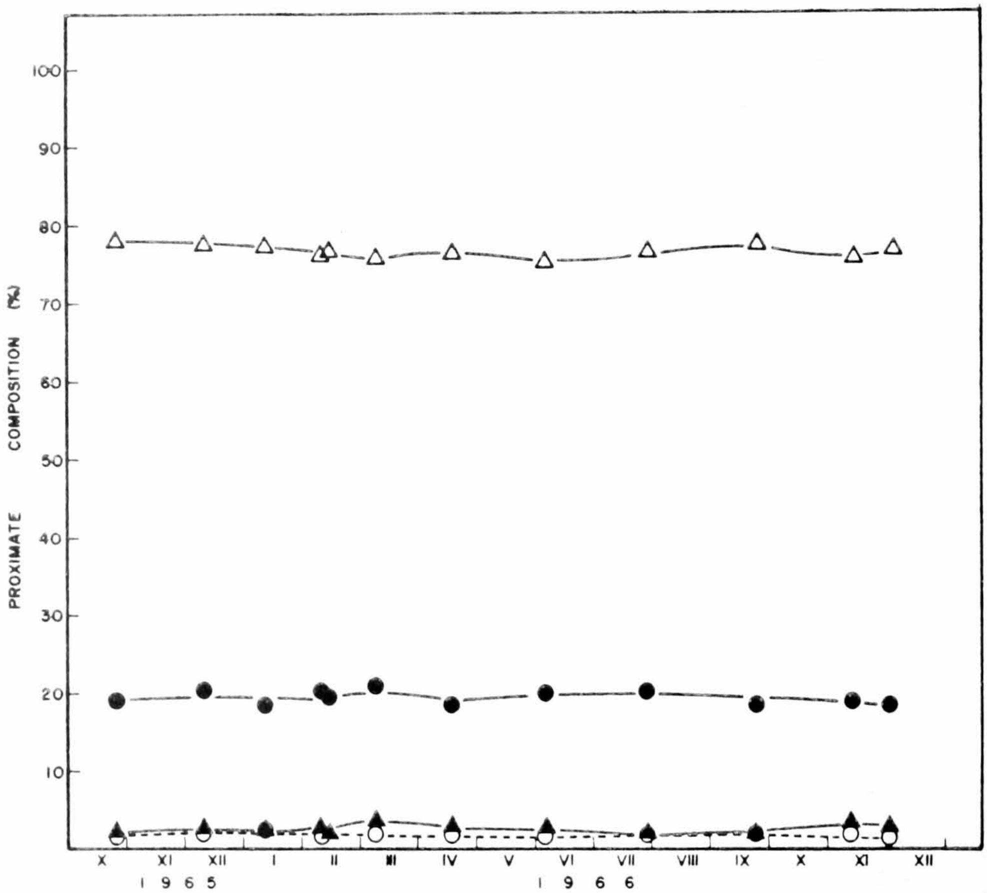

Figure 14.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Saurida undosquamis* from the Red Sea. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 9.—*Saurida tumbil*--total length, standard length, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1964											
10/5	5	--	--	18.0-21.0	--	--	--	17.7	0.8	1.6	19.8
1965											
6/5	5	--	--	19.5-27.0	--	92.0-237.0	--	--	1.7	--	--
12/20	3	28.0-30.5	29.3	24.5-26.0	25.3	178.0-199.9	191.0	23.5	1.1	2.2	22.6
11/5	5	--	--	--	--	--	--	20.7	1.2	1.4	23.7
1966											
1/20	7	21.0-25.0	22.9	18.0-21.0	19.2	81.0-125.0	89.4	19.5	1.11	1.9	23.0
2/25	6	21.5-25.0	23.4	18.0-21.5	20.1	73.5-116.5	95.6	19.1	1.05	1.8	20.9
4/1	7	--	--	18.0-21.5	19.5	77.5-117.0	91.2	19.8	1.36	2.01	22.7
5/1	5	--	22.5	--	19.5	--	81.5	17.4	0.90	1.78	19.8
5/25	5	23.0-25.0	23.7	19.0-21.0	20.0	94.0-122.5	106.6	18.8	1.65	1.64	21.7
6/28	5	27.5-30.0	28.9	23.0-25.5	24.4	168.5-231.0	197.1	19.2	1.14	1.58	21.3
7/10	7	23.0-28.0	24.5	19.5-24.0	21.2	90.0-157.5	117.0	18.7	1.23	1.74	22.6
8/10	8	23.0-27.5	24.4	19.0-23.5	20.6	82.0-156.0	106.2	18.6	1.42	1.65	21.7
9/8	6	21.5-23.5	22.3	18.0-19.5	18.7	70.0- 92.5	83.2	19.3	1.6	1.78	22.6
10/12	5	28.0-30.5	28.8	23.5-25.5	24.5	158.0-201.0	170.8	19.4	1.27	2.2	22.1
11/26	7	23.3-28.5	25.0	19.3-24.5	21.1	96.0-155.5	114.8	18.6	0.73	1.82	20.8

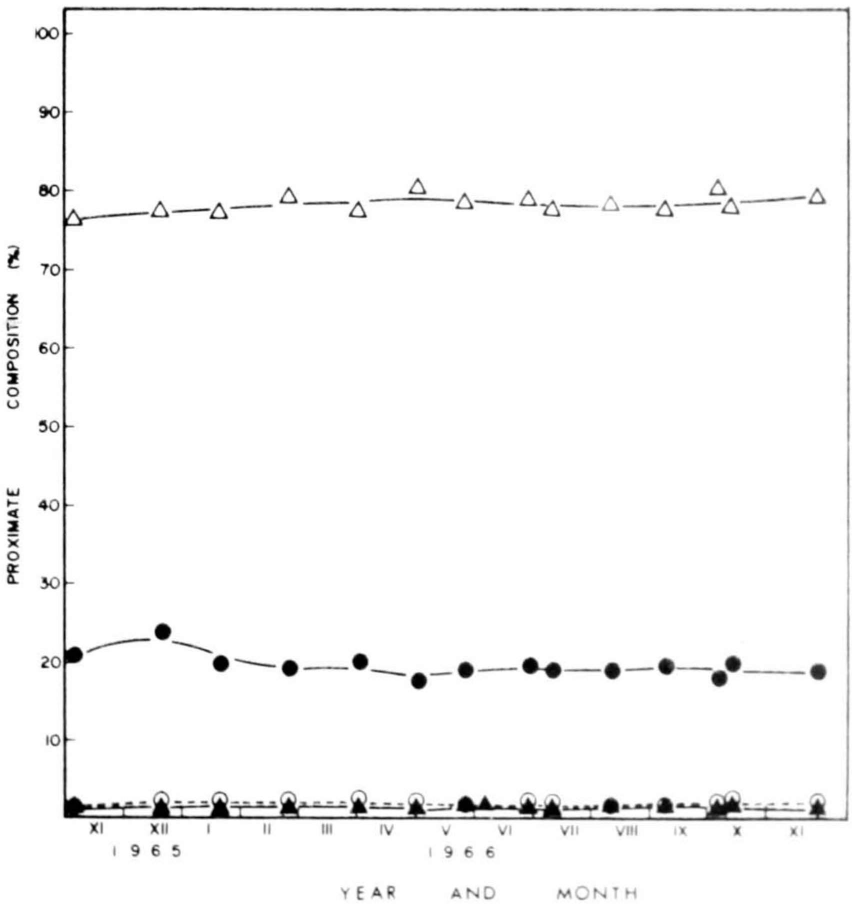

Figure 15.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Saurida tumbil* from the Red Sea. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 10.—*Mullus barbatus*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish analyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1965											
2/23	--	--	--	--	--	--	--	18.3	10.7	--	31.3
11/5	5	--	--	--	13.0	--	46.0	19.3	5.0	2.10	25.80
11/14	5	--	--	--	11.5	--	31.3	19.2	4.40	1.70	24.90
11/28	8	--	--	12.5-13.0	12.7	--	43.7	20.7	6.80	1.80	27.10
12/12	6	17.5-18.5	18.0	14.0-14.5	14.2	62.8-73.0	68.9	22.2	6.80	1.60	25.70
12/28	11	12.0-14.5	13.0	10.0-11.5	10.5	--	24.3	23.0	4.40	1.82	23.20
1966											
2/5	16	12.0-14.0	12.9	9.5-11.5	10.3	18.0-30.5	23.4	17.8	4.30	1.63	23.15
3/8	7	16.5-18.0	17.0	13.5-14.5	13.8	48.0-64.0	55.5	19.5	4.90	1.72	--
3/28	9	15.5-17.5	16.5	12.5-14.5	13.5	47.3-68.1	54.9	18.6	8.00	1.45	26.90
5/15	7	17.5-21.0	19.1	14.0-17.0	15.4	51.0-91.5	72.0	16.7	1.60	1.72	20.10
6/5	12	13.5-16.5	14.8	11.0-13.0	11.9	26.5-39.5	32.8	19.2	1.35	1.89	23.15
6/29	18	12.0-13.0	12.5	9.0-10.5	9.8	15.0-21.0	17.7	18.0	0.81	2.02	20.10
7/27	7	14.0-16.0	14.5	11.5-13.0	11.8	34.0-55.0	39.0	19.2	3.00	1.48	22.80
9/23	12	14.0-15.0	14.5	11.2-12.0	11.5	28.0-37.5	33.5	18.3	2.14	1.52	21.7
10/3	9	12.5-14.5	13.2	10.0-11.5	10.6	22.5-35.5	26.2	17.6	3.97	1.57	23.6
11/3	20	9.5-13.0	10.7	7.5-10.5	9.0	10.5-25.5	16.0	16.8	4.00	1.72	23.6
12/1	13	12.0-14.8	13.0	9.5-11.8	10.3	17.5-34.5	23.7	17.5	4.14	1.43	22.65

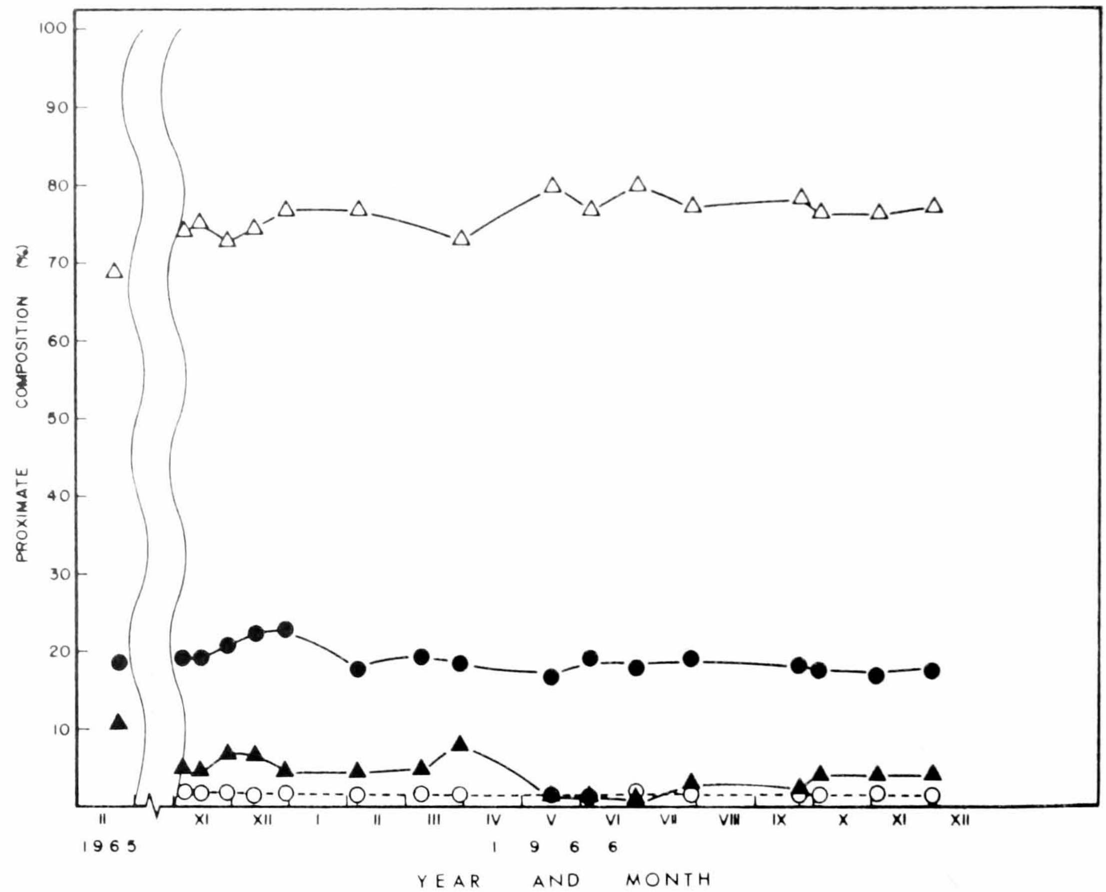

Figure 16.—Seasonal changes in the chemical composition of the edible parts, with skeletal frame and bones, of *Mullus barbatus* in the Eastern Mediterranean. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 11.—*Nemipterus japonicus*--total length, standard length, weight, and proximate composition, edible parts with skeletal frame and bones

Time of catch	Total fish ana-lyzed	Physical measurements						Average proximate composition			
		Total length		Standard length		Weight		Protein	Oil	Ash	Total solids
		Range	Average	Range	Average	Range	Average				
Date	*No.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Grams*	*Grams*	*Percent*	*Percent*	*Percent*	*Percent*
1964											
9/	--	--	--	13.0-15.0	--	--	--	16.6	1.2	3.5	21.6
1965											
6/	3	--	--	14.5-16.0	15.3	69.0-102.0	85.8	--	1.4	--	22.4
1966											
1/20	5	--	--	14.5-18.0	16.1	80.0-140.0	112.1	17.2	1.83	2.14	20.9
2/25	5	--	--	13.5-17.0	15.5	71.0-123.0	98.1	19.1	1.9	2.2	21.8
4/1	5	--	--	14.5-18.0	15.9	81.0-159.0	104.9	18.9	2.6	2.02	22.6
5/1	5	--	--	16.5-18.5	17.3	108.0-147.0	119.3	18.6	0.87	2.58	20.8
5/25	5	--	--	14.0-17.0	15.6	66.5-116.5	89.8	17.9	0.98	2.23	20.6
6/24	4	--	--	15.0-17.5	15.8	82.5-117.0	94.2	17.0	1.25	1.96	19.3
7/10	8	--	--	15.5-19.0	17.1	92.5-187.0	127.6	17.1	1.28	1.8	20.6
8/4	6	--	--	13.0-18.5	16.3	61.0-157.5	114.0	17.4	1.75	2.17	20.9
9/8	6	--	--	15.0-17.5	16.0	85.0-120.0	100.8	17.8	1.6	2.53	21.5
10/12	6	--	--	15.0-17.5	15.7	73.5-140.5	98.5	17.6	1.53	2.38	21.2
11/26	8	--	--	12.0-15.0	13.4	53.0- 85.0	67.6	18.3	1.86	--	21.2

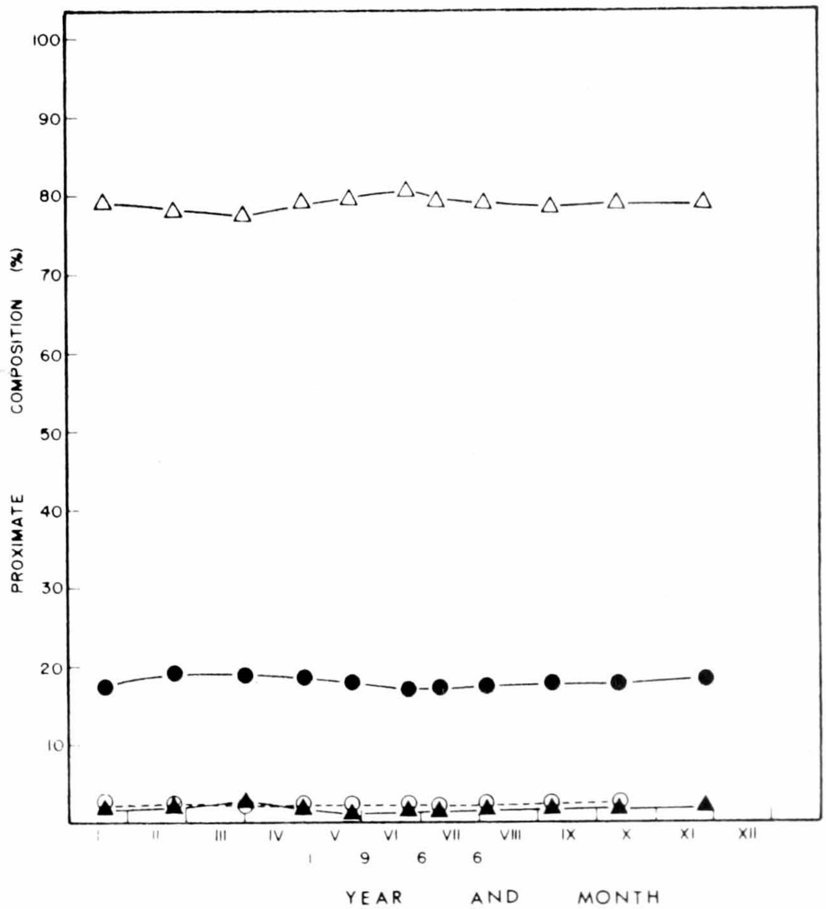

Figure 17.—Seasonal changes in the chemical composition of the edible parts with skeletal frame and bones, of *Nemipterus japonicus* from the Red Sea. [△ = water; ● = protein; ▲ = oil; ○ = ash.]

Table 12.—Average values and range of proximate composition, of the edible parts, with skeletal frame and bones, of the investigated species

Species	Protein		Oil		Ash		Total solids	
	Average	Range	Average	Range	Average	Range	Average	Range
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Sardinella aurita (gilt sardine)	20.7	17.0-22.3	3.7	0.4-20.0	1.9	1.4-2.9	25.2	21.9-30.1
Scomber (Pneumatophorus) japonicus (Pacific, chub or blue mackerel)	22.2	20.8-23.2	3.3	1.4- 7.6	1.8	1.5-2.4	26.7	24.7-30.5
Enthynnus alletteratus[1] (little tunny)	22.8	20.8-25.4	5.6	0.7-20.2	1.5	1.3-2.0	30.2	23.0-41.0
Sphyraena chrysotaenia (obtusata) (blunt jaw barracuda, sea pike)	19.9	18.3-21.7	5.5	1.7-10.2	1.8	1.5-2.3	26.5	22.9-30.9
Sphyraena jello (Red Sea barracuda, Red Sea pike)	20.1	18.4-22.1	1.4	0.7- 2.3	1.8	1.2-2.3	22.5	20.5-24.3
Upeneus moluccensis (golden banded goatfish)								
Mediterranean	19.9	18.9-20.4	4.4	2.0-. 7.0	1.8	1.5-2.5	25.6	23.3-28.3
Red Sea	19.6	18.7-20.6	2.4	1.9- 3.7	1.6	1.6-1.7	22.7	21.6-24.5
Saurida undosquamis (Red Sea lizardfish)	19.4	18.4-20.9	2.5	1.7- 3.4	1.8	1.5-2.2	23.2	22.0-24.4
Saurida tumbil (Red Sea lizardfish)	19.3	17.7-23.5	1.2	0.7- 1.7	1.8	1.4-2.2	21.8	19.8-23.7
Mullus barbatus (Red mullet)	19.9	16.7-20.7	4.5	0.8-10.7	1.7	1.4-2.1	24.1	20.1-31.3
Nemipterus japonicus (Red Sea threadfin bream)	17.8	16.6-19.1	1.5	0.9- 2.6	2.3	1.8-3.5	21.2	19.3-22.4

[1] In some samples, the vertebral column was removed, see Table 4.

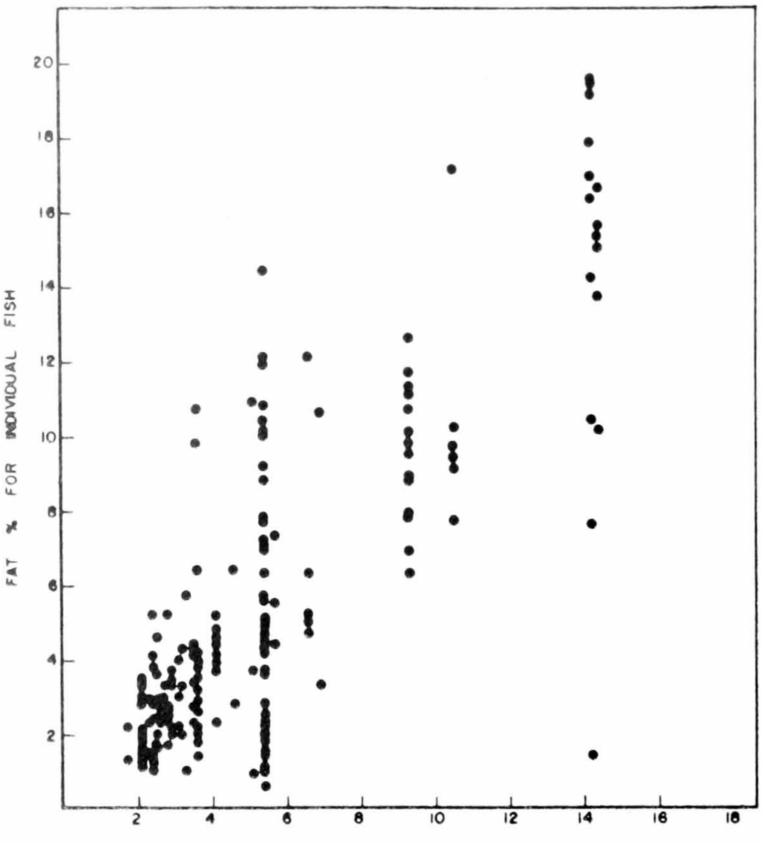

Figure 18.—The possible relation between average and individual at content in the catches of *Sardinella aurita* in the Eastern Mediterranean.

II. RELATION BETWEEN PHYSICAL FACTORS AND OIL CONCENTRATION

Discussed very briefly here is the effect of the environment on the concentration of oil in the fishes and then considered in greater detail is the effect of the biological development of the fishes on the concentration of oil in them.

A. ENVIRONMENT

The sampling area along Israel's Mediterranean Coast is so small that any differences in the chemical composition of the fish caught there can hardly be attributed to a marked variation in environmental factors. Although fishes from the Red Sea were generally leaner than were similar ones from the Mediterranean Sea, the number of samples taken for this study was too small to lead to any final conclusion about the relation between oil concentration and habitat.

B. BIOLOGICAL DEVELOPMENT

The age of a fish and the season of the year almost certainly influence the physiological cycle and, together with the food supply, cause a wide fluctuation in concentration of oil.

In this section we consider the effect on the concentration of oil in the fishes of (1) the spawning cycle and (2) the condition factor, which will be defined shortly.

1. Spawning Cycle

We consider the relation between the concentration of oil and the spawning cycle for the following species: (a) tunny and barracuda, (b) mackerel, and (c) sardine.

a. Tunny and barracuda.—For *Euthynnus alletteratus* at least, an inverse relation between RGS[1] and concentration of oil can be postulated as shown in Figure 19. This species spawns from May until August, depending on the age of the fish. As the gonads develop, the concentration of oil apparently decreases. In June, a relatively high oil concentration was found both in this species and in *Sphyraena chrysotaenia.* (Possibly the fish were examined at the same time or after they had spawned.) The fattening of *Euthynnus alletteratus,* which reaches a maximum in December, coincides with the decrease in the size of the gonads. The condition factor ($F = \frac{\text{Weight}}{\text{Length}}$) increases twice--once during June and July, mostly through gonadal development, and once during December, mostly through fattening.

The relation of the spawning cycle and fat content of clupeids has been reviewed by Blaxter and Holliday (1963). In herring as well as in *Sardina pilchardus,* the concentration of fat decreases during spawning. This decrease is due, at least partly, to a cessation of feeding.

b. Mackerel.—A similar, although fainter, picture shows up for *Scomber japonicus,* which spawns in this area during early summer (Ben-Tuvia, 1957a). These small mackerels appear during the summer and presumably gain weight and accumulate oil until they attain marketable size in the fall. The increase in size, combined with the accumulation of oil, causes a gain in total dry weight per fish. The gain in 1965 averaged about 0.69 grams per

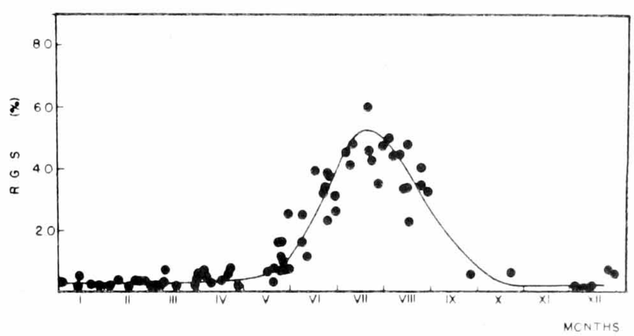

Figure 19.—Seasonal changes in RGS ($\frac{\text{gonad weight}}{\text{total weight}}$ %) of *Euthynnus alletteratus* from the Eastern Mediterranean.

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[1] RGS (rapport gonosomatique) = $\frac{[(\text{gonad weight})\ (100)]}{[(\text{body weight})]}$ [Bougis (1952) as cited by Postel (1955)].

day from August to November and about 0.57 grams per day for the same period in 1966--that is, between 2 and 3 grams total weight per day--quite an accomplishment for a fish of about 20 to 30 grams total weight in August.

c. Sardine.—Ben-Tuvia (1963b) reports that the spawning of *Sardinella aurita* continues throughout most of the summer. Spawning thus may be a partial explanation both for their extreme leanness during this period and for the wide divergences in the concentration of oil in different specimens within the same catch. These differences could also indicate that sardines have a fast metabolic rate, for they are capable of becoming fat within a very short time. The picture was somewhat obscured, however, because several year classes with possibly different seasonal cycles were taken from the same catch. One group may have been gaining fat while another was becoming leaner. This seeming paradox has been described by Clark (1928) for *Sardinops caerulea* (sardine) in the Pacific. The probability that different stocks were contributing to the catch (Ben-Tuvia, 1957b) adds further complexity to the picture.

2. Condition Factor

We could establish no relation between the concentration of oil and the condition factor for *Sardinella aurita* or *Scomber japonicus*. Nor could we find a relation between age and concentration of oil, except, perhaps in the summer catches of *Sardinella aurita* (July to August 1966). These small fish, which were spawned earlier in 1966, were fatter than the larger fish, which were in the middle of their spawning season. In the summer of 1965, all fish--small and large--were lean, and we observed no differences in their proximate composition.

Herzberg (1967) has assumed that a logarithmic relation exists between the ratio of total weight to standard length and the oil concentration of *Mullus barbatus*. The data in the present work support this assumption. From this relation, we calculated the regression equation, which is

$$Y = 6.973X + 0.965$$

where Y = oil concentration in percent and $X = \text{Log.} \frac{\text{Av.TW (g.)}}{\text{Av.SL (cm.)}}$; N = 45. The range of SL (standard length) is from 9.0 to 14.2 centimeters, the range of TW (total weight) is from 16.0 to 72.0 grams, and the range of fat concentration is from 0.8 to 8.0 percent.

$Sy.x$, the mean deviation from regression, is 1.507 percent oil.

Sy, the sample standard deviation of Y, is 0.44 to 0.50 percent for nearly the entire range (n = 44) of X (0.13 to 0.70).

Sy is 1.56 to 1.59 percent.

Thus, from the length and weight measurements, a rough estimate of oil content can be made.

Figure 20 shows the relation graphically.

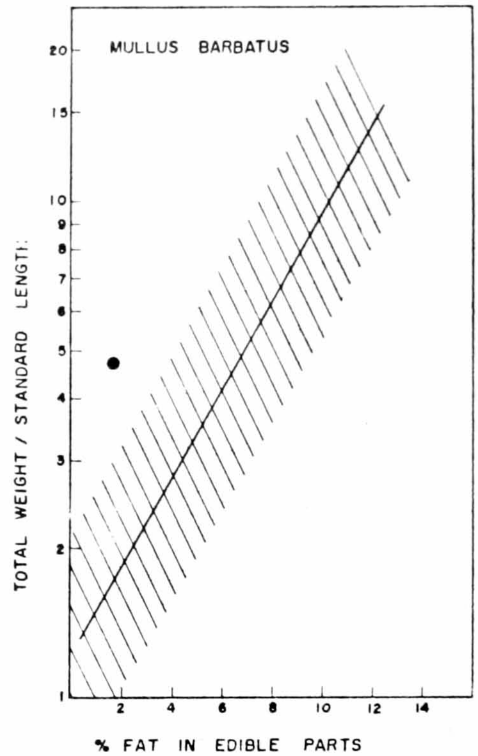

Figure 20.—The relation between a condition factor $\left(\frac{\text{total weight}}{\text{standard length}}\right)$ and the fat contents of the edible parts of *Mullus barbatus*. [The line represents the calculated regression and the shaded area covers all observations except one, which is shown as a dot.]

One should bear in mind that the samples reflect the commercial catch and that consecutive determinations often, but not always, follow the biological development of the fish. In general, no marked discrepancies in the results were observed between fish of different ages or between fish that might belong to different populations. This conclusion accords with the findings of Thompson (1966) on commercial fishes from the Gulf of Mexico.

CONCLUSIONS

Although the observations in this study are far from complete, they give a quantitative indication of the composition of raw material that might be available to fishery industries in this area. The relatively high concentration of protein in all of the fishes investigated, combined with the low concentration of oil in most of the demersal fishes, indicates that the fishes in the area could be a source of fish protein concentrate. This product has been prepared satisfactorily at our laboratory from *Nemipterus japonicus* and from *Saurida tumbil* by extraction with isopropanol. Both of these concentrates were almost tasteless and odorless, despite our rather primitive methods of producing them.

The large changes in the concentration of oil in pelagic fishes point to the necessity for determining the seasons when these and similar species are usable by the canning industry.

Our data do not establish differences in chemical composition between fishes from the Mediterranean Sea and the Red Sea. Our impression is, however, that the species from the Red Sea are generally leaner than are their Mediterranean counterparts. Yaroslavtseva's work (1966) on fishes from the Red Sea and the Gulf of Aden supports the validity of this impression.

RECOMMENDATIONS

The following subjects should be investigated:

1. In addition to proximate composition, other properties that are relevant to food technology should be determined. Studies should be made on how to preserve the fishes reported here. Workers at our laboratory have found that their spoilage patterns differ somewhat from those of fishes from cold or moderate waters.

2. Information should be obtained on amino acid composition. Researchers in this field have generally assumed that the amino acid patterns of these species do not differ materially from those of species from the North Atlantic and the Pacific. Little evidence, if any, however, underlies this assumption.

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MS #1882

GREEN ALGAE, *Chlorella*, AS A CONTRIBUTOR TO THE FOOD SUPPLY OF MAN

by

Norman W. Durrant and Carol Jolly

ABSTRACT

Both marine algae and fresh-water algae may help to solve the problem of world hunger. Of these two groups, the fresh-water algae show the greater promise; and of the fresh-water algae -- blue green and green -- the green algae show the greater promise. Accordingly, this report centers largely on green algae (*Chlorella* in particular) and discusses both their artificial production and nutritional value. By a suitable manipulation of variables, green algae containing as much as 50 percent or more protein, on a dry-weight basis, can be manufactured continuously on a large scale.

CONTENTS

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INTRODUCTION

Basically, efforts to solve the problem of world hunger have fallen into two categories -- those aimed at controlling the growth of population and those aimed at increasing the production of food. This paper is concerned with the latter.

In man's attempt to increase the production of food, he has expanded the amount of cultivable land through such means as clearance of forests or reclamation of deserts; used existing land more intensively through multiple-crop rotation or fertilization programs; and increased the yield through genetic improvement of crops, use of pesticides, and mechanization (Brown, 1963). Also, he has tried a variety of methods that would accelerate the growth of plants, often by cultivation in man-made environments, sometimes in aqueous solutions without soil. At present, the latter method, which is known as hydroponics, is generally considered to be impractical for producing food stuffs on a large scale.

Yet another approach that has received much attention, especially in the past two decades, is to increase the use of aquatic resources. These may include use of the resources latent in the marine fisheries; culturing fish in a wide range of environments ranging from salt-water estuarines to fresh-water ponds; and using plankton, the swarms of floating, small plants and animals that live near the ocean's surface (Osborn, 1953). Also suggested has been the expanded use of aquatic plants -- particularly the algae. This paper is concerned specifically with the tremendous potential of algae for increasing our supply of food.

Algae are a primitive group of plants, some of which have the simplest possible life cycle. They are usually classified according to the color of the dominant pigment -- for example, green, blue-green, brown, or red. No matter the color, however, they all contain chlorophyll, the substance essential to the use of solar energy for the production of organic matter. Green and blue-green algae, although found in both fresh and salt water and even in a terrestrial environment, are primarily fresh-water plants and compared with the brown and red algae are relatively small, the smallest being microscopic. Brown algae, which include kelps, oarweeds, and rockweeds, grow best in the colder areas of the ocean and often form large beds. Characteristically, red algae fluorish in the warmer areas and in relatively deep water; Irish moss, dulse, and laver belong to this latter group.

Since brown and red algae differ considerably from the green and blue-green algae both in size and structural complexity, and since their potential for artificial cultivation and hence for more effective use in combating world hunger is, we believe, less than that of green and blue-green algae, we will consider the two groups separately in the following discussion.

I. BROWN AND RED ALGAE

In the use of any natural resource, quantity and availability are crucial. Accordingly, in our consideration of the potential of brown and red algae as food for man, we consider their supply before investigating their use.

A. SUPPLY

The abundance of marine algae can be more easily envisioned when one considers that over 70 percent of the earth's surface is covered with water.

Our use of the many resources of the oceans, however, has been negligible. Although some 17,000 species of algae (including green and blue-green plants) have been identified, only about 20 have been thoroughly investigated for their potential commercial utilization. Of the many possible colloidal extracts from these thousands of species, only three -- agar, algin, and carrageenin -- have gained any substantial commercial importance. Yet, for centuries, seaweeds have been used in various parts of the world as human food.

Our exact knowledge of the seaweed resources of the world is limited. The data are few on where seaweeds are abundant and on what their concentration is in particular growing areas. The Japanese are ahead of the rest of the world in locating and utilizing their brown and red algae resources. If seaweeds are ever to become on important source of food, an international effort on the scale now used in Japan will be necessary. Supplies of seaweeds have been located along the coasts of Australia, Canada, Central and South America, Great Britain, New Zealand, Russia, United States, and Norway. Meanwhile, information regarding the seaweed resources of China, the Pacific Islands, and many other important geographical areas is very limited.

A number of techniques have been developed for locating and measuring the size of seaweed beds. Among these techniques are simple observation of floating portions of the algae by surveyors in boats cruising along the shoreline, use of aerial photography, and sonar recordings. A combination of these techniques should produce reliable data.

A comprehensive survey of the growth habits of algae is desirable. For many species, information about their capacity to regenerate after being harvested is still meager. To obtain maximum yields, industrial collectors must know how many harvests per year are possible and how far down in the water the plants can be cut without seriously interfering with growth. A survey of growth habits of algae is certainly possible, but a concerted effort by phycologists is required.

As the world population increases and the demand for food becomes greater, the need for using more of the ocean resources becomes correspondingly more urgent. Some day, the oceans will undoubtedly produce a greater proportion of man's food, both the material he consumes directly and the material he extracts from marine products for use in foods. At present, however, we are still in the first stages of what may be a momentous change in man's relation to the ocean, comparable to the change that made our remote ancestors food producers rather than mere food gatherers (Brittain, 1952).

B. USES

Seaweeds, as they are used today, have an indirect as well as a direct bearing on our food supply. They are used as fertilizer for food crops and are used as the food itself.

1. Fertilizer

Brown algae have been used as a soil fertilizer since the 12th century at least. They are still used fairly extensively in the coastal regions of France, England, Scotland, Ireland, Norway, Canada, and New Zealand. The use of seaweed for fertilizer in the United States has never been of major importance, because a great abundance of other more easily accessible fertilizing materials has been available. Because brown algae have an unusually high content of potassium, they have been used to fertilize root crops such as beets and potatoes, which require relatively large amounts of this element. The kelps and rockweeds are high also in nitrogen, organic matter, and trace minerals; but their phosphorus content is low, so phosphate has to be added to them when they are used as complete fertilizers. Algae do present a problem, however -- they are bulky, owing to their high content of water. Because of this bulk, their use as a fertilizer has been restricted largely to coastal areas, where they have improved the growth of crops significantly.

In the past few years, there is evidence to show that seaweed fertilizers improve the germination of seeds; increase the uptake of plant nutrients; impart a degree of frost resistance; and make plants better able to withstand phytopathological fungi and insect pests (Booth, 1966).

More recently, liquid seaweed extracts have been used, and growers in different parts of the world have reported improvements in yield and quality of a wide variety of crops (Challen and Hemingway, 1966).

2. Food

The use of seaweed as a food source has been increasing in recent years. This is particularly true in some of the far eastern countries.

a. Animal food. — Algae are used in a number of different countries as a food or a food supplement for domestic animals. For example, in Finland and Iceland, sheep and cattle are allowed to browse on the algae-strewn shores. In Norway, Scotland, France, and certain other coastal countries, seaweeds are a supplementary feed for sheep and cattle. Notably in Norway, alga meals have been used to supplement the diets of chicks, laying hens, and pigs.

b. Human food. — Algae are used as human food -- both as a primary foodstuff, wherein the seaweed itself may be eaten, and as a secondary foodstuff, wherein extracts from the seaweed may be added to various foods.

(1) Foodstuff. — In 1913, a writer for the *New York Evening Post* predicted:

> It is within the bounds of reasonable expectation that we shall soon see "Shredded Seaweed," "Flaked Fucus," "Dessicated Dulse," "Predigested Sargassum," "Puffed Nereocystis," "Malto Kelp," "Cream of Sea Moss," and a score more substitutes for hot cakes and maple syrup, done up in one-pound packages, "Guaranteed under the Pure Food Laws," and crammed down the throats of a long suffering and surfeited people (Chapman, 1952).

The predictions of the newspaper writer were a bit premature, yet someday algae may be used as a primary foodstuff throughout much of the world.

Today, seaweeds are used to augment food supplies only to a minor extent in Europe and North America. Perhaps the most commonly eaten seaweed on a worldwide basis is *Porphyra.*

Some of the primary species from the *Porphyra* genus that are commonly eaten include *P. perforata* (purple laver, United States), *P. naiadum* (red fringe, United States), *P. umbilicalis* (laver, England and Wales), *P. laciniata* (slack, Scotland), *P. tenera* (amanori and nori, Japan), *P. onoi* (ononori, Japan), *P. okamurai* (kuro-nori, Japan), *P. kunthiana* (luche apanodo fresco, Chile), *P. columbina* (New Zealand), and *P. capensis* (South Africa).

Another species of seaweed commonly used for food is *Rhodymenia palmata* (dulse). This species is unusual in that, unlike most seaweeds, it is completely digestible by man. It has long been used as a primary foodstuff rather than as a source of seaweed extract. It is dried and commonly eaten raw, chewed like gum, eaten with fish and butter, or boiled with milk and rye flour. In the countries of the Mediterranean region, dulse is used in ragouts and other prepared dishes. During the years of famine in Ireland, dulse and potatoes were the staple foods of the people inhabiting the coastal regions. Coastal inhabitants of the Canadian Maritime provinces eat dulse, which they consider to be health-giving.

Seaweeds constitute an essential portion of the Japanese diet (Okazaki, 1964).[1] Understandably, more seaweed is eaten in Japan than in any other nation. Algae are of such commercial and nutritional importance to the Japanese that the natural or uncultivated supply is insufficient to satisfy the demand. Accordingly, they have developed large industries to cultivate the plants.

Porphyra or "nori," a red alga, is probably the most important alga used for food in Japan. This species is raised to a large extent by "farming." Heavy netting supported by bamboo poles is stretched over the surface of the water and seeded naturally or artificially with spores that grow to be marketable leafy plants. It is important to place the netting at the proper depths within the range of tides so that it is covered most of the time, yet is occasionally exposed (4 hours per day) so that the nori can be harvested by farmers who move along the webbing in small boats and remove the algae from the nets by hand. The standard net is about 60 feet long and 4 feet wide with 6-inch mesh openings.

Porphyra is used to make Japanese "makizushi." This dish is prepared by wrapping toasted algae around a core of rice that encloses strips of fish or shellfish and sometimes vegetables. Despite an annual production of 130,000 tons, the demand is still greater than the supply.

[1] Akio, Okozaki. Seaweed. Tokyo Export Commodities Inspection Institute. Unpublished manuscript. 1964. 185 pages. Available for loan from the Branch of Technology, Bureau of Commercial Fisheries, U.S. Department of the Interior, Washington, D.C. 20240.

Among the several species of algae used as food by the Japanese, the brown alga *Undaria pinnatifida,* is second in popularity to *Porphyra.* The overall production of *Undaria* in Japan has increased steadily during the past 10 years, and the fraction of the crops produced by "farming" has grown to the point where, in 1966-67 for the first time, it exceeded that obtained from natural harvesting. Since 1960, the annual production of *Undaria* in Japan has averaged about 65,000 tons.

Another important algal foodstuff is a brown oarweed of the genus *Laminaria.* This seaweed is a source of the chemical seasoning monosodium glutamate, now used extensively in the United States.

Despite the widespread use and the potential of algae as a human food, remarkably little is known about their nutritive value. Various scientists suggest that the roughage of the algae compensates for the lack of peristalsis-inducing foods in the rice-and-fish diet of the Asiatic peoples. Others suggest that the major value of algae lies in the mineral salts and vitamins (A, B, and C) that both brown and red algae contain. These salts and vitamins help prevent deficiency diseases. Most scientists agree that the high iodine content in seaweed contributes to the low incidence of goiter in the Orient (Chapman, 1952; Okazaki, 1964[2]).

Yet no definitive experiments have been made on the digestibility of algal protein or carbohydrates. Although those who collect and eat seaweeds are aware that the number and the amount of the nutrients in seaweeds vary not only with the particular species but also with the locality and the season of collection, the extent of the variation has not been systematically analyzed. Almost nothing is known about the vitamin D, E, and K contents of algae under various conditions of growth. Although experiments with both livestock and humans indicate that digestibility improves after the subject has become adapted to the diet of algae, the experiments have all been short term; thus the conditioning that might have altered the results has been restricted. In most of the experiments with U.S. residents, people who are not accustomed to eating seaweeds have been used. This choice of subjects probably explains why tests that involve both Japanese and Americans produce such diverse results. Only the tests on agar-agar have produced any substantial proof that algae have a nutritive value for humans. This substance is low in calories and digestible carbohydrates, starch, and fat, yet it is valuable as a laxative and as a source of protein.

(2) Food additives. — Having considered the use of seaweeds directly as a food, let us now briefly consider their indirect use. Seaweeds are noted primarily for their yield of three commercially important colloidal substances -- algin, carrageenin and agar-agar -- that are widely used in the processing of food. Algin, the generic designation of the derivatives of alginic acid, is used as a stabilizer in ice cream, cheeses, and bakery goods. Carrageenin, the extract of Irish moss (*Chondrus crispus* and *Gigartina stellata*), is also used for stabilizing foodstuffs, as well as for thickening and gelling; it is used widely in commercially processed chocolate milk, pie filling, and milk puddings. Agar-agar (commonly called agar) is a product of certain species of red algae grown primarily in Japan; an industry for the extraction of this substance from algae collected in various parts of the world has also been established on the west coast of the United States. Agar-agar is most commonly used as a solidifying agent for culture media; however, because of its gelling properties, it has become increasingly important as a packing agent and as a thickener. In both Europe and North America, agar-agar is used in canning fish, fowl, and meat, since the jellylike coating it provides prevents breakage and other physical damage to the meat. It has been used also in the manufacture of jellies, sauces, cheeses, and pastries. Japan exports large quantities of agar-agar to other Asiatic countries, where poorer people eat it plain (Chapman, 1952; Okazaki, 1964[3]).

[2] See footnote 1.

[3] See footnote 1.

II. BLUE-GREEN AND GREEN ALGAE

In contrast with the brown and red algae, blue-green and green algae present a totally different spectrum of possibilities and problems as potential food sources. These plants are found mainly in fresh-water ponds. The food value of blue-green algae now lies primarily in their use in the cultivation of rice fields; their potential as a foodstuff is virtually unexplored. Green algae, on the other hand, are known to have the potential for direct use as food. Since 1947, when Spoehr and Milner (1948) first proposed the possibility of using the unicellular green alga *Chlorella* as a foodstuff, it has been intensively studied in many parts of the world.

Since little information exists about the food potential of blue-green algae, we will pass quickly over these algae; then we will probe the potentials of green algae in detail.

A. BLUE-GREEN ALGAE

Blue-green algae have been known for some time to be an important factor in the cultivation of rice. In the early growth stage of the usual wetland type of rice, the fields have to be not only flooded but also considerable nitrogen must be provided. Yet, rice has been grown in the same field year after year without artificial fertilization. This paradox is largely due to the presence of blue-green algae in the floodwaters. Bacteria associated with the algae have the power of nitrogen fixation, meaning they assimilate atmospheric nitrogen forming nitrogenous compounds that are utilized by algae. This symbiotic nitrogen cycle is completed when the algae decompose, thereby enriching the soil with its assimulated nitrogenous compounds. Algae also play a role in aeration of the rice fields, because the oxygen produced by photosynthesis aids in the rice plant's metabolism. Unless algae are present when fields are flooded, the amount of oxygen available to the rice plant is reduced, leading to oxygen-deficient plants more susceptible to disease (Chapman, 1952).

More than half the people in the world get at least 60 percent of their energy from rice (Brown, 1963). Surprisingly, however, little research has been done on the possibilities of using blue-green algae more effectively in the 16 principal countries where rice is the staple food. Perhaps scientists and economists have been so concerned with finding new food sources that they have neglected this means of improving an existing supply. Since most of the other methods for solving the problem of hunger will take some time to become effective, more work should be done on exacting greater yields in areas where blue-green algae are now used or on introducing these algae to rice-producing regions where they are not used.

B. GREEN ALGAE

When the need for greater supplies of food is considered, the possibility of large-scale culture of unicellular green algae has aroused great enthusiasm.

In the following discussion, we will consider the developmental investigations into problems of using green algae -- primarily *Chlorella* -- as a human food and then we will look into the future of alga-derived foods as a solution to the problem of world hunger.

1. Developmental Investigations

The developmental investigations include both production studies and nutrition studies. The process of manufacturing envisioned here will in all probability require a high capital investment. Accordingly, the process must be soundly engineered in order to make it pay, and the product must be palatable, digestible, and nutritious. Neither the production problem nor the nutrition problem will be easy to solve.

a. Production studies. — In our discussion of the production of algae, first we will consider some of the unusual characteristics of algal growth and then we will see how these characteristics can be turned to use in a closed system. It is the possibility of growing algae in a closed system -- even in desert countries -- that makes green algae so potentially valuable.

(1) Characteristics of algal growth.—Of all the factors affecting the production of algae, the efficiency of their growth mechanism and the ease with which their organic composition can be varied are most important to their use as a food crop.

(a) *Growth efficiency.* — Man, by concentrating his efforts on the more productive species of plants, depends principally on a dozen or so plants that he uses for food. Moreover, he usually eats only a small part of each plant; thus, most of the material synthesized by the few kinds of plants is not consumed as human food (Manglesdorf, 1961).

In the synthesis of organic material, plants use only a small proportion of the total solar energy falling upon them. Basically, this small return is due to three factors: (1) In the temperate zone, the growing season for plants is about 4 months. Only 2 or 3 weeks of this time is used for the manufacture of carbohydrates at maximum capacity. (2) Plants utilize only half of the incident radiation -- the visible wave lengths -- for photosynthesis. Even this part of the radiation is used at an efficiency of less than 1 percent. (3) Carbon dioxide is the raw material from which organic substances are formed. Since the concentration of this gas in the atmosphere is only 0.03 percent, the rate of photosynthesis is necessarily limited (Spoehr, 1951).

Unicellular algae, such as *Chlorella*, are potentially able to overcome these difficulties. Their efficiency as photosynthesizers is relatively high. The organic material they form is stored within the cell itself. The cells reproduce by dividing, each cell producing two cells, which also participate in the photosynthesis. Since the cells reproduce about every 12 hours, they can increase, under optimal conditions, their population about 200 times in 4 days. The plants' nutritive requirements are slight: water, in which they are suspended; carbon dioxide and other nutrients, which are dissolved in the water; and light, for photosynthesis. By ensuring a continuous supply of the necessary raw materials, one can harvest the plants at the rate at which they increase. Continuous cultivation, then, promises a high-yield crop and permits the most efficient use of land, sunlight, and manpower (Spoehr, 1951).

(b) *Composition variability.* — The characteristic that makes *Chlorella* even more promising is its organic composition, which can be altered at will. Spoehr (1951) and Milner (1955) found that changes in environmental conditions caused wide variations in the plant's protein, carbohydrate, and lipid contents. By keeping the fixed nitrogen concentration above a certain minimum value, they produced *Chlorella* with a protein content of more than 50 percent. When the level of nitrogen was dropped below this critical value, reproduction stopped, and lipid up to 85 percent of dry weight was synthesized. Carbohydrate content, too, can be made to vary, by from 6 to 39 percent (Cook, 1950; Brittain, 1952).

The fact that high-protein *Chlorella* grows exceedingly makes it especially advantageous as an economical source of protein. Conservative estimates indicate that an acre of *Chlorella* can be made to yield 20 tons of dry protein and 2 tons of fat annually. If the *Chlorella* were cultivated in such a way as to increase its content of fat, it would yield as much as 6 tons of fat from a single acre every year. When we realize that the best yield of oil per acre per year from corn is only $1\frac{1}{2}$ tons, from peanuts less than $\frac{1}{6}$ ton, and from soybeans less than $\frac{1}{9}$ ton, we begin to grasp the revolutionary possibilities of food-producing algae (Brittain, 1952).

(2) Growth of algae in a closed system.—After Spoehr (1951) and Milner (1955) made their momentous finding about the variability of algae's composition, Carnegie Institution of Washington (Stanford, California) arranged an engineering study that the Stanford Research Institute (Stanford, California) carried out to determine if large quantities of algae could be grown in a controlled system. Only if production can be controlled will *Chlorella*, or any other unicellular plant, ever become an important source of food. The Stanford scientists tried to answer such questions as: (a) Is it technically possible to grow large

quantities of algae? (b) If so, what production system should be used? (c) How valuable is the material that is produced? (d) What are the optimum conditions for maximum algae growth? (e) What is the cost of producing large quantities of algae?

The answers that the Stanford scientists obtained were most encouraging. They found that mass growth in a simple, continuous system is feasible and practical. If the system is properly engineered, large-scale production is economical. The conditions for optimum growth are relatively easy to attain. The optimum temperature for growth is from 20° to 25° C. If the needed carbon dioxide (which is low in cost and readily obtained), water, mineral nutrients, and fixed nitrogen in proper concentrations are recycled after the algae are harvested and fresh solution is added as necessary, cost can be kept low. Agitation is necessary to prevent the cells from settling out, and sterile conditions must be maintained to avoid contamination. Under these conditions, *Chlorella* could be harvested continuously in a simple, cheap, and efficient system (Cook, 1950).

Since this early project at Stanford Research Institute, many other scientists have experimented to determine the best methods of culturing *Chlorella*. Although they have reached the same basic conclusions as the Stanford researchers, they have found additional productivity factors. For example, they have discovered that yield can be increased by inoculating the culture medium with cells in the exponential stage of growth. Agitating the cells with an air blast is an efficient means of exposing them to equal amounts of sunlight and nutrients, and centrifuging is an effective method of harvesting (Geoghegan, 1951). Experiments with culture tanks indicate that cylinders inclined normal to the sun's rays represent the most efficient design; whereas flat horizontal surfaces or vertical cylinders are from 30 to 40 percent less efficient (Spoehr, 1951). Ammoniacal nitrogen and urea, although the cheapest, are the most efficient sources of fixed nitrogen; and a concentration of 5 percent carbon dioxide in air passed over the culture improves the yield markedly.

In 1951, the Arthur D. Little Company, Cambridge, Massachusetts, operated a pilot plant for the Carnegie Institution of Washington to determine possible yields of algae and costs of production. They used a tube 160 feet long that held 1,200 gallons of culture in a layer 2 to 3 inches deep. The algae material was circulated by a centrifugal pump and harvested in a centrifuge. Production over the 3 months of operation averaged about 10 grams dry product per square meter per day, or 16 tons per acre per year. The estimated cost of production was from 17 to 25 cents per pound (Milner, 1955).

All these findings have influenced the design of a model plant for the growth of algae in a closed system. Before we consider the theoretical model for the continuous culture of algae, however, we need to consider the factors that tend to restrict their yield.

(a) *Yield-restricting factors.*—During pilot-plant studies, a number of factors inimical to the optimum growth of algae were detected. For example, several workers found that sunlight reaches intensities too high to be fully utilized by *Chlorella*. Milner (1955) states that:

> In the low ranges of light intensity, the algae can convert nearly 25 percent of the light energy into chemical energy stored as plant material. The amount of growth is proportional to the amount of light. At medium intensities, the growth of the algae reaches its highest value, but the efficiency of energy conversion decreases (to 15 percent). Beyond the light-saturation point, the efficiency in use of light goes down as the light becomes brighter. At the very high intensities, the algae can use only a small fraction (2 to 3 percent) of the energy. Moreover, very much exposure to full sunlight will damage or kill the algae.

For maximum efficiency in natural sunlight, the culture must be agitated so that different cells will be exposed to the most intense light in turn. Controlled, artificial light can be used, of course, but the use of such light is economically impractical (Wassink, Kok, and Van Oorschot, 1953).

Open-pond culture, one of the simplest of production methods, does not appear to be practical in terms of yield. Such a method would preclude both the use of high concentrations of carbon dioxide and any chance of operating under sterile conditions. Also, without costly equipment, the suspension could not be stirred adequately. As a consequence, the effect of light of high intensity could not be counteracted. Furthermore, the difficulties of periodically harvesting *Chlorella* growing in an open pond would probably make the method impractical (Burlew, 1953).

(b) *Continuous-culture model.* — A theoretical model has been designed for the continuous culture of *Chlorella* (Figure 1). This alga farm has two major parts -- a culture site and a processing plant. At the culture site, the plants are grown in a series of long, horizontal cylinders, and fresh medium is introduced into the cylinder inlets at frequent intervals. By providing equal flow at each in-

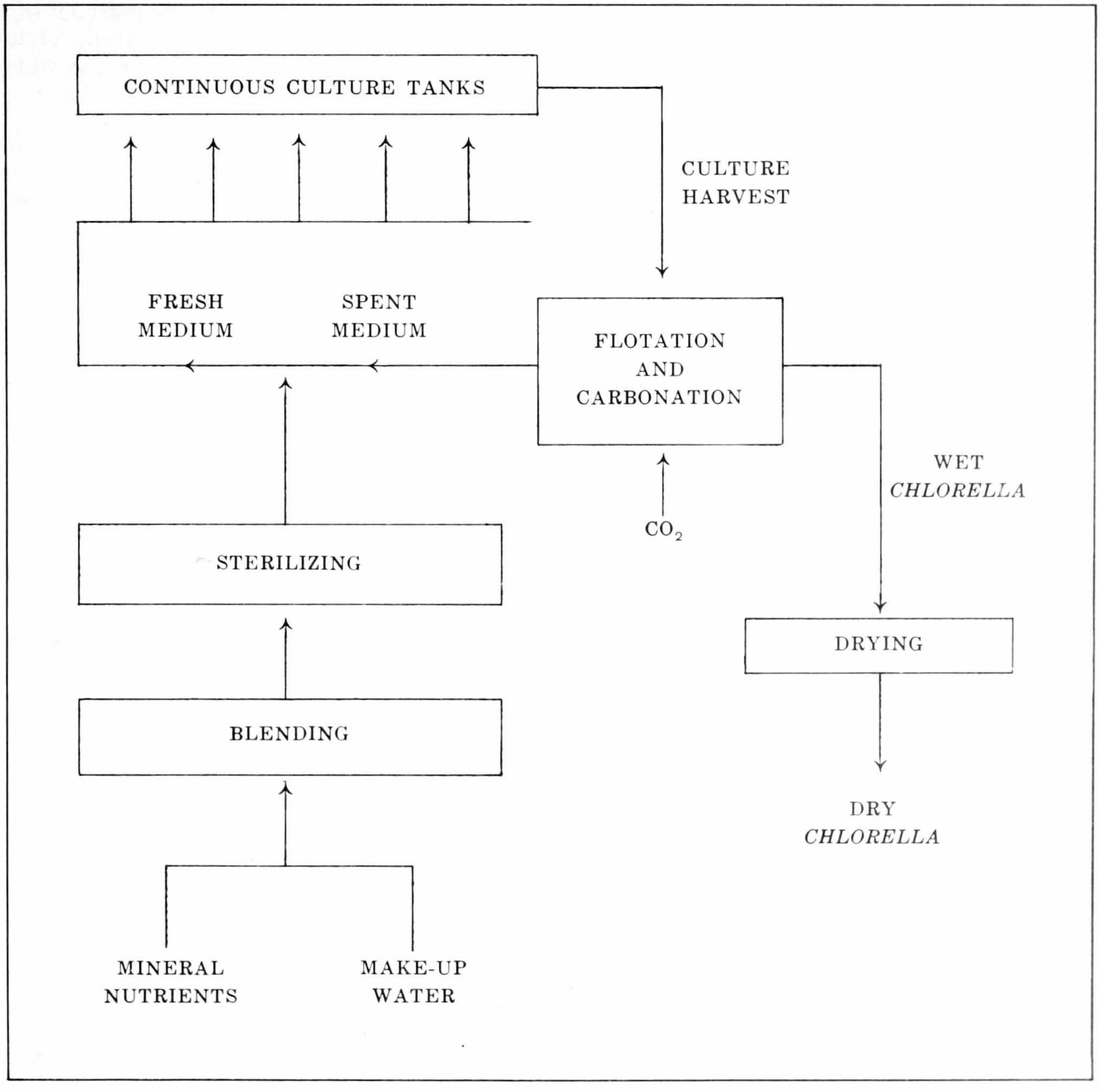

Figure 1.—Flow diagram of the continuous culture process (Cook, 1950, page 72).

let, the operator can keep the population density at an optimal level. For proper agitation, he recycles enough culture to create a turbulent rather than a streamlined flow. The necessary nutrients, including carbon dioxide in the form of carbonates and bicarbonates, are introduced with the fresh medium; air and additional carbon dioxide are circulated throughout the culture. In the processing plant, the cells are separated from the medium by flotation. Waste combustion gases from the fuel used to supply heat for sterilization and dehydration provide enough carbon dioxide for optimal growth. Supplementary water, to which necessary nutrients have been added, is sterilized and incorporated into the spent medium for return to the culture farm (Cook, 1950).

For a plant of this sort to be efficient, it would have to produce from 50 to 500 tons of alga per day. Since 2,500 pounds of water is needed for each pound of dry *Chlorella*, the equipment for any practical operation would have to be large.

Alga culture would seem especially adaptable for those regions in the tropics where the soil is poor but where many hours of sunlight and an equable temperature prevail the year around. It is adaptable to semiarid regions because, since the culture medium is reused, the consumption of water is low. Moreover, since no soil is required, algal culture can succeed where ordinary farming is impossible.

b. Nutritional studies. — Using *Chlorella* produced by different pilot plants, nutrition experts have investigated its composition and food value. They have found that the plant, as ordinarily grown, has a dry-weight composition of from 40 to 60 percent protein, from 10 to 20 percent fat, and about 20 percent carbohydrate. By appropriately modifying the culture conditions, the producer can vary the concentration of protein from 7 to 85 percent, that of fat from 4 to 86 percent, and that of carbohydrate from 5 to 38 percent. Vitamin assays show that *Chlorella* contains adequate supplies of vitamins B, C, and D and abundant supplies of vitamins A and K. Comparison of its vitamin content with the minimum daily requirements of man indicates that one-fourth of a pound of dried *Chlorella* per day would satisfy most if not all of a man's vitamin requirements (McDowell and Leveille, 1963).

In our further discussion of the nutritional value of algae, we will review work that has been done on the protein quality and digestibility of *Chlorella,* and then we will show how the results have been tested on men and animals fed alga-containing diets.

(1) Metabolic properties of algae.—It is not sufficient merely to produce protein-containing foods. The protein must be of a quality that is adequate to the needs of the protein-requiring body, and the food in which it occurs must be digestible by the body.

(a) *Nutritive compounds.* — Since the greatest need of people now suffering from malnutrition is for more protein, farmers will undoubtedly attempt to produce plants with the highest possible protein content. The protein content of high-protein *Chlorella* is comparable with that of white flour, corn gluten, or peanut meal.

But a high content of protein alone is not sufficient to ensure a nutritious food; it must also contain a suitable balance of the essential amino acids. The Arthur D. Little Company calculated an essential amino acid index for the algal product grown in the company's pilot plant and reached a figure of 62. In the index, whole egg protein is given a value of 100. The values of most animal proteins range between 80 and 90; those of cereal proteins generally range between 60 and 70 (Fisher and Burlew, 1953).

One of the major amino acids deficient in *Chlorella* is methionine. This deficiency is also characteristic of other vegetable-protein foods and is the cause of their relatively low index. Fortunately, synthetic methionine made from nonagricultural products is readily and economically available. Apparently, the method of preparing *Chlorella* largely determines which amino acids are available for digestion. Thus, variations in the methods of preparation may account for the conflicting values that have been reported for the amino acid availability in *Chlorella*-derived products (Krauss, 1962).

The experimental work on algal carbohydrates and lipids has not been as extensive as that on proteins. The carbohydrates in *Chlorella* are chiefly vegetable gums, especially pentosans (the hydrolyzed form of pentose sugars). Starches also constitute a sizable part of the carbohydrate content (McDowell and Leveille, 1963). Algal lipids are highly unsaturated, but aside from this fact, little is known about them.

(b) *Nondigestible elements.* — Although unicellular algae contain little or no cellulose (the indigestible part of higher plants), they do have tough cell walls, which are resistant to mechanical, chemical, or thermal attacks. Since this part of the cell passes through the human digestive tract without contributing to the nutritional effect, much work has been done on means of processing that will break down the cell walls and thus increase the cells' digestibility. Shefner and his colleagues have found potentially useful mixtures of wall-degrading enzymes in animals, such as the snail, which regularly eat algae (McDowell and Leveille, 1963). Much more experimental work will be necessary before such enzymes can be applied to alga products destined for human consumption.

(2) Feeding studies. — The nutritive properties that have been identified in the laboratory have also been observed in practical diets fed to both animals and people.

(a) *Animal-feeding studies.* — The results of experiments in which green algae were fed to animals have been highly ambiguous, partly because of poor techniques, but even more because the nutritive value of the plants depends so much on the method of growth and processing.

An extensive experiment was performed by Henry (Geoghegan, 1951 and 1953), who found that 17 percent freeze-dried *Chlorella* compared favorably with dried brewer's yeast and with peanut meal in promoting weight gain in rats. Geoghegan (1951 and 1953), on the other hand, found that it was less efficient than dried skim milk. Fink and Herold (McDowell and Leveille, 1963) reported that the protein of dried *Scenedesmus* (another unicellar green algae) was equal, or slightly superior, to skim milk or egg protein, and markedly superior to the vegetable protein in spinach and alfalfa in stimulating growth in rats. The Aerospace Medical Research Team of the U.S. Air Force found that ordinary rations kept in stock could consist of as much as 42 percent dried *Chlorella* and still increase growth when fed to weanling rats (McDowell and Leveille, 1963).

Feeding tests with rats conducted by Hayami and Shino (Tamiya, 1959) of the National Institute of Nutrition, Tokyo, Japan, showed that both the digestibility and the nutritive value of *Chlorella* cells varied widely according to the method of processing of algal material. The materials dried at high temperatures (100° C. without alcohol treatment) gave a digestibility as low as 47 to 57 percent, and the gain in weight occurring during 100 days feeding was only 66 percent of that of the control animals fed on a milk diet. The results were quite different when the rats were fed the algal materials that were dried at lower temperatures (lower than 40° C.). In this case, the digestibility was 75 percent or more. Comparable figures for the digestibility were also found with the algal material that had been partially decolorized by an alcohol treatment.

Nakamura (Tamiya, 1959) of the Utsunomiya University, Utsunomiya, Tochigi-ken, Japan, has found that the diet containing 10 percent decolorized algae (in addition to wheat flour used as the main source of carbohydrate) was an excellent feed for rats. The weight gain attained during a 120-day experiment was more than 50 percent higher than that obtained with the control milk diet. The gain seems to vary with the type of animal used in the feeding studies. For example, in chick-feeding tests performed by Nakamura, the addition of such algal materials to either the assorted chick diet or wheat was found to give no favorable growth-promoting effect; however, when fed to adult hens, the addition of the algal material to the assorted chick diet distinctly increased the number of eggs laid by the hens.

Part of the diversity in results from these experiments may be due to the different amino acid content of the algae used. In a study on weanling rats that were fed 18 percent of *Chlorella* as a source of protein, significant improvement in weight gain and feed efficiency was observed after the diet was supplemented with methionine and histidine (McDowell and Leveille, 1963). Results of another study, done in Japan, indicated that the addition of methionine alone doubled the weight gain in rats fed dried algae as the only source of protein (McDowell and Leveille, 1963). In yet another experiment, the addition of lysine and threonine was found to be the critical factor in the growth of rats fed on a basal diet of white bread (Hundley and Ing, 1956). Clearly, further work on the protein content and nutritional effects of alga diets will be needed before these discrepancies can be resolved.

(b) *Human-feeding studies.*—Only a small number of studies have been reported on the use of microscopic algae as human food. In Japan, where the consumption of aquatic algae is no novelty, dried powdered *Chlorella* has been described as tasting like dried seaweed or powdered green tea. Noodles prepared from a mixture containing 2 percent *Chlorella* and either buckwheat or wheat flour were pronounced acceptable. The powdered *Chlorella* has also been used in palatable bread, soup, and ice cream. In its hydrolyzed form, it is a promising substitute for soy sauce (Fisher and Burlew, 1953).

An experiment in the mid-1940's tested the nutritional value of a mixture of fresh-water microorganisms at the Cabo Blanco Leprosarium, Maiquetia, D.F., Venezuela. The mixture contained several species of algae, including *Chlorella*, and various microscopic animals. The method of preparation was far from the method that an operator would use on an alga farm today: The mixture was grown in clay bowls, in untreated municipal water to which commercial fertilizer was added, and was stirred twice daily with a dipper. The water siphoned off to harvest the culture was refertilized and returned to the bowls. The product, mixed with a little water to form a "soup" was boiled for 20 minutes, and a little salt was added to improve the flavor. The patients drank the soup willingly. It was fed for more than 5 years without any ill effects. In fact, the energy, weight, and general health of most of the patients improved markedly (Jorgensen and Convit, 1953).

Tamiya (1959) of the Tokugawa Institute for Biological Research, Tokyo, Japan, during a visit to the United States, tested the palatability of algal material with two different groups of people, American and Japanese. The test was performed by adding a dried algal powder in varying concentrations to such foods as bread, noodles, soups, ice cream, and "miso" or fermented soybeans. The conclusions of the tests indicated that *Chlorella* containing foods appealed more to Japanese than to American people. This may be attributed to the fact that the Japanese are accustomed to foods including seaweed dishes which are similar to *Chlorella* not only in appearance but also in odor and taste.

The procedure of treating algal cells with alcohol has been attempted with a view toward reducing the intense green color of the sample. The material partially decolorized by this procedure was found to be milder in odor and taste and therefore, it could be added to various foods in higher concentrations than the nontreated material.

More precise experimental data have been assembled in only three places -- at the Army Medical Corps in Denver; the University of Nebraska in Lincoln; and the National Institute in Tokyo.

In the study by the Army Medical Corps, five healthy young men between the ages of 18 and 25 consumed a mixture of *Chlorella* and *Scenedesmus* in amounts increased gradually every few days over a period of 40 days. After precautionary autoclaving, the algae were added to foods that would tend to disguise the algae taste, such as gingerbread, chocolate cake, chocolate cookies, and milk. Nevertheless, the experimenters still had a problem, for the food to which the algae were added became olive-drab in color (Krauss, 1962). The young men had little difficulty accepting or tolerating the algae up to the 100-gram (3.5-ounce) level; however, beyond this level, which exceeds that which would normally supply all necessary body proteins, they had difficulty in both accepting and digesting the mixture. Physical examinations failed to show any abnormalities other than those associated with the gastrointestinal tract, but these disorders were evident. The investigators concluded that heat-treated dried algae can be tolerated as a food supplement for at least short periods, but that further processing will be necessary if they are to be useful as a major source of food.

In two experiments at the University of Nebraska, *Scenedesmus* and *Chlorella* were used as the principal source of protein. In the first experiment, whole green algae (*Scenedesmus*) suspended in a colloidal liquid (not described) were fed to a group of people for 5 days. In the second, *Chlorella,* extracted and decolorized with alcohol, was fed to another group for 20 days. Although the experimenters found a slight nitrogen imbalance and high fecal excretion of nitrogen in both groups, the investigators concluded that people can eat these algae for up to 20 days without ill effects (Dam, Lee, Fry, and Fox, 1964).

In the Japanese experiment, five healthy college girls were used as subjects. They were fed a normal diet to which 30 grams (0.85 ounces) of algae per day was added. When the alga samples were dried, they were not as easily digested as was soybean meal. But when the samples were treated with alcohol, resulting in a partially decolorized product that was bland in both taste and odor, they were more easily digested than the soybean meal was. This experiment led to the conclusion that Japanese have a high tolerance and acceptability of an algal diet (Krauss, 1962).

Aside from this meager information, only two other reports of human reaction to algae were found. In one of the reports, a flavor panel at the Arthur D. Little Company appraised dry and fresh-frozen *Chlorella.* The conclusion was that the alga as well as the soups made from the alga, either fresh or frozen, were suggestive of vegetables and were generally palatable and acceptable. Their appearance, however, was not so generally acceptable. The panel felt that the flavor of dried *Chlorella* alone is too strong to be enjoyed in large quantities (Fisher and Burlew, 1953). When Air Force investigators studied the possibility of using algae as a space food, they concluded that the taste is indeed vegetablelike but it has a bitter, gagging aftertaste. More studies are needed to find the cause of this unpleasant taste and to develop modifications or new methods of preparation that will improve the appeal of green algae to human consumers.

2. Look Into the Future

Several problems still await solution before large-scale production of microscopic algae can become a reality. To begin with, experiments thus far have all been limited to either a few species of *Chlorella* or one species of *Scenedesmus.* Among the thousands of species of unicellular green algae, other species may be more amenable to culturing, more digestible or nutritious, or even more palatable than these two. For example, the Institute Francais de Petrole (1967) has been active recently in the search for a new type of algae whose nutritional value was at least as good as *Chlorella* and whose culture, collection and use were simpler. During 1962, this French research organization discovered that some tribes living in isolation in the center of Africa had been collecting and eating algae since ancient times. The algae are collected by the women in a simple straw basket, transported in jars, and dried in the sun. These dried crusts of algae make up the so-called "dihe," which is cooked as a sauce to accompany their millet balls.

This alga, *Spirulina maxima,* a blue-green species, was first discovered growing in some ponds near Lake Chad in Central Africa. *Spirulina* develops optimally under high alkaline conditions (pH 9-10) and temperatures around 35° C., whereas, *Chlorella* requires an acid medium. The dried product contains 62-68 percent protein; 18-20 percent carbohydrate; 2-3 percent lipids and vitamins pro A, B_1, B_2, B_6, B_{12}, and C. Institute Francais de Petrole is making additional studies on the culture and potential utilization of *Spirulina* in open air culture ponds.

Many factors bearing upon more efficient cultivation of alga farms have yet to be identified. Examination of the rate of growth and of reproduction of the cells at high intensities of light may yet reveal some way in which the high efficiencies known to be possible at lower intensities can be maintained. Since artificial lighting would make operating costs impractical, it is almost certain that sunlight will be used as the source of light for all farms. Under the conditions of high intensity of light present throughout the year in the tropics, where a project such as this is sorely needed to increase food supplies, new engineering techniques will have to be developed to ensure maximum yields.

At high density, algae apparently produce a metabolic product that accumulates and acts as an autotoxin. A clearer understanding of the extent of this effect and of the degree to which it may reduce yields would be useful. Limited evidence indicates also that contamination of the culture medium by bacteria or microscopic animals reduces algal yield. Again, the evidence is not conclusive, so more work should be done to determine if sterile conditions (the attainment of which, of course, raises the cost of production) are necessary, or if "clean conditions" are sufficient. Perhaps a selective pesticide or herbicide can be developed to kill the contaminants without affecting the algae, thus avoiding the need for sterility.

Most of these problems could be solved, at least partially, if a large pilot plant were operated for a longer period than any thus far has been. By setting up a plant in which a number of variables could be controlled in different combinations, we could answer a host of unresolved questions. Such a plant would permit us to test a number of techniques to determine which would produce the greatest yields of high-quality algae. It would allow an accurate estimate of capital and operational costs and might indicate ways of reducing them. Most important, at an experimental processing plant, the best method of converting the algal product into a palatable and nutritious food could be studied.

The cost of such a large-scale venture would be high. If all or even some of the countries interested in algal culture were to pool their efforts, the project would probably be both feasible and practicable. Though there is no evidence that any such joint enterprise is now being considered, within the next decade it may well be undertaken. As early as 1952, Brittain (1952) stated that "competent engineers are convinced that large-scale farming of *Chlorella* presents no problem that cannot be solved." With the advances in our research and knowledge over the past decade, this statement seems even more true today. An extensive practical test of our findings and a study of those questions that are still unanswered are the next necessary step.

If a large-scale pilot plant were built, it would help solve another whole spectrum of problems involving the nutritive value and acceptability of algae. Researchers have complained that the number of pilot plants has been so limited that accurate, long-term studies were not possible. Burlew (1953) estimated that he would need about 20 pounds of algae per day to test different methods of processing and cooking and to undertake extensive feeding trials. More animal-feeding studies are needed before any large-scale human experiments can be undertaken. These studies will also require substantial supplies of algae as will studies to determine what fraction of the total nutritional needs of man can be supplied by algae.

The effect of alga diets on longevity, reproductive performance, disease incidence, and behavior must be analyzed in several species of animals before long-term feeding can even be considered for man. Such studies would also indicate if people can develop a tolerance to larger quantities and what such adaptation would entail.

With the diversity and quality of biological experimental techniques now available, none of these studies seems beyond the range of feasibility or practicality. Probably within the next few years, most of them will be done. Unless they raise new questions, the world will be substantially closer to a new source of food.

The final unsolved problem is one to which no investigator has yet applied himself: Can people be persuaded to alter their food habits enough to make algae even a minor part of their diet? It is possible that technological advances in processing will make the green cells, palatable, but people in the Western world will still have to make social adjustments to accept algae as daily fare. If the nations that are now threatened by widespread starvation are ever to raise the level of their people beyond one of subsistence, a project such as this one, accompanied by a massive informational campaign, might be a useful solution.

Perhaps forward-thinking leaders of many nations will ultimately adopt the view expressed by Burlew (1953), who wrote:

> Such great advances in technology have already come from the coupling of engineering with biology that it seems inevitable that the production of food, at least in certain areas, will eventually be carried out by process industries. The large-scale culture of algae may well become the first of them. In regions of the world where population is especially dense, and fertile land is limited, it is entirely possible that process-industry methods of producing food may furnish a respite from the threat of famine, and so contribute toward more salutary conditions for civilized living.

It is not unduly optimistic to assert that mankind does possess today the necessary knowledge and power to solve the problem of hunger. The solution that has been discussed here is but one attempt among many that hold the promise of allowing all men -- and future generations as well -- to live in decency and comfort. If we have the vision, as well as the intelligence and will, to transform such possibilities into realities, the threat of starvation can be eliminated by the 21st century.

SUMMARY

Some 17,000 known species of algae inhabit the fresh and marine waters of the world. Of these 17,000, only a few have been carefully investigated to determine their value as a human food resource. Those few that are of known commercial value are used worldwide in many forms and in many types of products. These include uses in such products as fertilizers, animal foods, human foods, and incorporation into pharmaceuticals and cosmetics.

One of the more promising algae having potential as a continuing human food resource is the unicellular green alga, *Chlorella*. This alga has several unique characteristics that contribute to its potential value. These include (1) rapid growth rate, (2) variability of composition as a result of varying the environment, which can be controlled, and (3) ability to reproduce and grow in a closed system.

Animal and human feeding studies have been made to determine the nutritive properties of *Chlorella*. Though several of the tests were inconclusive, the results generally indicate that *Chlorella* in its natural form is rather difficult for humans to digest, and the appearance of the product was not generally well accepted. The Japanese, however, have a high level of acceptance and tolerance for the product. This indicates that the digestive system of humans can adapt to various changes in the diet. Also, breaking down the cellular structure of *Chlorella* by physical or chemical means would make this alga easily digestible. Additional studies to remove undesirable flavors and improve appeal are needed if this product is to be used widely.

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MS #1833

EXPLORATIONS FOR CALICO SCALLOP, *Pecten gibbus*, IN THE AREA OFF CAPE KENNEDY, FLORIDA, 1960-66

by

Shelby B. Drummond

ABSTRACT

A bed of calico scallops 200 miles long is now known off the east coast of Florida but is little fished. This article maps the location of the bed and reports on the rates of catch that may be expected on it. Exploratory fishing indicates that, other than during February, the supply of scallops is adequate to support a year-round fishery at the more favorable locations. Explorations also show that, at depths of from 15 to 35 fathoms, the area between Fort Pierce and the southeast shoal off Cape Kennedy is consistently the most productive.

CONTENTS

INTRODUCTION

Scallops have long been considered to be a gourmet item in the United States and Europe. In this country, the scallop industry originally depended on easily accessible bay scallops; later, it depended on sea scallops as well as on bay scallops. A thriving industry now exists for both kinds.

In June 1960, following reports by Florida fishermen of scallops being caught in shrimp trawls, the Bureau of Commercial Fisheries

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used the *Silver Bay*, an exploratory fishing vessel equipped with commercial scalloping gear, to explore the waters off the central east coast of Florida. During these explorations in 1960-66, the Bureau found an immense bed of calico scallops extending more than 100 miles north and about 100 miles south of Cape Kennedy, Florida. Despite the interest of the industry in this enormous 200-mile-long bed, the resource has remained largely unused, owing to the high cost of shucking calico scallops by hand.

The Cape Kennedy scallop grounds cover some 5,760 square miles and extend from about 11 miles south of Stuart, Florida, to about 6 miles north of St. Augustine (Figure 1). They lie at depths of from 5 to 40 fathoms. Relatively smooth bottom, which is composed mostly of sand and dead shell, makes the grounds ideal for dredging or for trawling with reinforced gear.

Recently, a fishery for calico scallops has developed in North Carolina on small but productive beds relatively near the Cape Kennedy grounds, and problems in shucking the scallops by machine are being solved. Thus, findings of the Bureau about the availability of calico scallops off the east coast of Florida are of immediate concern to prospective commercial scallop fishermen. The purpose of this report therefore is to make these findings known.

The report is divided into two main parts. The first part reports on the variations in rates of catch over the entire grounds; the second part, the variations in rates of catch in a single small area during 1 day.

I. VARIATIONS IN RATES OF CATCH OVER THE ENTIRE GROUNDS

Here we are concerned both with the overall picture of the entire period and with monthly changes in the overall picture.

A. VARIATIONS IN CATCH FROM AREA TO AREA OVER THE ENTIRE GROUNDS DURING 1960-66

1. Fishing Gear and Methods

In the exploration of the Cape Kennedy scallop grounds by the Bureau, an 8-foot and a 10-foot Georges Bank sea-scallop dredge and a 6-foot tumbler dredge (described by Bullis and Cummins, 1961) were used. The dredges were single rigged. Towing time depended on the abundance of scallops and the amount of debris; the tows averaged about 30 minutes. In areas where scallop catches were commercially significant (20 bushels in the shell or more per hour), other drags were made to establish more precisely the availability of the scallops. In the calculations of the rate of catch, the dredges were standardized to the fishing efficiency of an 8-foot Georges Bank sea-scallop dredge.

2. Results

Figure 2 gives a quick overall picture of the average rates of catch for the various areas during the 7 years. From the data, an attempt was made to determine if the abundance of scallops were related to such factors as depth, bottom temperature, and season. No clear relations were found between these variables. Erratic changes in the abundance of scallops from month to month, for example, masked any seasonal trends that might have existed. The data indicate that, in the extreme northern and southern parts of the grounds and in the areas shallower than 10 fathoms, the average rate of catch was generally low -- from 0 to 0.5 bushels per hour. In the grounds as a whole, two areas were the most productive. One of the areas lies off Daytona Beach, where the average rate of catch varied from 3.9 to 7.5 bushels per hour; the other is in deeper water (15 to 35 fathoms) extending from Fort Pierce to Cape Kennedy, where the average rates of catch varied from 3.9 to 12.8 bushels per hour.

Because these data are averaged for the entire period 1960-66, they do not indicate the

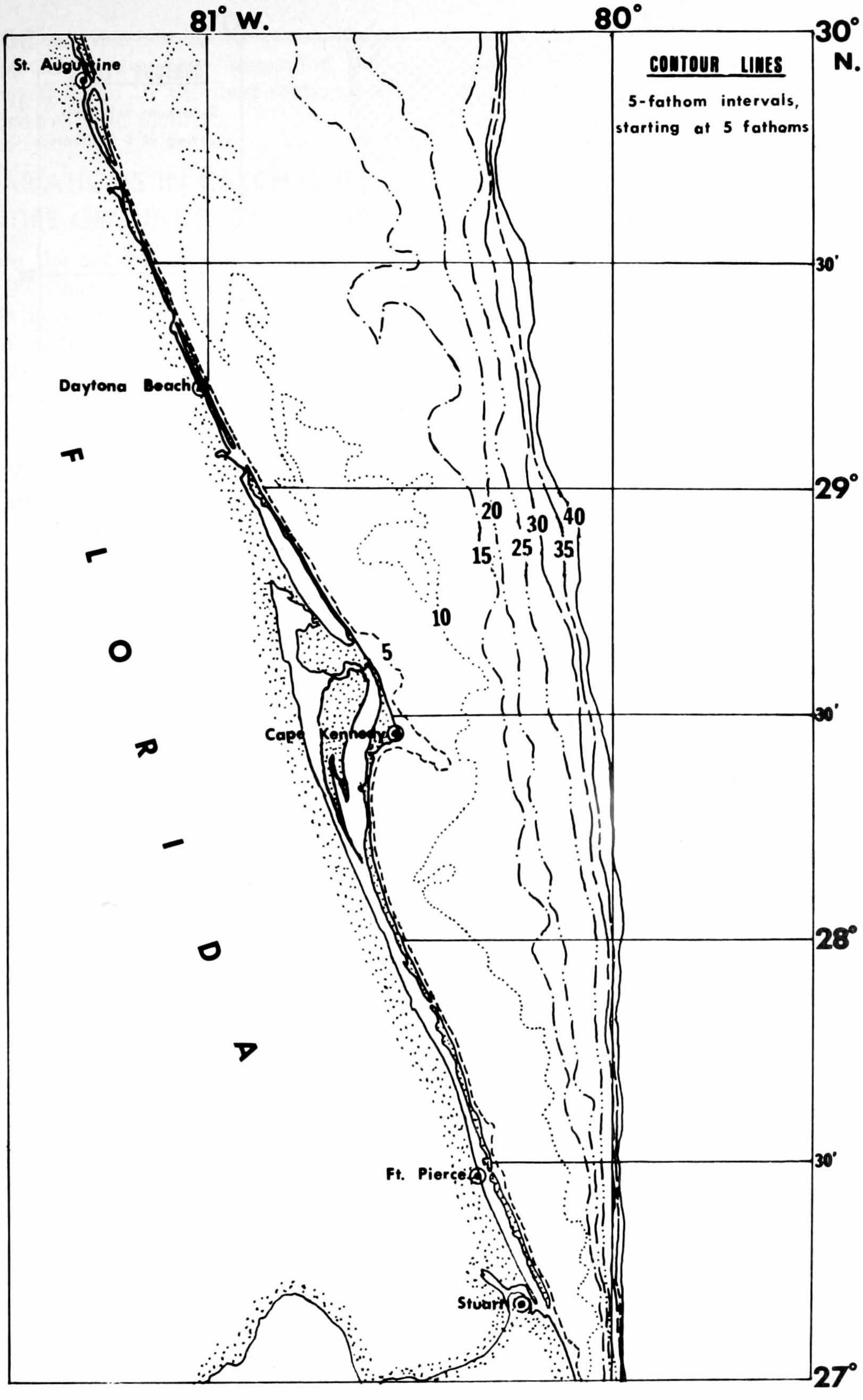

Figure 1.—Chart of the Cape Kennedy scallop grounds.

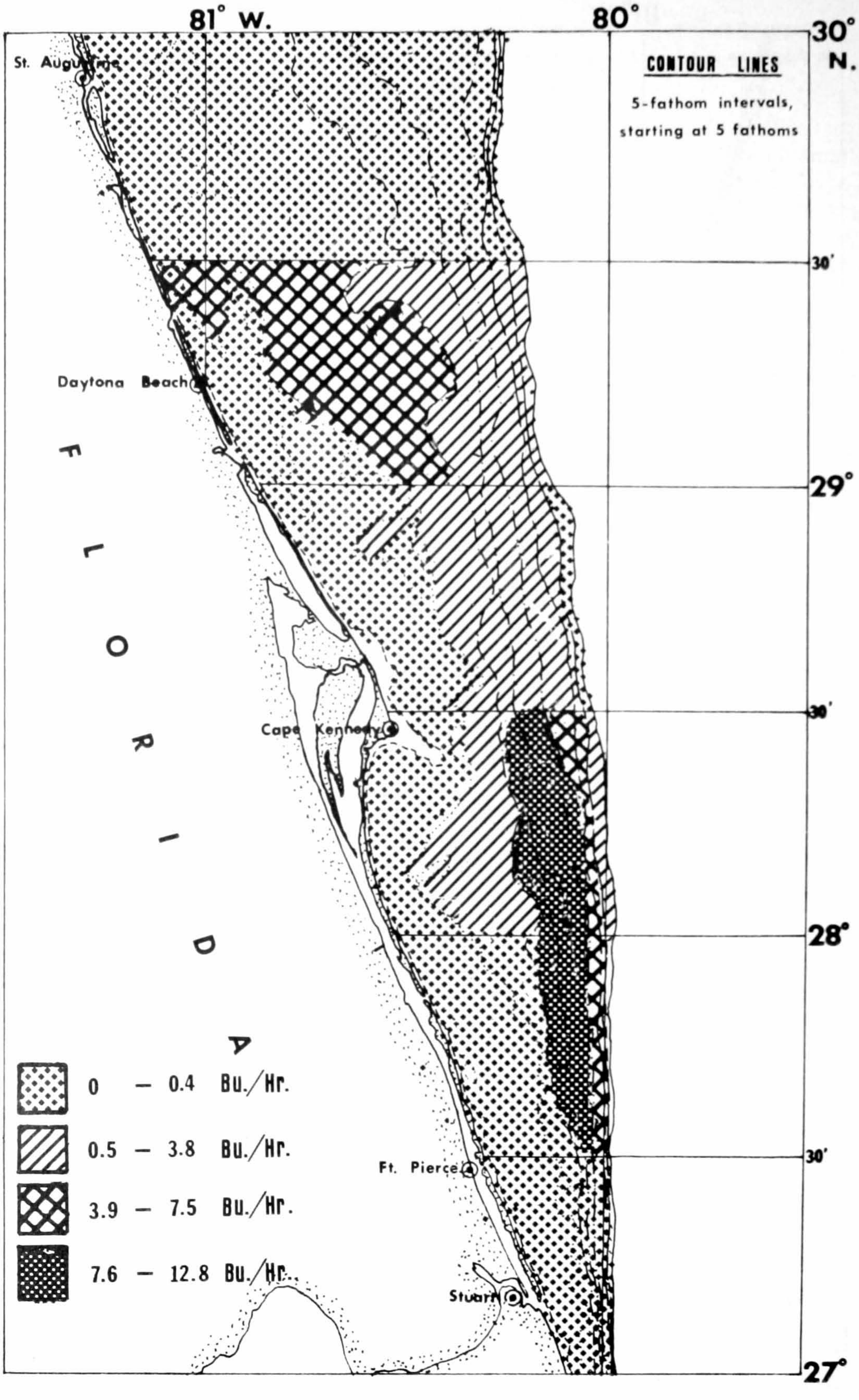

Figure 2.—Average scallop catch rates, 1960-66.

rates of catches when conditions were optimal. For that reason, the data presented on a monthly basis, given in the next section, provide a more realistic picture.

B. VARIATIONS IN CATCH OVER THE ENTIRE GROUNDS, BY MONTHS

Data on the catches of calico scallop were tabulated monthly by half degrees of latitude and by 5-fathom intervals of depth. Emphasis was placed on those catches and/or on catches of 20 bushels or more per hour and on catches containing scallops with shells 1.6 inches in diameter or larger (scallops should be of this size for commercial harvesting). These catches were considered to be maximum catches and are portrayed on the monthly charts (Figures 3-14) by the darker shading. The remaining data on the catches are portrayed by the lighter shading as being less than 20 bushels per hour.

Monthly maximum exploratory catches (Figures 3-14) indicated, other than for the month of February, the possibility of a year-round commercial fishery -- that is, one producing 20 bushels or more per hour -- at the more favorable locations.

II. VARIATIONS IN RATES OF CATCH IN A SINGLE SMALL AREA DURING 1 DAY

To show the variability of production in a single area and to indicate the potential of the Cape Kennedy grounds, Table 1 presents data (picked randomly from monthly exploratory data from a favorable area) reporting consecutive individual catches that were made during a 24-hour period under simulated commercial fishing. The table shows that, during this particular period and in the particular area dredged, the rates of catch varied from 0 to 54 bushels per hour and averaged 24 bushels per hour. This average rate is somewhat above the 20 bushels per hour required for a profitable commercial operation. The low rates of catch in some of the tows indicate that the scallops tend to cluster rather than to be evenly distributed.

Table 1.—A 24-hour log of the scallop catch off Cape Kennedy by an 8-foot Georges Bank sea-scallop dredge during simulated commercial fishing by R/V *Silver Bay* on December 1, 1961

Location of scallop dredging operation			Length of time dredge was fished	Rate of catch
Lat. N.	Long. W.	Depth		
		Fathoms	*Minutes*	*Bu./hr.*
29°04′	80°31′	13	30	--
29°24′	80°41′	13	30	36
29°24′	80°49′	13	30	41
29°19′	80°43′	14	30	48
29°22′	80°43′	14	30	54
29°24′	80°40′	14	30	8
29°24′	80°45′	14	30	7
29°24′	80°43′	14	30	15
29°06′	80°33′	15	30	18
29°09′	80°34′	15	25	--
29°11′	80°37′	15	30	10
20°13′	80°38′	15	30	43
29°14′	80°38′	15	30	39
29°16′	80°38′	15	30	38
29°18′	80°41′	15	30	26
29°25′	80°41′	15	30	3
29°07′	80°33′	16	30	16
Average rate of catch				24

Note 1: 1 bushel = 80 pounds of scallops in the shell.
Note 2: See the data in Figures 1, 2, and 14 when assessing the significance of the rates of catch at the location reported here.

LITERATURE CITED

Bullis, Harvey R., Jr., and Robert Cummins, Jr. 1961. An interim report of the Cape Canaveral calico scallop bed. Commercial Fisheries Review 23(10): 1-8.

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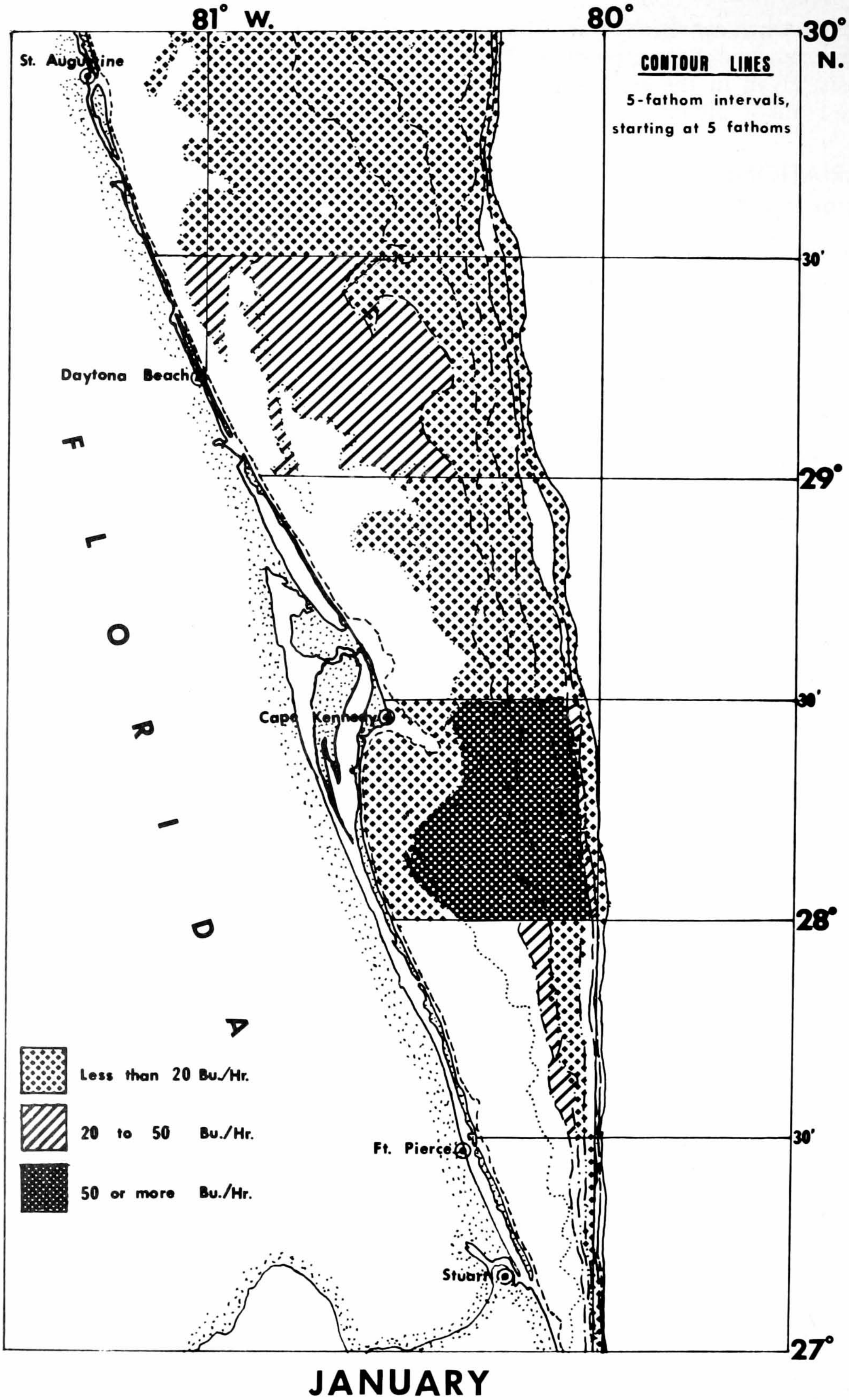

Figure 3.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in January.

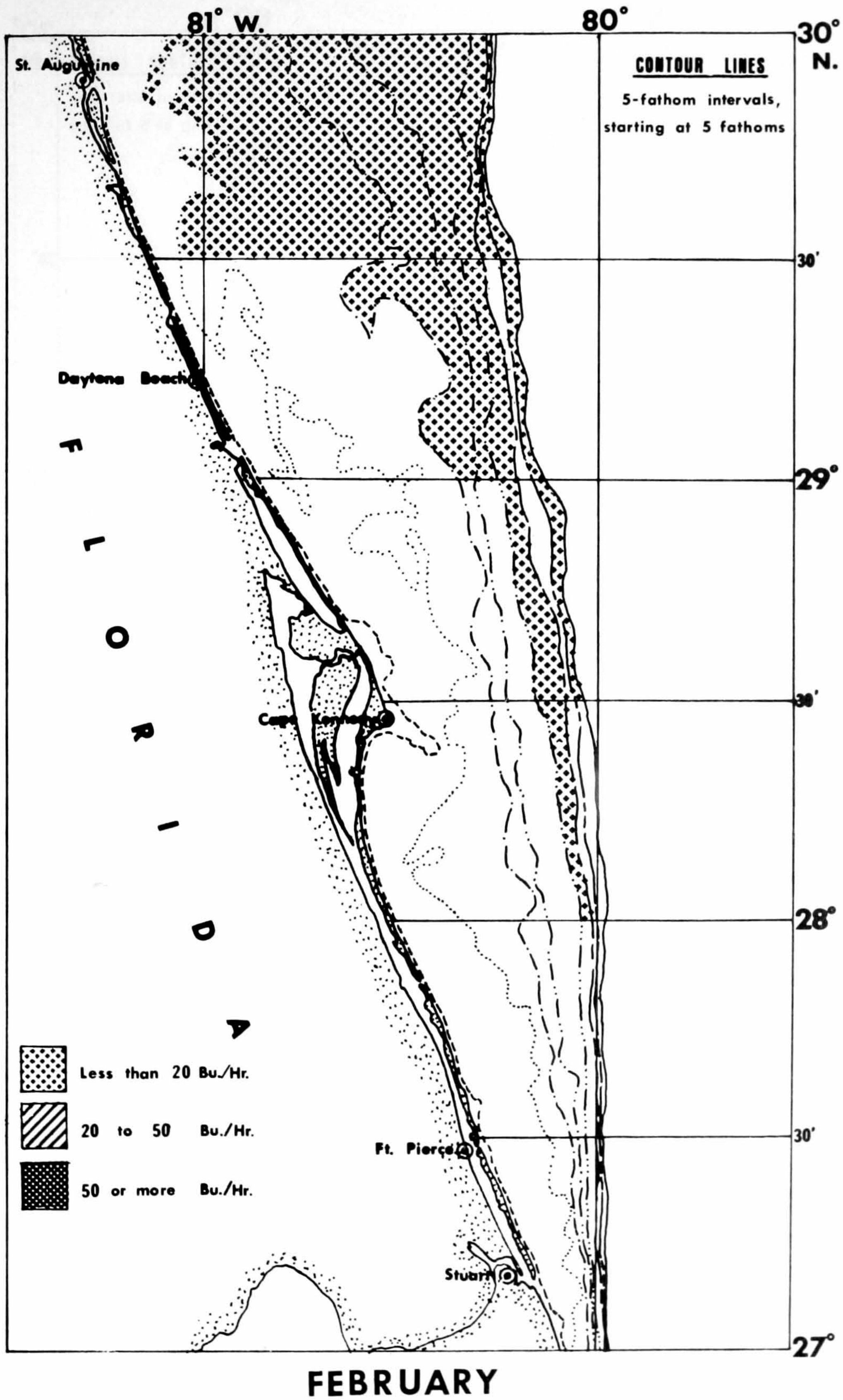

Figure 4.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in February.

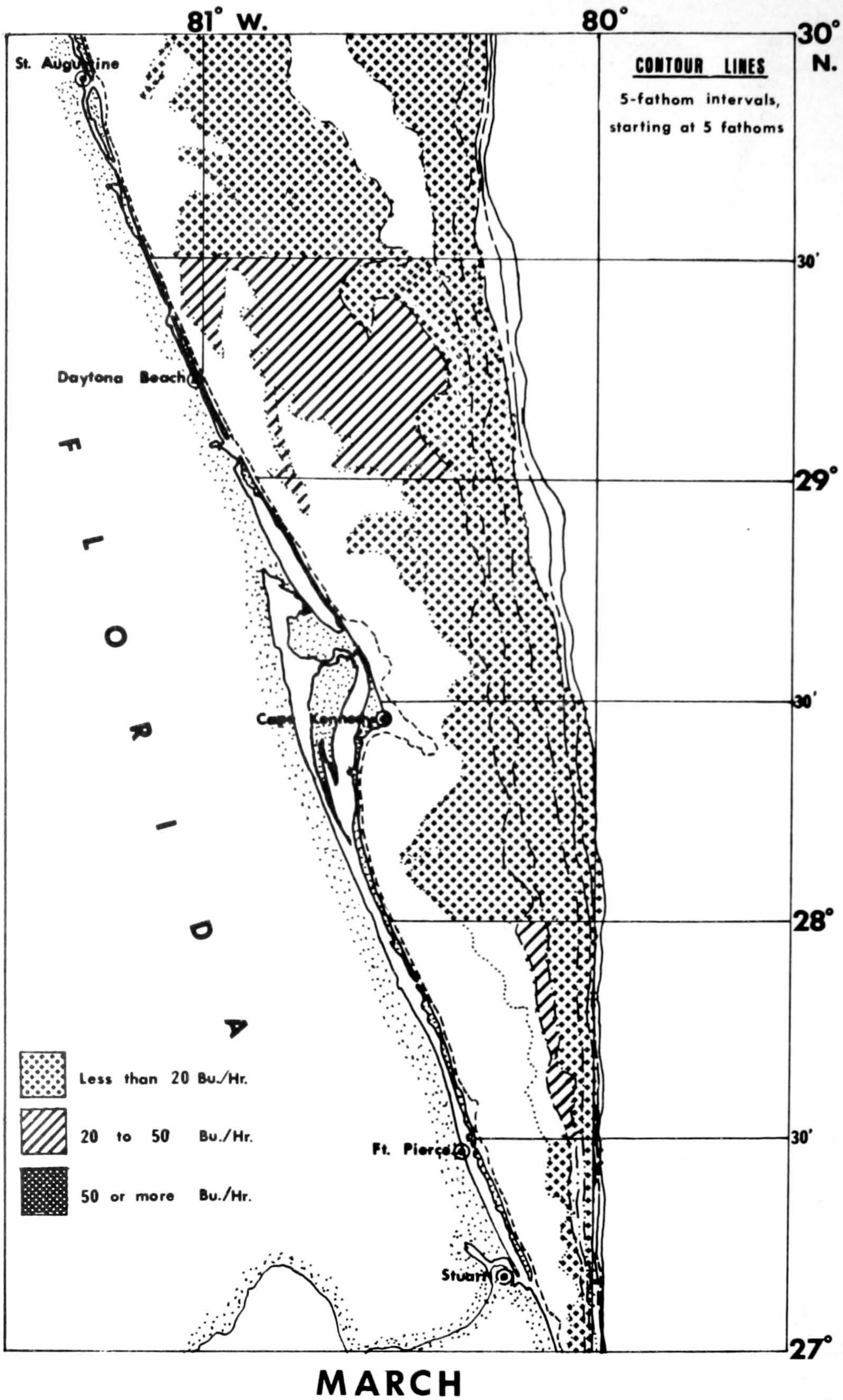

Figure 5.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in March.

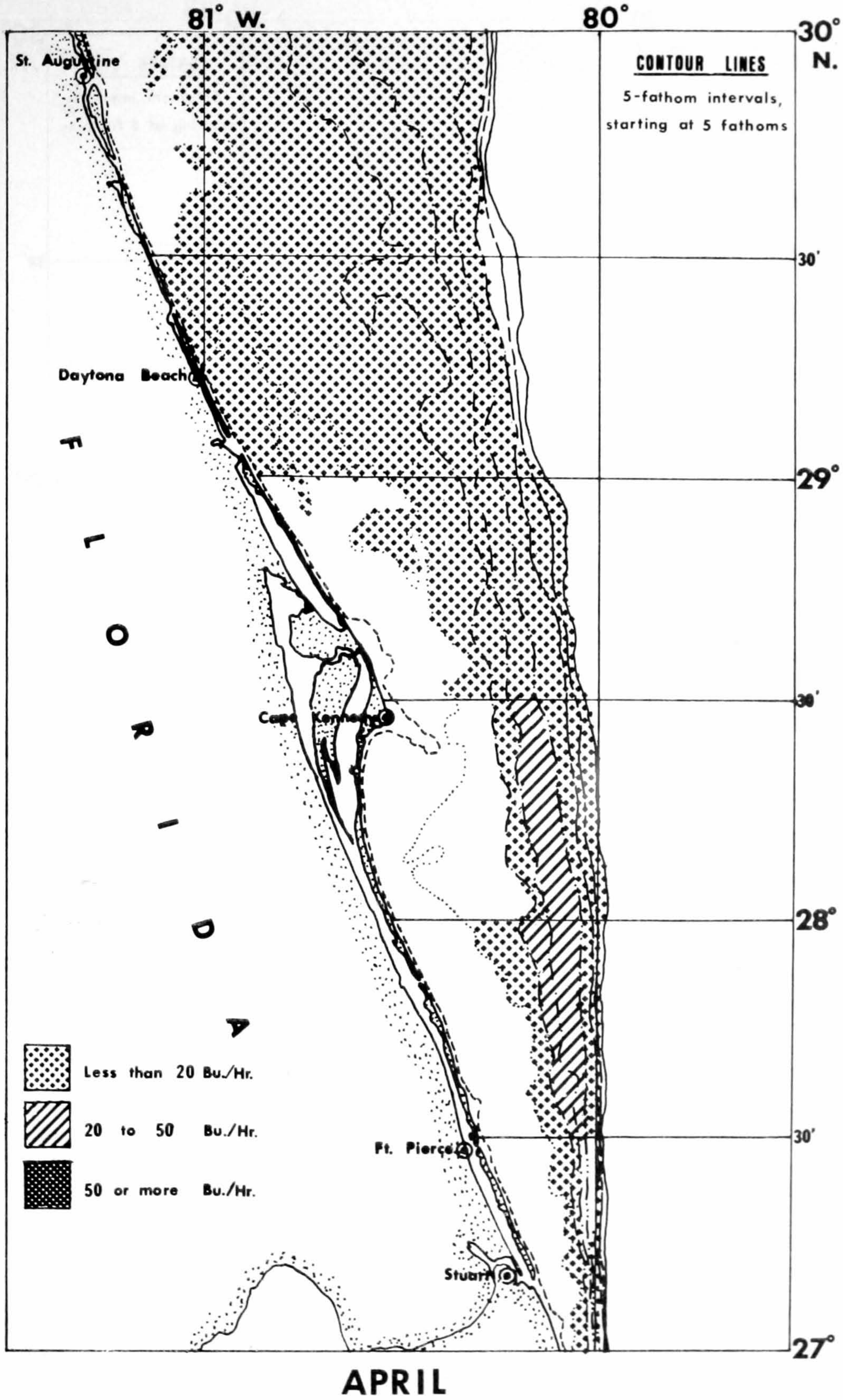

Figure 6.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in April.

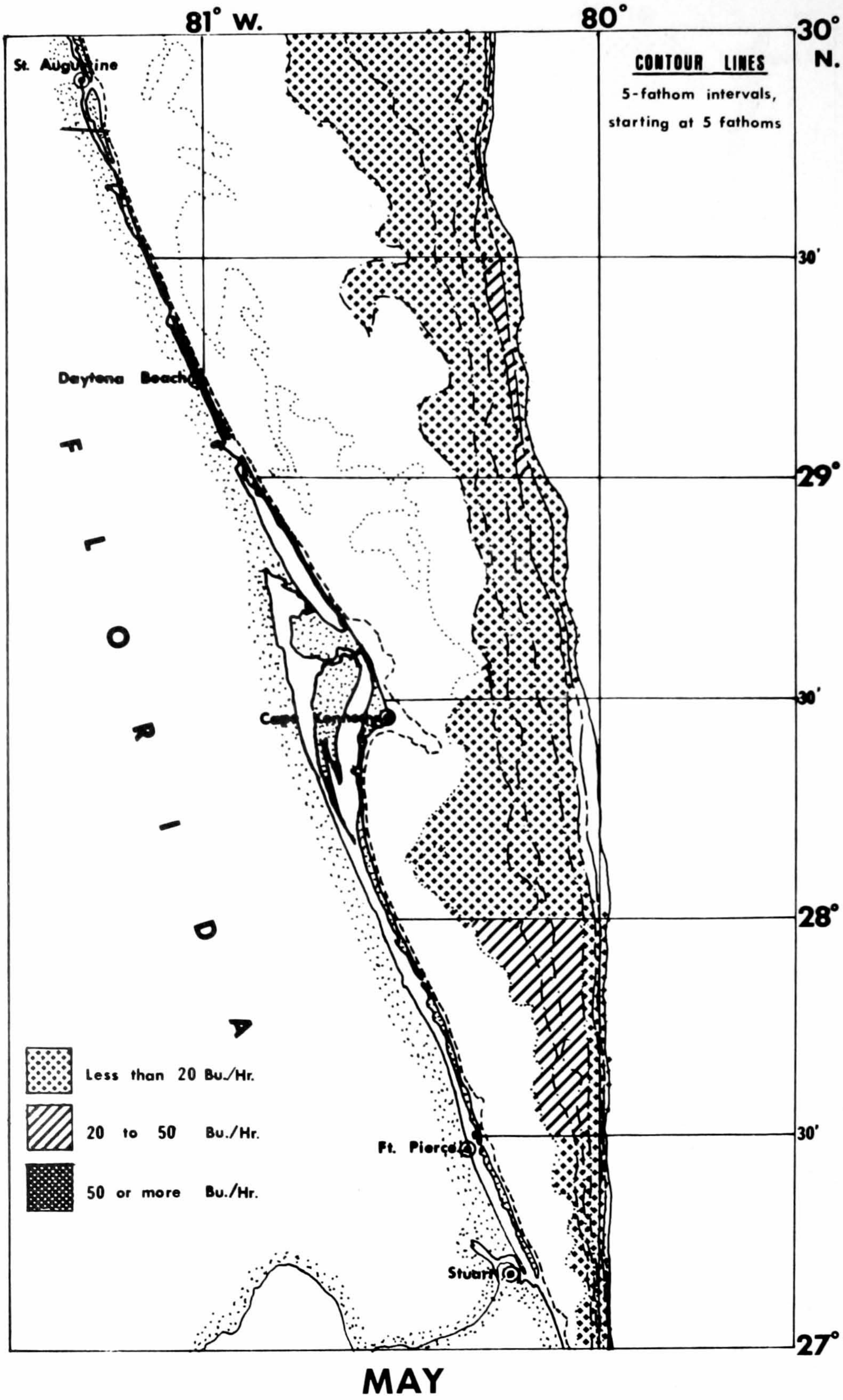

Figure 7.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in May.

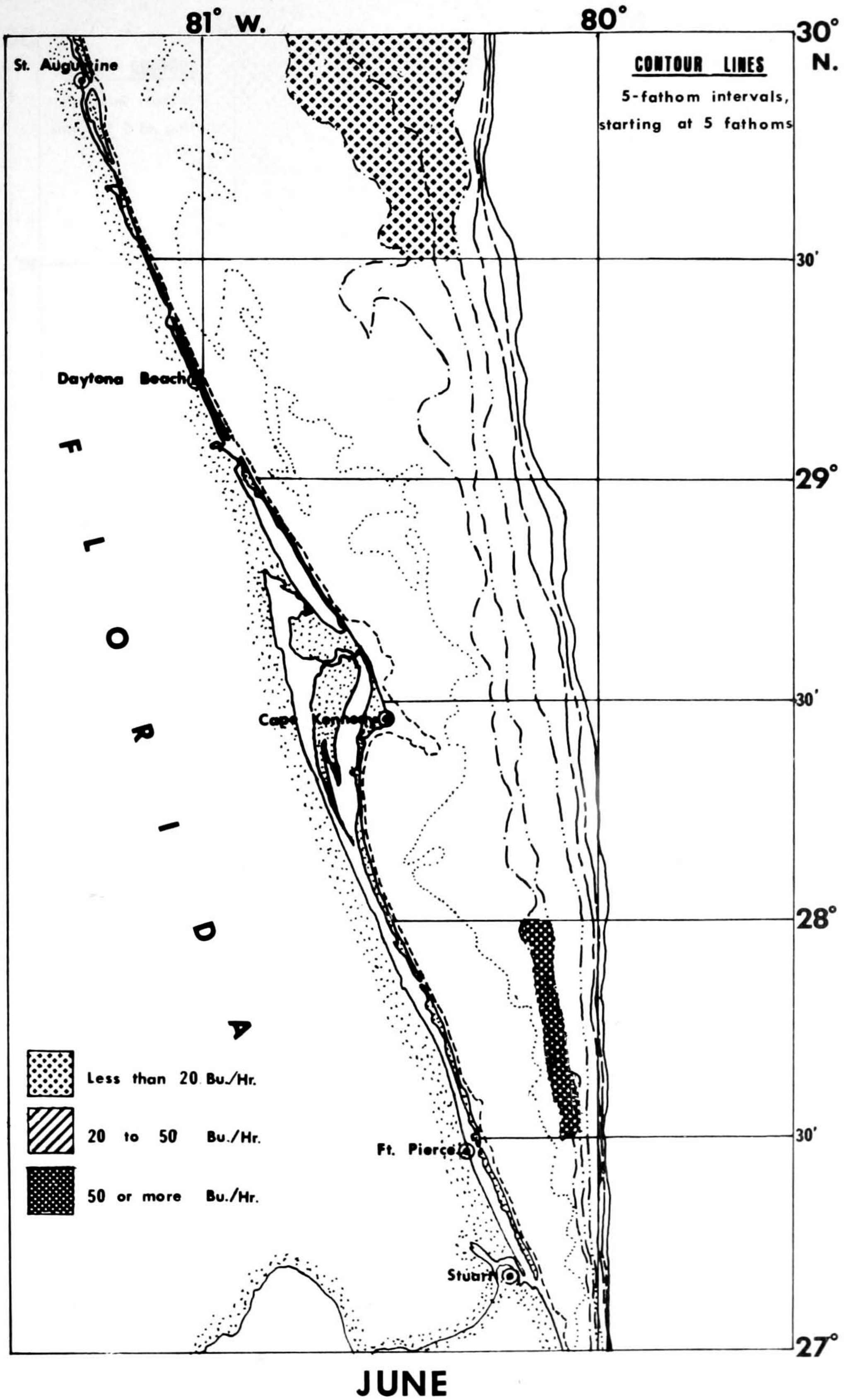

Figure 8.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in June.

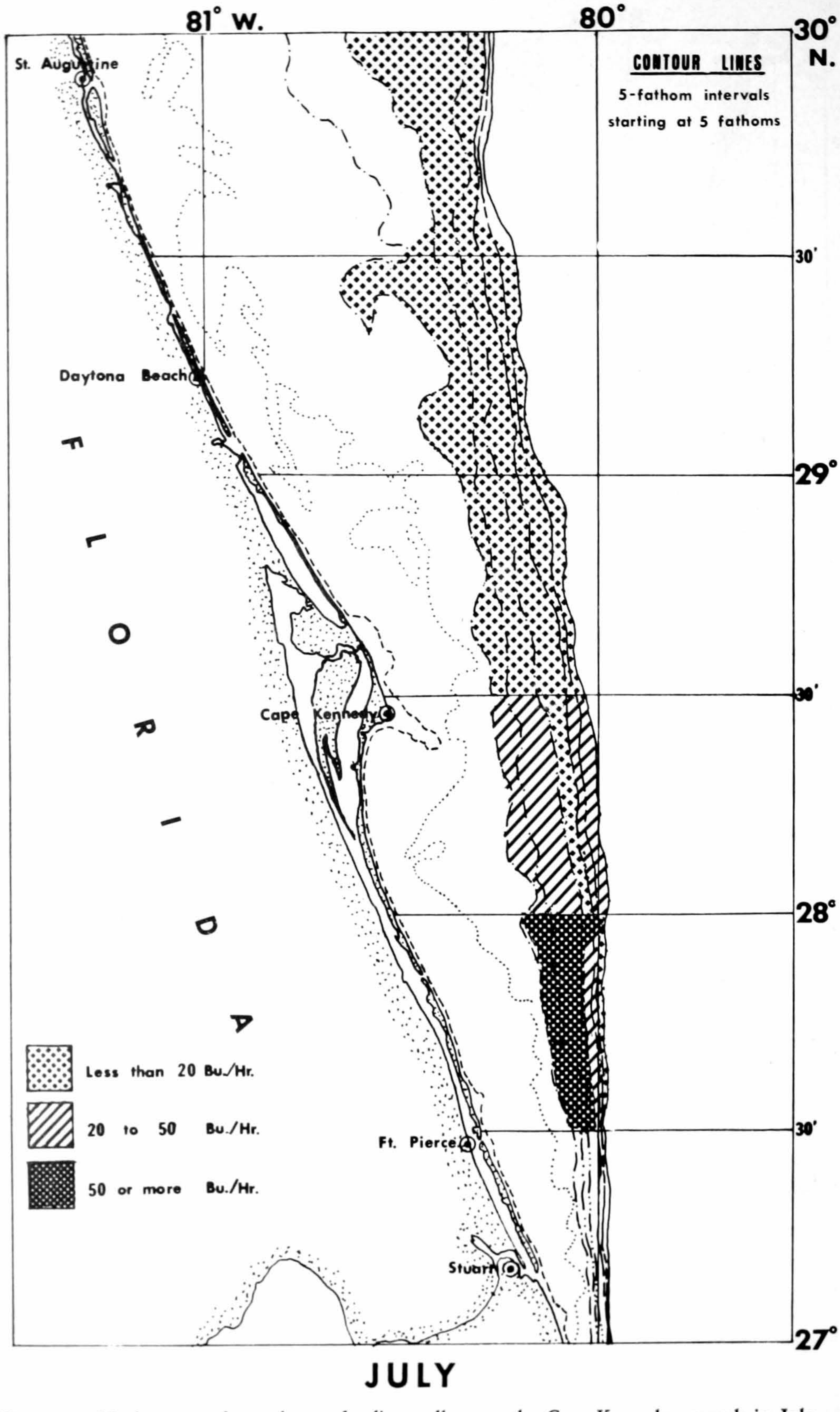

Figure 9.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in July.

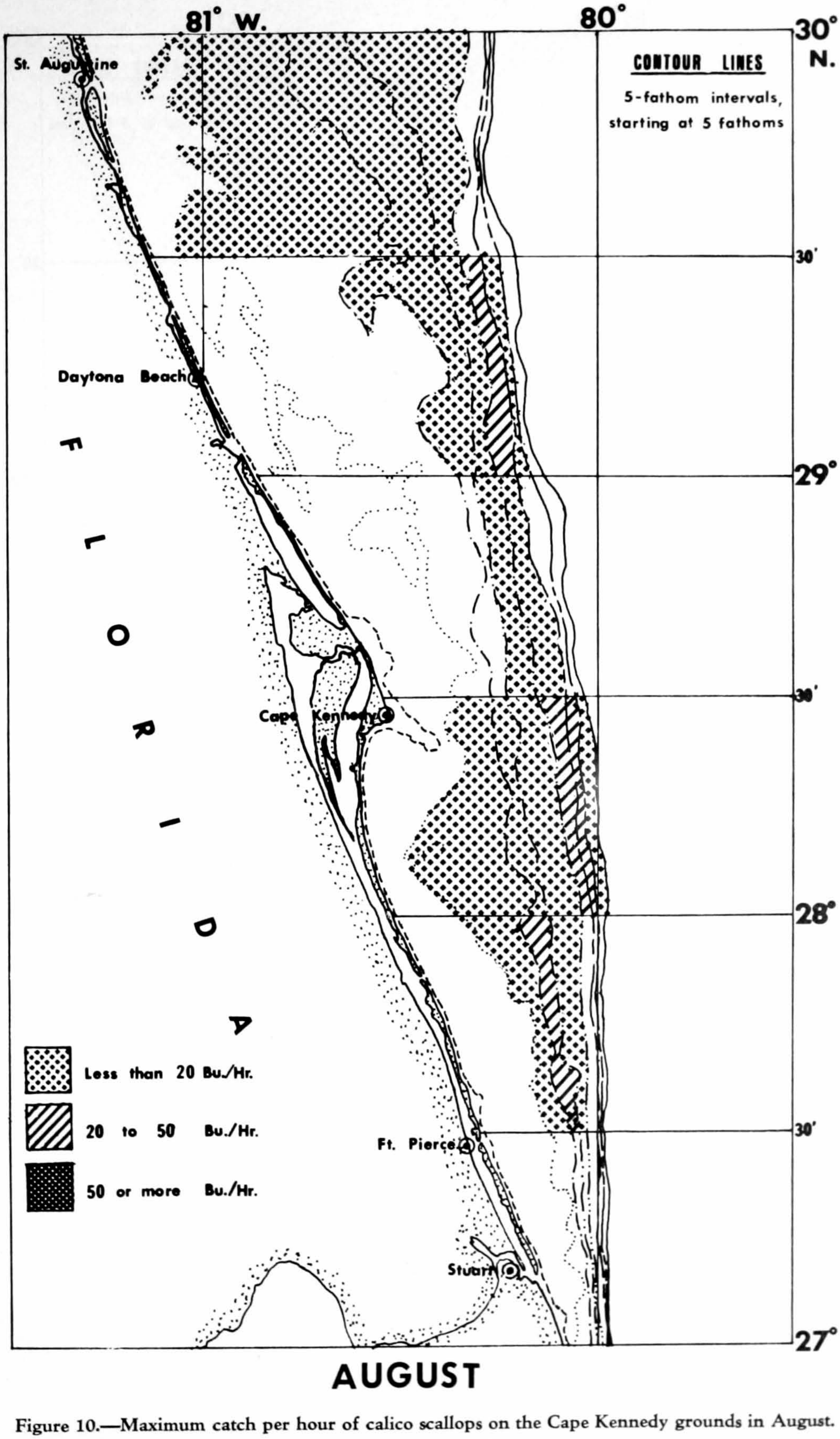

Figure 10.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in August.

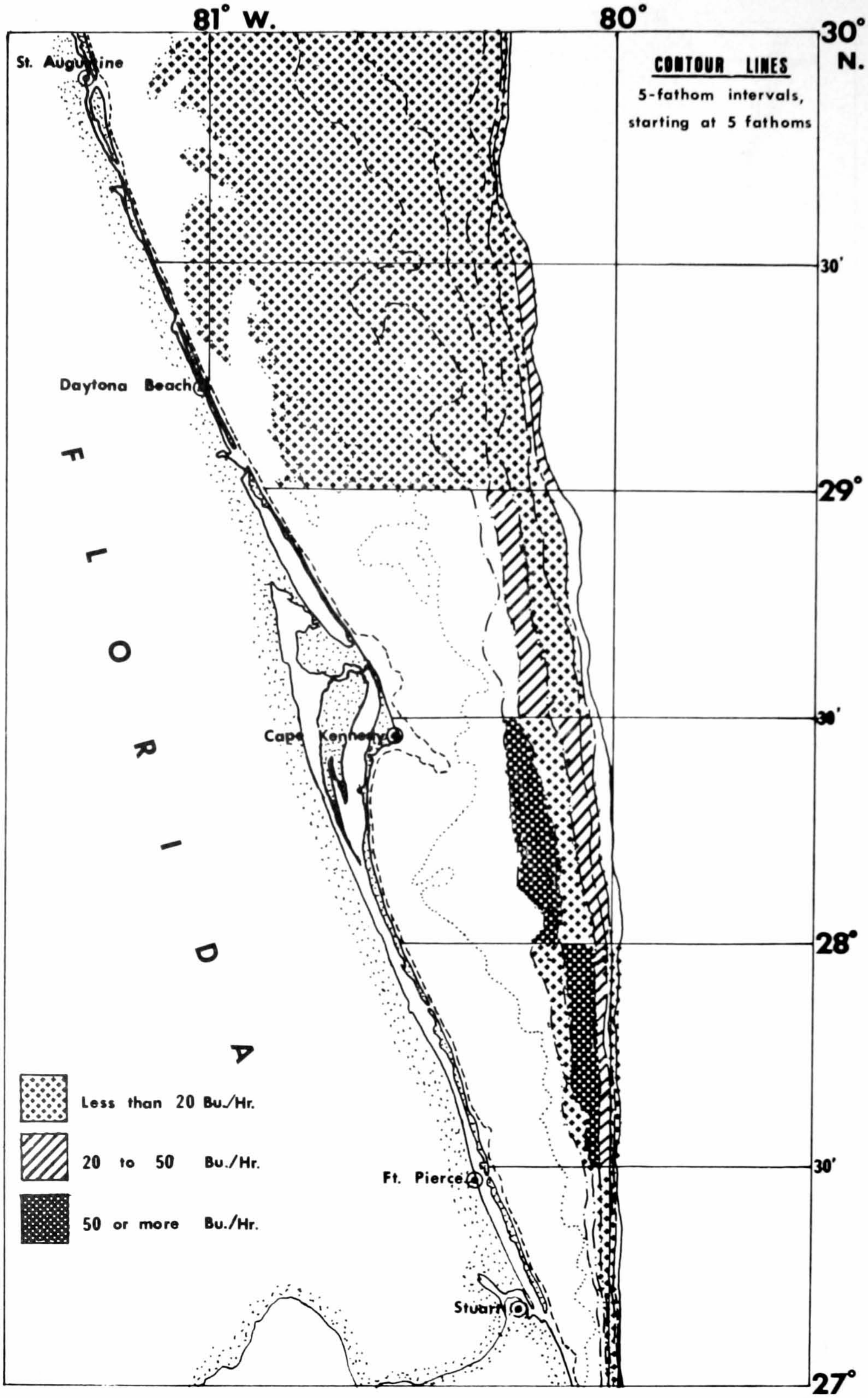

Figure 11.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in September.

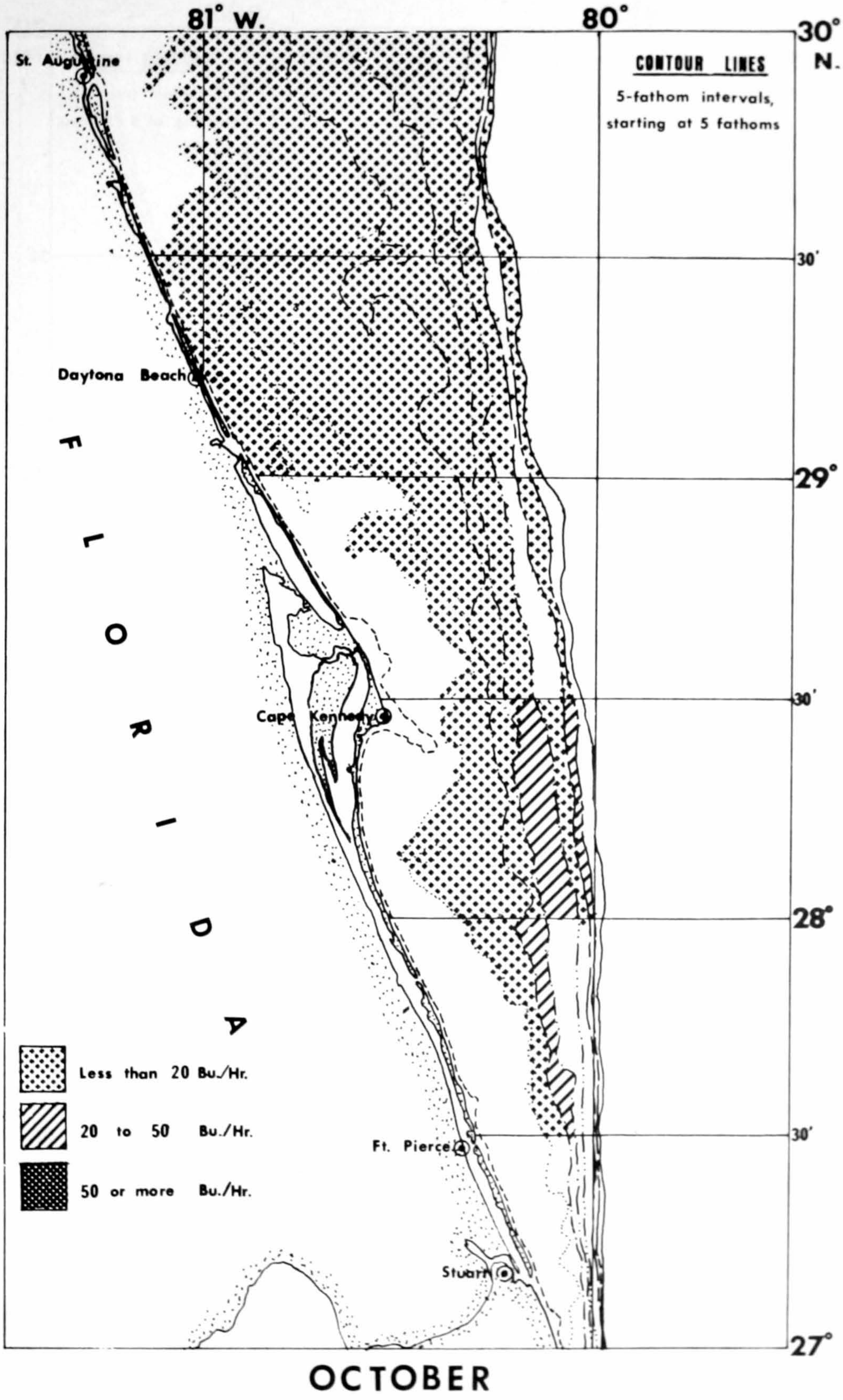

Figure 12.—Maximum catch per hour of calico scallops on the Cape Kennedy grounds in October.

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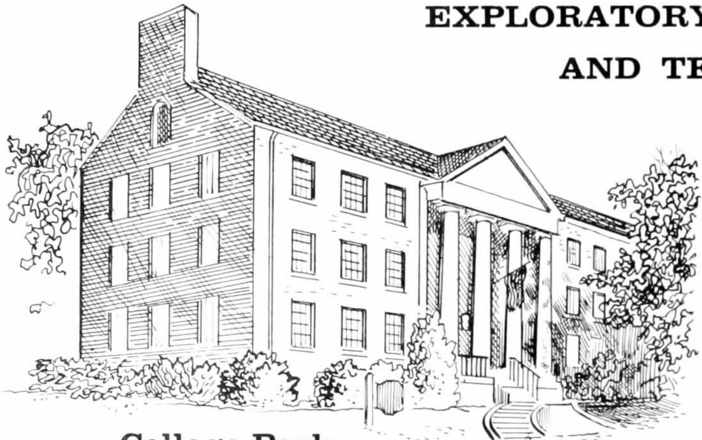

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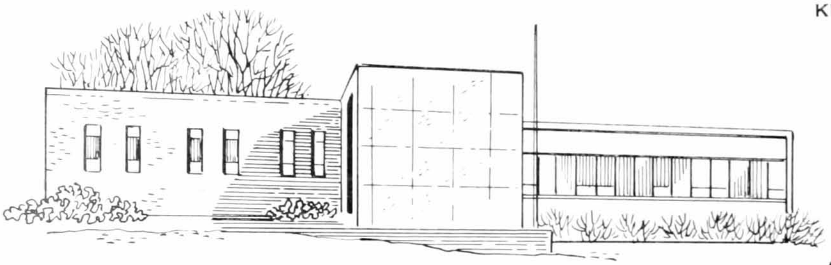

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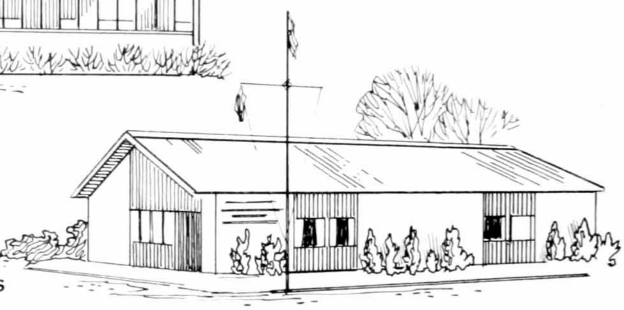

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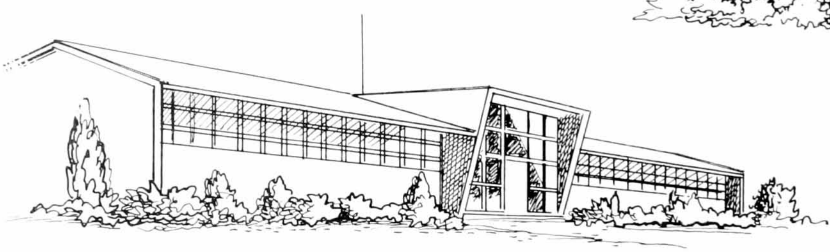

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To help a reader be selective, we present him with a three-sentence abstract at the beginning of each report. The first sentence states the problem that needed solution, the second sentence tells what was done about the problem, and the third sentence reveals the payoff of the research. With that information, the reader can quickly decide whether reading the report will be worth his time.

To help him read rapidly, we use several techniques. The most important of these is to reveal the structure, or plan, of the research to him in the opening part of the report, because to get a quick comprehensive grasp of the report, he must know what the plan of the research was.

We therefore recommend that, in writing a report for *Fishery Industrial Research*, you reveal the plan of your research early in the report and, furtehrmore, that you thereafter keep the plan prominently before the reader, so that he cannot become confused about it. To accomplish these ends, you will need to use the same plan, or outline, for your report that you used for your research. Assuming, for example, that your overall research involved two closely related experiments -- Experiments I and II -- we recommend that you use the following outline:

> **TITLE OF THE OVERALL RESEARCH**
>
> Introduction (states the need for, and precise purpose of, the overall research and reveals its main divisions)
>
> I. Title of Experiment I
>
> A. Materials and methods used in Experiment I
>
> B. Results from Experiment I and discussion of the data
>
> II. Title of Experiment II
>
> A. Materials and methods used in Experiment II
>
> B. Results from Experiment II and discussion of the data
>
> Discussion of, and conclusions from, the overall research
> Introduction (states the need for, and precise purpose of, the overall research and reveals its main divisions)

Thus, we do not recommend the following outline, though it is commonly used:

> **TITLE OF THE OVERALL RESEARCH**
>
> I. Procedure
>
> A. Materials
>
> B. Methods
>
> II. Results and discussion
>
> A. Results of Experiment I (plus any information needed on materials and methods to make the results clear)
>
> B. Results of Experiment II (plus any information needed on materials and methods to make the results clear)

Note that if you were to use the second outline, you would not reveal the plan of the research to the reader until he reads your results and discussion. Even then, you may not reveal the plan unless you present the results of each experiment separately, as indicated in the second outline. If you present them as a unit, as often is done, you may not reveal the plan of the research at any point in your report. In that event, the reader will have to figure backward from your tables and graphs and perhaps reread your report several times in order to infer the plan. Such inferences take time that he cannot afford to spend. So, to give the reader a quick grasp of your report, use the same plan for your report that you used for your research, as indicated in the outline recommended.

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