Proceedings, Third International Coral Reef Symposium
Rosenstiel School of Marine and Atmospheric Science
University of Miami
Miami, Florida 33149, U.S.A.
May 1977

FATTY ACIDS AND HYDROCARBONS OF CARIBBEAN CORALS

Philip A. Meyers
Department of Atmospheric and Oceanic Science
The University of Michigan
Ann Arbor, Michigan 48109

ABSTRACT

Lipid components have been characterized from 45 coral samples representing 27 scleractinian and 1 hydrozoan Caribbean species. The fatty acid compositions of most samples are low in polyunsaturated components. This is exceptional for marine animals. However, 6 samples from deeper locations contain relatively high amounts of polyunsaturated acids, revealing that these marine-type acids do occur in corals. Distinctive fatty acid compositions exist at the species level, and often close similarities are found between species within a genus. Substantial temporal and geographical variations can be superimposed upon these distinctive patterns.

While concentrations of total unsaturated hydrocarbons are nearly the same as those of total fatty acids, levels of saturated hydrocarbons are several orders of magnitude lower. Less than half the saturated hydrocarbons of these organisms is comprised of n-alkanes. No odd-carbon dominance is exhibited by these hydrocarbons.

KEY WORDS: Fatty acids, Hydrocarbons, Scleractinian, Lipid, Hydrozoan, Polyunsaturated acids

FATTY ACIDS AND HYDROCARBONS OF CARIBBEAN CORALS

Philip A. Meyers

Introduction

Corals are important and highly productive members of shallow-water tropical reef communities. For this reason, they have been the subjects of study for a large and varied group of marine scientists. The papers presented in this and preceeding symposia reflect the diversity of coral research. However, despite this strong interest in reef-building corals, there has been only a limited amount of investigation into the lipid content of these fauna.

Much of the initial coral lipid research was done with the intent of identifying precursors of the hydrocarbons found in petroleum reservoir formations, many of which are ancient carbonate reefs (1). Analysis of three Caribbean coral samples revealed distributions of straight-chain saturated hydrocarbons very similar to those found in ancient sediments (2). Because most living organisms have predominantly odd-carbon-number n-alkanes while ancient sediments do not, this is an interesting observation. In another study of coral lipids, it was found that between 0.25 and 0.5 percent by dry weight of *Acropora cervicornis* and *Manicina areolata* was the wax cetyl palmitate (3). The most extensive survey of possible petroleum precursors was conducted by Pasby (4), but was never published. In this study, the lipid contents of a total of 14 different Caribbean corals were determined. As noted before (2), hydrocarbons in living corals were surprisingly similar to those in ancient sediments and in petroleum. Cetyl palmitate was also a major component of total lipids.

More recently, investigations of coral lipids have been directed towards using specific lipids as chemical tracers of nutrient transfers in reef communities. Coral mucus has been shown to contain a high percentage of cetyl palmitate (5) and may therefore be an important energy source for reef fish that feed on it. Fatty acid content of seawater and of corals has been used to investigate exchanges of organic matter between reef communities and water flowing over them (6,7). No obvious correlation was found between the fatty acid compositions of the seawater and that of the dominant coral, *Acropora palmata*. If exchange of organic matter does occur as strongly suggested by other studies (8, 9, 10, 11, 12), then the lack of fatty acid composition agreement indicates it is a complex process indeed.

An observation that is common to many of the published coral lipid analyses is a low level of polyunsaturated compounds, either in fatty acids (4, 7) or in hydrocarbons (4). This is unusual, because polyunsaturation is considered characteristic of marine lipids (13). This low level of polyunsaturation may be characteristic of all Cnidaria, since the fatty acids of a Caribbean gorgonian have been shown to contain only 12% polyunsaturated acids (14), but before such a generalization can be made, more must be known about the lipids of animals in this phylum.

In an effort to learn more about coral lipids and specifically to investigate the question of polyunsaturation a survey of fatty acid and hydrocarbon compositions of Caribbean stoney corals has been begun. This report gives some of the results of the first two years of this study.

Methods

Coral samples were collected from five locations in the Caribbean Sea and the Gulf of Mexico by diving. The sampling areas were Discovery Bay, Jamaica (18°27'N, 77°25'W), West Bay, Grand Cayman (19°20'N, 81°25'W), Dry Tortugas, Florida (24°38'N 82°55'W), Summerland Key, Florida (24°40'N, 81°30' W), and the Florida Middle Ground (28°35'N, 84°20' W). The overall north-south range of these areas is about 1125km. A total of 45 samples have been examined, comprising 28 species from 11 families and 2 classes of Caribbean stoney corals.

Fatty acid and hydrocarbon compositions of these samples were measured by procedures developed from an earlier method (7). The first step of both procedures was designed to provide dry coral tissue for subsequent lipid analysis. Small pieces of coral samples (3-5gm wet weight) were decalcified with 3N HCL. After the carbonate skeleton was dissolved, tissue material was isolated from the liquid-tissue mixture by filtration using preweighed Whatman 541 filters held in a Millepore filtration apparatus. Dessication at reduced pressure was used to dry the filters and the freed tissue to a constant weight. This generally yielded between 0.3 and 1.5gm of dry tissue, representing the combined dry biomass of coral and algae in the original sample.

Lipids were released from the dry tissue by heating in a mixture of benzene and 0.5N methanolic KOH at 100°C for 5 minutes. Hydrocarbons and other non-saponifiable lipids were extracted from the basic (pH > 10) solution with petroleum ether. Fatty acids in this solution were converted to their methyl esters by adding a sufficient amount of a solution of boron trifluoride in methanol to lower the pH to below 2 and heating at 100°C for 5 minutes. The esters were then also extracted with petroleum ether.

The extracted liquids were separated into their various classes by chromatographic procedures. Fatty acid methyl esters were isolated by thin-layer chromatography as described elsewhere (7). Non-saponifiable lipid classes were

separated by column chromatography using alumina over silica gel, 1/1, and eluting successively with petroleum ether, benzene, and benzene/methanol, 9/1. These elutions isolated saturated and monounsaturated hydrocarbons, polyunsaturated and aromatic hydrocarbons, and fatty alcohols, respectively.

Qualitative and quantitative analysis of three of these isolated lipid classes was done using gas-liquid chromatography; the fatty alcohols have not been examined. Fatty acid methyl esters were chromatographed using 3.1mm OD x 2m stainless steel columns packed with 10% SP-216-PS (DEGS) on 100/120 Supelcoport (Supelco, Bellefonte, Pa.). The columns were operated at 150° for 2 minutes, then heated at 4°C/minute to 190°, and finally maintained at 190°C for 16 minutes. The hydrocarbon classes were chromatographed on two different column types. The first was 3.1mm OD x 4m stainless steel packed with 3% SP-2100 (OV-101) on 100/120 Supelcoport (Supelco, Bellefonte, Pa.) operated from 150°C to 325°C at 4 °/minute and then maintaining the upper temperature for 10 minutes. The second was 3.1mm OD x 2.5m stainless steel packed with 10% SP-1000 (FFAP) on 80/100 Supelcoport (Supelco, Bellefonte, Pa) operated from 120°C to 250°C at 8 °/minute, then holding 250°C for 30 minutes. Carrier gas in the three column types was nitrogen, and flow rates were adjusted daily to maximize column efficiencies for test mixtures. Analyses were performed using dual column differential modes of Hewlett-Packard 5710 and 5830 Gas Chromatographs, equipped with FID detectors. A Hewlett-Packard 3380 integrator was used with the HP 5710 gas chromatograph.

Identification of components of the isolated lipid classes was achieved by comparison of their relative retention times with those of authentic standards. The amount of each component was determined by comparison of its peak area with that of a quantitative standard present in the same chromatogram. A fatty acid quantitative standard was introduced prior to saponification of the dry tissue; appropriate hydrocarbon quantitative standards were added to each hydrocarbon class after column chromatography. Analysis of both fatty acid and hydrocarbon blanks showed negligible amounts of contamination due to glassware, solvents, and reagents.

Results

Totals of 44 fatty acid, 28 saturated hydrocarbon, and 22 unsaturated hydrocarbon analyses have been obtained from these samples of Caribbean corals. In 27 of the samples, both fatty acids and saturated hydrocarbons were determined. These analyses are summarized in Table 1, and the collection location, date and water depth of each sample are shown.

Concentrations of total fatty acids range from a low of 400 micrograms per gram of dry tissue to a high of 324 milligrams per gram. In two samples, *A. palmata* and *P. furcata*, fatty acids comprised nearly one-third the total dry weight of the tissue. However, the average fatty acid contribution to the total weight of all 44 samples was about 40 milligrams per gram. Analysis of samples of *M. areolata* showed that fatty acid concentrations can vary by as much as one order of magnitude among replicate samples. Therefore, little significance can be attached to the variation seen among the concentrations in Table 1.

The contributions of saturated, monounsaturated, and polyunsaturated fatty acids to the total concentrations are also listed in this table. Only 6 samples contain more than 15% total polyunsaturated acids, whereas 29 have 5% or less. Nearly all the compositions are dominated by saturated acids. The Acroporidae samples, for example, average over 80% saturated components, and in one sample of *A. cervicornis* saturated acids comprise 94% of the total.

Similarities exist in the totals of saturated, monounsaturated, and polyunsaturated acids between some of these corals. These are especially evident in samples of the same genus from the same sampling operation. Some examples are *C. natans* and *C. breviserialis* which show very good agreement and *M. annularis* and *M. cavernosa* from Grand Cayman which also agree well. Similarities are also found among samples which are not generically related but are from the same location. The samples of *P. furcata*, *M. decactis*, and *D. stokesii* collected at 32 m from the Florida Middle Ground in 1974 are similar in exhibiting relatively large percentages of polyunsaturated fatty acids. This is also true for *P. divaricata* and *M. alcicornis* from this area in 1974. Other samples from the Middle Ground do not contain these high amounts of polyunsaturation, nor do samples of these species from other collection locations or periods.

The concentrations of total saturated hydrocarbons shown in Table 1 are two to three orders of magnitude lower than those of fatty acids in the 27 samples in which both were measured. Polyunsaturated hydrocarbon concentrations, however, are nearly at the same level as those of fatty acids.

Fatty acid compositions of each sample are expressed in Table 2 as weight percents of total fatty acid concentrations. Palmitic acid (16.0) is the largest component in 40 of the 44 listed composition and comprises over half the total weight of fatty acid in 22 of them. Oleic acid (18.1) is the second-most abundant acid in many of the samples and stearic (18.0) and palmitoleic (16.1) acids are also major components. Six of the listed samples contain more than 10% docosahexaenoic (22.6) acid, and this is the largest component in

Table 1. Sources and Lipid Content of Caribbean Coral Samples. A - total fatty acids, mgm/gm; B - saturated fatty acid weight percent; C - monounsaturated fatty acid weight percent; D - polyunsaturated fatty acid weight percent; E - total saturated hydrocarbons, μgm/gm; F - total unsaturated hydrocarbons, μgm/gm; n.a. - not analyzed.

Species	Location	Depth(m)	Date	A	B	C	D	E	F
Class: Anthozoa									
Order: Scleractinia									
Family: Pocilloporidae									
Madracis decactis	Middle Ground	32	VI-74	75.9	57.5	16.6	26.0	147	773
Madracis decactis	Middle Ground	31	VI-75	28.5	54.3	36.7	8.7	344	20080
Madracis decactis	Middle Ground	31	VI-75	n.a.	71.0	25.2	3.7	210	2493
Madracis decactis	Jamaica	15	III-76	2.9	67.4	32.6	0	193	132
Madracis mirabilis	Jamaica	15	III-76	4.8	84.0	16.0	0	19	141
Family: Acroporidae									
Acropora palmata	Grand Cayman	1	III-74	25.7	81.3	16.4	2.3	n.a.	n.a.
Acropora palmata	Jamaica	6	III-76	324	89.3	10.7	0	n.a.	n.a.
Acropora cervicornis	Grand Cayman	11	III-74	71.9	73.3	22.3	3.7	n.a.	n.a.
Acropora cervicornis	Dry Tortugas	8	XII-74	94.9	76.9	19.8	2.4	n.a.	n.a.
Acropora cervicornis	Jamaica	6	III-76	1.6	94.1	5.5	0.5	n.a.	n.a.
Acropora prolifera	Jamaica	6	III-76	0.4	85.7	14.3	0	n.a.	n.a.
Family: Agariciidae									
Agaricia agaricites	Grand Cayman	11	III-74	22.1	83.5	4.5	11.9	n.a.	n.a.
Agaricia agaricites	Jamaica	12	III-76	2.9	82.2	14.3	3.5	9	n.a.
Helioseris cucullata	Jamaica	12	III-76	1.7	68.1	24.1	7.9	4	n.a.
Family: Siderastreidae									
Siderastrea siderea	Grand Cayman	11	III-74	8.4	50.1	40.8	9.1	n.a.	n.a.
Family: Poritidae									
Porites astreoides	Grand Cayman	12	III-74	9.7	52.8	36.4	10.9	n.a.	n.a.
Porites astreoides	Jamaica	12	III-76	2.7	82.8	17.2	0	4	27
Porites porites	Grand Cayman	12	III-74	7.0	67.5	23.5	8.9	n.a.	n.a.
Porites porites	Jamaica	12	III-76	2.3	80.1	20.0	0	17	88
Porites divaricata	Middle Ground	26	VI-74	89.1	43.8	20.9	35.3	18	4027
Porites divaricata	Middle Ground	31	VI-75	17.2	75.8	17.7	6.8	192	3054
Porites divaricata	Middle Ground	31	VI-75	6.2	76.2	20.1	0	67	1005
Porites furcata	Grand Cayman	1.5	III-74	130	55.4	35.4	9.2	n.a.	n.a.
Porites furcata	Middle Ground	32	VI-74	288	51.0	19.4	29.6	198	372
Porites furcata	Jamaica	12	III-76	1.5	83.7	16.3	0	1	21
Family: Faviidae									
Manicina areolata	Summerland Key	1.5	I-76	2.3	57.1	43.6	0	2	62
Colpophyllia natans	Grand Cayman	11	III-74	9.1	64.9	31.6	3.3	n.a.	n.a.
Colpophyllia breviserialis	Grand Cayman	11	III-74	9.8	67.1	29.3	3.0	n.a.	n.a.
Cladocora arbuscula	Middle Ground	30	VI-74	8.0	58.6	38.5	2.9	n.a.	n.a.
Montastrea annularis	Grand Cayman	11	III-74	3.4	82.7	16.9	0	n.a.	n.a.
Montastrea annularis	Middle Ground	30	VI-74	n.a.	n.a.	n.a.	n.a.	56	3140
Montastrea cavernosa	Grand Cayman	11	III-74	23.1	76.1	19.5	4.8	n.a.	n.a.
Solenastrea hyades	Middle Ground	31	VI-75	79.1	86.6	8.2	5.0	4968	7274
Solenastrea hyades	Middle Ground	31	VI-75	13.8	90.7	8.2	1.1	1820	10488
Family: Oculinidae									
Oculina diffusa	Middle Ground	31	II-76	1.7	77.8	21.7	0.5	13	226
Family: Meandrinidae									
Dichocoenia stokesii	Middle Ground	32	VI-74	121	39.1	24.7	36.1	49	15945
Family: Mussidae									
Mussa angulosa	Jamaica	12	III-76	n.a.	15.5	84.3	0.1	26	n.a.
Scolymia lacera	Middle Ground	36	VI-74	70	47.9	36.2	16.3	7	237
Isophyllia sinuosa	Jamaica	3	III-76	0.7	63.8	35.3	0.7	9	n.a.
Isophyllastrea rigida	Jamaica	6	III-76	n.a.	35.6	61.9	2.6	3	n.a.
Mycetophyllia ferox	Jamaica	6	III-76	2.4	87.5	12.2	0.3	4	n.a.
Family: Dendrophylliidae									
Balanophyllia floridana	Middle Ground	33	VI-74	13.1	52.5	40.2	7.4	n.a.	n.a.
Class: Hydrozoa									
Order: Milleporina									
Family: Milleporidae									
Millepora alcicornis	Middle Ground	26	VI-74	73.9	56.7	14.2	29.2	32	244
Millepora alcicornis	Middle Ground	31	VI-75	4.7	84.9	15.0	0	103	352
Millepora alcicornis	Middle Ground	31	VI-75	3.4	86.9	9.8	3.6	596	5174

Table 2. Fatty Acid Weight Percent Composition of Caribbean Corals. Samples listed in same order as in Table 1. Individual acids designated by number of straight-chain carbon atoms: number of double bonds. Compositions expressed as percent of fatty acid concentrations given in Table 1. Trace amounts indicated by tr.

Species	12:0	14:0	16:0	16:1	18:0	18:1	20:0	20:1	20:5	22:0	22:1	22:5	22:6	24:0	24:1
Pocilloporidae:															
M. decactis	0.5	4.7	40.4	tr	8.0	13.4	3.9	tr	0.7	tr	3.1	5.0	20.3	-	-
M. decactis	0.3	4.5	38.3	12.6	11.2	9.6	-	-	3.5	-	8.0	2.4	2.8	-	6.5
M. decactis	0.2	22.3	39.6	11.7	8.4	10.6	0.5	1.2	1.0	-	1.7	0.9	1.8	-	-
M. decactis	0.6	9.1	49.6	10.4	7.1	20.0	1.0	2.2	-	-	-	-	-	-	-
M. mirabilis	0.3	7.7	66.8	-	5.2	16.0	2.6	-	-	-	-	-	-	1.4	-
Acroporidae:															
A. palmata	0.3	6.3	60.7	tr	11.2	9.8	2.2	3.6	0.7	0.6	1.5	1.6	tr	tr	1.5
A. palmata	0.1	5.5	80.3	0.3	2.9	9.1	0.5	1.3	-	-	-	-	-	-	-
A. cervicornis	0.2	6.6	56.3	6.6	7.6	10.2	2.4	3.0	0.8	0.2	1.3	1.7	1.2	tr	1.2
A. cervicornis	0.3	5.5	64.2	5.6	5.0	9.3	1.5	2.8	0.9	0.4	0.9	1.5	tr	tr	1.2
A. cervicornis	0.1	12.3	78.1	2.5	3.2	2.5	-	tr	0.5	0.4	0.5	-	-	-	-
A. prolifera	0.1	6.5	67.4	-	11.3	11.3	0.4	3.0	-	-	-	-	-	-	-
Agariciidae:															
A. agaricites	0.2	2.7	55.1	tr	20.0	tr	5.5	-	1.9	tr	4.5	2.2	7.8	-	-
A. agaricites	0.6	6.8	64.1	7.6	7.5	5.0	1.8	-	1.5	0.2	1.7	-	2.0	1.2	-
H. cucullata	0.5	5.9	52.0	10.6	3.4	11.2	6.0	-	3.0	0.3	2.3	-	4.9	-	-
Siderastreidae:															
S. siderea	0.3	3.5	32.5	tr	13.2	18.6	0.6	7.0	4.3	tr	15.2	3.6	1.2	-	-
Poritidae:															
P. astreoides	0.6	3.2	30.0	tr	11.4	12.3	7.6	tr	1.4	-	14.6	1.7	7.8	-	9.5
P. astreoides	0.2	5.2	70.6	-	6.8	15.3	-	1.8	-	-	0.1	-	-	-	-
P. porites	1.4	5.8	48.7	tr	9.0	12.2	2.6	4.4	3.1	-	6.9	1.9	3.9	-	-
P. porites	0.1	7.0	64.4	-	4.3	12.3	3.7	3.1	-	-	4.6	-	-	0.6	-
P. divaricata	0.1	1.6	23.1	6.3	10.7	8.2	8.3	tr	2.0	tr	6.4	3.0	30.3	-	-
P. divaricata	0.1	4.7	48.9	-	16.8	8.2	5.3	5.2	-	-	4.3	2.1	4.7	-	-
P. divaricata	0.2	3.8	59.8	5.2	10.8	10.6	1.6	2.9	-	-	1.4	-	-	-	-
P. furcata	0.3	3.8	43.8	15.1	5.4	9.8	2.1	2.4	2.2	tr	8.1	2.3	4.7	-	-
P. furcata	0.1	3.4	34.5	tr	6.2	9.6	6.8	3.8	6.9	tr	6.0	4.4	18.3	-	-
P. furcata	0.1	5.9	64.6	-	11.8	13.8	1.3	2.5	-	-	-	-	-	-	-
Faviidae:															
M. areolata	0.1	3.4	36.5	4.4	12.7	25.4	3.0	9.8	-	-	4.0	-	-	1.4	-
C. natans	0.1	4.3	35.8	tr	19.1	17.7	4.7	6.1	0.5	0.9	6.2	1.2	1.6	-	1.6
C. breviserialis	0.1	3.9	36.3	tr	21.6	15.6	4.4	5.1	0.7	0.8	6.5	0.9	1.4	-	2.1
C. arbuscula	0.1	8.6	36.3	16.4	7.9	14.7	2.1	3.8	1.1	1.0	3.6	-	1.8	2.6	-
M. annularis	tr	2.0	58.1	tr	7.2	11.6	6.2	tr	-	3.3	5.3	-	-	5.9	-
M. cavernosa	0.1	3.8	56.0	-	14.1	12.3	2.1	3.1	1.4	tr	3.0	0.7	2.7	-	1.1
S. hyades		1.5	73.0	-	7.3	5.4	4.8	-	0.3	-	1.8	2.5	2.2	-	1.0
S. hyades	0.2	1.6	76.3	-	9.5	6.4	3.1	-	0.2	-	1.0	0.5	0.4	-	0.8
Occulinidae:															
O. diffusa	0.1	5.6	66.3	1.5	5.3	18.6	0.5	0.4	0.5	-	0.7	-	-	-	0.5
Meandrinidae:															
D. stokesii	0.1	0.8	19.8	tr	11.3	9.7	7.1	tr	2.6	-	8.1	4.3	29.2	-	6.9
Mussidae:															
M. angulosa	0.1	9.4	-	67.3	4.8	14.7	1.2	2.2	0.1	tr	-	-	0.1	-	0.1
S. lacera	0.1	3.7	29.2	tr	8.0	20.7	6.9	7.7	3.3	-	7.8	2.1	10.9	-	-
I. sinuosa	tr	4.1	46.0	8.8	9.1	17.2	3.6	3.5	0.4	0.3	5.8	-	0.3	0.7	-
I. rigida	0.2	4.6	14.0	33.0	11.5	17.5	3.2	4.7	1.0	0.4	6.7	-	1.6	1.7	-
M. ferox	0.2	5.1	75.1	-	6.5	11.2	0.5	tr	0.3	0.1	1.0	-	-	tr	-
Dendrophylliidae:															
B. floridana	0.4	5.9	28.0	11.1	14.3	15.5	3.9	7.0	3.4	tr	6.6	tr	4.0	tr	tr
Milleporidae:															
M. alcicornis	0.1	3.4	42.1	tr	5.4	11.1	4.7	tr	1.2	1.0	1.0	4.5	23.5	tr	2.1
M. alcicornis	0.2	6.2	58.3	3.8	7.1	10.6	12.2	-	-	0.9	0.6	-	-	-	-
M. alcicornis	0.2	3.8	65.7	-	6.3	8.5	8.1	-	0.6	1.0	1.3	-	3.0	1.8	-

Table 3. Hydrocarbon Weight Percent Composition of Caribbean Corals. Samples listed in same order as in Table 1. Normal alkanes listed by number of carbon atoms; isoprenoid hydrocarbons are pristane (Pr), phytane (Ph), and squalene (Sq). Compositions expressed as percent of hydrocarbon concentrations given in Table 1. Not analyzed indicated by na.

	Normal Alkanes															Isoprenoids		
Species	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Pr	Ph	Sq
Pocilloporidae:																		
M. decactis	1.5	3.0	1.3	0.7	1.3	0.4	1.2	3.8	8.3	11.6	9.8	5.8	3.1	2.2	0.8	-	0.5	5.5
M. decactis	3.9	6.2	5.2	4.1	1.8	0.8	0.8	1.5	0.5	1.2	0.5	0.6	-	-	-	4.6	3.2	0.4
M. decactis	1.2	3.2	2.0	2.2	0.6	0.4	0.4	0.7	-	-	0.9	0.8	1.3	4.7	3.9		1.2	0.7
M. decactis	5.9	10.3	4.6	12.8	0.9	0.4	0.1	0.2	0.6	1.1	0.5	-	0.1	-	0.1	8.0	4.7	6.3
M. mirabilis	2.2	13.0	4.2	3.7	1.6	0.9	1.5	2.0	3.1	4.5	8.8	1.8	3.5	1.1	1.3	4.2	2.1	1.2
Agariciidae:																		
A. agaricites	4.8	5.5	3.6	2.7	1.0	0.6	0.6	0.6	0.6	1.6	0.7	0.8	0.1	1.1	0.5	3.0	1.7	na
H. cucullata	8.8	12.7	8.3	5.5	2.2	1.3	1.6	1.8	2.3	3.5	2.3	1.9	2.2	2.1	1.4	6.1	3.7	na
Poritidae:																		
P. astreoides	3.1	6.3	3.6	-	-	-	-	-	-	80.0	-	-	-	-	-	4.1	-	6.2
P. porites	0.4	3.1	2.6	2.6	0.4	-	-	1.6	-	54.7	-	-	2.5	-	1.7	2.8	1.6	1.0
P. divaricata	1.2	4.8	2.6	2.3	2.4	-	0.4	0	0.3	-	0.8	-	1.2	12.5	1.6	2.2	1.4	-
P. divaricata	2.0	7.2	2.3	3.1	-	0.4	2.0	3.4	4.3	4.8	4.7	4.2	6.2	5.8	4.4	3.4	2.4	0.4
P. divaricata	4.8	15.2	6.0	3.7	3.2	0.4	1.8	0.3	1.8	-	2.1	-	1.1	7.4	5.1	5.4	3.4	1.9
P. furcata	1.9	4.4	1.3	0.9	1.5	0.8	2.1	5.4	7.5	8.6	6.9	6.3	3.5	2.2	1.2	0.9	0.5	10.6
P. furcata	8.8	14.4	8.5	-	-	-	-	-	-	61.8	-	-	-	-	-	-	-	2.2
Faviidae:																		
M. areolata	-	6.6	4.2	3.9	-	-	-	2.2	3.4	40.7	4.4	4.0	2.8	3.0	4.6	4.4	2.3	3.5
M. annularis	5.3	5.9	4.9	3.0	3.2	0.8	0.9	0.4	1.2	1.5	1.6	0.6	1.0	2.6	-	4.1	2.3	0.7
S. hyades	0.4	1.0	0.4	0.2	0.2	-	0.2	-	1.2	1.4	10.8	0.8	-	-	-	5.5	4.0	1.4
S. hyades	3.0	3.4	2.2	2.1	1.0	0.4	1.5	0.8	2.0	3.6	1.7	-	-	4.5	4.4	1.8	1.4	3.0
Oculinidae:																		
O. diffusa	-	5.0	0.7	6.0	3.8	1.2	1.8	0.5	1.4	-	1.1	1.0	0.6	-	2.5	3.9	-	1.4
Meandrinidae:																		
D. stokesii	2.4	1.8	2.5	1.2	na	na	na	na	na	na	na	na	na	na	na	6.6	4.3	1.1
Mussidae:																		
M. angulosa	1.5	25.3	2.5	4.0	1.1	0.9	0.7	0.7	0.9	0.3	0.5	-	0.3	-	0.1	0.9	1.2	na
S. lacera	0.2	0.7	-	0.2	0.6	-	-	-	-	-	-	-	-	-	-	-	-	0.2
I. sinuosa	0.3	2.9	0.5	0.5	0.2	0.1	0.1	0.1	0.2	-	-	-	-	-	-	0.2	0.2	na
I. rigida	1.0	13.7	3.7	5.8	1.3	0.6	0.6	0.7	1.2	2.3	0.5	-	-	-	0.6	1.9	2.2	na
M. ferox	0.2	0.9	2.0	2.2	1.0	0.8	0.9	1.6	1.3	4.4	1.0	4.3	0.7	1.7	0.2	-	0.8	na
Milleporidae:																		
M. alcicornis	2.2	3.5	2.1	1.6	1.3	0.2	0.8	0.3	1.0	1.4	1.2	2.0	0.6	2.1	1.9	2.2	0.6	-
M. alcicornis	3.1	3.0	2.2	1.0	1.2	0.2	2.0	0.5	2.2	-	1.5	-	-	3.2	1.9	2.4	1.3	27.4
M. alcicornis	2.5	7.1	2.2	1.5	1.1	0.4	1.1	0.8	1.6	1.3	1.6	2.1	1.7	2.4	2.9	1.1	1.0	0.9

the compositions of *P. divaricata* and *D. stokesii*, both collected in 1974 from the Florida Middle Ground.

Some of the similarities in fatty acid compositions of certain samples suggested by the data in Table 1 are strengthened by their weight percent compositions. The acids comprising the two species of *Colpophyllia* are very similar, as are those of the two species of *Montastrea*. However, the compositions of *P. furcata*, *M. decactis* and *D. stokesii*, which appeared to be similar in Table 1, are shown to be different in Table 2. Other differences appear between the compositions of the 5 genera in the Mussidae and between the 5 genera in the Faviidae. These are significant differences, exceeding the maximum relative standard deviation of ±15% found from replicate analysis of *M. areolata*. Significant differences in fatty acid composition are also found within the genera of *Madracis*, *Acropora*, and *Porites*, both between separate species and between conspecific organisms from different locations.

In Table 3, components of the hydrocarbon compositions of 28 coral samples which could be identified by gas chromatograph retention times are presented. Normal alkanes from C_{16} to C_{30}, pristane, and phytane are tabulated from the saturated hydrocarbon fraction; squalene is the only unsaturated hydrocarbon in this listing. The contribution of each component to the total concentration is given in weight percent. Only a fraction of the total hydrocarbon composition is represented by these listed compounds. Most of the components did not have retention times corresponding to available hydrocarbon standards and therefore could not be tentatively identified. This was especially true of the unsaturated fraction, in which most samples had similar patterns of peaks with retention indices of 1900 to 2300 on SP-2100 (OV-101) columns and of 2100 to 2500 on SP-1000 (FFAP) columns. Also, the peak tentatively identified as the C_{25} n-alkane appeared to be this compound plus some unknown compound with a slightly longer retention time in some samples.

Despite these shortcomings, it is evident that the hydrocarbon compositions of these corals display no strong odd-over-even n-alkane preference. Also, n-heptadecane, pristane, phytane, and squalene are important constituents of the overall hydrocarbon compositions of many of these organisms.

Discussion

As observed in earlier studies (4, 7, 14) of cnidarians, low levels of polyunsaturation are found in the fatty acids of most of these coral samples. This appears to be a general property of Cnidaria lipids.

Because many members of this phylum are hosts to symbiotic algae, the fatty acid compositions of the host animal may depend in part upon lipogenetic pathways of the algae or of the host-algae couple. A recently proposed pathway (15) involves transfer of acetyl units from host to algae where lipid synthesis occurs. Lipid is then transferred back to the host. The lipids of zooxanthellae isolated from the Pacific coral *Pocillopora capitata* are mostly saturated (16) and remarkably similar to those of the host animal. However, the overall fatty acid composition of the animal will be a combination of materials from the symbiotic algae plus those synthesized by the animal itself. Therefore, it is possible that those corals which rely heavily upon their symbiotic algae for lipogenesis will contain predominantly plant-like saturated fatty acids while those that perform most of their own lipogenesis will have more animal-like polyunsaturated acids.

While most of the coral samples in this survey exhibit low or nondetectable levels of polyunsaturated fatty acids, a few have relatively high amounts. These are from fairly deep locations ($\geq$26m) in the Florida Middle Ground. Samples from shallower locations ($\leq$12m) contain less than 12% total polyunsaturated acids. This distinction between deep and shallow compositions could indicate different degrees of dependence upon zooxanthellae as a source of coral lipids, with shallower corals being more dependent.

However, 11 of the 17 deep-water samples do not have high levels of polyunsaturation. Three of these are the same species as some of the highly polyunsaturated samples and are from equal or greater depths and about the same locations, but a year later. Lack of much polyunsaturation in these samples severely weakens any distinction between deep and shallow fatty acid compositions in these samples. Furthermore, one of the deeper samples having little polyunsaturation is the ahermatypic coral, *Balanophyllia floridana*. This sample contains a total of only 7.4 weight percent polyunsaturated acids, and its fatty acid synthesis can not have been performed by zooxanthellae. Therefore, while it appears that corals do not characteristically exhibit much polyunsaturation, a satisfactory explanation of occasional high levels of such fatty acids is not yet available.

Close similarities in fatty acid compositions among several samples are shown in Table 2. The two samples of *S. hyades*, obtained from locations within 5 km of each other in the Florida Middle Ground, are virtually identical, yet are different from other Middle Ground samples. Distinctive fatty acid compositions may exist for each coral species. Samples of species within the same genus, such as *Montastrea* and *Colpophyllia*, also display similarities, but not as close as for conspecifics. However, samples of a single species from different locations and sampling periods show only weak agreement in fatty acid compositions. Perhaps these patterns should be expected in Caribbean stoney corals, since Caribbean gorgonians have been shown to possess significant chemical differences between species which are modified by geographical location (17). The geographical variations may be due partly to different populations of zooxanthellae and partly to regional differences in light, temperature, currents and dietary sources of lipids.

Better understanding of factors leading to polyunsaturated acids and to variations or similarities in the fatty acid composition of a particular species might be available through refinements of the analytical procedure used in this survey. Separation of algal and host tissue might be useful, although the fatty acids of *P. capitata* and its symbionts are remarkably similar (16). In addition to measurement of total fatty acids, isolation of individual lipid classes prior to acid analysis could provide more information. Some preliminary work by this laboratory and others (15, 16) has shown triglycerides and wax esters to be the major forms in which acids are found.

The distributions of saturated hydrocarbons in Table 3 are unlike distributions found in most land organisms, which generally have an odd-carbon preference dominated by C_{27}, C_{29}, and C_{31} (18) n-alkanes. These coral samples have instead little odd-even preference and relatively high amounts of C_{17} and pristane. This type of saturated hydrocarbon distribution may result from analyzing algal and animal tissue together, or it may reflect input of dietary hydrocarbons and storage in the coral tissue. Possible dietary sources include phytoplankton, which contain substantial amounts of n-C_{17} and pristane (19), and copepods, which contain pristane (20). Saturated hydrocarbons such as pristane are not easily metabolized and can be passed along marine food chains (20), thus serving as chemical tracers in trophic webs.

Unsaturated hydrocarbon concentrations of these corals are much higher than saturated concentrations, and their distributions are typically only a few, major compounds. Although most of these compounds have not been identified, one which has been, squalene, is a metabolically active hydrocarbon. This is present at relatively high

levels. Because they are present at levels approaching those of the fatty acids, it is likely that all of the major components of the unsaturated hydrocarbon fraction are also metabolically active and are products of coral lipogenesis, rather than derived from dietary sources. Identification of more of these compounds is a goal of future research.

At present, this survey of coral lipid content is being extended to more species of Caribbean corals. As part of this, both hermatypic and ahermatypic samples of the same species from a common location are being examined for differences in lipid compositions. In addition, several transects have provided samples of a single species from a range of depths. Their analysis will indicate what, if any, changes in lipids occur over this range. It is hoped these new data will help resolve some of the problems presented by the existing information.

Acknowledgements

Collection and identification of the Jamaican and Grand Cayman samples was supervised by J. W. Porter and of the Middle Ground samples by T.S. Hopkins. B.L. Westrum provided *A. cervicornis* from the Dry Tortugas and E. C. Peters collected the *M. areolata* samples. Laboratory assistance was by J.E. Barak and N. Takeuchi. Research support was provided by the American Philosophical Society, the Rackham Fund and the Scott Turner Fund of the University of Michigan, and the Bureau of Land Management.

References

1. W. Bergman, 1963, Geochemistry of lipids, Organic Geochemistry, I.A. Breger (ed.), MacMillon, N.Y., N.Y., 503-542.
2. C.B. Koons, G.W. Jamieson, and L.S. Ciereszko, 1965, Normal alkane distributions in marine organisms; possible significance to petroleum generation, Bull. Am. Assoc. Petrol. Geol. 49: 301-304.
3. D. Lester and W. Bergman, 1941, Contributions to the study of marine products. VI. The occurrence of cetyl palmitate in corals, J. Org. Chem. 6: 120-122.
4. B. Pasby, 1965, A characterization of the lipids of the organisms which make up the main bulk of a coral reef with particular emphasis on the hydrocarbons, Ph.D. thesis, Texas A & M University.
5. A.A. Benson and L. Muscatine; 1974, Wax in coral mucus: Energy transfer from corals to reef fishes, Limnol. Oceanogr. 19: 810-814.
6. P.A. Meyers, 1976, Dissolved fatty acids in seawater from a fringing reef and a barrier reef at Grand Cayman, Limnol. Oceanogr. 21: 315-319.
7. P.A. Meyers, J.G. Quinn, and N. Marshall, 1974, A method for analysis of fatty acids in coral, Limnol. Oceanogr. 19: 846-848.
8. R.E. Johannes, 1967, Ecology of organic aggregates in the vicinity of a coral reef, Limnol. Oceanogr. 12: 189-195.
9. S.Z. Qasim and V.N. Sankaranarayanan, 1970, Production of particulate matter by the reef on Kavaratti Atoll (Laccadives), Limnol. Oceanogr. 15: 574-578.
10. S.L. Coles and R. Strathman, 1973, Observations on coral mucus "flocs" and their potential trophic significance, Limnol. Oceanogr. 18: 673-678.
11. N. Marshall, A.G. Durbin, R. Gerber, and G. Telek, 1975, Observations on particulate and dissolved organic matter in coral reef areas, Int. Revue ges. Hydrobiol. 60: 335-345.
12. B.L. Westrum and P.A. Meyers, 1977, Organic carbon content of sea water from over three Caribbean reefs, Bull. Mar. Science. 27 (3): in press.
13. H.W. Youngken and Y. Shimizu, 1975, Marine drugs: chemical and pharmacological aspects, Chemical Oceanography, 2nd Ed. Vol. 4, J.P. Riley and G. Skirrow, eds., Academic, London, 269-317.
14. S.N. Hooper and R.G. Ackman, 1972, Presence of trans-6-hexadecenoic acid in the white jellyfish *Aurelia aurita* Lamarck and in a Caribbean gorgonian, Lipids, 7: 624-626.
15. J.S. Patton, S. Abraham, T.B. Warner, and A.A. Benson, in press, Lipogenesis in intact coral and isolated zooxanthellae. II. Lipid quantification and the effect of light. Mar. Biol.
16. S. Abraham, J.S. Patton, and A.A. Benson, in press, Lipogenesis in intact coral and isolated zooxanthellae. I. Fatty acids and lipid classes. Mar. Biol.
17. L.S. Ciereszko, 1976, Chemical diversity in tropical reef octocorals, Food-Drugs From The Sea Proceedings 1974, H.H. Webber and G.D. Ruggieri, eds., Marine Technology Society, Washington, 297-301.
18. G. Eglinton and R.J. Hamilton, 1963, The distribution of alkanes, Chemical Plant Taxonomy, T. Swain, ed., Academic, London.
19. M. Blumer, R.R.L. Guillard, and T. Chase, 1971, 1971, Hydrocarbons of marine phytoplankton, Mar. Biol. 8: 183-189.
20. J. Avignan and M. Blumer, 1968, On the origin of pristane in marine organisms, J. Lipid Res. 9: 350-352.