Fatty Acid Composition of Fish Oils

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Fatty Acid Composition

INTRODUCTION

Knowledge of the chemical nature of fish-oil fatty acids and their distribution in marine life is important for the development of fishery products and in the evaluation of the nutritional significance of fatty acids in fish oil. Knowledge of the distribution of fatty acids is also important in order to understand the physical and chemical properties of fish oils and the biochemical role of fatty acids in fish and marine animals.

The early and early developments of the fatty acid composition of fish oils are documented by Hilditch and Williams (1964) and by Bailey *et al.* (Also, Lovern (1942, 1964) has reported extensive investigations of the early era. Recent investigations continue to add to current understanding of fish oils, and one now finds renewed interest in the many species and classes of compounds associated with fatty acids of marine

In this chapter, some background information is given about the nature of fatty and their chemical distributions in fish oils, the origin of fatty acids in fish, and the effects of environment on fish-oil fatty acids. Following background information, a discussion is given about fatty acid mixtures found in fish oils common to North America. Fish oils from other areas of the world are also included for comparison.

NATURE OF FATTY ACIDS AND CHEMICAL DISTRIBUTIONS

Fish and marine-animal oils are generally characterized by a rather large group of saturated and unsaturated fatty acids, which are commonly associated with mixed triglycerides. In addition to triglycerides, body oils from fish and marine animals usually include minor amounts of fatty acids as substituents of phospholipids and other lipids. In comparison to body oils, on the other hand, liver oils and oils from particular parts of fish and marine animals can often contain large amounts of fatty acids associated with phospholipids, glyceryl ethers (alkoxydiglycerides), and wax esters, depending on the source of oils and lipids (Lovern 1962). For a detailed discussion of classes of fish lipids see Chapter 2.

Nature of Fatty Acids

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The history and early developments of the fatty acid composition of fish oils are well documented by Hilditch and Williams (1964) and by Bailey *et al.* (1952). Also, Lovern (1942, 1964) has reported extensive investigations during the early era. Recent investigations continue to add to current understanding of fish oils, and one now finds renewed interest in the many types and classes of compounds associated with fatty acids of marine life.

In this chapter, some background information is given about the nature of fatty acids and their chemical distributions in fish oils, the origin of fatty acids in fish, and the effects of environment on fish-oil fatty acids. Following the background information, a discussion is given about fatty acid mixtures found in fish oils common to North America. Fish oils from other areas of the world are also included for comparison.

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Nature of Fatty Acids

The fatty acids derived from fish oils are of three principal types: saturated, monounsaturated, and polyunsaturated. The formula,

$$CH_3(CH_2)_x(CH{=}CHCH_2)_n(CH_2)_yCOOH$$

where $n = 0$ to 6, illustrates the type of fatty acid structures common to fish oils.

The saturated fatty acids have carbon chain lengths that generally range from C_{12} (lauric acid) to C_{24} (lignoceric acid). Also, traces of C_8 and C_{10} acids may be found in some fish oils. A C_5 acid (isovaleric), however, occurs in jaw-bone oil of dolphin and porpoise.

The monounsaturated type is comprised of monoethenoic acids, and the polyunsaturated type is comprised of polyethenoic acids which contain from 2 to 6 ethylenic bonds per acid. The carbon chain lengths of the unsaturated acids range generally from C_{14} (9-tetradecenoic acid) to C_{22} (4,7,10,13,16,19-docosahexaenoic acid). Small amounts of C_{10} and C_{12} monoenoic acids have been found in some fish oils. There are no naturally occurring acetylenic acids and hydroxy carboxylic acids presently known in fish oils.

Even-numbered carbon fatty acids make up about 97% of the total fatty acids, with a few notable exceptions. It was relatively recent that odd-numbered carbon fatty acids were generally acknowledged to be part of all fish oils. Branched-chain odd-carbon acids were isolated by Morice and Shorland (1956) from shark-liver oil. They isolated 13-methyltetradecanoic acid, (+)-12-methyltetradecanoic acid, and (+)-14-methylhexadecanoic acid, and found that together these acids comprised 0.1–0.2% of the liver-oil fatty acids. Earlier work by Morice and Shorland (1952) demonstrated the presence of other branched-chain acids in shark-liver oil that resembled 2,3-dimethyloctadecanoic acid and 2,3,4-trimethylhexadecanoic acid. The application of gas-liquid chromatography by Farquhar *et al.* (1959) to the analysis of menhaden-oil fatty acids has also demonstrated the existence of straight-chain and branched-chain, odd-carbon acids of fish oils. Saturated and unsaturated odd-carbon fatty acids were isolated from menhaden oil by Gellerman and Schlenk (1959) and from mullet oil by Sen and Schlenk (1964), respectively. Normal and branched-chain odd-numbered fatty acids in fish depot fats, seal blubber, and whale blubber were examined by Ackman and Sipos (1965). These workers noted the ratios of *iso* and *anteiso* fatty acid to be comparable in the fish and seal samples, but differed in a whale sample. (Cf. discussion under heading of Fish Diets, p. 8).

The nature of the ethylenic bonds in the unsaturated acids from fish oils has been known for many years to be of the *cis* geometric configuration. In addition, however, evidence has been sufficient only recently to prove as far as is known that the carbon-carbon atom separations of the ethylenic bonds of polyunsaturated acids are of a methylene-interrupted type (Klenk 1958; Farquhar *et al.* 1959; Kayama *et al.* 1963B). This type of

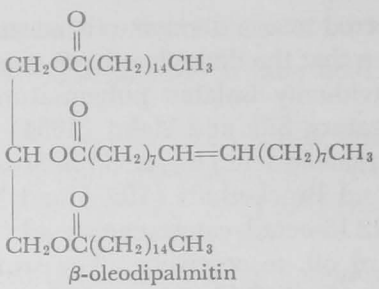
separation is also referred to as a divinylmethane structure. Numerous investigators have shown that the divinylmethane structure is common as far as we know for individually isolated polyunsaturated acids of fish oil. Among these investigators, Silk and Hahn (1954) positively identified a 6,9,12,15-hexadecatetraenoic acid (C_{16} acid) in South African pilchard oil. The work of Klenk and Brockerhoff (1957) and Matic (1958) revealed the presence of a 6,9,12,15-octadecatetraenoic acid (C_{18}) in herring oil and South African pilchard oil, respectively. The structures of 5,8,11,14,17-eicosapentaenoic acid (C_{20}), 7,10,13,16,19-docosapentaenoic acid (C_{22}), and 4,7,10,13,16,19-docosahexaenoic acid (C_{22}) were determined by such workers as Whitcutt and Sutton (1956); Whitcutt (1957); Klenk and Brockerhoff (1958); Toyama *et al.* (1959); Farquhar *et al.* (1959); Ackman *et al.* (1963); and Ackman (1964). Ahrens *et al.* (1959) were the first to point out that menhaden (*Brevoortia tyrannus*) oil is composed of at least 44 different fatty acids.

Other workers have approached the problem of proving the general divinylmethane structure by analyzing mixtures of fish-oil fatty acids. Privett (1956) investigated the effects of lipoxidase catalyzed oxidations on concentrates of fatty acids, and demonstrated the 1,4-diene nature of the double bond structures. More conclusively, however, Hashimoto *et al.* (1963) proved the gross divinylmethane structure in fish-oil polyunsaturated acids by analysis of nuclear magnetic resonance spectra.

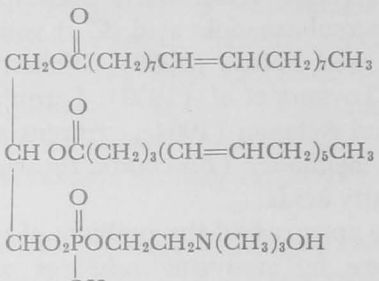
Chemical Distribution of Fatty Acids

There are differences in the natural distribution of fatty acids associated with lipids such as triglycerides and phospholipids. For example, it is generally believed that phospholipids, such as lecithins and cephalins, contain more polyunsaturated fatty acids than do the triglycerides when isolated from the same oil or tissues. Also, it is believed generally that depot fats consist largely of triglycerides, while the total lipids of various body organs and muscle tissues can by comparison contain large proportions of phospholipids. The reasons for such distributions are the subject of much research, which will not be discussed here. It is only important to point out some examples of these differences in order to understand better the composition of fish-oil fatty acids.

To aid the following discussion, examples of the molecular structures of triglycerides and phospholipids may be represented by the formulas for β-oleodipalmitin and α'-oleyl-β-eicosapentaenyl-α-lecithin, respectively, as follows:



β-oleodipalmitin



α′-oleyl-β-eicosapentaenyl-α-lecithin

Additional information about the kinds of lipids associated with fatty acids may be found in such texts as those by Deuel (1951), Gunstone (1958), and Hanahan (1960).

Fatty acids of the triglycerides, lecithins, and phosphatidyl ethanolamines (cephalins) from livers of cod and lobster and from muscles of cod and scallop were analyzed by Brockerhoff *et al.* (1963). They demonstrated that the polyunsaturated fatty acids were preferentially located in the β position of both the triglycerides and the lecithins. The phosphatidyl ethanolamines were also found to be highly unsaturated.

Brockerhoff and Hoyle (1963) analyzed the fatty acid distribution in the α and β positions of triglycerides from fish body and liver oils, and found that the polyenoic acids were preferentially distributed in the β position. They also analyzed seal blubber and whale oils, and found that the polyenoic acids occurred in the α position rather than in the β position of the blubber triglycerides.

Lecithin fractions from tuna, salmon, and menhaden muscle were shown by Menzel and Olcott (1964) to have fatty acids distributed similar to the lecithins isolated from muscle tissues by Brockerhoff *et al.* (1963). For the three species, 91–99% of the fatty acids in the β position were unsaturated and 36–86% of the fatty acids in the α position were saturated. Tuna

lecithin, for example, had 8.4% 20:5[1] acid and 39% 22:6 acid in the α position and 15% 20:5 acid and 48% 22:6 acid in the β position. In another investigation, for example, Schuster *et al.* (1964) showed that white muscle of five species of tuna contained cephalins and lecithins having 47% and 50% of the 22:6 acid, respectively Other instances of fatty acid distributions in fish phospholipids are cited by Schuster *et al.* (1964).

An interesting investigation of the triglycerides of sablefish (*Anaplopoma fimbria*) was begun by Dolev and Olcott (1965A), in which they found much less polyunsaturated fatty acids in the total triglyceride fraction than is customarily found in most marine oils. The most recent results of this work demonstrated that some of the α- and β-substituent fatty acids of sablefish triglycerides do not follow the usual distributional patterns (Dolev and Olcott 1965B). In this species, they observed for example that 18:3, 20:3 and 20:4 occur mainly in the α, α' positions compared to 14:0, 16:0 and 16:1 which occur mainly in the β position. The 18:0 and 18:1 acids appeared to be distributed evenly. Notably important was the finding that 22:6, which was present in the glycerides, was not detected as free fatty acid from hydrolysis by lipase.

ORIGIN OF FATTY ACIDS IN FISH

It has been known for many years that the nature of fat in fish diets can influence the proportionate distribution of fatty acids in fish oils (Lovern 1942). Natural oils in marine plant life, planktonic crustacea, and other plankton are consumed by fish in varying degrees depending on feeding habits. Feeding habits of fish can vary according to such factors as availability of food, which may be a geographic factor, periods of fasting, and spawning cycles. The food fat metabolism in fish is being investigated continuously in order to understand better the origin of the unique fatty acids in fish oils. To illustrate how the fatty acids of fish can change according to dietary fats, some recent findings are discussed.

[1] It has become common practice to use abbreviations when referring to particular fatty acids (Farquhar *et al.* 1959). Generally, the abbreviation is written as two numbers separated by a colon. The first number designates the number of carbon atoms in the fatty acid molecule and the second number (after the colon) designates the number of methylene-interrupted *cis* ethylenic bonds. In addition, polyunsaturated fatty acids may be regarded according to families of which the terminal structures are the same. For this reason, the position of the ethylenic bonds along the carbon atom chains may be designated by the Greek letter omega or ω and a number that refers to the number of carbon atoms separating the terminal methyl group from the ethylenic bond nearest to the terminal methyl (Mohrhauer and Holman 1963). For example, 18:3ω3 stands for 9,12,15-octadecatrienoic acid (linolenic acid), and fish-oil fatty acids designated with an ω 3 are said to belong to the linolenic acid family. Similarly, endings of ω 6 and ω 9 refer to the linoleic and oleic acid families, respectively.

Fish Diets

Experiments by Kelly *et al.* (1958A) with mullet (*Mugil cephalus*) gave indications that fish, like land animals, probably convert fatty dienoic acid into tetraenoic, pentaenoic, and hexaenoic acids. Unlike land animals, however, the mullet seemed capable of converting 18:2ω6 acid to a fatty trienoic acid. Other experiments have shown that young freshwater fish on low fat or cottonseed oil diets had no significant change in fatty acids, but when fed a diet containing other fish oil the fatty acids of the freshwater species changed to resemble the dietary fish oil (Kelly *et al.* 1958B). Similar results have been observed by Brenner *et al.* (1960, 1963), Mead *et al.* (1960), and Brockerhoff *et al.* (1964).

In another instance, rainbow trout were fed for 103 days on a diet containing soybean oil. Results showed that no 20:4, 20:5, and 22:6 acids could be detected in the trout oil after such treatment (Toyomizu *et al.* 1963).

Work on goldfish (*Carrassius auratus*) by Reiser *et al.* (1963) demonstrated that controlled diets depleted of polyunsaturated fatty acids, but containing principally 18:0, 18:1, 18:2 and 18:3, produced changes after 76 to 120 days in fatty acids of both triglycerides and phospholipids. It appears from their data that the triglycerides in these fish showed significantly less 20:5 and 22:6 acids when compared to the phospholipids.

Marine plankton, as a major food source for fish, have commanded the attention of scientists in recent years. Crabs and shrimps, which when immature are included in the crustacean class of plankton, are known to exhibit fatty acid changes in body fats analogous to fish, depending on their diets (Kelly *et al.* 1959). Klenk and Eberhagen (1962A, B) isolated from marine plankton a group of polyunsaturated fatty acids, which are like those found in fish and marine animal oils. Others have also shown the similarities between the fatty acids of fish oils and plankton-oil fatty acids (Farkas and Herodek 1961, 1964; Lewis 1962; Kayama *et al.* 1963A).

Ackman and Sipos (1965) examined a number of samples of fish oil fatty acids and made a detailed study of the saturated fractions. They noted that the normal odd-numbered fatty acids found in marine lipids originate in phytoplankton, but that there is little evidence to indicate that branched-chain fatty acids are prominent in these plankton. It is suggested that branched-chain fatty acids are formed to some degree in zooplankton.

Biogenesis of Fatty Acids

In order to understand how fatty acids are transformed or converted from the food chain to the fat and oil depots in the fish, it has been necessary to investigate what happens to the individual acids after ingestion.

Klenk and Kremer (1960) showed that when radioactive carbon-14 labelled acetate was incubated with liver slices of frog, carp, trout, flounder, smelt, and dab, the C_{20} and C_{22} polyenoic acids were synthesized from linoleic and linolenic acid precursor.

Kayama *et al.* (1963B) tested the supposition that dietary linolenic acid is incorporated in toto into the carbon chains of 20:5 and 22:6 acids of fish. Using mature kelp bass (*Paralabrax clathratus*) for intraperitoneal injections of methyl linolenate-l-C^{14} diluted with pure methyl linolenate, the investigators found that the acid of the latter ester was converted to 20:5 acid and that the 20:5 acid was incorporated into 22:6 acid. The probable conversion pathway for linolenic acid is as follows: 18:3ω3→18:4ω3→20:4ω3→20:5ω3→22:5ω3→22:6ω3. This indicates a retention of the linolenic-type structure throughout the conversions. However, it is possible, as Kayama *et al.* (1963B) pointed out, that the linolenic acid, unlike linoleic, undergoes extensive partial degradation and re-synthesis before chain elongation to the final products.

ENVIRONMENTAL INFLUENCE ON FATTY ACID COMPOSITION

It has been observed in the past that environmental factors such as geographic locations of catch and seasons of the year, which may be related to water temperatures, are related to the proportions of fatty acids of fish oils (Lovern 1942; Swain 1953). Re-evaluations of these factors have been important in light of modern instrumentation like gas-liquid chromatography (GLC) (Farquhar *et al.* 1959). Seasonal variations in fatty acids of commercial cod-liver oils were investigated by DeWitt (1963). He observed a range in iodine values, 146 to 168, for GLC analyzed fatty acids of the liver oils sampled from May to November.

The influence of season, as well as water temperatures and pressure effects, was observed by Lewis (1962) on fatty acids of Arctic plankton. When comparing plankton fatty acids from Arctic plankton and California coastal plankton, Lewis (1962) found two changes in the fatty acids, namely, an increase in the degree of unsaturation and a reduction in chain length with a reduction in environmental temperature.

It is unfortunate that Lewis (1962) reported for some two dozen species only those fatty acids with GLC retention times up to that of 20:1. Rodegker and Nevenzel (1964) point out that this indicates only about 45 to 90% of the total component fatty acids to be anticipated. Lewis (1962) proposed the ratio of 16:0 to 16:1 acids as a valuable index of the temperature of the habitat of marine ectotherms. However, in the work by Rodegker and Nevenzel (1964) on fatty acids of mussel, barnacle, and starfish, only one of their samples agreed with the 16:0 to 16:1 ratio reported by Lewis. They suggested that problems may be due to attempts to com-

pare fatty acids of different tissue types and, hence, different lipids which may have different biological functions. Rodegker and Nevenzel (1964) suggest that a clear picture of temperature effects, etc., would be anticipated from analyses of the same type of lipid fatty acid source, say for example the muscle phospholipids.

The effects of temperature on growing mullet (*Mugil cephalus*) and goldfish (*Carrassius auratus*) were investigated by Reiser *et al.* (1963). They concluded from analyses of fish raised in water at 13°C. and at 23°C. that these temperatures had little or no influence on the deposition or interconversion of polyunsaturated acids in the mullet. These findings were surprising. Based on controlled diets, they reasoned that possibly saturated fatty acids (12:0 and 14:0) are not absorbed at the lower temperature, thereby causing a lack of significant influence on the unsaturated fatty acids. Contrary to these findings, however, Kayama *et al.* (1963A) have demonstrated that guppies (*Lebistes reticulatus*) raised in water at 17°C. possessed more 22:6 acid in the oil than did guppies raised in water at 24°C.

In other work, Farkas and Herodek (1964) showed that the amount of C_{20} - C_{22} polyunsaturated acids in freshwater planktonic crustacea increased with decreasing temperatures, and in some species these acids exceeded the values common to marine animals. The fatty acids of freshwater fish which fed on these crustacea resembled fatty acids of marine fish. One might say then that temperature had an indirect influence on the fatty acids via the food chain.

NATURAL FATTY ACID MIXTURES

Now that we have discussed somewhat the chemical structures associated with fatty acids of fish oils, the origin of fatty acids, and the influence of some environmental factors upon the natural patterns of fatty acid mixtures, it will be easier to evaluate the fatty acid compositions of fish oils. The mixtures of fatty acids to be discussed below are related to fish oils and marine animal oils that are common principally to North America, but oils from elsewhere in the world are included for comparison.

Fatty acid compositions of fish oils have been known for many years to be complex. Only after the development and widespread application of gas-liquid chromatography (GLC) to the analysis of fish-oil fatty acids has this complexity become more vivid (Ahrens *et al.* 1959). The results of GLC have provided the data given in the subsequent tables. The technique of GLC is discussed in another chapter.

The fatty acid composition of some body oils from marine and freshwater fishes and marine animals are listed in Table 1. Tables 2 and 3 show similar compositions for oils of shellfish, and fish-liver and egg oils,

TABLE 1

FATTY ACID COMPOSITION OF BODY OILS OF MARINE AND FRESHWATER FISHES[1]

Name of Species		Fatty Acid Percentage Composition															
Common	Scientific	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3	18:4	20:1	20:4	20:5	22:1	22:5	22:6	Reference
Angler	*Lophiomus setigerus*	1.6	NK	28.2	6.1	NK	15.6	20.8	3.5	—[2]	NK	1.7[2]	—[3]	5.5	5.2[3]	NK	11.8	Shimma 1964A
Barracuda	*Sphyraena schlgeli*	2.9	NK	17.2	7.2	NK	4.0	20.3	1.1	—[2]	NK	1.8	—[3]	17.2	1.4[3]	1.2	25.7	Shimma 1964A
Bonito	*Sarda chilensis*	7	+	17	12	1	2	21	1	+	2	1	NK	22	NK	2	5	Klenk 1962
Butterfish	*Centrolophus japonicus*	1.3	+	18.6	4.2	+	8.4	16.1	1.2	—[2]	NK	4.6[2]	—[3]	3.7	6.1[3]	4.4	31.4	Shimma 1964A
Capelin (male)	*Mallotus villosus*	8.8	NK	12.0	14.9	NK	1.8	9.0	NK	NK	NK	21.5	NK	5.8	18.5	0.5	3.6	Ackman 1963
Capelin (female)	*Mallotus villosus*	8.6	NK	13.3	16.5	NK	1.6	10.7	NK	NK	NK	17.2	NK	8.6	14.2	0.9	4.8	Ackman 1963
Cod, Atlantic	*Gadus morhua*	1.8	0.5	33.4	2.4	0.9	4.0	11.8	1.2	0.8	1.2	1.6	3.2	12.4	0.7	0.6	21.9	Gruger 1964
Cod, Atlantic	*Gadus morhua*	0.4	0.1	24.1	1.1	0.1	3.4	7.8	0.3	0.1	0.1	1.2	3.7	17.6	1.1	0.9	37.5	Ackman 1964B
Cod, Pacific	*Gadus macrocephalus*	1.0	+	18.2	3.6	NK	4.7	14.5	1.0	—[2]	NK	2.0[2]	—[3]	17.9	5.6[3]	1.9	29.2	Shimma 1964A
Conger	*Astroconger myriaster*	5.5	0.8	17.8	9.7	NK	3.3	30.0	2.5	—[2]	1.6	4.9[2]	—[3]	8.0	3.4[3]	3.1	7.8	Shimma 1964A
Cuttlefish	*Ommastrephes sloani pacificus*	3.3	NK	15.0	7.2	NK	3.0	22.0	1.7	1.1	1.9	11.2	2.1	5.9	10.8	2.9	10.5	Ito 1963B
Dogfish	*Squalus sucklii*	1.9	NK	15.7	6.5	NK	3.7	24.7	2.3	—[2]	NK	12.6[2]	—[3]	8.7	4.4[3]	3.5	16.0	Shimma 1964A
Dogfish, Piked	*Squalus acanthias*	1.8	0.7	17.0	4.6	1.7	2.9	16.1	2.2	NK	1.3	5.2	2.7	8.3	4.0	2.7	21.8	Olley 1965
Dogfish, Spiny	*Squalus acanthias*	2.0	0.5	21.2	6.0	1.2	2.7	27.5	1.3	0.6	0.7	5.8	2.5	7.9	4.1	2.3	10.4	Gruger 1964
Dogfish, Spiny	*Squalus acanthias*	1.6	0.2	23.5	5.7	0.9	3.0	33.6	0.6	0.5	NK	6.4	2.8	6.5	3.5	1.7	7.0	Malins 1965
Flatfish	NK	4.0	NK	15.7	5.9	NK	2.3	16.5	1.5	0.8	0.7	11.9	1.9	11.9	7.7	1.3	15.4	Ito 1963B
Flying fish (dorsal)	*Prognichthys agoo*	1.1	NK	34.4	2.7	NK	11.7	10.9	1.1	—[2]	NK	1.8[2]	—[3]	4.8	4.8[3]	NK	25.6	Shimma 1964A
Flying fish (ventral)	*Prognichthys agoo*	3.5	1.2	20.5	6.7	3.1	6.9	20.3	1.4	—[2]	NK	7.5[2]	—[3]	4.7	3.4[3]	2.9	16.6	Shimma 1964A
Goby	NK	5.4	NK	12.8	9.5	NK	2.3	26.2	1.4	0.3	1.2	18.6	0.9	3.5	12.5	1.4	3.3	Ito 1963B
Goby	*Acanthogobius flavimanus*	2.2	1.4	20.2	5.8	2.0	10.4	11.8	3.4	—[2]	NK	3.2[2]	—[3]	15.6	4.4[3]	3.9	11.8	Shimma 1964A
Gurnard	*Chelidonichths kumu*	0.7	NK	13.9	2.8	1.2	8.9	10.9	0.7	—[2]	NK	1.3[2]	—[3]	7.3	4.1[3]	2.4	38.8	Shimma 1964A
Haddock	*Melanogrammus aeglefinus*	1.1	0.5	22.7	4.7	1.5	5.3	15.1	2.5	0.3	NK	3.5	1.8	14.3	NK	0.7	24.3	Beare 1962
Halibut, Pacific	*Hippoglossus stenolepsis*	2.8	0.3	15.1	8.9	0.7	3.4	25.7	0.9	0.3	3.6	8.0	2.5	10.1	5.1	1.6	7.9	Gruger 1964
Halibut	*Hippoglossus hippoglossus*	0.8	0.4	9.6	2.5	0.6	9.0	12.3	+	+	NK	4.0	14.4		2.8	2?	37.6	Olley 1965
Halibut	*Hippoglossus hippoglossus*	2.3	0.6	12.9	5.3	1.2	4.2	17.1	NK	NK	1.4	7.3	0.9	12.6	5.0	2.3	19.2	Olley 1965
Hake, Pacific	*Merluccius productus*	1.6	0.2	23.2	8.5	0.9	2.4	32.4	0.9	0.6	1.4	1.3	0.7	12.8	0.7	0.7	7.8	Stansby 1966
Herring	*Clupea harengus*	6	+	13	6	+	1	22	1	+	2	15	+	6	16	1	6	Klenk 1962
Herring, Lake	*Coregonus artedii*	5.5	0.4	17.7	7.1	0.6	3.0	18.1	4.3	3.4	1.8	1.2	3.4	5.9	2.8	3.3	13.3	Gruger 1964
Herring, Pacific	*Clupea harengus pallasi*	7.6	0.4	18.3	8.3	0.5	2.2	16.9	1.6	0.6	2.8	9.4	0.4	8.6	11.6	1.3	7.6	Gruger 1964
Herring, Pacific (dorsal)	*Clupea harengus pallasi*	3.2	NK	24.9	4.9	NK	3.6	13.5	+	—[2]	NK	7.4[2]	—[3]	11.4	8.6[3]	NK	22.5	Shimma 1964A
Herring, Pacific (ventral)	*Clupea harengus pallasi*	6.1	NK	14.1	7.1	NK	1.8	21.7	1.7	—[2]	NK	19.2[2]	—	4.6	19.9[3]	NK	3.8	Shimma 1964A
Herring, Round (dorsal)	*Etrumeus micropus*	3.7	0.9	27.2	6.2	1.7	7.3	12.1	1.4	—[2]	NK	1.4[2]	—[3]	10.2	3.2[3]	NK	24.1	Shimma 1964A
Herring, Round (ventral)	*Etrumeus micropus*	5.7	1.3	16.3	7.8	3.0	7.4	14.5	1.9	—[2]	NK	3.0[2]	—[3]	10.1	3.5[3]	3.7	20.3	Shimma 1964A

TABLE 1 (*continued*)

Name of Species		Fatty Acid Percentage Composition																
Common	Scientific	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3	18:4	20:1	20:4	20:5	22:1	22:5	22:6	Reference
Loach	*Misgurnus fossilus*	2.2	NK	18.4	16.7	NK	5.9	14.7	6.2	7.6[2]	NK	—[2]	—[3]	4.2	8.6[3]	2.7	2.5	Shimma 1964A
Mackerel	*Scomber scrombrus*	4.9	0.5	28.2	5.3	1.0	3.9	19.3	1.1	1.3	3.4	3.1	3.9	7.1	2.8	1.2	10.8	Gruger 1964
Mackerel, Horse	*Decapterus lajang*	2.4	0.6	33.0	4.4	+	13.7	12.3	2.7	—[2]	NK	2.0[2]	—[3]	4.8	3.6[3]	NK	20.5	Shimma 1964A
Mackerel, Jack	*Caranx mertensi*	NK	NK	18.8	1.2	NK	10.7	19.6	2.2	—[2]	NK	3.2[2]	—[3]	3.7	3.7[3]	3.0	34.2	Shimma 1964A
Menhaden	*Brevoortia tyrannus*	7.2	0.5	17.0	9.8	0.4	3.1	14.5	2.7	1.3	3.2	2.1	0.6	12.5	NK	2.1	8.9	Ahrens 1959
Menhaden	*Brevoortia tyrannus*	7.7	NK	25.3	6.7	NK	3.1	15.4	NK	1.6	4.0	NK	2.0	12.9	NK	2.3	14.0	Peifer 1962
Menhaden	*Brevoortia tyrannus*	8.0	0.5	28.9	7.9	1.0	4.0	13.4	1.1	0.9	1.9	0.9	1.2	10.2	1.7	1.6	12.8	Gruger 1964
Mullet, Striped	*Mugil cephalus*	4.6	6.3	17.3	11.0	0.8	5.0	8.4	3.2	1.4	3.0	0.7	2.6	7.5	0.7	3.9	13.4	Gruger 1964
Mullet, Striped	*Mugil cephalus*	7.5	4.5	13.9	15.5	1.0	5.1	9.1	2.2	1.0	3.1	0.6	3.6	11.8	NK	3.2	3.2	Gruger 1964
Mullet	*Mugil cephalus*	3.9	7.4	29.6	6.3	5.5	4.8	5.8	2.6	1.5	NK	NK	3.6	4.7	NK	3.1	10.3	Peifer 1962
Mullet	*Mugil cephalus*	5.3	11.2	32.0	6.0	1.2	2.0	4.6	1.5	0.8	0.6	1.1	2.5	5.0	NK	NK	5.7?	Sen 1964
Perch, Ocean	*Sebastes marinus*	5.5	NK	23.0	3.8	NK	3.9	18.5	1.6	NK	NK	7.2	1.2	7.9	NK	+	13.6	Peifer 1962
Perch, Ocean	*Sebastes marinus*	4.6	0.6	12.6	8.0	1.0	3.6	22.0	1.5	0.6	1.6	8.0	0.8	9.3	8.7	0.6	12.0	Gruger 1964
Pilchard	*Sardinops sagax; Sardinops caerulea*	7.6	0.6	16.2	9.2	0.7	3.5	11.4	1.3	0.9	2.0	3.2	1.6	16.9	3.8	2.5	12.9	Ackman 1964
Puffer	*Sphoeroides vermicularis*	1.9	NK	29.7	3.0	NK	12.4	18.3	3.0	—[2]	NK	4.7[2]	—[3]	5.1	4.8[3]	NK	17.1	Shimma 1964A
Redfish	*Sebastes* sp.	NK	NK	23.1	5.5	NK	10.7	14.4	4.8	—[2]	NK	5.1[2]	—[3]	6.1	3.7[3]	NK	26.6	Shimma 1964A
Rockfish	*Sebastodes pinniger*	4.1	0.6	14.9	6.6	2.6	6.0	20.8	1.6	0.8	1.3	1.4	1.5	11.7	0.8	1.6	17.4	Gruger 1964
Sablefish	*Anoplopoma fimbria*	4.6	0.4	18.1	8.0	0.8	3.1	20.4	0.8	0.5	1.3	5.6	0.8	8.5	8.9	1.8	12.1	Gruger 1964
Sablefish	*Anoplopoma fimbria*	4.1	0.5	14.8	11.6	1.0	3.8	38.0	2.1	1.3	NK	6.6?	1.0	4.6	4.1?	NK	2.2	Dolev 1965
Salmon, Chinook	*Oncorhynchus tshawytscha*	3.7	0.4	16.6	9.2	1.1	5.8	29.1	1.1	0.9	1.5	4.7	0.5	8.2	3.6	2.4	5.9	Gruger 1964
Salmon, Chum	*Oncorhynchus keta*	2.2	0.6	17.0	4.1	1.1	3.2	21.4	2.0	1.0	2.0	5.4	0.9	6.7	9.4	2.3	16.1	Gruger 1964
Salmon, Chum (dorsal)	*Oncorhynchus keta*	6.2	NK	16.3	8.3	NK	2.7	24.8	1.4	—[2]	NK	14.4[2]	—[3]	6.5	12.8[3]	NK	6.6	Shimma 1964A
Salmon, Chum (ventral)	*Oncorhynchus keta*	6.6	NK	13.5	9.0	NK	2.8	25.3	1.9	—[2]	NK	15.7[2]	—[3]	6.8	14.8	NK	3.6	Shimma 1964A
Salmon, Coho	*Oncorhynchus kisutch*	3.7	0.5	16.2	6.7	0.9	4.7	18.6	1.2	0.6	2.1	8.4	0.9	12.0	5.5	2.9	13.8	Gruger 1964
Salmon, Silver	*Oncorhynchus kisutch*	3.7	NK	22.5	5.0	NK	3.9	23.6	0.9	1.0	NK	5.3	1.4	11.0	NK	3.3	12.9	Peifer 1962
Salmon, Pink	*Oncorhynchus gorbuscha*	3.4	1.0	10.2	5.0	1.6	4.4	17.6	1.6	1.1	2.9	4.0	0.7	13.5	3.5	3.1	18.9	Gruger 1964
Sardine	NK	6.6	NK	15.5	9.5	NK	3.7	17.3	2.5	1.3	2.9	8.1	2.5	9.6	7.8	2.8	8.5	Ito 1963B
Sardine, Peruvian	*Clupea pilchardus*	8	+	19	10	+	3	14	1	+	3	2	1	22	+	2	4	Klenk 1962
Saury, Pacific	*Coloabis saira*	6.9	0.7	18.4	5.4	NK	3.5	7.3	1.7	—[2]	4.7	13.8[2]	—[2]	6.6	14.7[3]	1.2	13.5	Shimma 1964A
Sea bass	*Lateolabrax japonicus*	2.5	NK	20.1	8.8	2.3	5.9	16.9	1.7	—[3]	2.6	1.9[2]	—[3]	10.6	3.1[3]	1.8	21.8	Shimma 1964A
Sea-bream, "Ki"	*Taius tumifrons*	1.3	NK	30.4	5.0	NK	8.1	15.8	1.9	—[2]	NK	3.1[2]	—[3]	3.9	4.2[3]	2.9	23.4	Shimma 1964A
Sea-bream, "Ma"	*Chrysophyrs major*	2.8	NK	26.7	5.8	1.2	10.3	15.4	1.5	—[2]	NK	2.7[2]	—[3]	12.2	7.3[3]	2.8	11.3	Shimma 1964A
Seal, Harbor	*Phoca vitulina concolor*	3.3	0.1	6.5	17.6	0.1	0.4	30.2	0.8	0.2	0.7	13.6	0.5	5.5	6.0	4.3	7.5	Jangaard 1963A
Shad (dorsal)	*Dorosoma thrissa*	4.5	NK	24.5	5.1	NK	5.8	16.8	1.6	—[2]	1.2	1.5[2]	—[3]	8.4	2.1[3]	NK	28.5	Shimma 1964A
Shad (ventral)	*Dorosoma thrissa*	9.7	0.8	22.0	9.5	NK	5.1	22.9	2.7	—[2]	2.9	2.1[2]	—[3]	8.0	0.9[3]	1.4	10.9	Shimma 1964A
Shark, Porbeagle	*Lamna cornubica*	2.5	NK	12.2	8.1	NK	2.4	16.8	1.0	—[2]	NK	4.1[2]	1.2	2.8	1.5?	13.7	29.0	Shimma 1964A
Skipper	NK	6.9	0.7	13.4	5.1	NK	2.4	10.1	2.3	2.3	5.9	13.4	0.9	8.4	13.8	1.7	12.0	Ito 1963A
Smelt, Pond	*Hypomesus olidus*	1.9	NK	22.5	6.4	NK	3.8	11.3	1.1	—[2]	NK	2.7[2]	—[3]	13.4	2.8[3]	1.5	28.9	Shimma 1964A
Smelt, Sweet	*Pleocoglossus altirelis*	7.3	1.1	29.1	15.0	NK	2.6	11.5	4.8	17.2[2]	NK	—[2]	—[3]	2.4	1.2[2]	1.3	1.3	Shimma 1964A

Snapper	*Etelis evurus*	1.0	NK	24.9	3.4	+	9.0	12.8	1.3	—[2]	NK	1.4[2]	—[3]	3.7	2.9[3]	1.4	33.8	Shimma 1964A
Sole, Lemon	*Microstomus kitt*	4.3	0.7	16.5	14.4	1.4	2.4	12.2	0.3	2.0	1.6	3.9	4.0	11.9	+	10.6	7.0	Olley 1965
Sole, Lemon	*Microstomus kitt*	3.3	1.1	20.0	4.7	2.9	2.2	18.1	1.0	NK	0.5	6.6	1.6	17.5	0.5	6.4	6.6	Olley 1965
Squid	*Illex illecebrosus*	2.2	0.3	27.6	0.4	0.3	4.4	4.9	0.2	0.1	0.1	4.9	0.8	15.8	0.5	0.3	37.1	Jangaard 1965
Swordfish	NK	2.9	NK	17.5	6.3	NK	4.9	27.9	1.9	0.4	0.7	4.6	3.0	4.4	2.0	3.1	17.8	Ito 1963B
Trout, Rainbow	*Salmo gairdneri*	2.1	0.8	11.9	8.2	1.5	4.1	19.8	4.6	5.2	1.5	3.0	2.2	5.0	1.3	2.6	19.0	Gruger 1964
Trout, Rainbow	*Salmo gairdneri irideus*	1.6	NK	13.2	6.5	NK	4.3	19.2	9.1	9.3[2]	2.2	—[2]	—[3]	14.0	2.9[3]	1.7	16.0	Shimma 1964A
Tunny	NK	5.9	NK	19.2	11.5	NK	4.6	12.8	2.2	1.2	4.4	1.2	2.7	13.9	1.3	2.2	17.0	Ito 1963B
Tuna, Albacore	*Thunnus germo*	3.7	1.0	29.3	6.3	1.2	6.1	16.6	0.7	0.6	2.2	2.7	1.2	6.5	2.0	0.8	17.6	Roubal 1963B
Tuna, Bluefin	*Thunnus maccoii*	1.9	NK	15.4	4.8	1.2	8.2	21.2	1.7	—[2]	NK	7.3[2]	—[3]	6.8	2.0[3]	4.5	24.4	Shimma 1964A
Tuna, Bluefin	*Thunnus thynnus*	4.5	0.6	22.1	2.8	0.8	6.1	21.7	0.8	+	0.9	6.3	1.0	6.4	5.4	1.4	17.1	Roubal 1963B
Tuna, Bluefin (dark meat)	*Thunnus thynnus*	4.0	0.7	25.7	3.5	0.7	12.5	14.5	0.6	NK	1.0	3.2	1.4	5.5	2.1	1.8	21.0	Roubal 1963A
Tuna, Skipjack	*Katsuwonus pelamis*	7.0	1.0	24.0	6.3	1.1	3.0	16.2	2.1	1.2	0.5	2.0	3.0	13.2	+	1.5	17.3	Roubal 1963B
Tuna, Yellowfin	*Neothunnus macropterus*	2.6	0.6	27.1	4.4	2.1	7.5	17.8	0.9	0.4	+	1.1	3.6	4.6	+	1.3	22.2	Roubal 1963B
Whale	NK	10	+	14	13	1	1	38	3	1	1	2	+	6	NK	2	3	Klenk 1962
Whale, Beaked (blubber)	*Hyperdon rostratus*	4.2	0.2	4.3	11.9	NK	0.9	28.1	2.0	NK	NK	30.1	NK	NK	11.3	NK	NK	Mori 1964
Whale, Finback (outer blubber)	*Balaenoptera physalus*	5.7	0.2	7.1	8.4	0.4	1.4	28.9	2.0	0.8	0.5	19.6	0.6	0.9	17.9	0.7	1.1	Ackman 1965
Whale, Finback (inner blubber)	*Balaenoptera physalus*	5.1	0.3	12.1	7.1	0.8	3.0	27.9	1.6	0.4	0.7	14.8	0.8	4.1	11.0	2.5	5.2	Ackman 1965
Whale, Sperm, Antarctic	*Physeter macrocephalus*	8.3	0.4	11.9	18.0	NK	1.1	32.8	0.1	NK	NK	11.9	NK	NK	3.8	NK	NK	Mori 1964
Whale, Sperm, Arctic	*Physeter macrocephalus*	7.4	0.6	10.4	15.9	NK	1.0	27.7	0.7	NK	NK	16.6	NK	NK	8.6	NK	NK	Mori 1964
Whale, Sperm, Japan	*Physeter macrocephalus*	7.5	1.0	10.0	15.4	NK	1.2	26.2	0.5	NK	NK	16.7	NK	NK	9.9	NK	NK	Mori 1964
Whitebait	*Salangichthys microdon*	3.5	0.9	15.8	9.3	2.1	4.5	15.7	4.5	—[2]	2.3	5.1[2]	—[3]	10.8	6.3[3]	2.9	14.9	Shimma 1964A
Whitefish, Lake	*Coregonus clupeaformis*	2.2	0.3	12.1	10.5	1.1	4.0	27.2	5.5	3.7	1.0	2.1	3.9	6.4	0.5	3.3	8.8	Gruger 1964

[1] Not known or not mentioned in reference is designated as NK. Trace amounts indicated by a + sign.
[2] Combined 18:3 and 20:1 acids. More 18:3 than 20:1 acid in freshwater species.
[3] Combined 20:4 and 22:1 acids.

TABLE 2

FATTY ACID COMPOSITION OF SHELLFISH OILS

Name of Species		Fatty Acid Percentage Composition[1]																
Common	Scientific	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3	18:4	20:1	20:4	20:5	22:1	22:5	22:6	Reference
Abalone	*Haliotis discus*	3.9	2.9	20.9	3.3	NK	5.1	16.4	1.2	—[2]	NK	4.8[2]	—[3]	8.8	10.7[3]	7.3	NK	Shimma 1964B
Abalone, Kid	*Haliotis japonica*	4.9	3.2	19.8	4.4	+	3.9	17.1	1.6	—[2]	0.9	5.9[2]	—[3]	10.0	12.3[3]	8.4	NK	Shimma 1964B
Barnacle, Goose	*Mitella polymerus*	1.9	0.5	24.7	2.4	1.8	8.1	10.5	1.2	NK	NK	3.6	1.8	20.4	1.0	0.5	17.2	Rodegker 1964
Clam	*Meretrix meretrix lusoria*	2.1	2.3	18.2	4.9	4.5	4.9	6.7	1.0	—[2]	4.4	6.8[2]	—[3]	10.0	5.1[3]	3.2	16.5	Shimma 1964B
Clam, Hen	*Mactra sulcataria*	4.0	3.2	29.8	10.5	NK	9.7	8.2	+	—[2]	2.0	6.7[2]	—[3]	9.5	1.7[3]	NK	4.6	Shimma 1964B
Clam, Littleneck	*Protothaca stiminea*	3.2	0.8	23.8	9.6	1.3	5.4	10.8	1.4	1.6	3.0	3.5	1.7	10.0	2.6	1.7	14.5	Gruger 1964
Clam, Shortneck	*Tapes japonica*	2.7	2.6	18.8	9.4	+	8.9	8.9	+	—[2]	3.1	7.7[2]	—[3]	10.9	3.0[3]	+	14.3	Shimma 1964B
Corb shell	*Corbicula japonica*	4.7	3.1	20.3	10.7	+	5.1	8.3	1.9	—[2]	3.4	9.0[2]	—[3]	8.6	4.8[3]	3.9	10.3	Shimma 1964B
Crab, Blue	*Callinectes sapidus*	2.2	0.9	15.2	11.2	1.9	7.2	17.6	1.9	1.2	0.6	1.9	4.1	13.4	1.5	1.1	11.0	Gruger 1964
Mussel	*Mytilus californianus*	3.5	0.2	24.5	1.1	NK	1.7	3.2	3.2	NK	1.6	2.6	1.0	14.0	NK	1.1	27.7	Rodegker 1964
Oyster, Pacific	*Crassostrea gigas*	2.7	0.9	21.4	4.6	1.4	4.0	8.5	1.2	1.6	4.3	+	1.9	21.5	2.6	1.0	20.2	Gruger 1964
Oyster, Pacific	*Crassostrea gigas*	5.7	2.2	14.5	7.0	NK	3.2	10.9	2.1	—[2]	4.2	5.1[2]	—[3]	22.8	3.9[3]	NK	10.7	Shimma 1964B
Scallop, Sea	*Placopecten magellanicus*	1.9	0.7	23.0	2.0	0.8	5.3	5.2	0.6	0.3	1.8	1.7	4.5	21.3	0.2	1.0	26.2	Gruger 1964
Starfish, Pacific	*Pisaster ochraceus*	14.0	1.2	20.3	6.2	2.1	7.0	5.4	1.2	NK	NK	23.0	NK	NK	2.0	NK	NK	Rodegker 1964
Top shell	*Turbo cornutus*	1.4	4.9	13.6	NK	NK	4.9	6.6	3.5	—[2]	+	3.3[2]	—[3]	6.7	16.4[3]	8.7	NK	Shimma 1964B
"Tori-gai"	*Fulvia mutica*	3.4	4.0	18.9	10.3	NK	10.0	5.5	0.8	—[2]	NK	5.1[2]	—[3]	11.6	2.9[3]	+	16.7	Shimma 1964B

[1] Fatty acid not known or not mentioned in reference indicated by NK. Trace amounts indicated by + sign, i.e. less than 0.1%.
[2] Combined 18:3 and 20:1 acids.
[3] Combined 20:4 and 22:1 acids.

TABLE 3

FATTY ACID COMPOSITION OF OILS FROM FISH LIVERS[1]

Name of Species		Fatty Acid Percentage Composition																
Common	Scientific	14:0	15:0	16:0	16:1	17:0	18:0	18:1	18:2	18:3	18:4	20:1	20:4	20:5	22:1	22:5	22:6	Reference
Cod	*Gadus callarias*	}	+	12	5	1	3	24	1	1	1	9	1	8	5	1	19	Klenk 1962
Cod	*Gadus callarias* (?)	2.8	0.3	11.6	8.6	0.3	2.7	25.2	2.5	0.7	2.2	13.1	NK	9.3	6.3	1.0	8.6	DeWitt 1963
Cod	NK	2.9	NK	14.6	6.2	NK	3.5	39.0	1.7	0.3	+	9.1	2.1	2.6	4.6	1.5	9.7	Ito 1963B
Cod, Atlantic	*Gadus morhua*	2.8	0.4	10.7	6.9	1.2	3.7	23.9	1.5	0.9	2.6	8.8	1.0	8.0	5.3	1.3	14.3	Gruger 1964
Cod, Atlantic	*Gadus morhua*	3.5	0.5	10.4	12.2	0.1	1.2	19.6	0.8	0.2	0.7	14.6	1.7	5.0	13.3	2.0	10.5	Ackman 1964A
Dogfish, Piked	*Squalus acanthias*	3.0	0.6	15.0	4.9	1.0	3.4	19.0	1.4	NK	1.4	9.5	1.1	5.4	14.0	2.1	12.2	Olley 1962
Dogfish, Spiny	*Squalus acanthias*	1.6	0.3	13.2	5.7	1.0	4.3	28.5	0.7	0.6	0.8	10.5	0.8	3.7	10.3	3.1	6.5	Gruger 1964
Dogfish, Spiny	*Squalus acanthias*	2.7	0.3	23.2	6.8	0.8	4.0	35.7	0.7	0.5	NK	7.0	0.6	3.7	5.5	1.5	5.1	Malins 1965
Haddock	*Gadus aeglefinus*	2	+	16	6	1	3	30	1	+	1	4	1	15	1	1	14	Klenk 1962
Ling	*Molva molva*	2	+	15	4	1	3	37	1	1	1	6	1	6	3	1	15	Klenk 1962
Plaice	*Pleuronectes limanda*	3	1	14	8	2	1	22	1	1	+	2	3	15	+	6	12	Klenk 1962
Puffer	*Sphoeroides vermicularis*	5.7	NK	19.0	11.5	NK	7.3	24.0	NK	—[2]	NK	10.6[2]	—[3]	4.6	7.4[3]	4.2	5.7	Shimma 1964A
Sea devil	*Lophius piscatorius*	4	1	15	6	1	3	21	2	1	2	7	1	6	5	1	16	Klenk 1962
Shark	NK	3.3	NK	13.3	10.8	NK	2.9	25.2	2.3	0.4	1.4	9.2	3.1	9.2	6.6	3.4	7.3	Ito 1963B
Shark, Herring	*Isurus cornubicus*	3	+	13	3	1	2	9	1	1	2	22	+	3	31	1	5	Klenk 1962
Squid	*Illex illecebrosus*	4.4	0.2	13.7	9.0	0.4	1.8	16.3	0.8	0.7	0.8	12.4	0.8	13.9	8.2	1.4	16.9	Jangaard 1965
Turbot	*Rhombus maximus*	4	+	16	12	1	2	35	1	1	+	5	1	5	2	3	9	Klenk 1962
Whitefish	*Gadus merlangus*	4	+	16	4	1	3	25	2	1	2	7	1	8	6	1	16	Klenk 1962
Cod (eggs)	*Gadus morhua*	0.6	0.1	23.4	6.1	+	1.3	23.4	0.2	0.2	0.1	1.0	2.5	16.5	0.2	0.8	22.1	Ackman 1964C
Salmon, Pink (eggs)	*Oncorhynchus gorbuscha*	2.9	0.5	9.5	7.0	0.8	2.9	20.5	1.5	1.2	1.8	1.1	1.5	20.6	0.4	4.6	16.0	Gruger 1964

[1] Not known or not mentioned in reference is designated as NK. Trace amounts designated by a + sign.
[2] Combined 18:3 & 20:1 acids.
[3] Combined 20:4 & 22:1 acids.

respectively. The fatty acids listed in the tables are those generally common to all species. There are fatty acids that occur in trace amounts, which have been left out of the tables only to simplify the presentation. Where the latter acids seem important to a species, particular attention is drawn to them in the discussion.

Fish-Body Oil Fatty Acids

The data from many laboratories throughout the world illustrate markedly the wide distribution of fatty acids that can be found in fish body oils. Not only are there wide distributions in the types of fatty acids, i.e., those of different chain lengths and different degrees of unsaturation, as previously discussed, but more important there are wide differences in the relative amounts of individual fatty acids. The distribution of oleic acid, for example, which is generally thought to be the most common monoenoic acid in fish oils varies (in Table 1) from about 5 to 38% of the total fatty acids. Docosahexaenoic acid (22:6), as another example, can vary from about 3 to 38% according to the compiled data. As seen from the numerical values in Table 1, these fatty acid distributions are associated with the species differences and the sources of oil samples with respect to particular parts of fish. We emphasize that this latter point is quite important to interpretations that one may make because, for instance, the phospholipids, as a lipid fraction, contain proportionately more unsaturated fatty acids than do the triglycerides. As indicated earlier, the anatomical source of the sample has a bearing on whether or not an analysis is based more on one class of lipids than on another class. Thus, in some cases, it is noted in parentheses under the common name of the species in Table 1 the words dorsal and ventral, which cite the particular oil sample for those anatomical parts of the fish. Geographical and seasonal influences upon composition are not obvious from the data in Table 1, but these factors can be assumed for the cases of multiple data from the same species, e.g., Atlantic cod, spiny dogfish, menhaden, and mullet.

The data given in Table 1 represent only those of recent GLC analyses and do not represent all of the data available from other techniques. One might assume that wider distributions in fatty acid compositions than is presented in Table 1 are possible as additional data become available.

Oils from certain species of fish appear to exhibit above-average amounts of particular fatty acids. Nearly 10% myristic acid (14:0) is observed for capelin, menhaden, Peruvian sardine, skipjack tuna, some whales, and ventral tissues of shad. Palmitic acid (16:0) is usually about 15 to 20% of the total fatty acids, but some species, such as Atlantic cod, flying fish, mullet, and puffer, can have about 30% 16:0 acid. Rather large amounts of palmitoleic acid (16:1) have been found in capelin, mul-

let, lemon sole, and harbor seal. Similarly, stearic acid (18:0), which is generally about 4% of fish oil acids, can apparently range as high as 12 to 16% of the total.

The mullet appears to be a unique source of C_{15} and C_{17} acids. Up to 25% straight-chain odd-carbon fatty acids have been found in mullet (Gruger *et al.* 1960; Sen and Schlenk 1964). Sen and Schlenk (1964) report these acids to range from 15:0 (11%) to C_{21} (0.9% total) with unsaturated components having up to four ethylenic bonds, e.g., 17:4 and 19:4. The 17:1 acid was found as 4.6% of the total mixed fatty acids.

Based on the compiled data, the species of capelin, dogfish, goby, marine herring, and whale have among the highest percentages of monoenoic acids. However, this statement is made cautiously because we know that the sample source can be an influencing factor in the types of lipids of the oil analyzed. As an illustration, Pacific herring oil from the ventral area of the fish is found to contain more than twice the amount of 20:1 and 22:1 acids (38 vs 14%) compared to oil from the dorsal area of the fish (Shimma and Taguchi 1964A). By comparison, blubber oils of seal and whale appear very high (>65%) in monoenoic acids.

In regard to the pentaenoic and hexaenoic acids of the oils listed in Table 1, only a few species appear to have exceptional proportions of these fatty acids. These species, with percentages of pentaenes and hexaenes in parentheses, include the following: Atlantic cod (56%), Pacific cod (49%), halibut - *Hippoglossus hippoglossus* - (53%), pond smelt (45%), porbeagle shark (45%), and squid (53%). Most other species contain these component fatty acids in about 10 to 20% of the total fatty acids.

Recalling the previous discussion, one should recognize that the values just mentioned may be quite different due to several environmental factors. The values reported for halibut and lemon sole by Olley and Duncan (1965) illustrate this point. Their values show comparisons between summer and winter catches, whereby the amount of 22:6 acid was nearly doubled from one time of year to the other. Olley and Duncan (1965) imply that the phospholipid levels are relatively stable in comparison to the neutral lipid levels. For this reason, one could anticipate that their finding seasonal differences is reflected principally in the fatty acids of the triglycerides.

Seasonal effects are also shown for mullet-body oil (Gruger *et al.* 1964). Based on the work of Reiser *et al.* (1963) and others, one could say that the seasonal differences observed by Gruger *et al.* (1964) on mullet fatty acids could be complicated by maturity or size of fish and by availability and nature of food supply for these fish. The same comment can be made of seasonal observations of others as well.

Fatty acid analysis of some freshwater species, other than those found in

Table 1, have been reported by Brenner *et al.* (1961). Analyses of depot fats of *Prochilodus lineatus*, *Pimelodus maculatus*, *Salminus maxillosus*, *Parapimelodus valenenciennesi*, and *Pseudoagenius brivifilis* showed fatty acids from C_{11} to C_{24}.

Shimma and Taguchi (1964A, 1964C) reported extensive evaluations of fish and marine-animal oils by GLC. Their investigations are particularly interesting from the view that related parts of several species were examined, and their results show differences in composition related to the differences in anatomical sample source.

Whale oils are especially interesting oils because some contain fatty acids that are largely in the form of wax esters. Jangaard *et al.* (1963B) report GLC data of the Atlantic bottlenose whale (*Hyperoodon ampullatus*) and compare its fatty acids with the fatty acids of commercial winterized sperm whale oil. They found 1.2% 10:0 acid as well as the usual monoenoic acids in the sperm whale oil; however, the bottlenose whale oil contained nearly four times the amount of 20:1 and 22:1 acids compared to the sperm whale oil.

Sano and Murase (1965) report the GLC analysis of minor component fatty acids of Sei whale blubber oil. They found a wider range of fatty acids than has been usually found from recent fish oil analyses. Noteworthy is their report of fatty acids such as 13:1, 14:2, 19:5, 21:1, 21:5, and 24:6.

Fatty acids of the blubber of North Atlantic finback whale (*Balaenoptera physalus*) were reported by Ackman *et al.* (1965). Sections of blubber consisting of lateral slices of equal thickness were the source of fatty acids, which were shown to differ in total composition. The greatest differences in composition were between that of the outermost and of the innermost section, the data of which are summarized in Table 1. Ackman *et al.* (1965) point out that the total C_{20} and C_{22} monoenoic and polyenoic acids in each layer of blubber is nearly constant, but the ratios of the monoenoic to the polyenoic acids change very significantly. One can consider these findings in light of a physiological function of blubber as insulation. It would be interesting to know if this kind of distribution is present in depot fat layers of other species.

Relatively little is known about fish-oil fatty acids of chain lengths greater than C_{22}, because these acids occur in quite minor amounts. Also, these acids have been difficult to measure with the same degree of confidence as other fatty acids are measured. Ito and Fukuzumi (1963B) observed from 1.0% to 2.5% 24:1 acid in some species. Gruger *et al.* (1964) implied that 24:1 accounted for nearly all of the C_{24} acids found by the GLC analyses of numerous species of fish. Ackman and Sipos (1964) report that the normal range of C_{24} acids in marine teleost fish does not ex-

ceed 2% as determined by the classical methods (Hilditch and Williams 1964). Particular attention was given by Ackman and Sipos (1964) to pilchard-oil fatty acids, which were believed to contain abnormal amounts of C_{24} acids. Their results showed 0.5% 24:1, 0.2% 24:5, and 0.1% 24:6 acids in the pilchard oil. Such results are not at all unreasonable for most other fish oils.

Work by Adachi (1960) on cuttlefish oil was directed towards the C_{24}, C_{26}, and C_{28} acids. Results showed that these chain-length acids were more monoenoic, trienoic, and tetraenoic in character than they were pentaenoic and hexaenoic. Investigations of triglycerides of sablefish (*Anaplopoma fimbria*) by Dolev and Olcott (1965B) have shown that 24:6 and 26:4 acids are present. These findings were the result of very tedious chromatographic separations of triglyceride fractions.

Shellfish-Oil Fatty Acids

Relatively little is known about the fatty acid composition of shellfish oils compared to fatty acids of marine and freshwater fish oils. Only in the last few years has GLC data become available for shellfish oils. A comparison of the numerical values in Table 2 with those in Table 1 will show very few differences between the fatty acids of shellfish and the fatty acids of freshwater and marine fishes.

Gruger *et al.* (1964) reported about four per cent 20:4 acid in extracted oils of blue crab and sea scallop. This amount of the 20:4 acid may be considered rather high compared to the usual range of values for 20:4 in marine oils.

Fatty acids of hen clam differ from those of littleneck clam and shortneck clam in the relative amounts of the 22:6 acid. Not as great a difference in 22:6 is seen from the data on Pacific oysters from obviously wide geographic origins. Of the listed shellfish, the common mussel fatty acids contained the highest amount of 22:6.

It appears strange that the 22:6 acid is not observed in abalone and top shell (Shimma and Taguchi 1964B) and in starfish (Rodegker and Nevenzel 1964). Also, the amounts of 22:5 in abalone and top shell appear rather high for shellfish fatty acids, indicating a possible unusual biosynthetic pattern in these species or a selection of tissue samples which are high in phospholipid content.

Pacific starfish oil, analyzed by Rodegker and Nevenzel (1964), contained 14% 14:0, which appears high for shellfish but which may be normal for starfish. They also found 18 to 29% 20:1 and 30 to 45% C_{20}-C_{22} polyunsaturated fatty acids in starfish lipids.

Fatty acids from abalone and top shell show between 10 and 16% 22:1, while fatty acids from the remainder of shellfish oils indicate less than

about 5% 22:1. Sea scallop oil had as little as 0.2% 22:1, but contained 23% 20:1. The other shellfish oils ranged from about 2 to 9% of the 20:1 acid.

Fatty acid composition of *Chlamys nipponesis* and *Pecten yessoensis* are reported by Igarashi *et al.* (1961) using the classical distillation method of analysis. These oils had iodine values of 203 and 226, respectively. Other data similar to these are summarized by Hilditch and Williams (1964).

Fatty Acids Composition of Fish-Liver and Egg Oils

The livers of fish are known generally to be high in oil content. In many cases, research has demonstrated a considerable difference in fatty acid composition of fish liver oils compared to body oils. Fish-egg fatty acids, such as those from salmon, are usually higher in unsaturation than those acids from oils of other fish tissues (Kyte 1956).

Table 3 lists principally the fatty acid compositions for liver oils. Only the egg-oil fatty acids of two species are included for comparison.

Fatty acid mixtures from oils of dogfish livers and cod livers can be quite high in the amounts of 20:1 and 22:1 acids. With such oils, it is not surprising that the amounts of 20:5 and 22:6 acids may be correspondingly low. Oil of herring shark livers has the highest combined amounts (53%) of 20:1 and 22:1 (Klenk and Eberhagen 1962) of the liver oils listed in Table 3.

These data and others might indicate that high monoenoic acid content could be a general characteristic of shark-liver oil. However, it can be argued from such data as by Pathak *et al.* (1955, 1957) and by Kamath and Magar (1955, 1956A, B) that 20:1 and 22:1 in several other elasmobranch liver oils cannot be very high in proportion to the total amounts of C_{20} and C_{22} acids. For instance, data from the classical distillation technique show that if unsaturated C_{20} and C_{22} acids amount to 19 and 7%, respectively, and taking into account the presence of 20:4, 20:5, 22:5, and 22:6 acids, then there may not necessarily be high proportions of 20:1 and 22:1 present. As is the case with body oils, we have here the situation where extensive analyses of many liver samples are necessary to establish general patterns.

Dogfish-liver oils have provided interesting materials for the investigation of fatty acids associated with alkoxydiglycerides in the presence of triglycerides (Malins 1960). GLC analysis of fatty acids of alkoxydiglycerides of *Squalus acanthias* livers has shown that 20:1 comprised 90% of the C_{20} acids and that 22:1 comprised 68% of the C_{22} acids (Malins *et al.* 1965). This distinction was not as striking, however, among the fatty acids of the triglycerides of the same oil.

Fatty acid analyses of yellowtail (*Seriola quinqueradiata*) liver oil

showed over 50% C_{20} and C_{22} acids and over 8% polyunsaturated C_{24} acids (Tsuyuki *et al.* 1958). Analysis of liver-oil fatty acids of *Octopus dofleini* resulted in the isolation of 24:5 acid, among others (Hatano 1958A). Additional work on this oil showed the presence of 10:1ω7, 14:1ω9, and 12:1ω8, the latter of which is said to occur only in this octopus and not in other aquatic life (Hatano 1958B).

Concerning fatty acids of rainbow trout-egg oil, Ando (1962) observed changes during egg development. It was found that, after fertilization, the percentage of C_{16} acids decreased once and then increased gradually after which a marked increase occurred in the degree of unsaturation.

It should be pointed out for salmon-egg fatty acids that about 40% of the total fatty acids are 20:5, 22:5, and 22:6 acids. Only about 1% are 20:1 and 22:1 acids, as seen in Table 3 (Gruger *et al.* 1964).

Ackman and Burgher (1964C) reported GLC analysis of cod-roe fatty acids, (cf. Table 3), which contained larger amounts of 16:1 and 18:1 acids than the flesh lipids of a male cod. They also found that the amount of 22:6 was not as high among the roe fatty acids as in the male flesh lipids. This was partly attributed to a significant triglyceride content in the roe in contrast to the large phospholipid content of the flesh. There were marked differences in fatty acid composition between that of the roe oil and liver oil of the female cod and that of the liver oil of the male cod.

Other Sources of Marine Fatty Acids

There are a few other areas of research where the fatty acid composition of fish oils are of interest. Fatty acids of three species of sea anemone were analyzed by Toyama *et al.* (1955). Based on classical data, the fatty acids of sea anemone show little difference compared to fatty acids of body oils of other marine fish. It is desirable to have GLC analyses of such oils, however, to be conclusive.

The component fatty acids of the milk of Atlantic grey seal were analyzed by Ackman and Burgher (1963). Their GLC data confirmed the belief that the milk fat of marine mammals resembles the composition of the depot fats of these animals. The fatty acid composition of grey seal milk fat is compared to that of the blubber of lactating grey seal and the blubber of an adult harbor seal in a recent report by Ackman and Jangaard (1965). Different proportions were noted for 16:0 and 22:6ω3, as well as other acids. The milk fat had lower proportions (1:3) of 20:1 and 22:1 acids than the blubber.

Fatty acids of salmon offal oil were compared between two production years by Swain (1954). Such comparisons are important, since salmon offal is a large by-product of the salmon canning industry.

Some fatty acids from marine life mitochondria were investigated by Ri-

chardson *et al.* (1961, 1962). The mitochondrial samples were from the livers and hearts of marine birds, seals, and several fish. The results of GLC analyses showed very low levels of linoleic, linolenic, and arachidonic acids and high levels of 20:5 and 22:6 acids from these sources. The results of the study were biochemically implicated to the need of marine life for certain fatty acids.

Lipoproteins as a source of fatty acids in fish have gone virtually unnoticed in research. Olley (1961) has investigated phospholipids associated with fish lipoproteins, but did not include the constituent fatty acids. It would be interesting to speculate on the fatty acid composition of these and other conjugated proteins, such as those related to lipids complexed with ribonucleoproteins.

SUMMARY AND CONCLUSIONS

The fatty acid distribution patterns of fish and marine animal oils are very complex from the standpoint of molecular structure and also the overall composition at any given time for each species. Environmental factors can effect the makeup of body-oil fatty acids, and maturity and sex of fish have influences upon composition as well.

Fatty acid composition varies not only from species to species, but often to an even greater extent from one fish to another of the same species. From the compiled data, it should be apparent that an average value for a component fatty acid has little meaning. It is most important to establish ranges of composition values (Stansby 1954). This can only be done by numerous analyses of fish oils over periods of years, taking into account the many factors that influence fatty acid composition.

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