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ORIGINAL ARTICLE

Fatty Acid Profiles of Commercially Available Finfish Fillets in the United States

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Abstract Fillets of 76 finfish species (293 composites of three fish) were obtained from commercial seafood vendors in six regions of the United States (i.e., Great Lakes, Mid-Atlantic, New England, Northwest, Southeast, and Southwest). Full fatty acid profiles were determined for each species and are presented here. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have been associated with many health benefits. Thus, fillets of each species were compared for total EPA plus DHA content, which ranged from 17 mg/100 g (pangasius/swai) to 2430 mg/100 g (Chilean sea bass). Of the top ten most popularly consumed seafoods in the US, finfish, including salmon species (717–1533 mg/100 g), Alaskan pollock (236 mg/100 g), tilapia (76 mg/100 g), channel catfish (44 mg/100 g), Atlantic cod (253 mg/100 g), and pangasius/swai (17 mg/100 g), exhibited a wide concentration range of EPA plus DHA. Large variances were found within many of the farmed species analyzed, which likely stems from dietary differences in the farm-fed diet. The results of this study provide current information on a broad range of species and will help nutritionists and the public make informed decisions regarding seafood consumption.

Keywords Fatty acids · Eicosapentaeoic acid (EPA) · Docosahexaenoic acid (DHA) · Fish fillets · Consumption advice

Abbreviations

ALA	Alpha-linolenic acid (18:3n-3)
ARA	Arachidonic acid (20:4n-6)
ARS	Agricultural Research Service
DHA	Docosahexaenoic acid (22:6n-3)
DHHS	United States Department of Health and Human Services
DPAn-3	Docosapentaenoic acid (22:5n-3)
EPA	Eicosapentaenoic acid (20:5n-3)
GL	Great Lakes region
GLA	Gamma-linolenic acid (18:3n-6)
LNA	Linoleic acid (18:2n-6)
MA	Mid-Atlantic region
MUFA	Monounsaturated fatty acids
NE	New England region
NND	National nutrient database
NW	Northwest region
PUFA	Polyunsaturated fatty acids
RRF	Relative retention factor
SDA	Stearidonic acid (18:4n-3)
SE	Southeast region
SFA	Saturated fatty acids
SW	Southwest region
USDA	United States Department of Agriculture

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Introduction

Fish are an important part of the US diet. In 2012, Americans consumed an average of 6.35 kg (14.4 lbs) of seafood per capita [1]. Fish are the primary dietary source of long-chain n-3 fatty acids, particularly, eicosapentaenoic acid (EPA, C20:5n-3) and docosahexaenoic acid (DHA, C22:6n-3), which provide health benefits through all life stages [2].

EPA and DHA are ubiquitous components of cell membranes in the developing brain and photoreceptors of fetuses and infants [3, 4]. Human and animal studies have shown that the absence of n-3 fatty acids in infants impairs neurological development [5–10] and performance on tests of visual acuity [11–13]. In aging populations, EPA and DHA have been shown to reduce the incidence of cardiovascular disease [14, 15], heart failure [14, 16], and sudden cardiac death [17, 18], while also providing protection against the deleterious effects of cognitive aging [3, 4, 19–21]. In accordance with these benefits, the US Department of Agriculture (USDA) and US Department of Health and Human Services (DHHS) recommends adults (especially pregnant and nursing women and seniors) consume 227–340 g (8–12 oz) of seafood each week, which may provide 250 mg of EPA plus DHA per day [22].

Commercially-available fish originate from wild-caught and aquaculture sources. Over the past few decades, the availability of aquaculture-sourced seafood has risen dramatically and now accounts for half of all fish available in commercial markets [23]. Because the diet of farmed fish is controlled by the farmer, the fatty acid profiles are different than wild-captured fish of the same species [24, 25]. Farmed fish generally contain higher levels of total fat, EPA, and DHA than wild-caught fish of the same species [26]. However, farmed fish also contain significantly higher levels of other fatty acids as well (e.g., saturated, monounsaturated, and n-6 fatty acids) [26]. Additionally, as the diets of farmed fish are changed to lower production costs, differences in the flavor profiles of fish fillets have been noted in some studies [27, 28] but not in others [29, 30].

Given the myriad of possible health benefits associated with EPA and DHA and the differences between farmed and wild-caught fish, it is imperative that more information is made available to consumers concerning seafood. While the USDA Agricultural Research Service (USDA-ARS) maintains a National Nutrient Database (USDA-ARS NND), containing 267 listings for seafood items [31], there are less than 50 species of finfish and 25 categories of finfish (e.g., shark). The American consumer has access to far more species, especially considering that different species are preferred or available in different areas of the country. Thus, the objective of this study was to survey the most commonly consumed species in the U.S. to determine fatty acid profiles.

Materials and Methods

Collection Protocol

Fish were obtained from commercial vendors in six regions of the U.S., including the Great Lakes (GL), Mid-Atlantic (MA), New England (NE), Northwest (NW), Southeast (SE), and Southwest (SW). Three samples of at least 200 g were requested for each species in addition to tracking information (vendor, supplier, wild or farm raised, country/body of water of origin), length, and weight of each fish. Photos were taken by vendors and sent with the samples to help ensure positive identification of each species. From each region, samples of each species were collected during two seasons, 4–12 months apart. In total, 76 species (293 composites of three fish) were collected during this study. The species that were tested along with full tracking details, including the date received, region, and origin of all samples is available at www.fish4health.net.

Fish species were divided into three categories for collection. The “top ten species” are the most commonly consumed finfish in the US, according to the National Marine Fisheries Service [1]. The “other popular species” includes fish commonly consumed across the U.S. that are higher in n-3 fatty acids. Finally, in order to include species that are popular in different parts of the country, experts in each region were consulted in the development of “regionally-popular species” lists. All regions except MA were asked to provide “top ten”, “other popular” and “regionally-popular” species. For the MA region, only swordfish and striped bass from the “other popular species” list were requested in addition to the “regionally-popular species”.

The “top ten species” included Atlantic salmon (*Salmo salar*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), sockeye salmon (*Oncorhynchus nerka*), Alaskan pollock (*Theragra chalcogramma*), tilapia (family: Cichlidae; tribe: tilapiini), channel catfish (*Ictalurus punctatus*), Atlantic cod (*Gadus morhua*), and pangasius/swai (*Pangasius hypophthalmus*). The “other popular species” included striped bass (*Morone saxatilis*), swordfish (*Xiphias gladius*), Alaskan halibut (*Hippoglossus stenolepis*), rainbow trout (*Oncorhynchus mykiss*), monkfish (*Lophius* spp.), red snapper (*Lutjanus campechanus*), grouper (*Epinephelus* spp.) or red grouper (*Epinephelus morio*), black sea bass (*Centropristis striata*), mahi mahi (*Coryphaena hippurus*), and orange roughy (*Hoplostethus atlanticus*).

“Regionally-popular species” differed by region. GL vendors provided the following species: summer flounder (*Paralichthys dentatus*), lake trout (*Salvelinus namaycush*), walleye (*Sander vitreus*), yellow perch (*Perca flavescens*), lake whitefish (*Coregonus clupeaformis*), and rainbow smelt (*Osmerus mordax*). MA vendors provided the following species: striped bass, swordfish, Atlantic croaker (*Micropogonias undulatus*), bluefish (*Pomatomus saltatrix*), spot (*Leiostomus xanthurus*), summer flounder, white perch (*Morone americana*), scup (*Stenotomus chrysops*), spiny dogfish (*Squalus acanthias*), and skate (family: *Rajidae*). NE vendors provided the following species: yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), Atlantic pollock (*Pollachius pollachius*), yellowfin tuna (*Thunnus albacares*), haddock (*Melanogrammus aeglefinus*), grey sole (*Glyptocephalus cynoglossus*), silver hake (*Merluccius bilinearis*), tilefish–north Atlantic population (*Lopholatilus chamaeleonticeps*), American plaice (*Hippoglossoides platessoides*), and American shad (*Alosa sapidissima*). A NW vendor provided the following species: lingcod (*Ophiodon elongates*), sablefish (*Anoplopoma fimbria*), Pacific cod (*Gadus macrocephalus*), Pacific Dover sole (*Microstomus pacificus*), English sole (*Parophrys vetulus*), petrale sole (*Eopsetta jordani*), rex sole (*Glyptocephalus zachirus*), white sturgeon (*Acipenser transmontanus*), green sturgeon (*Acipenser medirostris*), albacore tuna (*Thunnus alalunga*), brown rockfish (*Sebastes auriculatus*), widow rockfish (*Sebastes entomelas*), Pacific Ocean perch (*Sebastes alutus*), Pacific whiting (*Merluccius productus*), and Chilean sea bass (*Dissostichus eleginoides*). SE vendors provided the following species: king mackerel (*Scomeromorus cavalla*), tilefish–Gulf of Mexico population, Spanish mackerel (*Scomberomorus maculatus*), Atlantic croaker, greater amberjack (*Seriola dumerili*), striped mullet (*Mugil cephalus*), yellowfin tuna, gag grouper (*Mycteroperca microlepis*), yellowedge grouper (*Hyporthodus flavolimbatus*), yellowtail snapper (*Ocyurus chrysurus*), vermilion snapper (*Rhomboplites aurorubens*), Florida pompano (*Trachinotus carolinus*), spotted seatrout (*Cynoscion nebulosus*), Gulf flounder (*Paralichthys albigutta*), and southern flounder (*Paralichthys lethostigma*). A SW vendor provided the following species: Pacific Dover sole, petrale sole, common thresher shark (*Alopias vulpinus*), white sea bass (*Atractoscion nobilis*), California halibut (*Paralichthys californicus*), yellowtail amberjack (*Seriola lalandi*), sablefish, albacore tuna, wahoo (*Acanthocybium solandri*), lingcod, and Chilean sea bass.

Sample Preparation

Samples were packed on ice and sent via overnight shipping to Purdue University, where testing was completed. Upon arrival, the temperature of each sample was measured to ensure that it was 7 °C or lower. All fish were immediately filleted, with skin and pin bones removed. Homogeneous composites of the three fillets of each species were created by grinding in a food processor (Robot-Coupe R2 Ultra, Robot Coupe USA, Inc., Ridgeland, MS, USA). Samples were packed in sampling bags (Fisher Scientific, Pittsburgh, PA, USA) and frozen at −20 °C until analysis.

Total Fat and Fatty Acid Determination

Chemicals

Chloroform (ACS grade), methanol (ChromAR grade), and anhydrous sodium sulfate (ACS grade) were purchased from Macron Fine Chemicals (Center Valley, PA, USA). Sodium chloride (ACS grade), sodium hydroxide (ACS grade), and isooctane (pesticide grade) were purchased from Fisher Scientific (Waltham, MA, USA). Butylated hydroxytoluene (BHT) was purchased from United States Biochemical Corp. (Cleveland, OH, USA). BF_3-methanol (10 % w/w) and PUFA No. 3 menhaden oil were purchased from Sigma-Aldrich (St. Louis, MO, USA). Methyl tricosanoate (>99 % pure) and GLC Reference Standard 462 were purchased from Nu-Chek Prep, Inc. (Elysian, MN, USA).

Extraction

Each composited fish sample was analyzed in duplicate. Extraction of fat from fish tissue was achieved using a modified Folch method [33, 34]. Raw fish tissue (5 g), 10 mg methyl tricosanoate (as an internal standard), and 100 mL chloroform–methanol (2:1 v/v) were homogenized with a hand held homogenizer (Tissue Tearor Model 985370-14, BioSpec Products, Inc., Bartlesville, OK, USA). The slurry was placed on a shaker at 200 rpm for 2 h (IKA KS 260 Basic, IKA Works, Inc., Wilmington, NC, USA). The resulting slurry was filtered, with the filtrate placed in a separatory funnel and rinsed with 30 mL potassium chloride solution (0.88 % w/v). The organic layer was removed and filtered through anhydrous sodium sulfate. Solvent was removed via a TurboVap II Concentration Workstation (Zymark Corp., Westborough, MA, USA) at 40 °C. The concentrated samples were transferred to test tubes and further concentrated with a Meyer N-Evap (Organomation Association Inc., South Berlin, MA, USA). The concentrated fatty acids were placed in a desiccator overnight to remove residual solvent. Extracted fat was weighed the following morning to determine the total fat in the fillet tissue of each sample.

Derivatization

The extracted fat was derivatized to fatty acid methyl esters following a modified AOAC Official Method, 991.39 [35]. Methanolic sodium hydroxide (2 mL, 0.5 N) was added to the extracted fat and heated for 10 min at 105 °C on a heating block (VWR International, Radnor, PA, USA). Upon cooling, BF_3-methanol (3 mL) was added and again heated for 30 min at 105 °C. Isooctane (1 mL) was added to the cooled mixture and vortexed for 30 s. A saturated solution of sodium chloride (4 mL) was added and vortexed for 30 s before centrifuging at 1,500 rpm for 5 min (international clinical centrifuge model CL, International Equipment Co., Needham Heights, MA, USA). The organic layer was removed and set aside. To the aqueous layer, BHT-methanol (50 µL, 10 mg/mL) and isooctane

(1 mL) were added. The mixture was again vortexed and centrifuged. The organic layer was removed and combined with the first extract. An aliquot (1 mL) was transferred to a GC vial and blanketed with nitrogen.

GC-FID Determination of Fatty Acids

The derivatized fatty acid methyl esters were analyzed by gas chromatography with a flame ionization detector and split/splitless injector (GC/FID, Varian 3,900 GC, CP-8,400 auto sampler, CP-8,410 auto injector, Varian Analytical Instruments, Walnut Creek, CA, USA). A CP-52CB wax capillary column was used for analysis (CP 8,843, 30 m × 0.32 mm ID, DF-25 coating thickness 0.25 µm; Agilent Technologies, Inc., Santa Clara, CA, USA). Operating conditions were: injection port temperature, 250 °C; detector temperature, 300 °C; oven programmed from 170 °C for 4 min to a final hold temperature of 240 °C for 4 min, with an increase of 3 °C/min; helium carrier gas, 2.5 mL/min (99.995 % pure, Indiana Oxygen Co., Indianapolis, IN, USA). The FID operated with the following flow rates: helium, 25 mL/min; hydrogen, 30 mL/min (99.8 % pure, Inweld Corp., Indianapolis, IN, USA); compressed air, 300 mL/min (commercial grade, Specialty Gases of America, Toledo, OH, USA).

Peaks were identified using two known standards (PUFA No. 3 and GLC 462). These standards were run monthly to verify the method of peak identification. Blanks were run for all new solvents and other chemicals to verify purity before using them for analysis of tissue samples. Additionally, duplicate samples displaying differences greater than 10 % in multiple fatty acids were repeated. Applying this criterion, 13.4 % of all samples needed to be retested.

Calculations/Quantitative Analysis

Quantitation of fatty acids was achieved using AOAC Official Method 991.39 [35] and the work of Tvrzická et al. [36]. A total of 31 fatty acids were measured, with a limit of quantification (LOQ) of 1 mg/100 g. The equation $C_{FA} = (m_{IS} \times A_{FA} \times RRF_{FA})/(1.04 \times m_{fish} \times A_{IS})$ was used to quantify all measured fatty acids [35], where C_{FA} is the concentration of the fatty acid in mg/g, m_{IS} is the weight of the internal standard, A_{FA} is the fatty acid peak area in the GC spectrum, RRF_{FA} is the relative retention factor for each fatty acid [36], 1.04 is the correlation factor between fatty acids and fatty acid methyl esters, m_{fish} is the weight of the fish tissue, and A_{IS} is the internal standard peak area in the GC spectrum. The RRF value accounts for the effective carbon number and is calculated according to previously published methods [36]. The following fatty acids (with their RRF values) were measured: lauric acid, C12:0 (RRF = 1.114); myristic acid, C14:0 (RRF = 1.080); myristoleic acid, C14:1n-5 (RRF = 1.071); palmitic acid, C16:0 (RRF = 1.055); palmitoleic acid, C16:1n-7 (RRF = 1.047); hexadecadienoic acid, C16:2n-4 (RRF = 1.039); hexadecatrienoic acid, C16:3n-4 (RRF = 1.031); stearic acid, C18:0 (RRF = 1.035); vaccenic acid, C18:1n-7 (RRF = 1.028); oleic acid, C18:1n-9 (RRF = 1.028); linoleic acid (LNA), C18:2n-6 (RRF = 1.021); alpha-linolenic acid (ALA), C18:3n-3 (RRF = 1.014); octadecatetraenoic acid, C18:3n4 (RRF = 1.014); gamma-linolenic acid (GLA), C18:3n-6 (RRF = 1.014); stearidonic acid (SDA), C18:4n-3 (RRF = 1.007); arachidic acid, C20:0 (RRF = 1.019); gondoic acid, C20:1n-9 (RRF = 1.012); eicosadienoic acid, C20:2n-6 (RRF = 1.006); eicosatrienoic acid, C20:3n-3 (RRF = 1.000); homo-γ-linolenic acid, C20:3n-6 (RRF = 1.000); eicosatetraenoic acid, C20:4n-3 (RRF = 0.994); arachidonic acid (ARA), C20:4n-6 (RRF = 0.994); eicosapentaenoic acid (EPA), C20:5n-3 (RRF = 0.987); behenic acid, C22:0 (RRF = 1.006); erucic acid, C22:1n-9 (RRF = 1.000); docosadienoic acid; C22:2n-6 (RRF = 0.994); adrenic acid, C22:4n-6 (RRF = 0.983); docosapentaenoic acid (DPAn-3), C22:5n-3 (RRF = 0.977); docosahexaenoic acid (DHA), C22:6n-3 (RRF = 0.971); tricosanoic acid, C23:0 (RRF = 1.000); lignoceric acid, C24:0 (RRF = 0.995); and nervonic acid, C24:1n-9 (RRF = 0.990).

Results

Full fatty acid profiles were determined for fillets of all species obtained in this study.

A summary of total fat, n-3, n-6, SFA, MUFA, and PUFA for each species is presented in Table 1. Several prominent fatty acids (including myristic acid, palmitic acid, stearic acid, oleic acid, linoleic acid (LNA), α-linolenic acid (ALA), γ-linolenic acid (GLA), stearidonic acid (SDA), arachidonic acid (ARA), EPA, docosapentaenoic acid (DPAn-3), and DHA) are presented in Tables 2 and 3. Full fatty acid profiles, including all 31 fatty acids measured in this study, are available at www.fish4health.net.

Total fillet fat ranged from 0.38 % (southern flounder) to 32.65 % (Chilean sea bass), with Atlantic salmon (16.47 %), sablefish (15.62 %), green sturgeon (14.78 %), farmed Chinook salmon (14.18 %), and Florida pompano (13.87 %) having the next highest fat content. For the five species that were obtained from both aquaculture and wild-capture sources, the farm-raised samples, on average, contained more fillet fat than the wild-caught samples.

Total n-3 fatty acids, including ALA, SDA, 20:3n-3, 20:4n-3, EPA, DPAn-3, and DHA, in fillets ranged from 26 mg/100 g (pangasius/swai) to 3,011 mg/100 g (Chilean

Table 1 Total fat, n-3, n-6, SFA, MUFA, and PUFA in fillets of commercially-available U.S. finfish

Species	*n*[a]	Total Fat (g/100 g)	n-3 (mg/100 g)[b]	n-6 (mg/100 g)[c]	SFA (mg/100 g)[d]	MUFA (mg/100 g)[e]	PUFA (mg/100 g)[f]
Amberjack, Greater	2	0.91 ± 0.28	148 ± 16	43 ± 10	139 ± 16	52 ± 11	193 ± 14
Amberjack, Yellowtail	2	2.41 ± 0.14	714 ± 72	75 ± 2.0	671 ± 44	576 ± 39	806 ± 75
Bass, Striped (F)[g]	5	6.17 ± 1.70	699 ± 184	914 ± 179	1450 ± 390	2524 ± 610	1653 ± 299
Bass, Striped (W)[g]	5	2.42 ± 0.91	610 ± 244	85 ± 33	567 ± 244	576 ± 290	746 ± 312
Bluefish	3	4.53 ± 3.28	896 ± 549	159 ± 113	1242 ± 866	1087 ± 751	1088 ± 684
Catfish, Channel (F)	11	7.96 ± 1.68	130 ± 24	1201 ± 262	1717 ± 394	3649 ± 882	1335 ± 283
Cod, Atlantic (F)	1	1.04 ± 0.07	265 ± 15	22 ± 0.8	127 ± 8.6	84 ± 4.8	287 ± 15
Cod, Atlantic (W)	8	0.80 ± 0.25	254 ± 40	16 ± 5.1	120 ± 16	69 ± 17	271 ± 43
Cod, Lingcod	4	1.30 ± 0.18	333 ± 59	30 ± 9.5	221 ± 61	229 ± 111	370 ± 71
Cod, Pacific	2	0.52 ± 0.05	205 ± 38	18 ± 3.5	99 ± 19	56 ± 14	223 ± 41
Cod, Sablefish	4	15.62 ± 3.50	1571 ± 1016	291 ± 52	3319 ± 614	7363 ± 979	1959 ± 1087
Croaker, Atlantic	5	4.41 ± 2.73	675 ± 382	142 ± 61	1382 ± 1016	1330 ± 1033	837 ± 458
Flatfish, American Plaice	2	2.47 ± 1.45	351 ± 114	74 ± 31	518 ± 321	782 ± 697	435 ± 152
Flatfish, English Sole	2	1.24 ± 0.30	303 ± 83	39 ± 2.8	230 ± 83	247 ± 85	351 ± 91
Flatfish, Grey Sole	2	0.69 ± 0.12	158 ± 15	45 ± 3.0	109 ± 20	59 ± 18	203 ± 18
Flatfish, Gulf Flounder	2	0.47 ± 0.09	74 ± 14	34 ± 2.9	81 ± 15	34 ± 13	108 ± 17
Flatfish, Pacific Dover Sole	4	1.03 ± 0.42	187 ± 27	38 ± 11	134 ± 26	99 ± 16	229 ± 36
Flatfish, Petrale Sole	4	1.31 ± 0.21	327 ± 29	25 ± 2.1	226 ± 20	225 ± 44	360 ± 32
Flatfish, Rex Sole	2	0.71 ± 0.25	213 ± 25	33 ± 2.3	140 ± 22	87 ± 20	249 ± 28
Flatfish, Southern Flounder	1	0.38 ± 0.05	98 ± 13	39 ± 4.1	96 ± 14	45 ± 13	138 ± 18
Flatfish, Summer Flounder	5	0.78 ± 0.31	217 ± 57	28 ± 11	170 ± 61	106 ± 74	248 ± 68
Flatfish, Winter Flounder	1	1.38 ± 0.06	467 ± 95	67 ± 6.1	252 ± 11	237 ± 16	541 ± 102
Flatfish, Yellowtail Flounder	2	0.80 ± 0.12	280 ± 29	25 ± 8.2	134 ± 18	105 ± 7.6	309 ± 41
Grouper (unspecified)	3	1.26 ± 0.44	259 ± 105	62 ± 26	324 ± 156	302 ± 202	326 ± 134
Grouper, Gag	2	0.54 ± 0.03	129 ± 7.3	42 ± 5.8	109 ± 5.2	63 ± 4.1	173 ± 4.1
Grouper, Red	4	0.95 ± 0.26	118 ± 39	58 ± 14	175 ± 26	104 ± 18	178 ± 28
Grouper, Yellowedge	1	0.55 ± 0.02	147 ± 4.0	31 ± 1.3	116 ± 3.8	73 ± 9.0	178 ± 5.3
Haddock	4	0.56 ± 0.07	192 ± 24	20 ± 3.5	102 ± 15	52 ± 13	212 ± 22
Hake, Silver	2	0.81 ± 0.26	224 ± 18	12 ± 0.5	117 ± 8.2	68 ± 21	236 ± 19
Halibut, Alaskan	10	1.63 ± 1.78	299 ± 120	39 ± 40	255 ± 334	415 ± 834	345 ± 168
Halibut, California	2	0.62 ± 0.19	187 ± 64	23 ± 1.2	123 ± 31	63 ± 22	211 ± 65
Mackerel, King	1	1.34 ± 0.07	259 ± 37	74 ± 11	454 ± 57	300 ± 12	336 ± 48
Mackerel, Spanish	2	3.82 ± 0.42	633 ± 172	131 ± 18	1241 ± 177	1079 ± 88	776 ± 196
Mahi Mahi	11	0.85 ± 0.25	166 ± 50	33 ± 6.5	146 ± 60	96 ± 47	203 ± 55
Monkfish	9	0.52 ± 0.06	113 ± 31	17 ± 4.3	87 ± 8.4	67 ± 12	130 ± 35
Mullet, Striped	2	2.75 ± 2.07	707 ± 652	143 ± 91	812 ± 793	386 ± 395	905 ± 801
Pangasius/Swai (F)	8	1.21 ± 0.51	26 ± 8.9	142 ± 57	446 ± 199	411 ± 203	169 ± 64
Perch, Pacific Ocean	2	3.63 ± 0.47	638 ± 391	72 ± 21	657 ± 307	861 ± 160	743 ± 433
Perch, White	2	5.78 ± 0.90	1,025 ± 40	458 ± 28	1,239 ± 76	2,173 ± 128	1,530 ± 66
Perch, Yellow	2	0.97 ± 0.31	175 ± 19	57 ± 6.2	157 ± 20	110 ± 23	236 ± 28
Pollock, Alaskan	7	3.77 ± 5.01	249 ± 44	11 ± 4.3	127 ± 27	71 ± 19	260 ± 47
Pollock, Atlantic	4	1.10 ± 0.20	357 ± 87	25 ± 7.6	161 ± 37	130 ± 58	381 ± 94
Pompano, Florida	2	13.87 ± 5.38	925 ± 18	393 ± 70	4,444 ± 834	3,538 ± 689	1,361 ± 91
Rockfish, Brown	2	1.71 ± 0.15	396 ± 62	40 ± 2.6	312 ± 26	366 ± 106	444 ± 62
Rockfish, Widow	2	1.52 ± 0.39	376 ± 66	31 ± 11	317 ± 135	262 ± 154	416 ± 83
Roughy, Orange	5	5.80 ± 2.15	200 ± 65	190 ± 211	135 ± 33	2479 ± 656	422 ± 236
Salmon, Atlantic (F)	11	16.47 ± 4.02	2,544 ± 988	2,530 ± 1,508	2,983 ± 864	5,290 ± 1,620	5,212 ± 1,834

Table 1 continued

Species	n[a]	Total Fat (g/100 g)	n-3 (mg/100 g)[b]	n-6 (mg/100 g)[c]	SFA (mg/100 g)[d]	MUFA (mg/100 g)[e]	PUFA (mg/100 g)[f]
Salmon, Chinook (F)	2	14.18 ± 2.86	2,179 ± 433	1,173 ± 406	3,730 ± 705	6,682 ± 682	3,485 ± 139
Salmon, Chinook (W)	5	7.20 ± 1.75	1,525 ± 269	140 ± 45	1,908 ± 293	2,649 ± 497	1,738 ± 316
Salmon, Coho	7	3.48 ± 1.44	894 ± 308	66 ± 29	687 ± 290	757 ± 348	979 ± 342
Salmon, Sockeye	6	4.87 ± 1.74	934 ± 248	98 ± 38	835 ± 304	1,120 ± 484	1,052 ± 291
Scup	2	2.35 ± 1.51	450 ± 172	100 ± 52	594 ± 434	577 ± 512	561 ± 232
Sea Bass, Black	3	1.51 ± 0.71	320 ± 63	48 ± 11	297 ± 114	284 ± 154	373 ± 74
Sea Bass, Chilean	3	32.65 ± 11.00	3,011 ± 1,762	704 ± 362	5,403 ± 2,307	15,545 ± 4,443	3,798 ± 2,130
Sea Bass, White	2	0.87 ± 0.11	195 ± 37	24 ± 2.3	137 ± 40	65 ± 30	219 ± 39
Seatrout, Spotted	1	4.54 ± 0.10	804 ± 14	294 ± 5.9	1,214 ± 23	1,072 ± 29	1,161 ± 21
Shad, American	1	3.16 ± 0.03	726 ± 21	62 ± 1.4	659 ± 14	856 ± 31	801 ± 22
Shark, Common Thresher	1	0.77 ± 0.02	218 ± 3.1	42 ± 2.4	165 ± 3.3	89 ± 6.8	260 ± 5.5
Shark, Spiny Dogfish	2	6.13 ± 3.33	1,650 ± 1,001	302 ± 138	1,193 ± 681	1,770 ± 1,003	1,971 ± 1,151
Skate	2	0.80 ± 0.10	197 ± 13	30 ± 2.5	143 ± 12	71 ± 5.3	227 ± 15
Smelt, Rainbow	2	2.17 ± 0.37	632 ± 85	196 ± 25	453 ± 52	428 ± 38	838 ± 112
Snapper, Red	7	1.26 ± 0.40	281 ± 133	43 ± 16	252 ± 125	181 ± 135	328 ± 140
Snapper, Vermilion	2	1.04 ± 0.27	259 ± 70	43 ± 13	247 ± 97	106 ± 40	305 ± 85
Snapper, Yellowtail	3	1.29 ± 0.69	288 ± 160	54 ± 23	322 ± 208	159 ± 121	348 ± 188
Spot	2	11.65 ± 5.07	1,294 ± 615	320 ± 136	3,813 ± 1,829	3,566 ± 1,568	1,652 ± 780
Sturgeon, Green (F)	1	14.78 ± 1.20	1,428 ± 100	1,770 ± 147	3,043 ± 266	5,202 ± 441	3,295 ± 259
Sturgeon, White (F)	1	11.16 ± 0.16	1,277 ± 22	1,377 ± 38	2,695 ± 49	4,300 ± 71	2,743 ± 61
Sturgeon, White (W)	1	7.27 ± 0.07	1,129 ± 38	542 ± 15	1,542 ± 68	2,616 ± 41	1,780 ± 56
Swordfish	12	6.82 ± 3.96	897 ± 566	155 ± 88	1,486 ± 854	2,902 ± 1,865	1,096 ± 654
Tilapia (F)	11	2.47 ± 0.91	125 ± 40	370 ± 166	744 ± 326	764 ± 359	498 ± 200
Tilefish, (Mexico)	1	0.51 ± 0.00	164 ± 4.0	24 ± 0.6	103 ± 0.5	48 ± 0.8	191 ± 4.8
Tilefish, (North)	1	0.79 ± 0.17	151 ± 6.2	27 ± 1.9	115 ± 6.7	82 ± 6.5	178 ± 8.0
Trout, Lake	2	5.47 ± 1.96	1,216 ± 558	409 ± 163	1,157 ± 366	1,787 ± 515	1,662 ± 748
Trout, Rainbow (F)	9	5.81 ± 1.84	1,031 ± 370	598 ± 390	1,422 ± 492	1,716 ± 736	1,676 ± 445
Trout, Rainbow (W)	1	4.67 ± 0.41	414 ± 17	665 ± 37	1,140 ± 69	1,454 ± 84	1,096 ± 55
Tuna, Albacore	3	7.86 ± 4.91	2,631 ± 1,765	228 ± 143	2,144 ± 1,316	1,747 ± 1,165	2,894 ± 1928
Tuna, Yellowfin	6	0.98 ± 0.46	174 ± 125	34 ± 15	198 ± 124	131 ± 105	212 ± 140
Wahoo	2	2.11 ± 0.67	440 ± 214	63 ± 35	597 ± 359	474 ± 352	516 ± 262
Walleye	2	2.05 ± 0.79	401 ± 278	131 ± 107	303 ± 218	461 ± 448	545 ± 398
Whitefish, Lake	6	4.43 ± 0.62	1,025 ± 250	341 ± 62	892 ± 174	1,426 ± 316	1,412 ± 321
Whiting, Pacific	2	1.58 ± 0.23	432 ± 51	32 ± 4.9	344 ± 22	307 ± 33	478 ± 55

[a] Number of composite samples; each composite contains three fish

[b] Total of all n-3 fatty acids in fillets, including 18:3n-3, 18:4n-3, 20:3n-3, 20:4n-3, 20:5n-3, 22:5n-3, and 22:6n-3

[c] Total of all n-6 fatty acids in fillets, including 18:2n-6, 18:3n-6, 20:2n-6, 20:3n-6, 20:4n-6, 22:2n-6, and 22:4n-6

[d] Total of all SFA in fillets, including 12:0, 14:0, 16:0, 18:0, 20:0, 22:0, and 24:0

[e] Total of all MUFA in fillets, including 14:1n-5, 16:1n-7, 18:1n-7, 18:1n-9, 20:1n-9, 22:1n-9, and 24:1n-9

[f] Total of all PUFA in fillets, including n-3, n-6, 16:2n-4, 16:3n-4, and 18:3n-4

[g] (F) indicates farmed species and (W) indicates wild species. All unlabeled species are wild

sea bass), with albacore tuna (2,631 mg/100 g), Atlantic salmon (2,544 mg/100 g), and farmed Chinook salmon (2,179 mg/100 g) having the next highest total n-3 content. Total n-6 fatty acids, including LNA, GLA, 20:2n-6, 20:3n-6, ARA, 22:2n-6, and 22:4n-6, in fillets ranged from 11 mg/100 g (Alaskan pollock) to 2,530 mg/100 g (Atlantic salmon). Interestingly, the six species with the highest n-6 content were all farmed, including Atlantic salmon (2,530 mg/100 g), green sturgeon (1,770 mg/100 g), white sturgeon (1,377 mg/100 g), channel catfish (1,201 mg/100 g), Chinook salmon (1,173 mg/100 g), and striped bass (914 mg/100 g).

Table 2 SFA and MUFA in fillets of commercially-available U.S. finfish (mg fatty acid/100 g raw tissue)

Species	*n*[a]	14:0	16:0	18:0	18:1n-9
Amberjack, Greater	2	2.3 ± 0.5	92 ± 11	43 ± 3.9	33 ± 8.0
Amberjack, Yellowtail	2	81 ± 9.1	428 ± 45	152 ± 11	335 ± 15
Bass, Striped (F)[b]	5	162 ± 66	1,098 ± 284	178 ± 43	1,843 ± 441
Bass, Striped (W)[b]	5	97 ± 57	382 ± 161	81 ± 24	240 ± 108
Bluefish	3	155 ± 99	808 ± 562	252 ± 181	562 ± 434
Catfish, Channel (F)	11	72 ± 17	1,297 ± 294	330 ± 91	3,227 ± 802
Cod, Atlantic (F)	1	4.1 ± 0.1	98 ± 6.8	25 ± 1.6	44 ± 3.3
Cod, Atlantic (W)	8	4.9 ± 1.1	93 ± 12	23 ± 3.8	17 ± 6.6
Cod, Lingcod	4	26 ± 12	154 ± 43	40 ± 8.8	121 ± 58
Cod, Pacific	2	3.4 ± 0.6	77 ± 16	19 ± 3.1	31 ± 6.7
Cod, Sablefish	4	430 ± 149	2,417 ± 454	428 ± 52	4,474 ± 542
Croaker, Atlantic	5	92 ± 76	1,059 ± 788	218 ± 146	621 ± 485
Flatfish, American Plaice	2	199 ± 162	261 ± 138	52 ± 16	215 ± 169
Flatfish, English Sole	2	33 ± 14	159 ± 59	37 ± 10	118 ± 52
Flatfish, Grey Sole	2	7.0 ± 4.2	78 ± 12	23 ± 3.8	22 ± 5.6
Flatfish, Gulf Flounder	2	2.8 ± 1.6	57 ± 10	20 ± 2.2	21 ± 3.4
Flatfish, Pacific Dover Sole	4	13 ± 4.5	94 ± 14	26 ± 8.4	43 ± 4.7
Flatfish, Petrale Sole	4	26 ± 3.3	164 ± 18	36 ± 3.1	113 ± 26
Flatfish, Rex Sole	2	9.3 ± 1.9	103 ± 14	27 ± 6.4	35 ± 6.2
Flatfish, Southern Flounder	1	4.0 ± 1.4	67 ± 9.5	25 ± 3.6	30 ± 7.4
Flatfish, Summer Flounder	5	14 ± 9.4	123 ± 40	33 ± 10	58 ± 42
Flatfish, Winter Flounder	1	37 ± 2.5	172 ± 7.5	41 ± 0.6	97 ± 7.4
Flatfish, Yellowtail Flounder	2	15 ± 3.1	94 ± 12	26 ± 2.9	45 ± 3.2
Grouper (unspecified)	3	36 ± 21	219 ± 105	64 ± 28	178 ± 122
Grouper, Gag	2	4.2 ± 1.0	70 ± 3.2	35 ± 1.6	42 ± 3.3
Grouper, Red	4	15 ± 6.7	114 ± 17	44 ± 3.6	59 ± 6.6
Grouper, Yellowedge	1	3.9 ± 0.9	82 ± 2.5	29 ± 0.5	46 ± 5.1
Haddock	4	4.0 ± 1.0	76 ± 12	21 ± 3.6	26 ± 7.6
Hake, Silver	2	4.2 ± 2.4	88 ± 7.2	25 ± 2.9	35 ± 8.8
Halibut, Alaskan	10	48 ± 90	165 ± 211	41 ± 30	211 ± 443
Halibut, California	2	8.6 ± 3.6	86 ± 21	28 ± 6.4	35 ± 11
Mackerel, King	1	23 ± 1.8	299 ± 37	121 ± 16	194 ± 10
Mackerel, Spanish	2	58 ± 20	858 ± 135	288 ± 28	800 ± 106
Mahi Mahi	11	7.3 ± 5.3	90 ± 43	47 ± 11	67 ± 32
Monkfish	9	3.8 ± 1.3	62 ± 5.8	21 ± 3.0	37 ± 7.2
Mullet, Striped	2	92 ± 101	627 ± 630	85 ± 54	147 ± 148
Pangasius/Swai (F)	8	37 ± 17	310 ± 137	94 ± 43	378 ± 190
Perch, Pacific Ocean	2	90 ± 46	477 ± 229	84 ± 31	434 ± 85
Perch, White	2	125 ± 9.9	963 ± 59	137 ± 11	1,148 ± 55
Perch, Yellow	2	9.3 ± 3.3	113 ± 14	34 ± 3.1	40 ± 6.5
Pollock, Alaskan	7	5.3 ± 1.9	98 ± 21	30 ± 6.3	36 ± 13
Pollock, Atlantic	4	5.9 ± 3.4	118 ± 26	38 ± 8.5	74 ± 28
Pompano, Florida	2	320 ± 105	3,016 ± 508	1,022 ± 204	2,412 ± 540
Rockfish, Brown	2	45 ± 12	211 ± 16	52 ± 3.7	163 ± 34
Rockfish, Widow	2	46 ± 39	217 ± 82	51 ± 12	141 ± 86
Roughy, Orange	5	26 ± 6.0	79 ± 20	26 ± 7.7	1,511 ± 436
Salmon, Atlantic (F)	11	489 ± 236	1,895 ± 532	533 ± 209	3,764 ± 1,604
Salmon, Chinook (F)	2	446 ± 72	2,599 ± 485	643 ± 141	4,803 ± 419

Table 2 continued

Species	n[a]	14:0	16:0	18:0	18:1n-9
Salmon, Chinook (W)	5	328 ± 149	1,268 ± 162	291 ± 40	1,685 ± 288
Salmon, Coho	7	119 ± 76	469 ± 197	93 ± 27	387 ± 134
Salmon, Sockeye	6	142 ± 64	590 ± 212	96 ± 26	591 ± 247
Scup	2	52 ± 44	378 ± 276	154 ± 107	384 ± 363
Sea Bass, Black	3	25 ± 14	208 ± 82	58 ± 16	148 ± 82
Sea Bass, Chilean	3	1,851 ± 1,216	2,969 ± 1,129	550 ± 200	8,685 ± 1,873
Sea Bass, White	2	6.2 ± 3.9	95 ± 28	35 ± 8.0	36 ± 16
Seatrout, Spotted	1	149 ± 2.6	866 ± 17	179 ± 3.5	427 ± 13
Shad, American	1	132 ± 1.4	441 ± 10	78 ± 2.1	199 ± 5.0
Shark, Common Thresher	1	4.0 ± 0.0	107 ± 2.2	54 ± 1.0	35 ± 5.4
Shark, Spiny Dogfish	2	77 ± 46	936 ± 550	176 ± 81	842 ± 466
Skate	2	4.0 ± 0.2	115 ± 9.8	24 ± 2.0	37 ± 2.7
Smelt, Rainbow	2	81 ± 8.9	317 ± 45	50 ± 4.4	233 ± 15
Snapper, Red	7	24 ± 19	170 ± 83	56 ± 30	104 ± 73
Snapper, Vermilion	2	22 ± 19	160 ± 52	62 ± 22	58 ± 15
Snapper, Yellowtail	3	28 ± 17	211 ± 138	73 ± 43	92 ± 69
Spot	2	260 ± 153	2,872 ± 1,370	621 ± 276	2,101 ± 1,044
Sturgeon, Green (F)	1	368 ± 37	2,304 ± 206	347 ± 21	3,983 ± 331
Sturgeon, White (F)	1	329 ± 6.3	2,061 ± 36	285 ± 6.2	3,263 ± 79
Sturgeon, White (W)	1	139 ± 5.1	1,205 ± 58	148 ± 4.3	1,564 ± 32
Swordfish	12	159 ± 115	979 ± 546	316 ± 191	1,904 ± 1,236
Tilapia (F)	11	73 ± 41	519 ± 223	134 ± 53	566 ± 275
Tilefish, (Mexico)	1	2.8 ± 0.4	78 ± 0.1	23 ± 0.2	31 ± 0.3
Tilefish, (North)	1	5.0 ± 0.7	87 ± 4.8	23 ± 1.2	50 ± 3.6
Trout, Lake	2	149 ± 74	814 ± 260	177 ± 30	1,040 ± 243
Trout, Rainbow (F)	9	170 ± 62	986 ± 346	250 ± 115	1,157 ± 616
Trout, Rainbow (W)	1	97 ± 5.6	801 ± 49	230 ± 14	1,077 ± 63
Tuna, Albacore	3	238 ± 172	1,434 ± 851	443 ± 280	1,091 ± 721
Tuna, Yellowfin	6	10 ± 13	128 ± 82	55 ± 25	84 ± 59
Wahoo	2	25 ± 17	438 ± 266	122 ± 69	328 ± 246
Walleye	2	42 ± 42	226 ± 156	34 ± 19	255 ± 255
Whitefish, Lake	6	134 ± 40	639 ± 127	105 ± 21	737 ± 163
Whiting, Pacific	2	36 ± 6.1	266 ± 21	42 ± 1.3	157 ± 26

[a] Number of composite samples; each composite contained three fish

[b] (F) indicates farmed species and (W) indicates wild species. All unlabeled species were wild

Total SFA, including 12:0, myristic acid, palmitic acid, stearic acid, 20:0, 22:0, and 24:0, in fillets ranged from 81 mg/100 g (gulf flounder) to 5,403 mg/100 g (Chilean sea bass), with four of the eight highest SFA containing species being farmed (Chinook salmon, green sturgeon, Atlantic salmon, and white sturgeon). Total MUFA, including 14:1n-5, 16:1n-7, 18:1n-7, oleic acid, 20:1n-9, 22:1n-9, and 24:1n-9, in fillets ranged from 34 mg/100 g (gulf flounder) to 15,545 mg/100 g (Chilean sea bass), with the same farmed species plus farmed channel catfish accounting for five of the seven highest MUFA species. Finally, total PUFA, including n-3, n-6, 16:2n-4, 16:3n-4, and 18:3n-4, in fillets ranged from 108 mg/100 g (gulf flounder) to 5,212 mg/100 g (Atlantic salmon), with farmed salmon and sturgeon species again having some of the highest total PUFA concentrations.

Figures 1 and 2 show the average amount of EPA plus DHA obtained from consuming 100 g (uncooked weight) of fillets from each species, and compares the results of this study to the USDA-ARS NND [31]. The data from the database was obtained by performing an exhaustive search for each species and obtaining the amount of EPA and DHA in 100 g of each species. In general, the results of this study compared well with the database, though a few

Table 3 PUFA in fillets of commercially-available U.S. finfish (mg fatty acid/100 g raw tissue)

Species	n[a]	LNA 18:2n-6	ALA 18:3n-3	GLA 18:3n-6	SDA 18:4n-3	ARA 20:4n-6	EPA 20:5n-3	DPAn-3 22:5n-3	DHA 22:6n-3
Amberjack, Greater	2	3.9 ± 0.3	nd[b]	nd	nd	31 ± 7.8	11 ± 0.9	13 ± 1.0	125 ± 15
Amberjack, Yellowtail	2	27 ± 4.0	14 ± 4.9	2.9 ± 0.4	22 ± 11	33 ± 4.5	157 ± 30	64 ± 9.6	442 ± 32
Bass, Striped (F)[c]	5	775 ± 166	79 ± 16	16 ± 4.2	24 ± 12	53 ± 6.8	234 ± 71	74 ± 21	267 ± 63
Bass, Striped (W)[c]	5	26 ± 16	26 ± 20	3.7 ± 3.1	36 ± 25	37 ± 11	178 ± 88	52 ± 20	293 ± 88
Bluefish	3	44 ± 29	38 ± 33	5.0 ± 3.6	43 ± 24	63 ± 44	166 ± 98	94 ± 65	523 ± 313
Catfish, Channel (F)	11	983 ± 227	61 ± 12	27 ± 5.9	5.0 ± 1.9	53 ± 12	8.5 ± 2.4	11 ± 2.7	35 ± 9.0
Cod, Atlantic (F)	1	3.1 ± 0.5	1.1 ± 0.2	nd	1.7 ± 0.1	19 ± 0.3	85 ± 4.8	7.8 ± 0.3	168 ± 9.6
Cod, Atlantic (W)	8	3.9 ± 1.2	1.1 ± 0.5	nd	2.3 ± 1.5	12 ± 3.6	74 ± 24	7.4 ± 2.5	167 ± 29
Cod, Lingcod	4	10 ± 3.8	4.6 ± 1.6	nd	11 ± 5.0	17 ± 4.9	99 ± 23	14 ± 5.0	202 ± 29
Cod, Pacific	2	2.1 ± 0.3	nd	nd	nd	16 ± 3.3	62 ± 9.9	7.0 ± 0.6	134 ± 29
Cod, Sablefish	4	124 ± 24	61 ± 26	8.4 ± 3.9	102 ± 85	102 ± 20	653 ± 493	125 ± 49	566 ± 354
Croaker, Atlantic	5	28 ± 20	17 ± 13	2.8 ± 2.5	26 ± 23	63 ± 18	207 ± 135	106 ± 64	287 ± 126
Flatfish, American Plaice	2	23 ± 16	12 ± 9.7	nd	10 ± 5.2	39 ± 9.0	160 ± 51	29 ± 12	126 ± 27
Flatfish, English Sole	2	6.8 ± 1.3	3.2 ± 0.8	nd	6.4 ± 2.3	24 ± 1.6	130 ± 41	29 ± 3.7	130 ± 34
Flatfish, Grey Sole	2	3.1 ± 0.6	nd	nd	nd	30 ± 1.2	59 ± 7.2	19 ± 2.0	79 ± 5.8
Flatfish, Gulf Flounder	2	2.0 ± 0.6	nd	nd	nd	27 ± 1.1	9.9 ± 3.1	13 ± 8.9	52 ± 3.3
Flatfish, Pacific Dover Sole	4	4.6 ± 1.4	1.2 ± 0.9	nd	2.3 ± 1.0	25 ± 7.0	70 ± 10	22 ± 4.8	90 ± 14
Flatfish, Petrale Sole	4	7.1 ± 0.8	3.4 ± 0.4	nd	7.9 ± 1.1	15 ± 1.2	102 ± 12	31 ± 4.1	180 ± 14
Flatfish, Rex Sole	2	5.6 ± 2.2	nd	nd	2.4 ± 0.8	20 ± 0.5	82 ± 13	19 ± 3.8	107 ± 6.0
Flatfish, Southern Flounder	1	2.7 ± 0.5	nd	nd	nd	31 ± 2.6	13 ± 2.1	12 ± 0.8	73 ± 11
Flatfish, Summer Flounder	5	3.8 ± 1.7	nd	nd	2.0 ± 1.3	20 ± 5.8	30 ± 14	26 ± 14	156 ± 29
Flatfish, Winter Flounder	1	13 ± 1.5	8.3 ± 1.2	nd	35 ± 9.6	37 ± 1.3	179 ± 37	36 ± 6.2	194 ± 38
Flatfish, Yellowtail Flounder	2	5.4 ± 1.3	2.1 ± 0.9	nd	9.5 ± 8.0	15 ± 2.7	103 ± 19	19 ± 6.3	141 ± 11
Grouper (unspecified)	3	11 ± 6.0	4.5 ± 3.3	nd	2.7 ± 2.5	35 ± 13	42 ± 24	35 ± 16	168 ± 57
Grouper, Gag	2	3.8 ± 0.2	nd	nd	nd	30 ± 3.8	12 ± 2.9	9.4 ± 0.7	108 ± 5.1
Grouper, Red	4	4.8 ± 0.7	nd	nd	1.0 ± 1.9	38 ± 9.6	13 ± 2.8	15 ± 7.9	87 ± 37
Grouper, Yellowedge	1	2.7 ± 0.2	nd	nd	nd	21 ± 0.3	12 ± 0.5	13 ± 1.2	123 ± 2.3
Haddock	4	2.6 ± 0.4	nd	nd	1.4 ± 1.2	14 ± 2.3	69 ± 15	9.4 ± 0.9	110 ± 26
Hake, Silver	2	3.8 ± 1.0	nd	nd	nd	7.7 ± 1.1	36 ± 3.3	7.1 ± 0.3	178 ± 21
Halibut, Alaskan	10	14 ± 23	5.4 ± 11	nd[b]	9.7 ± 17	18 ± 7.8	90 ± 36	20 ± 11	166 ± 45
Halibut, California	2	4.1 ± 1.2	nd	nd	1.2 ± 1.4	16 ± 1.7	25 ± 6.5	20 ± 3.3	139 ± 50
Mackerel, King	1	13 ± 1.6	4.9 ± 0.5	1.3 ± 0.2	3.3 ± 0.1	47 ± 7.1	42 ± 5.0	20 ± 2.5	186 ± 29
Mackerel, Spanish	2	35 ± 2.3	15 ± 11	3.2 ± 0.6	11 ± 5.6	69 ± 12	102 ± 36	37 ± 11	461 ± 105
Mahi Mahi	11	4.4 ± 1.4	nd	nd	nd	26 ± 4.8	17 ± 7.0	8.0 ± 3.6	139 ± 39
Monkfish	9	4.5 ± 1.1	nd	nd	nd	12 ± 3.6	22 ± 7.7	4.7 ± 2.2	86 ± 24
Mullet, Striped	2	61 ± 64	19 ± 21	13 ± 13	161 ± 184	56 ± 10	174 ± 153	68 ± 41	263 ± 231
Pangasius/Swai (F)	8	96 ± 46	5.0 ± 2.5	2.8 ± 1.4	nd	20 ± 4.6	2.1 ± 0.9	3.9 ± 0.9	15 ± 5.5
Perch, Pacific Ocean	2	34 ± 7.6	15 ± 7.5	2.9 ± 1.8	45 ± 36	26 ± 8.0	272 ± 212	22 ± 14	272 ± 116
Perch, White	2	166 ± 20	156 ± 13	11 ± 0.8	36 ± 5.0	218 ± 6.7	345 ± 12	119 ± 8.6	313 ± 16
Perch, Yellow	2	18 ± 1.5	5.3 ± 1.1	nd	2.4 ± 0.5	34 ± 4.0	52 ± 6.8	14 ± 1.7	99 ± 9.0
Pollock, Alaskan	7	4.1 ± 3.0	nd	nd	2.2 ± 0.5	6.8 ± 2.2	88 ± 19	7.4 ± 2.2	148 ± 27
Pollock, Atlantic	4	7.4 ± 4.0	2.3 ± 1.4	nd	2.2 ± 1.6	16 ± 3.3	69 ± 17	8.9 ± 3.4	271 ± 67

Table 3 continued

Species	n[a]	LNA 18:2n-6	ALA 18:3n-3	GLA 18:3n-6	SDA 18:4n-3	ARA 20:4n-6	EPA 20:5n-3	DPAn-3 22:5n-3	DHA 22:6n-3
Pompano, Florida	2	43 ± 4.0	32 ± 9.1	9.7 ± 0.2	27 ± 5.9	157 ± 10	148 ± 23	204 ± 29	469 ± 26
Rockfish, Brown	2	14 ± 3.1	5.8 ± 1.8	nd	9.4 ± 3.9	21 ± 3.9	107 ± 15	23 ± 2.2	244 ± 41
Rockfish, Widow	2	14 ± 4.6	5.7 ± 4.0	nd	11 ± 8.0	13 ± 2.5	110 ± 51	16 ± 5.3	228 ± 10
Roughy, Orange	5	42 ± 12	11 ± 7.4	6.2 ± 9.9	5.6 ± 4.9	29 ± 14	40 ± 19	6.8 ± 6.3	112 ± 29
Salmon, Atlantic (F)	11	2,207 ± 1,386	406 ± 191	28 ± 13	131 ± 91	66 ± 17	664 ± 271	333 ± 126	845 ± 470
Salmon, Chinook (F)	2	963 ± 345	154 ± 19	18 ± 1.7	112 ± 4.9	75 ± 4.6	737 ± 241	272 ± 90	796 ± 130
Salmon, Chinook (W)	5	76 ± 34	52 ± 26	4.4 ± 2.5	100 ± 65	35 ± 4.0	496 ± 40	184 ± 51	610 ± 141
Salmon, Coho	7	32 ± 15	24 ± 12	2.3 ± 1.9	45 ± 29	17 ± 4.3	227 ± 81	74 ± 24	490 ± 190
Salmon, Sockeye	6	56 ± 24	30 ± 12	2.7 ± 1.0	46 ± 18	18 ± 5.0	262 ± 93	75 ± 26	479 ± 93
Scup	2	11 ± 5.4	4.2 ± 3.1	nd	6.0 ± 3.1	61 ± 29	131 ± 63	74 ± 37	229 ± 62
Sea Bass, Black	3	8.7 ± 2.4	3.8 ± 1.1	nd	4.7 ± 1.6	27 ± 5.8	85 ± 33	28 ± 8.3	193 ± 23
Sea Bass, Chilean	3	431 ± 280	124 ± 72	32 ± 21	245 ± 169	128 ± 51	1,277 ± 951	102 ± 28	1,153 ± 560
Sea Bass, White	2	5.0 ± 1.9	nd	nd	1.3 ± 1.5	17 ± 0.8	27 ± 11	7.8 ± 0.4	157 ± 23
Seatrout, Spotted	1	85 ± 2.0	66 ± 1.4	21 ± 0.5	41 ± 0.9	123 ± 2.1	191 ± 4.2	87 ± 2.1	382 ± 4.3
Shad, American	1	30 ± 0.7	17 ± 0.5	2.6 ± 0.1	32 ± 0.8	18 ± 0.5	133 ± 3.3	45 ± 0.8	470 ± 15
Shark, Common Thresher	1	3.4 ± 1.8	nd	nd	nd	28 ± 0.4	13 ± 0	38 ± 0.5	166 ± 2.6
Shark, Spiny Dogfish	2	93 ± 51	36 ± 23	5.2 ± 3.2	48 ± 30	133 ± 79	337 ± 206	119 ± 70	1064 ± 646
Skate	2	6.6 ± 0.3	1.8 ± 0	nd[b]	1.3 ± 0.1	18 ± 1.8	32 ± 2.7	20 ± 1.4	139 ± 9.0
Smelt, Rainbow	2	89 ± 6.4	88 ± 20	5.7 ± 0.3	58 ± 27	73 ± 5.4	173 ± 13	26 ± 14	248 ± 76
Snapper, Red	7	9.0 ± 5.6	3.6 ± 3.9	nd	6.1 ± 9.2	26 ± 11	57 ± 54	15 ± 5.2	196 ± 66
Snapper, Vermilion	2	8.3 ± 4.6	2.6 ± 3.0	nd	3.0 ± 3.4	26 ± 6.3	32 ± 20	13 ± 2.8	207 ± 40
Snapper, Yellowtail	3	14 ± 5.4	5.4 ± 4.2	nd	3.3 ± 1.6	29 ± 10	37 ± 25	15 ± 12	222 ± 115
Spot	2	72 ± 50	38 ± 27	4.9 ± 3.5	42 ± 38	128 ± 56	485 ± 166	219 ± 43	464 ± 307
Sturgeon, Green (F)	1	1,331 ± 115	84 ± 8.2	93 ± 8.8	50 ± 4.5	178 ± 10	404 ± 29	172 ± 12	663 ± 41
Sturgeon, White (F)	1	1,109 ± 31	80 ± 2.5	48 ± 1.8	48 ± 1.9	112 ± 1.7	410 ± 8.9	155 ± 2.9	529 ± 4.9
Sturgeon, White (W)	1	161 ± 3.6	131 ± 4.9	11.7 ± 0.1	65 ± 2.0	226 ± 7.4	511 ± 16	161 ± 6.7	156 ± 5.0
Swordfish	12	43 ± 34	17 ± 16	1.7 ± 2.1	13 ± 22	60 ± 30	130 ± 133	123 ± 81	574 ± 327
Tilapia (F)	11	268 ± 133	20 ± 7.9	14 ± 7.1	2.5 ± 1.5	38 ± 8.5	5.9 ± 2.1	21 ± 10	70 ± 21
Tilefish, (Mexico)	1	2.2 ± 0	nd	nd	nd	18 ± 0.5	13 ± 0.1	10 ± 0.1	141 ± 3.8
Tilefish, (North)	1	2.7 ± 0.7	nd	nd	nd	18 ± 1.0	12 ± 1.0	17 ± 1.9	123 ± 3.2
Trout, Lake	2	166 ± 68	115 ± 58	9.2 ± 4.9	49 ± 28	136 ± 42	234 ± 85	138 ± 47	571 ± 261
Trout, Rainbow (F)	9	471 ± 330	49 ± 20	10 ± 6.4	32 ± 13	51 ± 15	229 ± 125	89 ± 49	598 ± 179
Trout, Rainbow (W)	1	527 ± 29	35 ± 1.9	14 ± 1.1	12 ± 0.7	45 ± 1.7	64 ± 3.2	26 ± 1.1	264 ± 9.3
Tuna, Albacore	3	94 ± 66	51 ± 39	11 ± 7.4	110 ± 85	85 ± 48	646 ± 492	108 ± 87	1,658 ± 1046
Tuna, Yellowfin	6	6.1 ± 4.2	1.4 ± 2.3	nd	1.5 ± 2.8	23 ± 7.0	26 ± 29	8.3 ± 6.8	135 ± 81
Wahoo	2	14 ± 8.2	2.6 ± 3.1	nd	4.1 ± 2.3	36 ± 17	45 ± 23	25 ± 18	356 ± 163
Walleye	2	52 ± 52	46 ± 45	2.5 ± 2.9	18 ± 17	64 ± 43	109 ± 76	30 ± 20	186 ± 111
Whitefish, Lake	6	142 ± 42	108 ± 32	12 ± 3.5	77 ± 33	118 ± 20	277 ± 60	100 ± 15	387 ± 103
Whiting, Pacific	2	15 ± 2.3	8.3 ± 2.7	1.2 ± 0.1	17 ± 4.1	13 ± 1.7	193 ± 17	11 ± 1.0	196 ± 25

[a] Number of composite samples; each composite contained three fish

[b] nd indicates samples that were below the limits of quantitation or not detected. The LOQ was 1 mg fatty acid/100 g raw tissue

[c] (F) indicates farmed species and (W) indicates wild species. All unlabeled species were wild

species, including common thresher shark, Spanish mackerel, American shad, Chilean sea bass, green sturgeon, and white sturgeon, exhibited large differences. These differences may be due to the small number of composites in either this study or the USDA-ARS NND or the lack of specificity in the database's classification of species (e.g.,

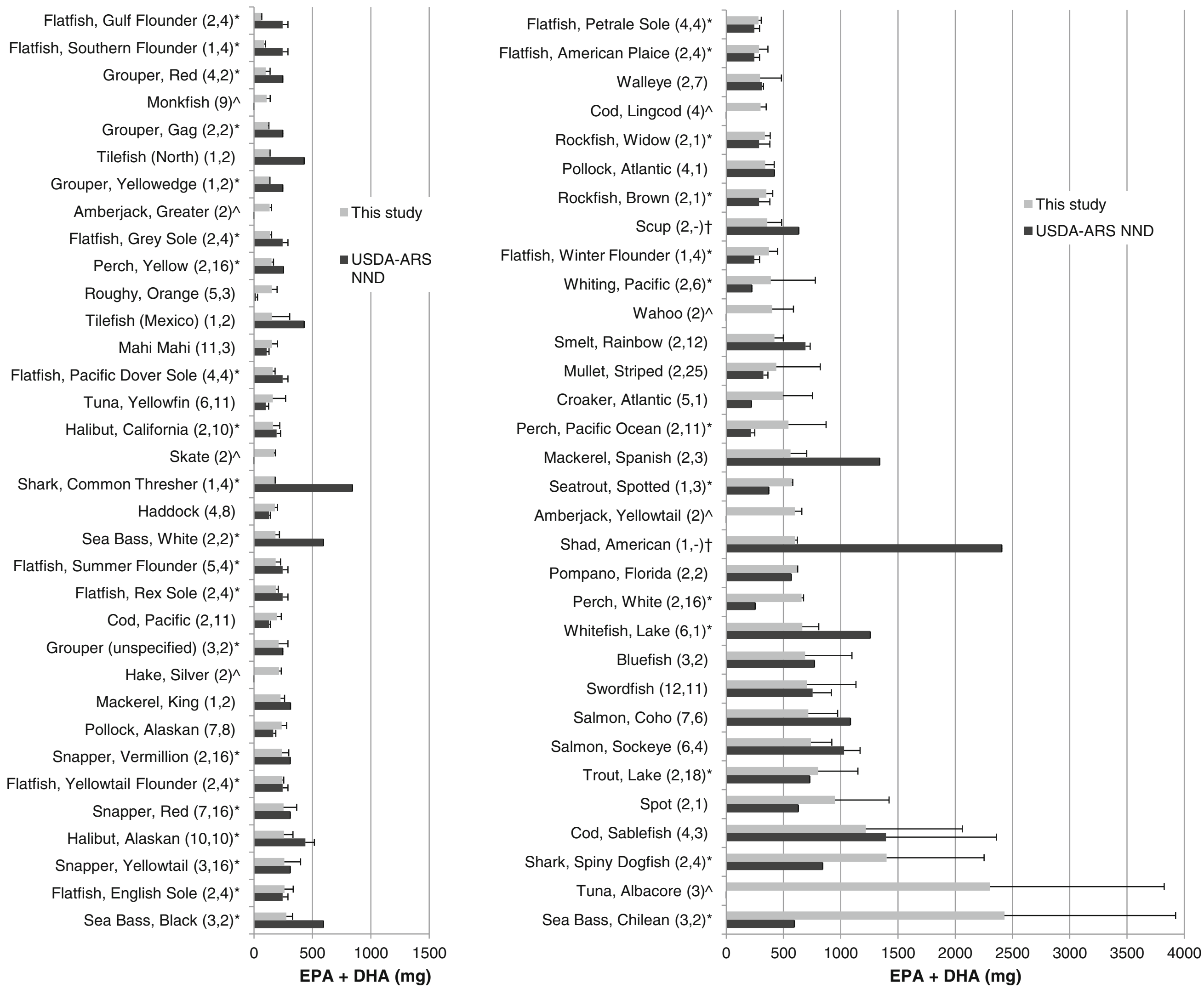

Fig. 1 EPA plus DHA content in 100 g of fillets from wild-caught species collected in this study, with a comparison to the USDA-ARS NND [31]. *Numbers in parentheses* represent the number of composites (three fish each) collected for each species in this study, followed by the "number of data points" included in the USDA-ARS NND. *Error bars* represent the standard deviation for the data in this study and the standard error for data from the USDA-ARS NND (when listed in the database). *Asterisk* indicates that USDA-ARS NND data is not specific to the species, but is the closest approximation. For example, all flatfish are listed as "flatfish–flounder and sole species" in the database, while the current study differentiates between individual species. *Cap symbol* indicates that no data is available on the EPA plus DHA content in the USDA-ARS NND. *Dagger* indicates that data for the EPA plus DHA content was given in the USDA-ARS NND, but the total number of data points was zero

shark species are not differentiated). Because EPA and DHA are considered important fatty acids for health, the USDA-DHHS Dietary Guidelines for Americans, 2010, recommends consuming 227–340 g (8–12 oz) of fish per week [22], which may provide an average of 250 mg EPA plus DHA per day [22], or 1,750 mg per week, for a healthy diet. Based on the results of this study, consuming 227 g (8 oz) of albacore tuna, Atlantic salmon, Chilean sea bass, Chinook salmon (farmed or wild), green sturgeon, lake trout, farmed rainbow trout, sablefish, spiny dogfish, spot, or farmed white sturgeon will, on average, provide the recommended amount of EPA plus DHA each week.

Discussion

When examining the fatty acid concentrations of the fish analyzed in this study, large standard deviations were observed for all species, due to fish being harvested from different locations, at different times of the year, and with potentially different feed formulations [37, 38]. Large standard deviations have also been observed in other studies [39, 40], illustrating the challenges in creating accurate nutrient databases. Thus, studies like this one are important to continually update and expand available information, while reflecting the current status of commercially-available fish.

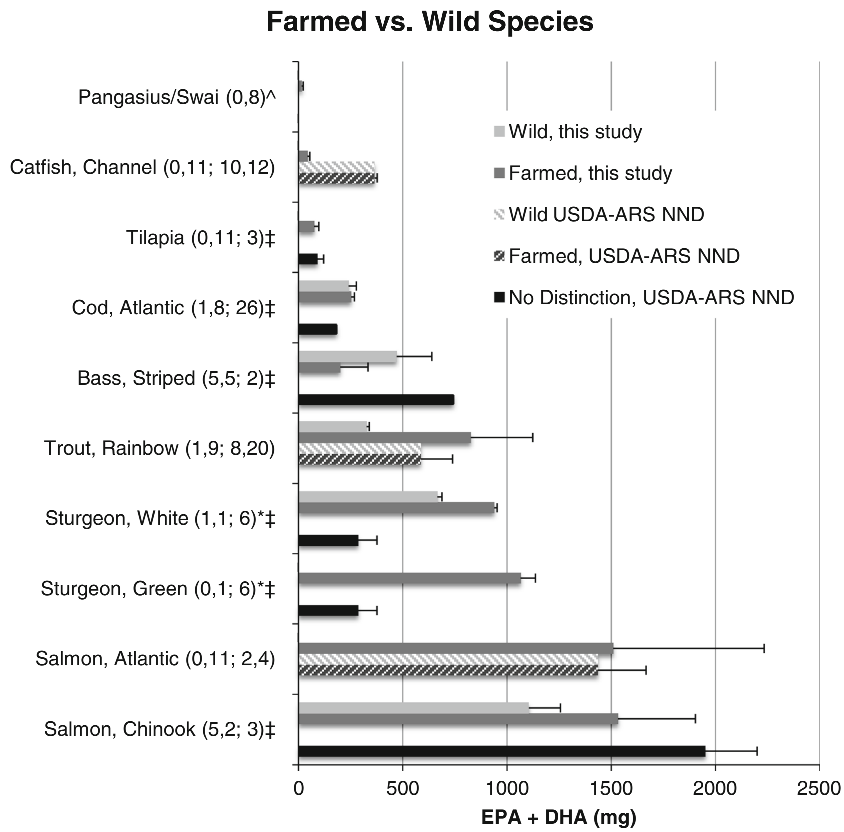

Fig. 2 EPA plus DHA content in 100 g of fillets from farmed species collected in this study. A comparison to the USDA-ARS NND [31] is also shown. Only channel catfish, rainbow trout, and Atlantic salmon are differentiated as farmed or wild in the database, while other species are not differentiated (shown as "No Distinction"). *Numbers in parentheses* represent the number of composites (three fish each) collected for each species in this study and the "number of data points" included in the USDA-ARS NND. The numbers are given in the following format: (number of wild composites in this study, number of farmed composites in this study; number of wild data points USDA-ARS NND, number of farmed data points USDA-ARS NND). *Error bars* represent the standard deviation for the data in this study and the standard error for data from the USDA-ARS NND (when listed in the database). *Asterisk* indicates that USDA-ARS NND data is not specific to the species, but is the closest approximation. *Cap symbol* indicates that no data is available on the EPA plus DHA content in the USDA-ARS NND. *Double dagger* indicates that there is no distinction between farmed and wild fish in the USDA-ARS NND; the number of data points from the database represents the total number for that species

In an effort to bolster the USDA-ARS NND [31], the samples collected in this study were tracked (i.e., for harvest location and size parameters), and they were collected from different regions of the US during different seasons. In addition, related species (i.e., species in the same family or genus) were differentiated to provide clarity to consumers. For example, although Chilean, black, and white sea bass are all members of different genera, each species is sold as "sea bass" in retail markets. The current study found that Chilean sea bass had higher concentrations of all fatty acids than black or white sea bass. These differences were magnified when comparing the EPA plus DHA content of each sea bass species. Chilean sea bass (2,430 mg per 100 g) contained far more EPA plus DHA than black sea bass (278 mg per 100 g) or white sea bass (184 mg per 100 g). However, the USDA-ARS NND only lists "sea bass, mixed species", with average EPA plus DHA content at 595 mg per 100 g [31]. Sea bass, in particular, is a highly substituted species; several vendors substituted Chilean sea bass for black sea bass during this study. Based on the results of this study, several other related species, including flatfish, grouper, perch, rockfish, shark, snapper, and sturgeon, also exhibit differences between species and would benefit from being differentiated as separate species.

Fatty acid profiles in fish depend on a number of factors, with dietary nutrients being the easiest factor to manipulate [41]. For wild-caught species, the diet is determined by changes in environmental conditions, while the composition of farmed species is dependent upon the amount and composition of the feed [32]. In order to control costs, diets high in inexpensive and readily available fatty acids, like SFA, MUFA, and n-6 obtained from plant or animal sources, are often used in aquaculture [41, 42]. Although the fillets analyzed in this study were obtained from commercial vendors and no information on the feed formulations of farmed fish was available, SFA, MUFA, and n-6 fatty acids were measured in much higher concentrations in many farmed species than in the wild species analyzed. Total n-3 content was higher in many farm-raised fillets than wild-caught fillets, but the difference was not as dramatic as it was with other fatty acids. This is most likely due to the higher costs associated with diets high in n-3 fatty acids, which are derived from fish oils [41, 42]. Because of the additional costs associated with diets high in n-3 fatty acids, they are often incorporated into the diet late in the lifetime of farmed fish [43]. These differences, combined with the ability of farmers to continually modify diets, requires constant monitoring of fatty acids–particularly EPA, DHA, and n-3 content–in farmed species to provide consumers with current and accurate information.

Figure 2 illustrates how farmed species in this study compare to those in the USDA-ARS NND [31]. Most species compared well, though Chinook salmon and sturgeon showed differences. The EPA plus DHA content of farmed (1,533 mg/100 g) and wild (1,106 mg/100 g) Chinook salmon in this study were found to be quite different and did not match the USDA-ARS NND (1,952 mg/100 g) [31]. Sturgeon (farmed green: 1,067 mg/100 g, farmed white: 939 mg/100 g, wild-caught white: 667 mg/100 g, and mixed species (USDA-ARS NND [31]): 287 mg/100 g) exhibited even larger differences. Figure 2 also illustrates the differences in five species that were obtained from both farmed and wild origins. In all five cases, EPA plus DHA content was higher in farmed samples than wild samples, indicating that farm-raised fish are better sources of EPA plus DHA than their wild-caught counterparts.

Studies like the one presented here have many strengths, but are not without limitations. For the current study, fish were obtained directly from commercial seafood vendors to most accurately reflect products that are being sold in U.S. markets and consumed by the public. This methodology has direct relevance for public health, but did limit the ability to monitor the quality of the product from harvest to analysis. EPA and DHA are easily oxidized and may have been affected before samples were received and tested. However, all fish sold in commercial markets are subject to these same conditions and challenges. Thus, this was a necessary limitation in the current study. Additional limitations included the inability to monitor the dietary status of farmed samples and budget constraints that did not allow for genetic testing to confirm species identification. Finally, compositing samples helped control costs, shorten analysis time, and achieved the overall goal of providing data on a variety of species, but limited statistical analysis because composites contained fish of different sizes.

In conclusion, this study gives a broad overview of fatty acids in fillets of many commercially-available finfish species in the U.S. The results of this study are comparable to other reports, while providing more specificity within certain species (e.g., sea bass) and confirming large differences in fatty acid content within and between species. Farmed species had higher concentrations of SFA, MUFA, and n-6 fatty acids than wild species. Additionally, farmed species showed vast differences in n-3 content. These differences most likely stem from dietary changes by fish farmers and necessitate the constant monitoring of fatty acids in farmed species. Finally, EPA plus DHA content was measured in all species to illustrate the amount of these fatty acids provided by each species. The results of this study provide a current snapshot of the fatty acid content of commercially available finfish and such studies should be continually performed to monitor and expand the available information.

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Conflict of interest The authors declare that there are no conflicts of interest.

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