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# Lipids Classes, Fatty Acids, and Sterols in Seafood from Gilbert Bay, Southern Labrador

LOUISE A. COPEMAN*,† AND CHRISTOPHER C. PARRISH†,§

Ocean Sciences Centre and Chemistry Department, Memorial University of Newfoundland, St. John's, Newfoundland A1C 5S7, Canada

Seafood from Gilbert Bay, southern Labrador, was sampled for lipid classes, fatty acid, and sterol composition. Gilbert Bay is a proposed Marine Protected Area, and the composition of seafood from this region is interesting from both human health and ecological perspectives. Analyses included four species of bivalves and flesh and liver samples from four fish species. Lipids from a locally isolated population of northern cod (*Gadus morhua*) were also compared to lipids from other cod populations. Lipid classes were analyzed by Chromarod/Iatroscan TLC-FID, fatty acids by GC, and sterols by GC-MS. Three cod populations had similar levels of total lipid per wet weight (0.6%) with triacylglycerols (TAG), sterols, and phospholipids comprising on average 13, 11, and 51%, respectively, of their total lipids. Fatty fish such as capelin and herring contained on average 8.4% lipid with 86% present as TAG. Fish livers from cod and herring showed opposite trends, with cod having elevated lipid (27%) and TAG (63%) and herring containing only 3.8% lipid and 20% TAG. Shellfish averaged 0.6% lipid; however, significant lipid class differences existed among species. Fatty acid analysis showed few significant differences in cod populations with on average 57% polyunsaturated fatty acids (PUFA), 18% monounsaturated fatty acids (MUFA), and 24% saturated fatty acids (SFA). Cod livers had lower PUFA (34%) and elevated MUFA (44%) relative to flesh. Bivalves averaged 25% SFA, 18% MUFA, and 57% PUFA, whereas scallop adductor muscle had the highest PUFA levels (63%). Bivalves contained 20 different sterols with cholesterol present as the major sterol (19−39%). *trans*-22-Dehydrocholesterol, brassicasterol, 24-methylenecholesterol, and campesterol individually accounted for >10% in at least one species. High levels of PUFA and non-cholesterol sterols observed in Gilbert Bay seafood demonstrate their positive attributes for human nutrition.

**KEYWORDS: Cholesterol; docosahexaenoic acid; eicosahexaenoic acid; ω−3 fatty acids; phytosterols**

## INTRODUCTION

Human consumption of seafood is increasing, in part due to its positive effects on health. In particular, ω−3 fatty acids are known to have therapeutic attributes with respect to human cardiovascular disease, hypertension, autoimmune disorders, and infant neural development (*1*−*3*). However, despite increased demand for seafood products, global supplies have plateaued, and many fish stocks have been damaged due to overfishing (*4*). The fishing industry of Atlantic Canada has been economically devastated due to the collapse of ground fish stocks (*5*). Specifically, communities along the coast of southern Labrador have been dramatically influenced by a closure in the northern cod fishery (1992) and a moratorium on Atlantic salmon fishing (1998). Consequently, fishing efforts have diversified to include scallops, shrimp, and snow crabs. In addition, there is an increased interest in the development of Icelandic scallop (*Chlamys islandica*), blue mussel (*Mytilus edulis*), and Atlantic cod (*Gadus morhua*) aquaculture industries.

Here we describe the lipid composition of fish and bivalves that have traditionally been included in the diet of the Métis people living near Gilbert Bay, located along the Labrador coast (52° 35′ N, 56° 00′ W) proximate to the communities of William's Harbour and Port Hope Simpson. Gilbert Bay is currently designated an Area of Interest in the Marine Protected Areas Program (DFO, Canada) primarily because of the genetically distinct Atlantic cod population that inhabits this bay (*6*, *7*). These cod are referred to locally as "golden cod" due to the coloration of their skin, which is characterized as having reddish brown spots present over golden brown hues (*8*), distinguishing them from the silvery-gray color of offshore northern cod.

Gilbert Bay is sheltered and ice covered for 6 months of the year and has a constant bottom temperature (at >50 m) of −1.5 °C (*7*, *9*). Previous studies on bivalves and finfish have indicated that temperature is a major environmental factor influencing the fatty acid composition of seafood (*10*, *11*). A recent review of seafood from the Indo-Pacific region found

* Author to whom correspondence should be addressed [e-mail lcopeman@mun.ca; telephone (709) 737-2521; fax (709) 737-3220].
† Ocean Sciences Center.
§ Chemistry Department.

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**Table 1.** Collection Method, Location, and Size of Seafood Analyzed from Gilbert Bay, Southern Labrador (August 2000)

| species | collection method | sampling location | wet wt (g) | fork length (cm) | shell height (cm) |
|---|---|---|---|---|---|
| *Gadus morhua* northern cod | hook and line | Fox Cove Tickle 52° 35.1′ N, 55° 47.8′ W | 847 ± 105 | 43.7 ± 3.0 | |
| *Gadus morhua* golden cod | hook and line | Fox Cove Tickle 52° 35.1′ N, 55° 47.8′ W | 378 ± 18 | 29.5 ± 3.6 | |
| *Gadus ogac* rock cod | 3-in. mesh trout net | Starvation Cove 52° 32.9′ N, 55° 4.5′ W | 433 ± 21 | 28.7 ± 0.6 | |
| *Clupea harengus* herring | 3-in. mesh trout net | Starvation Cove 52° 32.9′ N, 55° 44.5′ W | 315 ± 32 | 27.7 ± 0.8 | |
| *Mallotus vilosus* capelin | hook and line | Starvation Cove 52° 32.9′ N, 55° 44.5′ W | 12.8 | 12.5 | |
| *Serripes groenlandicus* Greenland cockle | dredge | Kelly's Cove 52° 35.9′ N, 55° 52.5′ W | 3.4 ± 3.0 | | 3.0 ± 0.7 |
| *Mytilus edulis* blue mussel | collected from shoreline rocks | Windsor Tickle 52° 33.0′ N, 55° 46.0′ W | 8.0 ± 1.4 | | 5.4 ± 0.3 |
| *Chlamys islandica* Icelandic scallops | dredge | Kelly's Point 52° 35.9′ N, 55° 52.5′ W | 25.1 ± 14.3 | | 6.3 ± 1.3 |
| *Spisula solidissima* little surf clam | dredge | Kelly's Point 52° 35.9′ N, 55° 52.5′ W | 0.4 | | 2.3 |

that with increased latitude there was an increase in health-promoting $\omega-3$ fatty acids (*10*). This relationship applied to the long-chain $\omega-3$ fatty acids docosahexaenoic acid (DHA) (22:6$\omega-3$) and eicosahexaenoic acid (EPA) (20:5$\omega-3$), with DHA being particularly high in lean fish and EPA in shellfish. Given the ability of marine ectotherms to adjust their cell membrane fatty acid, sterol, and phospholipid composition in relation to temperature (*11*), it is likely that seafood from Gilbert Bay contains high levels of $\omega-3$ fatty acids, thus making it an excellent source for human consumption.

For over 30 years, dietary cholesterol has been linked to high incidence of cardiovascular disease. Due to overestimations in the measurement of cholesterol, shellfish have unnecessarily been left out of many low-cholesterol diets (*12*). Fish and bivalves are actually low in cholesterol ($\sim$50 mg 100 g$^{-1}$ of wet weight) compared to other traditional protein sources, such as beef ($\sim$100 mg 100 g$^{-1}$ of wet weight). Although fish and crustaceans have a simple sterol composition typified by >95% cholesterol, bivalves have a complex sterol makeup with more than 20 different sterols, of which cholesterol may be present at levels of <25% (*13*). The consumption of non-cholesterol sterols derived from plants, phytosterols, has previously been found to reduce blood serum cholesterol levels in humans (*14*). Despite the interest in dietary phytosterol sources, little detailed information exits on the sterol composition of many shellfish species. Here we provide the first data on the sterol composition of previously unsampled bivalve populations while also presenting lipid class and fatty acid data on seafood from an ecologically important coastal environment.

## MATERIALS AND METHODS

**Animal Sampling.** Methods of collection and locations where seafood was gathered are given in **Table 1**. Fish were placed on ice immediately after collection and were frozen within 2 h of sampling. Samples were stored at −20 °C and within 2 months were sampled for flesh and liver lipid composition. White muscle was collected in triplicate from each fish along the dorsal margin, by first dissecting the skin and then sampling halfway along the anterior−posterior plane. Samples were $\sim$1 g of wet weight. Liver samples were also collected by dissection on ice, and $\sim$1 g of this tissue was taken per fish. From each fish, one sample of flesh and liver was removed to determine moisture content, and these were dried at 85 °C for 72 h. Fork length and wet weight were also recorded for each animal (**Table 1**).

Bivalves were placed on ice immediately after collection and were frozen within 2 h of sampling. They were maintained for 1 month at −70 °C until lipid sampling, at which time wet weight and shell height, the distance between the dorsal and ventral margins, were measured. Bivalves were then shucked and sampled according to normal human consumption patterns. This resulted in sampling of only the adductor muscle in scallops, whereas the whole organism was sampled for other bivalve species.

**Lipid Analysis.** Lipids were extracted in chloroform/methanol using a modified Folch procedure (*15*). Tissues were homogenized in chloroform/methanol (2:1) using a Kinematica GmbH homogenizer. Samples were then sonicated in chloroform/methanol/water (8:4:3) and centrifuged, and the organic layer was removed and pooled with subsequent ones. This procedure was repeated five times for fish liver and bivalve samples and three times for fish tissue. Extracts were concentrated by rotoevaporation under vacuum using a flash evaporator (Buchler Instruments, Fort Lee, NJ).

**Lipid Classes.** Lipid classes were determined using thin-layer chromatography with flame ionization detection (TLC-FID) with a MARK V Iatroscan (*16*). Lipid extracts were spotted on silica gel coated Chromarods and a three-stage development system was used to separate lipid classes. The first separation consisted of two developments in 99:1:0.05 (v/v/v) hexane/diethyl ether/formic acid. The first development was for 25 min followed by a second development for 20 min. The second separation consisted of a 40-min development in 80:20:1 (v/v/v) hexane/diethyl ether/formic acid. The last separation consisted of two 15-min developments in 100% acetone followed by two 10-min developments in 5:4:1 (v/v/v) chloroform/methanol/water. After each separation, the rods were scanned and the three chromatograms were combined to form one complete chromatogram using T-data scan software (RSS Inc., Bemis, TN). Peak areas were quantified using calibration curves obtained from scans of Sigma standards (Sigma Chemical Inc., St. Louis, MO).

**Fatty Acids.** Fatty acid methyl esters (FAMEs) were prepared by transesterification with 10% $BF_3$ in methanol (*17*) for 1 h at 85 °C. A Varian model 3400 GC equipped with a Varian 8100 autosampler was used for fatty acid analysis. The column was an Omegawax 320 column, 30 m in length, 0.32 mm i.d., 0.25 $\mu$m film thickness (Supelco, Bellefonte, PA). Hydrogen was used as the carrier gas, and the flow rate was set at 2 mL min$^{-1}$. The column temperature profile was as follows: 65 °C for 0.5 min, hold at 195 °C for 15 min after ramping at 40 °C min$^{-1}$, and hold at 220 °C for 0.75 min after ramping at 2 °C min$^{-1}$. The injector temperature increased from 150 to 250 °C at 200 °C min$^{-1}$. Peaks were detected by flame ionization, and the detector was held at 260 °C. Fatty acid peaks were integrated using Varian Star chromatography software (version 4.02), and identification was made with reference to known standards (PUFA 1 and 3 and 37 Component FAME Mix, Supelco Inc.).

To express our fatty acid data in grams per 100 g, as commonly used in nutritional studies, we used simple conversion factors (*18*, *19*).

**Table 2.** Lipid Class Composition of Fish Flesh Collected from Gilbert Bay, Southern Labrador (August 2000)

| | northern cod, *G. morhua* ($n = 3$) | golden cod, *G. morhua* ($n = 3$) | rock cod, *G. ogac* ($n = 3$) | herring, *C. harengus* ($n = 3$) | capelin, whole body *M. vilosus* ($n = 1$) |
|---|---|---|---|---|---|
| total lipid (% dry wt) | 2.7 ± 0.2a | 3.3 ± 0.4a | 3.7 ± 0.7a | 25.9 ± 6.3b | |
| total lipid (% wet wt) | 0.5 ± 0.0a | 0.6 ± 0.0a | 0.7 ± 0.2a | 6.8 ± 1.7b | 9.9 |
| lipid class (% total) | | | | | |
| hydrocarbons | 0.8 ± 0.3 | 0.9 ± 0.0 | 0.4 ± 0.3 | 1.1 ± 0.4 | 0.6 |
| steryl/wax esters | 2.5 ±1.2a | 3.1 ± 0.7a | 4.0 ± 1.1a | 0.2 ± 0.2b | |
| methyl ketones | 0.9 ± 0.9 | 0.6 ± 0.1 | 0.9 ± 0.5 | 0.5 ± 0.7 | |
| triacylglycerols | 11.4 ± 3.5a | 12.2 ± 0.2a | 15.9 ± 2.4a | 86.3 ± 1.9b | 85.8 |
| free fatty acids | 6.6 ± 2.7a | 8.0 ± 1.1a | 10.9 ± 1.6a | 0.9 ± 0.7b | 0.7 |
| alcohols | | | | 0.1 ± 0.2 | |
| sterols | 13.8 ± 1.7a | 11.0 ± 1.2a | 9.1 ± 1.7a | 0.8 ± 0.9b | 0.9 |
| diacylglycerols | 3.7 ± 2.6 | 5.3 ± 4.9 | 5.6 ± 2.9 | 0.4 ± 0.4 | |
| acetone mobile polar lipids | 5.4 ± 1.1a | 3.6 ± 1.1a | 9.4 ± 0.5b | 3.1 ± 1.0a | 4.7 |
| phospholipids | 54.9 ± 6.5a | 55.5 ± 3.3a | 43.9 ± 5.4a | 6.4 ± 2.1b | 7.2 |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$. Capelin not tested as $n = 1$.

**Table 3.** Lipid Class Composition of Fish Livers Collected from Gilbert Bay, Southern Labrador (August 2000)[a]

| | northern cod, *G. morhua* ($n = 3$) | golden cod, *G. morhua* ($n = 3$) | rock cod, *G. ogac* ($n = 3$) | herring, *C. harengus* ($n = 3$) |
|---|---|---|---|---|
| total lipids | | | | |
| % dry wt | 48.9 ± 28.2a | 50.5 ± 11.1a | 60.8 ± 7.7a | 14.1 ± 5.23b |
| % wet wt | 24.0 ± 15.1a | 23.9 ± 6.4a | 34.3 ± 1.9a | 3.8 ± 1.3b |
| hydrocarbons | 3.8 ± 3.0 | 4.0 ± 1.7 | 3.8 ± 1.0 | 2.6 ± 0.9 |
| steryl/wax esters | 0.8 ± 1.1 | 2.2 ± 1.6 | 0.0 ± 0.0 | 0.9 ± 1.3 |
| methyl ketones | 0.0 ± 0.0 | 0.0 ± 0.0 | 1.7 ± 2.5 | 3.3 ± 3.1 |
| triacylglycerols | 66.9 ± 13.8a | 55.0 ± 9.1a | 66.2 ± 4.4a | 19.6 ± 10.5b |
| free fatty acids | 2.4 ± 1.8a | 4.9 ± 2.4a | 2.3 ± 0.6a | 20.4 ± 5.1b |
| sterols | 2.3 ± 3.2 | 6.9 ± 2.8 | 2.6 ± 3.7 | 7.3 ± 2.9 |
| diacylglycerols | 4.9 ± 1.8 | 5.7 ± 1.7 | 2.9 ± 2.2 | 5.2 ± 0.8 |
| acetone mobile polar lipids | 6.6 ± 3.5 | 8.2 ± 1.3 | 8.8 ± 1.4 | 5.0 ± 1.9 |
| phospholipids | 12.3 ± 7.0a | 13.3 ± 4.4a | 11.6 ± 2.3a | 35.8 ± 7.8b |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$.

These calculations are based on subtracting the glycerol, phosphate, and other functional groups from the acyl lipid class mass in order to obtain the mass of fatty acids per lipid class. On the basis of an average fatty acid chain length in seafood, these conversion factors for the major lipid classes used here were ~0.47 steryl/wax esters, ~0.95 triacylglycerols (TAG), 1.0 free fatty acids (FFA), ~0.90 diacylglycerols (DAG), 0.37 acetone mobile polar lipids (AMPL), and ~0.72 for phospholipids (PL). Due to differences in the lipid class composition of Gilbert Bay seafood, this resulted in overall conversion factors for total lipid that ranged from 0.6 to 0.9. Low conversion factors (0.6−0.7) resulted for gadoids and shellfish with low neutral lipids, whereas higher conversion factors (0.8−0.9) were applied to high-fat pelagic fish and gadoid livers. These conversion factors are in agreement with previous reviews on the nutritional composition of fats in seafoods (*18*).

**Sterols.** Sterols were separated from methylated extracts using column chromatography. Glass wool was placed in the tip of a Pasteur pipet so that it just filled the tip, and pipets were then burned in a muffle furnace (450 °C) for 12 h. Approximately 0.8 g of activated silica gel (150 °C for 1 h) was packed into each pipet. Columns were washed with 2 mL of diethyl ether followed by 4 mL of hexane. Derivatized extracts were applied to the top of the washed column, and methyl esters were eluted with 10 mL of 93:7 (v/v) diethyl ether/hexane, whereas sterols and alcohols were eluted using 10 mL of 50:50 diethyl ether/hexane. Sterols were evaporated to dryness under nitrogen, and two drops of *N*,*O*-bis(trimethylsilyl)acetamide (BSA) and four drops of *N*,*O*-bis(trimethylsiyl)trifluoroacetamide (BSFA) were added. Samples were heated for 15 min at 85 °C in order to form trimethylsilyl ethers and then were dried under nitrogen and resuspended in hexane; all chromatographic analyses were performed within 48 h of formation.

Sterols were identified using a Varian 3800 GC connected to a Varian 2000 MS. The column was a low-bleed CP Sil-8 column, 30 m in length, 0.32 mm i.d., 0.25 $\mu$m film thickness (Varian). Helium was used as the carrier gas, and the pressure was constant at 10 psi. The column temperature profile was as follows: 60 °C for 1.0 min, ramping to 100 °C at a rate of 25 °C min$^{-1}$, ramping to 150 °C at a rate of 15 °C min$^{-1}$, and holding at 315 °C for 2 min after ramping at 3 °C min$^{-1}$. The MS was in EI mode (70 eV) with a 1.0 scan s$^{-1}$ interval over a 40−650 *m*/*z* range. Sterols were identified using Varian Saturn GC-MS workstation software version 5.4 with reference to their mass spectra, retention times, known standards, and published spectral data (*20*).

To more accurately quantify peak heights, integration of previously identified samples for percent of total sterols was completed on an HP 6890 GC-FID equipped with an HP 7683 autosampler. The column was an HP-5 (cross-linked 5% PH ME siloxane) 30 m in length, 0.32 mm i.d., 0.25 $\mu$m film thickness. The column pressure and temperature profile was set to the same parameters as previously described for the GC-MS analyses, whereas the detector was set a 310 °C and the injector at 315 °C.

**Statistical Analysis.** Triplicate flesh samples per fish were averaged to obtain a lipid composition per fish. To avoid pseudo-replication, all data are expressed using fish as replicates ($n = 3$ per species) rather than flesh samples ($n = 9$ per species). Differences in lipid parameters between fish (ANOVA, $F_{3,11}$, $P < 0.05$) and bivalve (ANOVA, $F_{2,14}$, $P < 0.05$) species were compared using a one-way analysis of variance with Tukey's pairwise comparisons. Residuals versus fitted values were examined to check for normality and heteroscedasticity, and certain percentage data were arcsine square root transformed in order to meet these assumptions (Minitab, version 10.5).

## RESULTS AND DISCUSSION

The genetically distinct northern cod population (*6*), referred to here as "golden cod", was on average smaller (378 g, 30 cm) than other northern cod (847 g, 44 cm, **Table 1**) from

**Table 4.** Lipid Class Composition of Bivalves Collected from Gilbert Bay, Southern Labrador (August 2000)[a]

| | surf clam, whole animal, *S. solidissima* ($n = 1$) | Greenland cockle, whole animal, *S. groenlandicus* ($n = 7$) | blue mussel, whole animal, *M. edulis* ($n = 3$) | Icelandic scallop muscle, *C. islandica* ($n = 5$) |
|---|---|---|---|---|
| total lipid (% wet wt) | 0.8 | 0.6 ± 0.2 | 0.6 ± 0.1 | 0.5 ± 0.1 |
| lipid class (% total lipid) | | | | |
| hydrocarbons | 0.5 | 0.1 ± 0.1 | 0.1 ± 0.2 | 0.0 ± 0.0 |
| steryl/wax esters | 0.4 | 1.0 ± 2.5 | 1.8 ± 2.6 | 0.0 ± 0.0 |
| methyl ketones | 0.0 | 0.0 ± 0.0 | 0.3 ± 0.4 | 0.0 ± 0.0 |
| triacylglycerols | 0.0 | 14.3 ± 6.5a | 34.7 ± 8.5a | 0.5 ± 0.8b |
| free fatty acids | 6.2 | 12.4 ± 1.6a | 9.0 ± 2.6a | 0.6 ± 0.6b |
| sterols | 18.1 | 10.9 ± 1.3a | 8.6 ± 0.4a | 21.3 ± 2.6b |
| diacylglycerols | 0.7 | 0.7 ± 0.7 | 0.8 ± 0.2 | 0.0 ± 0.0 |
| acetone mobile polar lipids | 10.7 | 10.7 ± 1.3a | 6.8 ± 0.8b | 3.1 ± 1.2c |
| phospholipids | 63.3 | 49.9 ± 7.6a | 37.8 ± 3.1a | 74.6 ± 3.7b |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$. Clam not tested as $n = 1$.

Gilbert Bay. Both rock cod (*Gadus ogac*) and golden cod (*G. morhua*) showed signs of mature gonad development, whereas northern cod (*G. morhua*) did not. Sexual maturity in golden cod of this size has previously been reported with cod as small as 32 cm releasing milt and 36 cm releasing eggs (*21*). Length-at-age relationships for this population showed that males and females mature between 4 and 6 and between 4 and 8 years, respectively. Despite differences in sexual maturity, genetics, and coloration between the three gadoid groups, there was no significant difference in total lipid per wet weight from flesh or liver (**Tables 2** and **3**). Levels of total lipid ranged from 0.5 to 0.7% in flesh and from 24 to 34% in liver. In both tissues, *G. ogac* tended toward higher levels of lipid per wet weight and higher proportions of TAG; however, these differences were not significant.

Levels of total lipid in Gilbert Bay northern cod flesh (0.5%) and liver (24%) are within the lower range of previous reports on cod from other Atlantic regions. Previous studies in Nova Scotia, Canada, reported levels of lipid in cod flesh that ranged from 0.6 to 0.7% (*18*, *22*), whereas the lipid content of livers ranged over an annual cycle but were on average 40% of the liver (*22*). However, during August, the same period during which our sampling took place, it was found that this level rose to ~55% (*22*). Atlantic cod collected off Tromso, Norway, of a size similar to those described here, contained 0.8 and 38.3% lipid, respectively, in their flesh and liver (*23*).

The distribution of total lipid between the flesh and liver in Gilbert Bay herring (*Clupea harengus*) was characteristic of previous reports on pelagic fatty fish. Relative to gadoids, elevated levels of lipid were found in their flesh (8.4%) and lower levels in the liver (3.8%, **Tables 2** and **3**). Previous reports on the lipid composition of pelagic fish from Atlantic Canada reported flesh values of 12% for herring and capelin at 10.8 and 2.6% in offshore and inshore populations, respectively (*18*). Examination of the seasonal changes in the lipid composition of herring from the North Sea found that lipid content was generally higher in the summer when food was more abundant (19%) and lower in the winter (~7%) (*24*). Therefore, our values for total lipid in herring flesh are low compared to previous reports for this species.

**Lipid Classes.** The lipid class distribution within the flesh of fish from Gilbert Bay showed gadoids with high levels of polar lipids, whereas herring and capelin had elevated neutral lipids (**Table 2**). Triacylglycerols (TAG), sterols (ST), and phospholipids (PL) comprised on average 13, 11, and 51% in gadoids. Previous analysis of PL in flesh of cod from Nova Scotia showed 87% phospholipids, of which 60% was phosphatidylcholine (PC) and 16% phosphatidylethanolamine (PE) (*25*). Free fatty acids (FFA) were present in Gilbert Bay cod at levels ranging from 7 to 11%. Using similar analytical methods, cod fish that were fed both natural prey and fish-based feeds were found to contain between 6 and 8% FFA in their flesh (*23*). An early study on cod flesh demonstrated that during cold storage dramatic lipid class changes occur due to hydrolysis of PL (*26*). Over a 9-month period at −12 °C, the PL composition of cod flesh was found to have dropped from 84 to 32%, and only 13% of the original PE and PC remained. Therefore, it is likely that most of the FFA observed in Gilbert Bay fish was due to hydrolysis of PL during storage and sampling procedures. Very little FFA or DAG was observed in herring and capelin, demonstrating the higher stability of TAG relative to PL.

The only significant difference in lipid class composition between gadoid species ($P < 0.05$, **Table 2**) was in acetone mobile polar lipids (AMPL). AMPL can contain monoacylglycerols (MAG), glycolipids, and chlorophyll *a* (*16*); therefore, it is likely that elevated levels of MAG in *G. ogac* are due to lipolysis of PL and/or TAG into DAG and FFA followed by MAG and FFA. *G. ogac* showed a trend toward elevated levels of TAG and FFA compared to the other two *G. morhua* populations (**Table 2**).

There were no significant differences in the lipid class composition of the livers of different gadoids (**Table 3**); however, gadoid liver contained significantly higher levels of total lipids and proportions of neutral lipids than seen in herring. TAG was present as the major lipid class in gadoids at between 55 and 67%. Herring had higher levels of phospholipids and free fatty acids. High levels of free fatty acids in herring liver may reflect metabolic processes rather than lipolysis due to storage and sampling procedures.

**Table 4** illustrates that on average all four bivalve species contained ~0.6% of their wet weight as lipid. We provide the first detailed analysis of the lipid composition of both Greenland cockles (*Serripes groenlandicus*) and Icelandic scallops (*Chlamys islandica*). However, previously surf clams, blue mussels, and sea scallops from Nova Scotia were found to contain 1.4, 1.3, and 1.0%, respectively, of their wet weight as lipid (*18*). Furthermore, blue mussels (*M. edulis*) that were collected from Notre Dame Bay, Newfoundland, and analyzed using techniques identical to those described here, contained 1.3% lipid (*27*). Investigation of the lipid composition of the adductor muscle in sea scallops (*Placopecten magellanicus*) from Georges Bank revealed that lipids comprised 1.1% in the winter and 0.8% in the summer (*28*). Further, *P. magellanicus* from Trinity Bay, Newfoundland, contained 0.5% of adductor muscle as lipid (*29*). Therefore, total lipid levels in shellfish from Labrador (~0.6%) generally are at the lower range of previous studies (~1%).

Gilbert Bay cockles and mussels contained higher levels ($P < 0.05$) of TAG (14−34%) and FFA (9−12%) and lower levels

**Table 5.** Fatty Acid Composition of Fish Flesh Collected in Gilbert Bay, Southern Labrador (August 2000)[a]

| | northern cod, *G. morhua* ($n = 3$) | golden cod, *G. morhua* ($n = 3$) | rock cod, *G. ogac* ($n = 3$) | herring, *C. harengus* ($n = 3$) | capelin, *M. vilosus* ($n = 1$) |
|---|---|---|---|---|---|
| 14:0 | 1.4 ± 0.3a | 1.5 ± 0.2ab | 2.1 ± 0.2b | 4.5 ± 0.1c | 5.9 |
| i-15:0 | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.1 ± 0.0 | 0.6 ± 0.3 | 0.2 |
| ai-15:0 | –[a] | – | 0.2 ± 0.3 | – | |
| 15:0 | 0.2 ± 0.0 | 0.3 ± 0.1 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.2 |
| i-16:0 | – | – | – | Tr[c] | – |
| ai-16:0 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.2 ± 0.1 | 0.1 |
| 16:0 | 18.0 ± 0.3a | 17.6 ± 0.7a | 17.7 ± 0.2a | 10.5 ± 0.6b | 8.7 |
| i-17:0 | 0.2 ± 0.0a | 0.3 ± 0.1b | 0.2 ± 0.0ac | 0.1 ± 0.0ad | 0.1 |
| ai-17:0 | 0.1 ± 0.1 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.1 ± 0.1 | 0.2 |
| 17:0 | 0.1 ± 0.0a | 0.2 ± 0.1a | 0.1 ± 0.0a | Tr[b] | 1.0 |
| 18:0 | 3.4 ± 0.2a | 3.8 ± 0.0ac | 3.1 ± 0.2ad | 0.8 ± 0.0b | 0.6 |
| 20:0 | – | – | – | 0.3 ± 0.3 | 0.1 |
| 22:0 | 0.1 ± 0.1 | tr | Tr | Tr | – |
| 23:0 | 0.1 ± 0.2 | 0.1 ± 0.2 | 0.1 ± 0.1 | 0.5 ± 1.0 | – |
| **SFA** | **23.8** ± **0.7**a | **24.3** ± **0.5**a | **23.9** ± **0.3**a | **18.2** ± **0.7**b | 17.1 |
| 15:1 | – | – | – | 0.1 ± 0.2 | 0.1 |
| 16:1*n*–7 | 3.3 ± 0.4a | 3.3 ± 0.3a | 4.4 ± 0.2b | 7.5 ± 0.2c | 10.3 |
| 16:1*n*–5 | 0.3 ± 0.0a | 0.4 ± 0.1a | 0.4 ± 0.1a | 0.9 ± 0.2b | 0.2 |
| 17:1 | – | 0.1 ± 0.1 | – | – | – |
| 18:1*n*–11 | 0.8 ± 1.1 | – | 1.0 ± 1.2 | – | – |
| 18:1*n*–9 | 6.4 ± 0.7 | 6.7 ± 0.6 | 7.0 ± 0.6 | 5.5 ± 1.2 | 3.8 |
| 18:1*n*–7 | 3.0 ± 0.4a | 3.4 ± 0.1a | 3.1 ± 0.4a | 1.9 ± 0.0b | 1.6 |
| 18:1*n*–5 | 0.5 ± 0.1 | 0.6 ± 0.1 | 0.6 ± 0.1 | 0.1 ± 0.5 | 0.6 |
| 20:1*n*–9 | 2.4 ± 0.5a | 2.0 ± 0.1a | 3.0 ± 0.9a | 16.3 ± 0.6b | 16.6 |
| 20:1*n*–7 | 0.2 ± 0.3 | 0.5 ± 0.4 | 0.1 ± 0.1 | 1.0 ± 0.2 | 1.0 |
| 22:1*n*–11 | 0.5 ± 0.1a | 0.4 ± 0.1a | 0.6 ± 0.0a | 24.4 ± 2.5b | 9.3 |
| 22:1*n*–9 | 0.2 ± 0.1a | 0.1 ± 0.1a | 0.1 ± 0.0a | 2.3 ± 0.1b | 18.5 |
| 24:1 | 0.4 ± 0.1 | 0.4 ± 0.1 | 0.4 ± 0.0 | 0.5 ± 0.1 | 0.5 |
| **MUFA** | **17.8** ± **1.7**a | **17.9** ± **1.0**a | **20.6** ± **1.5**a | **61.3** ± **3.5**b | **62.6** |
| 16:3*n*–4 | 0.1 ± 0.0a | 0.1 ± 0.1a | 0.1 ± 0.0a | 0.4 ± 0.2b | 0.8 |
| 16:4*n*–3 | 0.1 ± 0.1 | – | Tr | – | 0.1 |
| 16:4*n*–1 | 0.1 ± 0.0a | 0.1 ± 0.0a | 0.1 ± 0.0a | 0.8 ± 0.4b | 2.0 |
| 18:2*n*–6 | 1.0 ± 0.1a | 0.9 ± 0.1a | 1.0 ± 0.1a | 0.6 ± 0.1b | 0.5 |
| 18:2*n*–4 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.2 ± 0.0 | 0.1 ± 0.0 | 0.1 |
| 18:3*n*–4 | 0.1 ± 0.0a | 0.1 ± 0.0a | 0.1 ± 0.0a | –[b] | – |
| 18:3*n*–3 | 0.2 ± 0.1 | 0.3 ± 0.1 | 0.3 ± 0.1 | 0.2 ± 0.1 | 0.2 |
| 18:4*n*–3 | 0.3 ± 0.1 | 0.4 ± 0.1 | 0.5 ± 0.2 | 0.9 ± 0.6 | 1.2 |
| 18:4*n*–1 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.3 |
| 20:2*n*–6 | 0.3 ± 0.1 | 0.3 ± 0.1 | 0.3 ± 0.1 | 0.1 ± 0.0 | 0.1 |
| 20:3*n*–6 | 0.1 ± 0.0 | Tr | 0.1 ± 0.0 | – | – |
| 20:4*n*–6 | 2.0 ± 0.2a | 1.9 ± 0.4a | 1.7 ± 0.3a | 0.2 ± 0.0b | 0.2 |
| 20:3*n*–3 | 0.1 ± 0.1 | – | – | – | – |
| 20:5*n*–3 | 19.1 ± 0.4a | 18.2 ± 1.4a | 19.6 ± 0.6a | 7.0 ± 1.4b | 9.3 |
| 22:4*n*–6 | Tr | 0.2 ± 0.2 | Tr | Tr | – |
| 22:5*n*–3 | 2.0 ± 0.2a | 1.7 ± 0.1a | 1.9 ± 0.2a | 0.8 ± 0.1b | 0.9 |
| 22:6*n*–3 | 32.6 ± 1.5a | 33.1 ± 2.6a | 29.2 ± 1.4a | 8.8 ± 0.5b | 4.1 |
| **PUFA** | **58.3** ± **2.1**a | **57.8** ± **1.0**a | **55.4** ± **1.6**a | **20.3** ± **3.3**b | 20.0 |
| PUFA/SFA | 2.4 ± 0.1a | 2.4 ± 0.1a | 2.3 ± 0.1a | 1.1 ± 0.2b | 1.2 |
| Σ*n*–3 | 52.5 ± 1.7a | 52.3 ± 1.3a | 50.0 ± 1.2a | 17.2 ± 2.6b | 15.2 |
| Σ*n*–3/Σ*n*–6 | 15.6 ± 0.7 | 15.9 ± 2.3 | 16.8 ± 1.0 | 18.8 ± 3.7 | 17.6 |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$. Capelin not tested as $n = 1$. [b] Not detected. [c] Trace amounts were <0.1% of total fatty acids

of ST (9−11%) and PL (38−50%) than found in scallops (**Table 4**). These differences in lipid class composition are related to the analysis of whole animals in the case of mussels and cockles compared to adductor muscle in scallops. These data on Icelandic scallop lipid class composition are in agreement with an anatomical analysis of sea scallops from Nova Scotia, where the lipid class composition of the adductor muscle, gill, and mantle lead them to be termed "lean organs" (*27*). Lean organs were not found to vary significantly seasonally and had lipid profiles similar to that of the adductor muscle containing 1% TAG, <1% FFA, 18% ST, and 80% PL. It was found that the digestive gland in the scallop was the major site for lipid storage, and this organ varied seasonally, containing higher levels of lipid in the summer and lower levels of storage lipid in the winter.

Due to changes in both reproductive status and food availability, levels of total lipid, lipid classes, and fatty acid vary within bivalves throughout the year (*28*, *30*). In blue mussels, total energy content and lipids have been found to be highest in summer and autumn and then decrease throughout the winter to a postspawning minimum in spring (*30*). Furthermore, levels of specific fatty acids have been demonstrated to mimic levels found in the plankton, with elevated proportions of diatom markers found in blue mussel flesh in early summer and increased proportions of flagellate markers in late summer. This is the first detailed analysis of the lipid composition of

**Table 6.** Fatty Acid Composition of Fish Livers Collected from Gilbert Bay, Southern Labrador (August 2000)[a]

| | northern cod, *G. morhua* ($n = 3$) | golden cod, *G. morhua* ($n = 3$) | rock cod, *G. ogac* ($n = 3$) | herring, *C. harengus* ($n = 3$) |
|---|---|---|---|---|
| 14:0 | 3.6 ± 0.4 | 4.0 ± 0.3 | 3.9 ± 2.0 | 3.4 ± 0.1 |
| 15:0I | 0.1 ± 0.0 | 0.2 ± 0.0 | 0.1 ± 1.9 | 0.1 ± 0.0 |
| 15:0 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.3 ± 0.1 | 0.3 ± 0.1 |
| i-16:0 | 0.1 ± 0.0 | 0.1 ± 0.0 | –[b] | 0.1 ± 0.0 |
| ai-16:0 | Tr[c] a | 0.1 ± 0.0a | 0.1 ± 0.1a | 0.2 ± 0.1b |
| 16:0 | 11.5 ± 2.3 | 13.5 ± 2.0 | 13.6 ± 6.8 | 14.4 ± 0.4 |
| i-17:0 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.3 ± 0.0 | 0.4 ± 0.1 |
| ai-17:0 | 0.2 ± 0.1 | 0.2 ± 0.0 | 0.2 ± 0.1 | 0.3 ± 0.1 |
| 17:0 | 0.1 ± 0.0 | 0.1 ± 0.1 | 0.1 ± 0.1 | 0.2 ± 1.0 |
| 18:0 | 3.0 ± 0.8 | 3.3 ± 0.7 | 3.2 ± 1.3 | 3.0 ± 0.7 |
| 20:0 | – | Tr | 0.2 ± 0.2 | – |
| 22:0 | – | – | Tr | – |
| 23:0 | – | – | Tr | – |
| **ΣSFA** | **19.4 ± 2.5** | **22.3 ± 2.3** | **22.1 ± 1.0** | **22.5 ± 0.7** |
| 15:1 | 0.1 ± 0.0 | – | Tr | – |
| 16:1*n*–7 | 11.7 ± 3.6a | 10.8 ± 1.1ab | 11.1 ± 1.5ab | 6.1 ± 0.2b |
| 16:1*n*–5 | 0.2 ± 0.0 | 0.3 ± 0.0 | 0.3 ± 5.4 | 0.4 ± 0.0 |
| 17:1 | – | - | Tr | – |
| 18:1*n*–11 | – | – | Tr | – |
| 18:1*n*–9 | 15.7 ± 1.7 | 12.1 ± 2.2 | 13.6 ± 7.0 | 10.5 ± 1.1 |
| 18:1*n*–7 | 5.7 ± 0.5 | 5.4 ± 1.1 | 3.6 ± 5.6 | 5.5 ± 0.7 |
| 18:1*n*–5 | 0.6 ± 0.2a | 0.6 ± 0.1a | 0.7 ± 0.3a | 1.1 ± 0.1b |
| 20:1*n*–9 | 8.9 ± 1.6 | 7.1 ± 1.6 | 8.3 ± 4.2 | 3.8 ± 2.7 |
| 20:1*n*–7 | 0.2 ± 0.3 | – | 0.4 ± 4.0 | 0.2 ± 0.2 |
| 22:1*n*–11 | 3.0 ± 2.3 | 3.7 ± 0.7 | 2.8 ± 2.0 | 3.4 ± 0.7 |
| 22:1*n*–9 | 2.0 ± 1.9 | 0.5 ± 0.1 | 1.9 ± 2.1 | 2.3 ± 2.5 |
| 22:1*n*–7 | – | – | Tr | 0.2 ± 0.3 |
| 24:1 | 0.3 ± 0.0 | 0.4 ± 0.1 | 0.3 ± 6.2 | 0.4 ± 0.0 |
| **ΣMUFA** | **48.4 ± 4.6**a | **40.9 ± 2.5**ab | **43.0 ± 3.0**ab | **33.9 ± 2.9**b |
| 16:3*n*–4 | 0.3 ± 0.0 | 0.3 ± 0.1 | 0.2 ± 0.0 | 0.2 ± 0.1 |
| 16:4*n*–1 | 0.4 ± 0.1ab | 0.4 ± 0.0ab | 0.6 ± 0.3a | 0.2 ± 0.1b |
| 18:2*n*–6 | 1.5 ± 0.6 | 1.3 ± 0.2 | 1.1 ± 0.3 | 0.6 ± 0.2 |
| 18:2*n*–4 | 0.3 ± 0.1 | 0.3 ± 0.0 | 0.3 ± 0.4 | 0.3 ± 0.0 |
| 18:3*n*–6 | 0.1 ± 0.0a | 0.1 ± 0.0a | 0.1 ± 0.1a | – |
| 18:3*n*–4 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.1 ± 0.0 | 0.1 ± 0.0 |
| 18:3*n*–3 | 0.4 ± 0.0 | 0.5 ± 0.1 | 0.4 ± 0.1 | 0.3 ± 0.1 |
| 18:4*n*–3 | 1.0 ± 0.1ab | 1.2 ± 0.1a | 1.2 ± 0.4a | 0.6 ± 0.2b |
| 18:4*n*–1 | 0.2 ± 0.1 | 0.2 ± 0.1 | 0.3 ± 0.5 | 0.3 ± 0.1 |
| 20:2*n*–6 | 0.3 ± 0.1a | 0.2 ± 0.0ab | 0.2 ± 0.2ab | 0.1 ± 0.1b |
| 20:4*n*–6 | 0.6 ± 0.1 | 0.6 ±0.1 | 0.5 ± 0.3 | 0.8 ± 0.1 |
| 20:3*n*–3 | 0.1 ± 0.0 | – | 0.1 ± 0.2 | – |
| 20:5*n*–3 | 12.2 ± 1.7 | 14.3 ± 0.9 | 15.0 ± 7.6 | 14.4 ± 1.5 |
| 21:5*n*–3 | 0.4 ± 0.0a | 0.5 ± 0.0ab | 0.5 ± 0.3b | 0.2 ± 0.0c |
| 22:5*n*–3 | 1.7 ± 0.3 | 1.7 ± 0.4 | 1.5 ± 0.8 | 1.9 ± 0.2 |
| 22:6*n*–3 | 12.7 ± 1.2a | 15.0 ± 1.4a | 12.7 ± 6.4a | 23.5 ± 3.3b |
| **ΣPUFA** | **32.0 ± 2.1**a | **36.6 ± 2.5**ab | **34.6 ± 2.8**ab | **43.4 ± 3.5**b |
| ΣPUFA/ΣSFA | 1.7 ± 0.1 | 1.7 ± 0.2 | 1.6 ± 0.1 | 1.9 ± 0.2 |
| Σ*n*–3 | 26.7 ± 2.9a | 31.5 ± 2.1ab | 29.9 ± 2.6a | 39.2 ± 3.4b |
| Σ*n*–3/Σ*n*–6 | 12.0 ± 4.2a | 14.3 ± 1.7a | 15.2 ± 2.7a | 26.9 ± 4.9b |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$. [b] Not detected. [c] Trace amounts were <0.1% of total fatty acids

both Greenland cockles and Icelandic scallops; however, it is likely that they follow the same general pattern for whole-body lipid composition, showing elevated levels in the late summer and reduced levels following spawning in the spring.

**Fatty Acids.** There were few significant differences in the fatty acid composition of gadoids from Gilbert Bay and certainly no difference from the human nutrition perspective (**Table 5**). Previous studies on cod have shown that both genetics (*32*) and dietary factors (*33*) play important roles related to determining fatty acid composition in cod. Due to the difference in population structure between golden cod and northern cod from Gilbert Bay (*6*, *8*) we postulated that there could be differences in fatty acid composition. Furthermore, coloration divergence between the populations was hypothesized to result from differences in foraging behavior. Recently, it has been demonstrated that the color difference between golden cod and northern cod populations disappears when both are fed a trash fish diet under aquaculture conditions (*34*). Previous studies that have distinguished between populations on the basis of fatty acid composition or have shown a change in fatty acid composition due to diet have used large sample numbers and multivariate statistics to elucidate these difference (*32*, *33*). Unfortunately, the number of animals that were available from this remote sampling location limited us in this respect.

Levels of total PUFA in Gilbert Bay fish were similar to those given in previous studies on other Atlantic stocks. Gilbert bay

**Table 7.** Fatty Acid Composition of Bivalves Collected from Gilbert Bay, Southern Labrador (August 2000)[a]

| | surf clam, *S. solidissima* ($n = 1$) | Greenland cockle, *S. groenlandicus* ($n = 7$) | blue mussel, *M. edulis* ($n = 3$) | Icelandic scallop, *C. islandica* ($n = 5$) |
|---|---|---|---|---|
| 14:0 and TMTD | 2.6 | 6.5 ± 0.6a | 4.1 ± 0.8b | 2.0 ± 0.4c |
| i-15:0 | 1.1 | 0.1 ± 0.1 | –[b] | – |
| ai-15:0 | Tr[c] | 0.1 ± 0.1 | Tr | Tr |
| 15:0 | Tr | 0.6 ± 0.1 | 0.5 ± 0.0 | 0.6 ± 0.1 |
| i-16:0 | 0.8 | 0.4 ± 0.1a | 0.1 ± 0.1b | 0.1 ± 0.0b |
| ai-16:0 | Tr | 0.5 ± 0.1a | 0.4 ± 0.1a | 0.1 ± 0.1b |
| 16:0 | 10.5 | 10.2 ± 0.4a | 12.1 ± 0.4b | 16.6 ± 0.7c |
| i-17:0 | 1.2 | 1.0 ± 0.2a | 0.4 ± 0.0b | 0.5 ± 0.1b |
| ai-17:0 | 0.8 | 0.7 ± 0.2 | 0.7 ± 0.1 | 0.5 ± 0.1 |
| 17:0 | 1.1 | 0.3 ± 0.0a | 0.5 ± 0.0ab | 0.5 ± 0.1b |
| 18:0 | 3.0 | 5.2 ± 1.0a | 2.7 ± 0.2b | 3.7 ± 0.5b |
| 20:0 | 5.7 | 0.1 ± 0.1 | 0.2 ± 0.1 | 0.1 ± 0.1 |
| **ΣSFA** | **28.2** | **25.7** ± **0.9**a | **21.8** ± **0.5**b | **24.8** ± **1.2**a |
| 15:1 | 0.0 | Tr a | 0.1 ± 0.1b | Tr |
| 16:1*n*–7 | 5.6 | 7.1 ± 1.3a | 10.4 ± 1.9b | 3.9 ± 0.5c |
| 16:1*n*–5 | 0.7 | 0.4 ± 0.0ab | 0.3 ± 0.1a | 0.5 ± 0.0b |
| 17:1 | – | 0.0 ± 0.0 | 0.1 ± 0.0 | 0.0 ± 0.0 |
| 18:1*n*–11 | – | 0.2 ± 0.0 | 0.2 ± 0.1 | 0.3 ± 0.6 |
| 18:1*n*–9 | 1.5 | 1.2 ± 0.2a | 1.1 ± 0.1a | 1.9 ± 0.6b |
| 18:1*n*–7 | 3.4 | 3.2 ± 1.3 | 3.0 ± 0.0 | 3.4 ± 1.6 |
| 18:1*n*–5 | 2.0 | 0.3 ± 0.1a | 0.2 ± 0.1b | 0.2 ± 0.1b |
| 20:1*n*–9 (11) | 4.1 | 5.2 ± 1.4a | 1.7 ± 1.0b | 0.8 ± 0.4b |
| 20:1*n*–7 | 4.3 | 0.2 ± 0.5a | 1.9 ± 0.7b | 0.7 ± 0.4a |
| 22:1*n*–11+9 | – | 0.1 ± 0.1 | 0.1 ± 0.0 | 0.0 |
| 24:1 | Tr | Tr a | 0.2 ± 0.1b | Tr ± 0.0a |
| **ΣMUFA** | **21.6** | **18.1** ± **0.9**c | **20.6** ± **2.1**b | **11.8** ± **0.7**c |
| 16:2*n*–4 | Tr | 0.8 ± 0.4a | 0.9 ± 0.2 | 0.2 ± 0.1b |
| 16:3*n*–4 | 0.9 | 0.8 ± 0.2a | 0.7 ± 0.0a | 0.2 ± 0.1b |
| 16:4*n*–3 | Tr | 0.6 ± 0.2a | 5.3 ± 1.5a | 0.3 ± 0.5b |
| 16:4*n*–1 | Tr | 0.2 ± 0.1ab | 0.7 ± 0.6a | 0.2 ± 0.0b |
| 18:2*n*–6 | 0.9 | 0.8 ± 0.2a | 1.4 ± 0.1b | 1.0 ± 0.1c |
| 18:2*n*–4 | 0.9 | 0.4 ± 0.1 | 0.4 ± 0.0 | 0.3 ± 0.1 |
| 18:3*n*–6 | Tr | 0.1 ± 0.1 | 0.2 ± 0.0 | 0.1 ± 0.1 |
| 18:3*n*–4 | Tr | 0.2 ± 0.0a | 0.2 ± 0.0a | Tr b |
| 18:3*n*–3 | Tr | 0.5 ± 0.1a | 0.9 ± 0.1b | 0.4 ± 0.1a |
| 18:4*n*–3 | 1.0 | 1.1 ± 0.7a | 3.0 ± 0.9b | 3.1 ± 0.6b |
| 18:4*n*–1 | 0.6 | 0.9 ± 1.8 | 0.3 ± 0.0 | 0.0 ± 0.0 |
| 20:2f | Tr | 2.9 ± 1.2a | 1.3 ± 0.1ab | 0.7 ± 0.3b |
| 20:2g | Tr | 0.2 ± 0.1a | 1.9 ± 0.8b | 0.1 ± 0.1a |
| 20:2h | Tr | 0.4 ± 0.1a | 0.9 ± 0.6ab | 0.1 ± 0.1ac |
| 20:2*n*–6 | 2.0 | 0.6 ± 0.2 | 0.5 ± 0.1 | 0.5 ± 0.1 |
| 20:3*n*–6 | 0.5 | 0.1 ± 0.1a | Tr b | Tr b |
| 20:4*n*–6 | 3.4 | 1.3 ± 0.3a | 2.0 ± 0.1b | 1.2 ± 0.2a |
| 20:3*n*–3 | Tr | 0.2 ± 0.2 | 0.3 ± 0.2 | 0.1 ± 0.1 |
| 20:4*n*–3 | Tr | 0.4 ± 0.1a | 0.1 ± 0.1b | 0.1 ± 0.1b |
| 20:5*n*–3 | 22.9 | 22.6 ± 1.3a | 19.6 ± 1.3a | 26.9 ± 2.9b |
| 22:2i | Tr | 0.5 ± 0.1a | 0.9 ± 0.6ab | Tr ac |
| 22:2j | Tr | 0.5 ± 0.1a | 3.1 ± 0.0b | Tr c |
| 21:5*n*–3 | 1.1 | 1.6 ± 0.1a | 1.2 ± 0.2b | 0.9 ± 0.1c |
| 22:4*n*–6 | Tr | 0.2 ± 0.2 | 0.1 ± 0.1 | 0.3 ± 0.1 |
| 22:5*n*–6 | Tr | 0.1 ± 0.1 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| 22:5*n*–3 | 1.9 | 1.6 ± 0.3a | 1.0 ± 0.1b | 0.7 ± 0.1b |
| 22:6*n*–3 | 14.3 | 16.5 ± 1.0a | 13.2 ± 1.0a | 25.9 ± 2.6b |
| **ΣPUFA** | **50.2** | **56.2** ± **0.8**a | **57.2** ± **2.2**a | **63.4** ± **1.6**b |
| ΣPUFA/ΣSFA | 1.8 | 2.2 ± 0.1a | 2.6 ± 0.1b | 2.6 ± 0.2b |
| Σ*n*–3 | 41.2 | 45.2 ± 1.6a | 43.6 ± 1.2a | 58.5 ± 2.1b |
| Σ*n*–3/Σ*n*–6 | 6.1 | 13.8 ± 1.7a | 11.0 ± 0.2a | 19.0 ± 2.3b |

[a] Data are mean ± SD. Values with different letters represent a significant difference between samples $n = 3$, $P < 0.05$. [b] Not detected. [c] Trace amounts were <0.1% of total fatty acids; 20:2f, 20:2g, 20:2h, 22:2i, and 22:2j were identified with reference to previously published retention times (*47*).

cod had ~57% PUFA in their flesh, of which 52% were $\omega-3$. Furthermore, cod livers contained PUFA and $\omega-3$ at 34 and 29%, respectively (**Table 5**). *G. morhua* from Norway were reported as having 52 and 30% of their total fatty acids present in the flesh and liver as $\omega-3$ (*23*), whereas cod from Nova Scotia were found to contain similar levels in their flesh (51%) and liver (25%) (*35*). Atlantic cod captured off Dartmouth, Nova Scotia, were also analyzed for whole-body lipids and found to contain 37% $\omega-3$ fatty acids (*33*). Furthermore, juvenile cod reared in enclosures in northern Norway that were fed a natural zooplankton diet contained 47% of their total fatty acids as $\omega-3$ (*36*). Levels of total PUFA (20%) and $\omega-3$ fatty acids (from 17 to 15%) were lower in pelagic fish than in gadoids. Previous studies on herring fillets have shown that the levels of $\omega-3$

**Table 8.** Factors Used To Convert Total Lipids into Absolute Amounts of Fatty Acids, Absolute Amounts of DHA+EPA, and Wet Weight Required To Obtain 1 g of EPA+DHA[a]

| total lipid (% wet wt) | NC | GC | RC | HR | CA | NCL | GCL | RCL | HRL | CL | CO | MU | SC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CVF for absolute fatty acids from percentage data | 0.6 | 0.7 | 0.7 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.6 | 0.6 | 0.7 | 0.6 |
| total fatty acids (g/100 g) | 0.3 | 0.4 | 0.5 | 6.1 | 8.8 | 19.7 | 18.2 | 27.1 | 2.7 | 0.5 | 0.3 | 0.4 | 0.3 |
| DHA+EPA/100 g of wet wt | 0.2 | 0.2 | 0.2 | 1.0 | 1.2 | 4.9 | 5.4 | 7.5 | 1.0 | 0.2 | 0.1 | 0.1 | 0.2 |
| wet wt (g) required for 1 g of EPA+DHA | 654 | 487 | 410 | 104 | 84.8 | 20.4 | 18.7 | 13.3 | 97.7 | 538 | 852 | 763 | 633 |

[a] NC, northern cod; GC, golden cod; RC, rock cod; HR, herring; CA, capelin; NCL, NC liver; GCL, GC liver; RCL, RC liver; HRL, HR liver; CL, clam; CO, cockle; MU, mussel; SC, scallop; CVF, conversion factor.

**Table 9.** Sterol Composition of Bivalves Collected from Gilbert Bay, Southern Labrador (August 2000)[a]

| systematic name | trivial name | surf clam, whole animal, *S. solidissima* ($n = 1$) | Greenland cockle, whole animal, *S. groenlandicus* ($n = 3$) | blue mussel, whole animal, *M. edulis* ($n = 3$) | Icelandic scallop, muscle, *C. islandica* ($n = 3$) |
|---|---|---|---|---|---|
| 24-norcholest-5,22*E*-dien-3$\beta$-ol | 24-nordehydrocholesterol | 2.8 | 9.5 ± 0.6a | 5.6 ± 0.5b | 9.1 ± 0.9a |
| 24-nor-5$\alpha$-cholest-22*E*-en-3$\beta$-ol | 24-nordehydrocholestanol | 0.4 | 0.3 ± 0.1a | 0.1 ± 0.0b | 0.1 ± 0.1b |
| 27-nor-24-methylcholest-5,22*E*-dien-3$\beta$-ol | occelasterol | 1.9 | 2.6 ± 0.1a | 2.8 ± 0.1a | 3.7 ± 0.2b |
| cholesta-5,22*E*-dien-3$\beta$-ol | *trans*-22-dehydrocholesterol | 10.2 | 10.1 ± 0.5a | 8.0 ± 0.3b | 11.5 ± 0.6a |
| cholest-5-en-3$\beta$-ol | cholesterol | 35.2 | 19.7 ± 4.7a | 39.4 ± 0.2b | 25.2 ± 1.8a |
| 5$\alpha$-cholestan-3$\beta$-ol | cholestanol | 1.4 | 0.5 ± 0.1a | 0.8 ± 0.0b | 0.2 ± 0.1c |
| 24-methylcholesta-5,22*E*-dien-3$\beta$-ol | brassicasterol | 9.2 | 5.8 ± 2.2a | 8.8 ± 0.9ab | 11.7 ± 0.6b |
| C27 steradienol | | 0.0 | 3.9 ± 0.9a | 7.5 ± 2.1ab | 0.0 ± 0.0ac |
| 24-methyl-5$\alpha$-cholest-22*E*-en-3$\beta$-ol | brassicastanol | 0.3 | 0.2 ± 0.1a | 0.1 ± 0.1ab | 0.0 ± 0.0b |
| cholesta-7,22*E*-dien-3$\beta$-ol | stellasterol | 2.2 | 2.5 ± 1.4 | 2.8 ± 0.3 | 1.8 ± 0.3 |
| 24-methycholesta-5,24(28)-dien-3$\beta$-ol | 24-methylenecholesterol | 7.9 | 16.8 ± 1.8a | 7.6 ± 0.3b | 12.1 ± 0.4c |
| 24-methylcholest-5-en-3$\beta$-ol | campesterol | 13.4 | 2.9 ± 0.3a | 1.3 ± 0.1b | 2.7 ± 0.3a |
| 24-ethylcholesta-5,22*E*-dien-3$\beta$-ol | stigmasterol | 0.9 | 1.3 ± 0.2a | 1.1 ± 0.1ab | 0.9 ± 0.0b |
| C28 steradienol | | 2.0 | 8.2 ± 0.9a | 5.4 ± 0.4b | 6.2 ± 0.3b |
| 24-ethylcholest-5-en-3$\beta$-ol | sitosterol | 5.5 | 6.3 ± 0.4a | 2.9 ± 0.2b | 5.7 ± 0.3a |
| 24-ethylcholesta-5,24(28)*E*-dien-3$\beta$-ol | fucosterol | 0.0 | 3.8 ± 0.6a | 1.5 ± 0.2b | 3.9 ± 0.4a |
| C29 stanol | | 2.0 | 0.9 ± 0.3 | 1.9 ± 0.7 | 0.9 ± 0.2 |
| 24-ethylcholesta-5,24(28)*Z*-dien-3$\beta$-ol | isofucosterol | 0.8 | 0.8 ± 0.1 | 0.6 ± 0.1 | 0.7 ± 0.1 |
| 4,23,24-trimethyl-5$\alpha$-cholest-22*E*-en-3$\beta$-ol | dinosterol | 0.4 | 0.6 ± 0.1a | 0.2 ± 0.2b | 1.2 ± 0.1c |
| 4,23,24-trimethyl-5$\alpha$-cholestan-3$\beta$-ol | dinostanol | 2.9 | 3.5 ± 0.6 | 1.8 ± 0.3 | 2.5 ± 0.9 |

[a] Data are mean ± SD.

vary significantly throughout the year, with the highest levels observed in the summer (~25%) and lowest levels in the winter (~14%) (*24*).

Levels of saturated fatty acids (SFA) were relatively constant across fish species in both flesh (17−24%) and liver (19−23%), with 16:0 present as the major fatty acid in all cases (**Tables 5** and **6**). MUFA was lower ($P < 0.05$) in cod flesh (18%) than in pelagic species (62%). The major MUFA was 18:1$\omega$−9 in gadoids, whereas C20 and C22 MUFA dominated in herring and capelin. High levels of 20:1$\omega$−9 and 22:1$\omega$−11 are in agreement with previous reports on herring flesh, and it is believed that these fatty acids originate in fatty alcohols found in their copepod zooplankton prey items (*37*).

The distribution of SFA (25%), MUFA (18%), and PUFA (57%) in bivalves was similar to that found in cod flesh (**Table 7**). However, the division between levels of 22:6$\omega$−3 and 20:5$\omega$−3 differed, with cod having higher levels of 22:6$\omega$−3 (~32%) and lower proportions of 20:5$\omega$−3 (~19%) than seen in bivalves (~18 and ~23%, respectively). Furthermore, although few differences existed between cod populations, there were many significant differences between bivalve species. Notably, scallop adductor muscle was higher in both the long-chain fatty acids 20:5$\omega$−3 (27%) and 22:6$\omega$−3 (25.9%), and this is related to a higher proportion of highly unsaturated PL relative to elevated proportions of TAG in mussels and cockles. Total levels of $\omega$−3 fatty acids in scallop adductor muscle were particularly high and account for 59% of the total fatty acids (**Table 7**). These proportions are slightly higher than those found in the giant scallop from Trinity Bay, Newfoundland; 51% $\omega$−3, 21% 20:5$\omega$−3, and 24% 22:6$\omega$−3 (*29*). Furthermore, in six species of marine and estuarine scallops it was found that $\omega$−3 fatty acids ranged from 25.1 to 50.0% (*38*). Therefore, it can be said that Gilbert Bay scallops are highly enriched with C20 and C22 $\omega$−3 fatty acids.

Mussels from Gilbert Bay contained on average 47% $\omega$−3 fatty acids. This is higher than the level of $\omega$−3 (36.6%) found in mussels from Barred Island Cove, Newfoundland (*39*). Furthermore, a review of mussels from the Northwest Atlantic Ocean reported only 26.2% $\omega$−3 fatty acids (*38*), whereas surf clams and mussels from Nova Scotia contained levels of $\omega$−3 at 41 and 30%, respectively (*18*). Thus, lipid analyses of all bivalve species in Gilbert Bay also show comparatively high levels of $\omega$−3 C20 and C22 fatty acids.

A recent review summarizing epidemiological and randomized control trials on the importance of fish-derived $\omega$−3 fatty acids in the reduction of human cardiovascular disease recommended increased consumption of fish oils (*40*). Recommendations were as follows: for people without documented coronary heart disease (CHD) at least two servings of fish per week and a variety of plant $\omega$−3 fatty acids; for patients with CHD at least 1 g of fish-derived EPA+DHA per day with the possibility of supplements; and finally for patients with elevated TAG at least 2−4 g of EPA+DHA per day, which would require supplements under a physician's care (*40*, *41*).

Given that the average North American consumes only 0.13 g day$^{-1}$ of EPA+DHA, there is a clear need for increased human consumption. However, this demand must be framed by the current limitation on essential fatty acids in aquatic ecosystems.

Recent reviews have demonstrated clearly that sources of essential fatty acids are limited and that innovation is required to develop new environmentally sustainable sources (*3*).

**Table 8** demonstrates that on average gadoids from Gilbert Bay contain 0.2 g of DHA+EPA per 100 g of wet weight, thus requiring the consumption of ~400−650 g of fish in order to meet the daily recommendation of 1 g of DHA+EPA. Fatty fish had higher levels of DHA+EPA per wet weight, resulting in lower weight rations, ~100 g. Cod liver oil is an ideal supplement with only ~13−20 g a day required. Shellfish showed levels of DHA+EPA per wet weight similar to those of gadoids, thus necessitating a range of 530−850 g of wet weight per day. Clearly, Gilbert Bay is a prime source of high-quality seafood with health-promoting benefits. Therefore, the management of Gilbert Bay as a Marine Protected Area could balance the production of high-quality seafood products with the overall health of the local ecosystem, thus providing a sustainable future for the local seafood industry.

**Sterols.** Twenty sterols were identified in bivalves from Gilbert Bay (**Table 9**). Significant differences existed among species, with mussels showing relatively higher levels of cholesterol (39%) than seen in cockles (20%) or scallops (25%). Other major sterols included 24-nordehydrocholesterol (~3−10%), *trans*-22-dehydrocholesterol (~8−12%), brassicasterol (~6−12%), an unidentified C27 steradienol (~4−8%), 24-methylenecholesterol (~8−17%), campesterol (~1−13%), an unidentified C28 steradienol (~5−8%), and sitosterol (~3−6%). Unlike humans and fish, it is thought that the ability of bivalves to modify dietary sterols is low or absent (*42*). Therefore, the wide array of sterols seen in bivalves compared to fish and crustaceans reflects their varied phytoplankton food sources. Examination of the sterol composition of different organs in the sea scallop (*P. magellanicus*) demonstrated that, unlike fatty acids, sterols were similar across all organs (*13*). However, when scallops were fed different microalgal diets, changes were observed in the sterol composition of the digestive gland and gonad but not in the adductor muscle. This indicated that unmodified dietary sterols do play a role in determining bivalve sterol composition. Furthermore, seasonality may have an affect on the sterol composition of bivalves from Gilbert Bay.

Examination of the sterol composition of plankton from Trinity Bay, Newfoundland, revealed that on average 8−14 different sterols were present in each net tow (*43*). In Trinity Bay plankton, cholesterol was on average ~15% of the total sterols, which is lower than that found in Labrador bivalves. There is some evidence from feeding trials that bivalves do selectively retain dietary cholesterol (*44*). Furthermore, in preliminary feeding trials with *P. magellanicus* postlarvae we fed five different mixed microalgal diets and found that scallop sterol composition after 4 weeks of feeding reflected dietary levels. However, we also observed some selective retention of dietary sterols such as cholesterol, brassicasterol, and campesterol, indicating a degree of membrane specificity (*45*).

The growing recognition of health benefits associated with dietary phytosterols may lead to an increased demand for shellfish (*14*). Furthermore, a recent review of phytosterols termed them "cholesterol busters" due to their lowering effect on blood serum cholesterol levels (*46*). The presence of phytosterols and phytostanols in the gut inhibits the uptake of cholesterol both by causing increased precipitation of sterols in the intestine and through displacement of cholesterol from micelles that are absorbed into the bloodstream (*14*). Although phytosterols are readily available from plant sources, seafood has the added benefit of containing high levels of DHA+EPA. Consequently, it seems that bivalves could be a new "cardiac superfood".

**Conclusion.** Despite differences in genetics and skin color, golden cod, northern cod, and rock cod did not differ in total lipid, major lipid classes, or nutritionally important fatty acids. Gadoids from Gilbert Bay showed lower levels of lipid per wet weight when compared to other analyses of gadoids from the North Atlantic region, whereas proportions of individual fatty acids were comparable. When considered from a nutritional perspective, Gilbert Bay cod is an excellent source of low-fat flesh with high relative proportions of $\omega-3$ fatty acids. Of all the seafood analyzed from Gilbert Bay, rock cod liver oil would most easily satisfy the American Heart Association guidelines of 1 g of DHA+EPA day$^{-1}$, which is recommended for people with cardiac disease. This recommendation would require ~13 g of cod liver oil day$^{-1}$. Bivalves also showed levels of total lipid that were at the lower range of those previously described in the North Atlantic. Scallop adductor muscle contained higher levels of phospholipid compared to whole-body analyses for other bivalves, also in agreement with previous studies. Levels of $\omega-3$ fatty acids in bivalves from Gilbert Bay were elevated compared to previous studies, with Icelandic scallop adductor muscle containing the highest levels, 63%. Combining the high levels of $\omega-3$ fatty acids with elevated levels of phytosterols (>62%) emphasizes the suitability of Gilbert Bay seafood for human consumption. Marine Protected Area status and local aquaculture development may help to secure this highly nutritional cold-water seafood resource.

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## LITERATURE CITED

(1) Leaf, A.; Weber, P. Cardiovascular effects of n-3 fatty acids. *N. Engl. J. Med.* **1988**, *318*, 549−557.

(2) Newton, I. S. Long chain fatty acids in health nutrition. In *Seafood in Health and Nutrition*; Shahidi, F., Ed.; ScienceTech Publishing: St. John's, Canada, 2000; pp 15−28.

(3) Arts, M. T.; Ackman, R. G.; Holub, B. J. "Essential fatty acids" in aquatic ecosystems: a crucial link between diet and human health and evolution. *Can. J. Fish. Aquat. Sci.* **2001**, *58*, 122−137.

(4) O'Rielly, A. Transformation in fisheries and aquaculture: An industry perspective. In *Seafood in Health and Nutrition*; Shahidi, F., Ed.; ScienceTech Publishing: St. John's, Canada, 2000; pp 1−6.

(5) Hutchings, J. A.; Walters, C.; Haedrich, R. L. Is scientific inquiry incompatible with government information control*? Can. J. Fish. Aquat. Sci.* **1997**, *54*, 1198−1210.

(6) Ruzzante, D. E.; Wroblewski, J. S.; Taggart, C. T.; Smedbol, R. K.; Cook, D.; Goddard, S. V. Bay-scale population structure in coastal Atlantic cod in Labrador and Newfoundland, Canada. *J. Fish Biol.* **2000**, *56*, 431−447.

(7) Morris, C.; Simms, J. M.; Anderson, T. C. Biophysical overview of Gilbert Bay: a proposed marine protected area in Labrador. *Can. Man. Rep. Fish. Aquat. Sci*. **2002**, *2595*, 1−25.

(8) Wroblewski, J. The colour of cod: Fishers and scientists identify a local cod stock in Gilbert Bay, Southern Labrador. In *Finding our Sea Legs*; Neis, B., Felt, L., Eds.; ISER Books: Newfoundland, Canada, 2000; pp 70−79.

(9) Green, J. M.; Wroblewski, J. S. Movement patterns of Atlantic cod in Gilbert Bay, Labrador: evidence for bay residency and spawning site fidelity. *J. Mar. Biol.* **2000**, *80*, 1077−1085.

(10) Dunstan, G. A.; Olley, J.; Ratkowsky, D. A. Major environmental and biological factors influencing the fatty acid composition of seafood from Indo-Pacific to Antarctic waters. *Rec. Res. Dev. Lipid Res.* **1999**, *3*, 63−86.
(11) Hall, J. M.; Parrish, C. C.; Thompson, R. J. Importance of unsaturated fatty acids in regulating bivalve and finfish membrane fluidity in response to changes in environmental temperature. In *Seafood in Health and Nutrition*; Shahidi, F., Ed.; ScienceTech Publishing: St. John's, Canada, 2000; pp 435−448.
(12) Krzynowek, J. Sterols and fatty acids in seafood. *Food Technol.* **1985**, 61−68.
(13) Napolitano, G. E.; Ackman, R. G.; Silva-Serra, M. A. Incorporation of dietary sterols by the sea scallop *Placopecten magellanicus* (Gmelin) fed on microalgae. *Mar. Biol.* **1993**, *117*, 647−654.
(14) Piironen, V.; Lindsay, D. G.; Miettinen, T. A.; Toivo, J.; Lampi, A. M. Plant sterols: Biosynthesis, biological function and their importance to human nutrition. *J. Sci. Food Agric.* **2000**, *80*, 939−966.
(15) Folch, J.; Lees, M.; Sloane, S. G. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* **1957**, *22*, 497−509.
(16) Parrish, C. C. Separation of aquatic lipid classes by Chromarod thin-layer chromatography with measurement by Iatroscan flame ionization detection. *Can. J. Fish. Aquat. Sci.* **1987**, *44*, 722−731.
(17) Morrison, W. R.; Smith, L. M. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride methanol. *J. Lipids Res.* **1964**, *5*, 600−608.
(18) Ackman, R. G. Nutritional composition of fats in seafoods. *Prog. Food Nutr. Sci.* **1989**, *13*, 161−241.
(19) Budge, S. M. Fatty acid biomarkers in a cold water marine environment. Ph.D. Thesis, Chemistry Department, Memorial University of Newfoundland, 1999.
(20) Jones, G. M.; Nichols, P. D.; Shaw, P. M. Analysis of microbial sterols and hopanoids. In *Chemical Methods in Prokaryote Systematics*; Goodfellow, M., O'Donnell, A. G., Eds.; Wiley Press: Chichester, U.K., 1994; pp 163−195.
(21) Morris, C. J.; Green, J. M. Biological characteristics of a resident population of Atlantic cod (*Gadus morhua* L.) in southern Labrador. *ICES J. Mar. Sci.* **2002**, *59*, 666−678.
(22) Jangaard, P. M.; Brockerhoff, H.; Bugher, R. D.; Hoyle, R. J. Seasonal changes in general condition and lipid content of cod from inshore waters. *J. Fish. Res. Board Can.* **1967**, *24*, 607−612.
(23) Santos, J. D.; Burkow, I. C.; Jobling, M. Patterns of growth and lipid deposition in cod (*Gadus morhua* L.) fed natural prey and fish-based feeds. *Aquaculture* **1993**, *110*, 173−189.
(24) Aidos, I.; Van Der Padt, A.; Luten, J. B.; Boom, R. M. Seasonal changes in crude and lipid composition of herring fillets, byproducts, and respective produced oils. *J. Agric. Food Chem.* **2002**, *50*, 4589−4599.
(25) Addison, R. F.; Ackman, R. G.; Hingley, J. Distribution of fatty acids in cod flesh lipids. *J. Fish. Res. Board Can.* **1968**, *25*, 2083−2090.
(26) Bligh, E. G.; Scott, M. A. Lipids of cod muscle and the effect of frozen storage. *J. Fish. Res. Board Can.* **1966**, *23*, 1025−1035.
(27) Alkanani, T.; Parrish, C. C. Unpublished data.
(28) Napolitano, G. E.; Ackman, R. G. Anatomical distributions and temporal variations of lipid classes in sea scallops *Placopecten magellanicus* (Gmelin) from Georges Bank (Nova Scotia). *Comp. Biochem. Physiol.* **1992**, *103B*, 645−650.
(29) Napolitano, G. E.; MacDonald, B. A.; Thompson, R. J.; Ackman, R. G. Lipid composition of eggs and adductor muscle in giant scallops (*Placopecten magellanicus*) from different habitats. *Mar. Biol.* **1992**, *113*, 71−76.
(30) Dare, P. J.; Edwards, B. D. Seasonal changes in flesh weight and biochemical composition of mussels (*Mytilus edulis* L.) in the Conwy Estuary, North Wales *J. Exp. Mar. Biol. Ecol.* **1975**, *18*, 89−97.
(31) Budge, S. M.; Parrish, C. C.; Thompson, R. J.; McKenzie, C. H. Fatty acids in plankton in relation to bivalve dietary requirements. In *Seafood in Health and Nutrition*; Shahidi, F., Ed.; ScienceTech Publishing: St. John's, Canada, 2000; pp 495−520.
(32) Joensen, H.; Steingrund, P.; Fjallstein, I.; Grahl-Nielsen, O. Discrimination between two reared stocks of cod (*Gadus morhua*) from the Faroe Islands by chemometry of the fatty acid composition in the heart tissue. *Mar. Biol.* **2000**, *136*, 575−580.
(33) Kirsch, P. E.; Iverson, S. J.; Bowen, W. D.; Kerr, S. R.; Ackman, R. G. Dietary effects on the fatty acid signature of whole Atlantic cod (*Gadus morhua*). *Can. J. Fish. Aquat. Sci.* **1998**, *55*, 1378−1386.
(34) Gosse, K. Brown cod and bay stocks: science and fish harvesters' knowledge of coloration in populations of Atlantic cod (*Gadus morhua*) in Newfoundland and Labrador. M.Sc. Thesis, Environmental Science Department, Memorial University of Newfoundland, 2002.
(35) Jangaard, P. M.; Ackman, R. G.; Sipos, J. C. Seasonal changes in fatty acid composition of cod liver, flesh, roe and milt lipids. *J. Fish. Res. Board Can.* **1967b**, *24*, 613−630.
(36) Olsen, R. E.; Henderson, R. J.; Pedersen, T. The influence of dietary lipid classes on the fatty acid composition of small cod *Gadus morhua* L. juveniles reared in an enclosure in northern Norway. *Exp. Mar. Biol. Ecol.* **1991**, *148*, 59−76.
(37) Ratnayake, W. N.; Ackman, R. G. Fatty alcohols in capelin, herring and mackerel oils and muscle lipids: 1. fatty alcohol details linking dietary copepod fat with certain fish depot fats. *Lipids* **1979**, *14*, 795−803.
(38) Joseph, J. D. Lipid composition of marine and estuarine invertebrates. Part II: Mollusca. *Prog. Lipids Res.* **1982**, *21*, 109−153.
(39) Budge, S. M.; Parrish, C. C.; McKenzie, C. H. Fatty acid composition of phytoplankton, settling particulate matter and sediments at a sheltered bivalve aquaculture site. *Mar. Chem.* **2001**, *76*, 285−303.
(40) Kris-Etherton, P. M.; Harris, W. S.; Appel, L. J. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. *Circulation* **2002**, *106*, 2747−2757.
(41) American Heart Association. Fish Oil and Omega-3 Fatty Acids Dietary Recommendations, 2002; http://216.185.112.5/presenter.jhtml?identifier=4632.
(42) Teshima, S. Sterols of crustaceans, mollusks and fish. In *Physiology and Biochemisty of Sterols*; Patternson, G. W., Nes, W. D., Eds.; American Oil Chemists' Society: Champaign, IL, 1991.
(43) Hudson, E. D.; Parrish, C. C.; Helleur, R. J. Biogeochemistry of sterols in plankton, settling particles and recent sediments in a cold ocean ecosystem (Trinity Bay, Newfoundland). *Mar. Chem.* **2001**, *76*, 253−270.
(44) Soudant, P.; Marty, Y.; Moal, J.; Robert, R.; Quere, C.; Le Coz, J. R.; Samain, J. F. Effect of food fatty acid and sterol quality on *Pecten maximus* gonad composition and reproduction process. *Aquaculture* **1996**, *143*, 361−378.
(45) Copeman, L. A.; Parrish, C. C. Unpublished data.
(46) Hicks, K. B.; Moreau, R. A. Phytosterols and phytostanols: functional food cholesterol busters. *Food Technol.* **2001**, *55*, 63−67.
(47) Ackman, R. G. WCOT (capillary) gas−liquid chromatography. In *Analysis of Oils and Fats*; Hamilton, R. J., Rossell, J. B., Eds; Elsevier Applied Science Publishers: New York, 1986; pp 137−206.

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