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RESEARCH ARTICLE

Partial characterization of the lipidome of the cold-water scallop,
Chlamys islandica

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Abstract

Fingerprinting of the main lipid components of the digestive gland of the Icelandic scallop—*Chlamys islandica*—has been performed by ultra-high-performance liquid chromatography coupled with time of flight high-resolution mass spectrometry, UHPLC-HRMS/ToF. This method allowed the identification of 224 lipids, including phosphatidylcholines (PC), plasmalogen (PC-O)/plasmalogen (PC-P) phosphatidylcholines, lyso-phosphatidylcholines (LPC), and their plasmalogen/plasmalogen forms (LPC-O/LPC-P). Diacylglycerols (DG), triacylglycerols (TG), and cholesteryl esters (CE) were the neutral lipids (NL) analyzed. While all of the lipids showed a strong seasonal dependence in terms of quantity, only NLs presented significant qualitative changes. Principal component analysis (PCA) of TG and DG profiles evidenced a prevalence of low unsaturated TGs and DGs in spring, which were replaced by species with a higher degree of unsaturations in summer. In autumn, long and highly unsaturated TGs constitute the lipid fraction of the digestive gland of the scallop, while DG species offer a mixed profile. This study contributes to the characterization and the elucidation of the lipidome of *Chlamys islandica* and provides baseline data for further study of the effects of pollutants on the lipidome of the Icelandic scallop, often used as a sentinel species in biomonitoring programs.

Keywords Lipidomics · Bivalves · Digestive gland · UHPLC-HRMS/ToF · Seasonal variation

Introduction

Human activities are expected to increase in Arctic areas due to sea water warming and reduced sea ice cover (Meier and Hovelsrud 2014). These activities will increase the release of chemicals and, consequently, environmental pollution, which might have numerous ecological consequences, including changes in organism physiology, shifts in species distribution

and behavior, and significant changes on trophic interactions (Wassmann et al. 2011; Sagerup et al. 2016; Tran et al. 2016). Hence, biological relevant indicators are required to monitor the ecosystem status in relation to diffuse anthropogenic pollutants or acute accidental discharges in these areas (Hannam et al. 2010; Geraudie et al. 2016).

Benthic animals, including bivalves, are frequently used for the biomonitoring of ecosystem health and pollution (Porte et al. 2001). Data on biological relevant indicators and their responses to anthropogenic stressors is still scarce in Arctic and sub-Arctic seas. The Icelandic scallop *Chlamys islandica* is a widely distributed sub-Arctic species; it is a filter feeder bivalve that lives on sandy, gravelly or shell sandy bottoms between 20 and 110 m depth. They thrive best at temperatures between − 1.4 and 10 °C; the spawning occurs between June and end of July, mainly influenced by the rise in sea temperature, ice thaw, and feeding conditions (Thorarinsdóttir 1993; Guijarro Garcia 2006). *C. islandica* has been proposed as sentinel species for ecotoxicological investigations by using a combination of biomarkers of oxidative stress, biotransformation, or general stress (Hannam et al. 2010; Nahrgang et al. 2013; Geraudie et al. 2016)

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Lipids play a fundamental role in cellular metabolism as energetic, structural, and cell signalling molecules, but also in the biochemical adaptations of organisms living under severe conditions in the northern latitudes (Kakela and Hyvarinen 1996; Vance and Vance 1996; Tocher 2003; Tkatcheva et al. 2004). They are key components of the plasma membrane and other cellular compartments, including the nuclear membrane, the endoplasmic reticulum, the Golgi apparatus, and trafficking vesicles, such as endosomes and lysosomes (Muro et al. 2014). Lipids are exceptionally diverse in their structural, chemical, and physical properties. Although, sterols and lipid class composition are the primary modification of membrane lipids of poikilotherms during homeoviscous adaptation (Hazel 1995; Crockett 1998; Ernst et al. 2016), the functionality of membranes (e.g., fluidity, permeability, mobility) is also determined by the desaturation and the length of the fatty acid chains in membrane lipids; viz. short and highly unsaturated phospholipids allow poikilothermic organisms to survive at low temperatures (Velansky and Kostetsky 2008; Murzina et al. 2013). Consequently, the lipid content of marine organisms, including bivalves, varies depending on biological and environmental factors, such as taxonomy, reproductive and energetic status, diet, water temperature, and habitat's latitude (Ezgeta-Balić et al. 2012; Lazzara et al. 2012; Ventrella et al. 2013).

The digestive gland is the organ where the storage of nutrients and the transformation of energy in molluscs occur. It plays a key role in the metabolism of endogenous compounds (e.g., steroids, lipids) and xenobiotics (Mateos et al. 2010). Moreover, exposure to contaminants may disrupt homeostatic control of adipogenesis and energy balance by altering lipid metabolism. Indeed, accumulation of NL, alteration of fatty acid homeostasis, and peroxisome proliferation (PP) have been reported in molluscs exposed to organotin compounds, nanoparticles, and metals (Banni et al. 2016; Mleiki et al. 2018), as well as in molluscs living in polluted environments (Perrat et al. 2013; Fokina et al. 2014). These studies have shown that qualitative and quantitative oscillations in lipid composition of marine organisms could be useful for the evaluation of pollution exposure.

Recent advances in electrospray ionization coupled to mass spectrometry (ESI-HRMS) have facilitated the rapid and sensitive characterization of different lipid classes in a single analysis and, thus, the rising of lipidomics as a promising research field (Watson 2006; Blanksby and Mitchell 2010). The chromatographic separation of analytes previous to mass spectrometry provides increased sensitivity due to low spectra complexity, which together with information on retention times makes the technique suitable for the detection of new, even low abundant lipids (van Smeden et al. 2011). Among the drawbacks, the low detection limit of lipids that are not ionized or poorly ionized, and the lack of structural information on the detected lipids, as only the number of carbons and

number of double bonds of the molecule are attained (Sandra and Sandra 2013).

Thus, a better knowledge of the lipidome of sentinel species of Arctic and sub-Arctic areas will probably allow a deeper understanding of the alterations caused by xenobiotics in target organs and will facilitate the development of biomarkers of lipid disruption. In this context, the aim of this work was to partially characterize the lipidome of the digestive gland of the Icelandic scallop *Chlamys islandica* by focusing on phosphocholines and neutral lipids, in an attempt to provide fundamental knowledge for further investigation of the impact of environmental stressors on lipid dynamics. Since lipidome varies depending on biological and environmental factors, a seasonal study was carried out.

Materials and methods

Sampling

Icelandic scallops *C. islandica* (60–80 mm shell length) were collected seasonally (April/May, July, October) from Tromsø fjord (69° 35.060' N, 18° 55.701' E) by dredging between 10 and 20 m depth. At this depth, the temperature varied between 4 and 8 °C during the sampling period. The scallops were taken to the laboratory in clean glass containers, and the digestive gland immediately dissected, snap frozen in liquid nitrogen, and stored at – 80 °C until analysis.

Lipid extraction

Lipids were extracted by a modification of Folch et al. (1957). Each sample consisted in a pool of 3–5 digestive glands. A subsample (100–150 mg) was homogenized in ice-cold chloroform:methanol (2:1 v/v) containing 0.01% butylated hydroxytoluene (BHT). After centrifugation (3000 rpm, 10 min, 10 °C), 0.88% KCl was added to the supernatant (1:4 v/v) and thoroughly mixed. The chloroform layer was collected and the solvent evaporated under nitrogen. The extraction was repeated twice and the dry lipid residue was determined gravimetrically (Sartorius, BP210D, ± 0.01 mg) and stored at – 20 °C.

Instrumental analysis

Lipid extracts were resuspended in methanol before the addition of ~ 200 pmol of an internal standard mix, covering all the lipid subclasses analyzed, including 16:0D31-18:1 phosphatidylcholine; 17:0 lyso-phosphatidylcholine; 1,3-17:0D5 diacylglycerol, 1,2,3-17:0 triacylglycerol, and 17:0 cholesteryl ester (Avanti Polar Lipids, Inc). The analysis was carried out in a Waters Acquity UHPLC system connected to a Waters LCT Premier XE Time of Flight Mass Spectrometer (Waters,

153 Millford, MA), operated in positive electrospray ionization
154 mode (ESI+) as described in Garanto et al. (2013). Briefly,
155 full scan spectra from 50 to 2000 Da were obtained. Mass
156 accuracy and reproducibility were maintained by using an
157 independent reference spray via LockSpray. A 100 mm ×
158 2.1 mm id, 1.7 μm C8 Acquity UPLC BEH (Waters) analyt-
159 ical column was used. The two mobile phases were 1 mM
160 ammonium formate in methanol (phase A) and 2 mM ammo-
161 nium formate in water (phase B); both phases with 0.2% of
162 formic acid. The programmed gradient was 0 min, 80% A; 3
163 min, 90% A; 6 min, 90% A; 15 min, 99% A; 18 min, 99% A;
164 20 min, 80%. The flow rate was 0.3 ml min⁻¹. The column
165 temperature was kept at 30 °C. The linear dynamic range was
166 determined by injection of the lipid standard mix. The relative
167 standard deviation (RSD) of the internal standards ranged be-
168 tween 9 and 26%. Positive identification of lipids was based
169 on the accurate mass measurement with an error < 10 ppm and
170 the retention time (± 2%). An inventory of lipids, containing
171 PCs, PC-O/PC-Ps, LPCs, LPC-O/LPC-Ps, TGs, DGs, and
172 CEs, based on reported identified species was first generated.
173 Their theoretical exact masses were determined using a spec-
174 trum simulation tool of MassLynx software and LIPID MAPS
175 Lipidomics Gateway, and the obtained list was used as a ref-
176 erential database. Individual chromatographic peaks of dis-
177 tinct lipid species were isolated from full-scan MS spectra
178 when selecting their theoretical exact masses, extracted from
179 the database. Then, a list of potential candidates fitting the
180 specific exact mass was generated using formula determina-
181 tion tools (elemental composition search) of Micromass
182 MassLynx software.

183 **Data analysis**

184 The resulting data matrices for the distribution of the major
185 lipid subclasses, PCs, PC-O/PC-Ps, TGs, and DGs were
186 imported to MetaboAnalyst 3.0 (Xia et al. 2015) to perform
187 principal component analysis (PCA) and two-dimensional
188 color representations, also called heatmaps. Prior to statistical
189 analyses, all variables were auto-scaled (mean-centered and
190 divided by the standard deviation of each variable).
191 Alterations in lipid concentrations considering the sampling
192 time factor were individually evaluated applying one-way
193 ANOVA and correcting *p* values for false discovery rates

(FDR) according to the Benjamini-Hochberg multiple com-
parison testing procedure (Benjamini and Hochberg 1995). In
addition, one-way ANOVA followed by a Tukey test (post
hoc test) was performed to assess seasonal differences. The
threshold for statistical significant difference was set at *p* <
0.05.

Results

Biometric data of the studied scallops, gonadosomatic (GSI),
and hepatosomatic (HSI) indexes are presented in Table 1. A
decrease in the GSI index was observed in July, which was
maintained in October, indicating that spawning began before
the summer sampling. Regarding the HSI, a significant de-
crease was detected in October.

The analysis of lipid extracts by UHPLC-HRMS/ToF allowed
the identification of 224 lipid species; their molecular formula,
accurate ionized mass, error (ppm), and retention time are shown
in Table S1 (supplementary information). LPCs and LPC-O/
LPC-Ps were the first groups of lipids to elute in the chromato-
gram appearing at the early 5 min. They were totally resolved
from PCs, PC-O/PC-Ps, and DGs, which eluted in the subse-
quent 10 min. TGs and CEs eluted between 15 and 20 min.
Individual lipid species unresolved in the total ion chromatogram
were successfully isolated when their exact masses were selected.
TGs, DGs and CEs were detected as [M + NH₄]⁺ adducts,
whereas the rest of lipids were identified in the protonated form
[M + H]⁺. A further discrimination between PCs and their iso-
baric phosphatidylethanolamine (PE) species was achieved
through the analysis of a representative sample in ESI negative
mode, where PCs were detected as [M + HCOO]⁻ adducts and
PEs were identified in the deprotonated form [M-H]⁻. All the
lipid subclasses, except CEs, were quantified.

The concentration of each lipid subclass out of the total lipid
fraction in the digestive gland of *C. islandica* is shown in Table 2.
Quantitative seasonal changes were observed in all lipid sub-
classes, with the exception of DGs. The highest concentration
of PCs was detected in April (43 ± 2 nmol/mg lipid) followed by
a sharp decrease in July (22 ± 2 nmol/mg lipid) and a rise in
October (35 ± 3 nmol/mg lipid). A similar seasonal fluctuation
was detected for PC-O/PC-Ps, LPCs, and LPC-O/LPC-Ps, al-
though the increase in October was not statistically significant.

t1.1 **Table 1** Descriptive parameters
of the scallops collected in spring
(May), summer (July), and
t1.2 autumn (October). HSI calculated
as HSI = digestive gland weight/
t1.3 soft weight; GSI = gonad weight/
soft weight. Values are mean ±
t1.4 SEM. Distinct letters indicate
t1.5 statistically significant differences
(*p* < 0.05)

Season	<i>n</i>	Length (mm)	Width (mm)	Soft weight (g)	HSI	GSI
May	8	71.8 ± 2.0 ^a	68.0 ± 1.5 ^{a,b}	28.5 ± 2.1 ^a	6.0 ± 0.4 ^a	14.2 ± 1.3 ^a
July	6	69.3 ± 2.1 ^a	64.3 ± 2.0 ^a	21.3 ± 1.6 ^b	5.9 ± 0.3 ^a	7.4 ± 0.2 ^b
October	8	79.0 ± 1.2 ^b	72.2 ± 0.9 ^b	29.4 ± 1.1 ^a	4.7 ± 0.2 ^b	5.0 ± 0.8 ^b

t2.1 **Table 2** Total amount of lipids
 t2.2 per subclass detected in the
 t2.3 digestive gland of *Chlamys*
 t2.4 *islandica*. Data expressed in
 t2.5 pmol/mg extracted lipid as mean
 t2.6 $\pm$ SEM ($n = 3$ in May, $n = 4$ in
 t2.7 July and October). Each sample is
 t2.8 a pool of 3–5 organisms. Distinct
 t2.9 letters indicate statistically
 significant differences ($p < 0.05$)

Lipid subclass	May	July	October
PC	43349 $\pm$ 2233 ^a	22013 $\pm$ 2185 ^b	35221 $\pm$ 2880 ^a
PC-O/PC-P	9338 $\pm$ 1571 ^a	4855 $\pm$ 459 ^b	6606 $\pm$ 416 ^b
LPC	5042 $\pm$ 878 ^a	2942 $\pm$ 404 ^b	3869 $\pm$ 339 ^b
LPC-O/LPC-P	585 $\pm$ 91 ^a	304 $\pm$ 53 ^b	432 $\pm$ 47 ^{a,b}
TG	317641 $\pm$ 18740 ^a	346896 $\pm$ 74842 ^{a,b}	492929 $\pm$ 24592 ^b
DG	30450 $\pm$ 6189 ^a	67259 $\pm$ 13228 ^{a,b}	57648 $\pm$ 3982 ^b
Total	406407 $\pm$ 29702 ^a	444269 $\pm$ 90944 ^{a,b}	596706 $\pm$ 30710 ^b

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In contrast, the content of NL increased from July to October. The results revealed a higher abundance of NL (DGs and TGs) compared with other lipids.

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Seven LPCs, 2 LPC-O/LPC-Ps, 43 PCs, and 20 PC-O/PC-Ps were identified. Figure 1 depicts the concentration (pmol/mg lipid) of PCs and PC-O/PC-Ps detected in the digestive gland

Fig. 1 Concentration of individual (a) PCs and (b) PC-O/PC-Ps in the digestive gland of *C. islandica* over the sampling period. Data in pmol/mg lipid as mean $\pm$ SEM ($n = 3$ May, $n = 4$ July, October). Each sample is a pool of 3–5 organisms

of *C. islandica* over the sampling period. The most abundant PCs and PC-O/PC-Ps species were PC36:5, PC38:6, PC-O38:6/PC-P38:5, and PC-P38:6. A similar seasonal pattern was observed for both subclasses, which consisted in a general decrease from April to July, rising again in October. LPCs presented similar seasonal behavior (Fig. S1). Regarding glycerolipids, 102 TGs and 51 DGs species were identified. TGs of 52 to 58 carbons in their acyl chains and 5 to 11 double bonds, together with DGs of 36 to 44 carbons and 5 to 11 double bonds were the predominant ones (Fig. 2). Concerning sterols, 11 CEs were detected, but not quantified nor included in the statistical analysis due to their low abundance (Table S1).

The data matrices of the main lipid subclasses were subjected to PCA to study the relationships among groups of variables and to discriminate groups according to the sampling season. The analysis of the relative abundance of the individual lipids within a subclass evidenced significant seasonal changes for TGs and DGs, while the profile of PCs and PC-O/PC-Ps did not suffer significant alterations (Fig. S2). The scores plot showed a complete separation of the tested groups (May, July, and October), which is described by two non-dependent principal components that explained 81% of the total variance for TGs and 79% for DGs (Fig. 3). The heatmap revealed a high dissimilarity of TG profiles along the year (Fig. 4). TGs with relatively low number of unsaturations were the most abundant species in May (TG48:0-2, TG50:0-4, TG52:0-5, TG54:1-5), while highly unsaturated TGs were

more abundant in July (TG48:3-7, TG50:5-9, TG52:6-10, TG54:8-12). Regarding October, the TG profile was dominated by few TG species with high number of carbons and unsaturations (TG54:6, TG56:5, TG58:9,10 and TG60:9,10,13,14); only 15 TGs were detected, whereas about 30 TGs were identified in May and July. Likewise, the profile of DGs also changed seasonally. The heatmap depicted this dissimilarity (Fig. 5). Samples from May were mainly characterized by the presence of DG34:1, DG34:2, DG36:2, DG38:5, and DG40:6, as well as the presence of larger and highly unsaturated species, such are DG44 with 10, 11, and 12 unsaturations. On the contrary, a greater number of DG species were detected in July (DG34:5-8, DG36:4,6-9, DG38:8-10, DG40:9-10 and DG42:11). Regarding October, DG profile exhibited a rich composition in species with an intermediate number of double bonds, viz. DG34:3, DG36:3,5, DG38:6,7, DG40:8 and larger DGs, which were undetected in spring and summer (DG42:6-10 and 44:8). Hence, the lipid profile of the Arctic scallop in May was characterized by the presence of low unsaturated DGs and TGs, while species with a higher degree of unsaturations were mainly found in July. Finally, in October, long and highly unsaturated TGs mostly constituted the lipid fraction of the digestive gland of the scallop, while DG species offered high diversity. The biplot generated by the PCA helps to visualize the seasonal changes detected for TGs and DGs (Fig. S3).

Fig. 2 Concentration of individual (a) TGs and (b) DGs in the digestive gland of *C. islandica* over the sampling period. Data in pmol of lipid species/mg lipid as mean $\pm$ SEM ($n = 3$ May, $n = 4$ July, October). Each sample is a pool of 3–5 organisms

Fig. 3 Principal component analysis of the relative abundance of (a) TG and (b) DG over the sampling period. The data matrix was auto scaled. An excellent separation of the samples was obtained, defined by the sum of both principal components

Discussion

This study reports for the first time the identification of 224 lipid species in the digestive gland of *C. islandica* measured by UHPLC-MS/ToF. Although other studies have evaluated the total lipid content in the digestive gland of the Icelandic

scallop and its potential use as sentinel organism in Arctic areas (Brokordt and Guderley 2004; Nahrgang et al. 2013), to the best of our knowledge, no data is available regarding the seasonal variation of the specific lipid species that build up the membranes (i.e., phosphatidylcholines) or the neutral lipid depots (triacylglycerols, diacylglycerols) in *C. islandica*.

The quantitative analysis demonstrates that NLs (DGs and TGs) are the predominant lipid fraction in the digestive gland as reported in other bivalves (Martínez-Pita et al. 2012; Fernández-Reiriz et al. 2015). Both, phosphocholines (PCs, PC-O/PC-Ps, LPCs, and LPC-O/LPC-Ps) and NLs (TGs, DGs) presented differential seasonal variation, which was probably influenced by the reproductive cycle, energy transfer during this cycle, food supply, and light availability. The measured GSI indicates that spawning takes place between end of May and end of July, the precise timing being mostly influenced by the increase of sea light and the subsequent feeding conditions (Thorarinsdóttir 1993; Guijarro Garcia 2006). During gonad maturation, the mobilization of macromolecular reserves from somatic tissues to the gonads occurs (Brokordt and Guderley 2004). Thus, the consequent migration of lipids from the digestive gland to the gonads might have accounted for a decreased concentration of TGs in digestive gland in May and July in comparison to October. Moreover, TG content in July is possibly influenced by the rise in food availability that occurs in sub-Arctic seas after spring, competing with the migration of TGs from the digestive gland to the gonad. Besides, the sharp decrease observed for phosphocholines in July might be consequence of the need of phosphorous to form lipovitellin associated with the development of the oocytes (Lee et al. 2006; Aubert et al. 2013). In autumn, the organism must prepare itself for tougher conditions, mostly related to limited food availability and absence of light, and consequently, the total content of lipids, peaked in this season.

Interestingly, despite of the observed quantitative changes, the PC and PC-O/PC-P profiles remained unchanged over the different sampling periods. Along the year, phosphatidylcholines maintain high abundance of double bonds in their structures, suggesting that the physico-chemical properties of the membranes do not significantly change, which is in accordance to the fact that water temperature remains stable through the year. Individual phospholipids perform regulatory functions in the adaptation of organisms to low temperature and a fixed distribution ensures the correct activity of numerous membrane-bound enzymes (Murzina et al. 2013; Arish et al. 2015; Casas et al. 2017). On the contrary, in spring, before the food bloom in Arctic and sub-Arctic seas occurs, TG profiles are enriched in species with a low number of double bonds. Although bivalves might modulate

Fig. 4 Heatmap of auto-scaled TG levels in the digestive gland of *C. islandica*. The most abundant species (orange/red) differ from one season to another. In spring, TGs with a low number of unsaturations were detected. In autumn, a lower number of TG species defined the subclass profile. Distinct letters indicate statistically significant differences ($p < 0.05$). (a) May vs. July; (b) July vs. October; (c) May vs. October

the synthesis of FAs independently of their diet (Ventrella et al. 2013; Aranda-Burgos et al. 2014), their ability to biosynthesize de novo PUFAs is limited (Pirini et al. 2007; Fernández-Reiriz et al. 2015). Consequently, they must acquire most PUFAs from filtering phytoplankton, which is composed of 40 to 50% PUFAs in Balsfjorden and other northern ecosystems (Sargent et al. 1985; Velansky and Kostetsky 2008). Besides, it is known that bivalve fatty acids are enriched of ω -3 long-chain PUFAs, as eicosapentaenoic acid (FA20:5 n-3) and docosahexanoic acid (FA22:6 n-3) (Ventrella et al. 2013); specifically, it has been reported that phosphatidylinositols (PI), which are involved in DGs

metabolic route, are rich in PUFAs 20:4 and 20:5 in *C. islandica* (Bell and Bell and Sargent 1985; Coleman and Lee 2004). Taking all this into account, the lipid composition of the digestive gland of the Icelandic scallop is expected to be enriched in highly polyunsaturated lipids, as observed during the summer sampling, when TG and DG profiles were enriched in species with a high number of unsaturations, viz. DG38:9, DG40:10, TG48:5, or TG54:11, as well as the phosphocholine fraction (PC38:6, PC-O38:6/PC-P38:5). In contrast, the TG profile was dominated by few TGs with high number of carbons and unsaturations (TG58:9,10 and TG60:9,10,13,14) in October. Thus, NL content was composed by the longest

Fig. 5 Heatmap of auto-scaled DGs within the sampling seasons. The plot revealed a high seasonal dependence of lipids. Distinct letters indicate statistically significant differences ($p < 0.05$). (a) May vs. July; (b) July vs. October; (c) May vs. October

and most energetic molecules before winter and the subsequent food decrease arrive (Berg et al. 2002). Accordingly, an accumulation of PUFAs has been observed in the digestive gland of bivalves from temperate areas before gonad maturation, and their subsequent migration to gonads for their development (Marty et al. 1992; Soudant et al. 1996; Martínez-Pita et al. 2012).

In conclusion, bivalve lipid metabolism has been the subject of a number of studies, largely because of the important position held by this group in marine food chains. Although the Icelandic scallop has been used as sentinel species for eco-toxicological research, there is a lack of fundamental knowledge on its lipid composition. Therefore, this work describes a significant part of the lipidome of the digestive gland of *Chlamys islandica*, as well as its seasonal changes. The characteristic lipidome

and its alterations along the year are modulated by the reproductive status of the organism, the latitude, and the subsequent fluctuations in food quality and quantity. This report provides baseline data on neutral lipid and phosphocholines for further study of the effects of ongoing warming conditions alone or in combination with contaminant exposure on the lipidome of the Icelandic scallop.

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