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1 **Lipid dynamics in early life stages of the icefish *Chionodraco hamatus* in the**
2 **Dumont d'Urville Sea (East-Antarctica)**
3

4 Carolina Giraldo^{1,2*}, Marc Boutoute², Patrick Mayzaud^{1,2} Eric Tavernier^{3,4}, An Vo Quang^{1,2}, and
5 Philippe Koubbi⁵

6 ¹UPMC Université Paris 06, UMR 7093, Laboratoire d'Océanographie de Villefranche, BP28,
7 06234 Villefranche-sur-Mer, France.

8 ²CNRS, UMR 7093, LOV, BP 28, 06234 Villefranche-sur-Mer, France.

9 ³Université Lille Nord de France, F-59000 Lille, France.

10 ⁴ULCO, LOG, 32 avenue Foch, F-62930 Wimereux, France.

11 ⁵ Unité Biologie des organismes et écosystèmes aquatiques (BOREA, UMR 7208), Sorbonne
12 Universités, Muséum national d'Histoire naturelle, Université Pierre et Marie Curie, Université
13 de Caen Basse-Normandie, CNRS, IRD; CP26, 57 rue Cuvier 75005 Paris, France.

14 *Corresponding author: carolina.giraldo@univ-lille1.fr

15 **Abstract**
16

17 Lipids play a crucial role in polar regions and are of particular importance in early life stages of
18 Antarctic fish. This work presents the significance of lipids and fatty acids (FA) in the early life
19 stages of the icefish *Chionodraco hamatus*. Analysis of lipid classes (Polar lipids, LP;
20 Cholesterol, Chol; and Triacylglycerol, TAG) suggested different energy allocation strategies in
21 preflexion (<25 mm) and postflexion larvae (>25 mm). Structural PL dominated lipid dynamics
22 for preflexion larvae, indicating that small individuals allocate the majority of energy toward
23 somatic growth. Conversely, postflexion larvae appear able to switch between growth
24 (contribution of PL) and energy storage (contribution of TAG) strategies. The condition index

25 ratio TAG:Chol varied from 0.2 to <2 with no differences between the two larval stages. Further,
26 FA composition of the TAG and PL fractions suggests that both developmental stages share the
27 same carnivorous diet and that *C. hamatus* relies on a few key prey items.

28 **Key-words:** Larvae, fatty acids, nutritional condition, diet, Antarctica

29 **Introduction**

30

31 In the pelagic ecosystem of the Southern Ocean, icefish (Channichthyidae, ‘white-
32 blooded’ fish) form a family within the perciform suborder Notothenioidei, the most
33 predominant suborder of demersal Antarctic fishes (Kock 2005). Early life stages of most species
34 of channichthyids have been described (Efremenko 1987; Kellermann and Schadwinkel 1991)
35 and their distribution and relative abundance reviewed elsewhere (La Mesa and Ashford 2008;
36 Loeb et al. 1993). At hatching, larvae of channichthyids are relatively large (13–17 mm),
37 suggesting greater likelihood of survival compared to smaller larvae of other Antarctic fishes
38 (Kock 2005). In addition, larval channichthyids exhibit relatively fast growth rates and feed
39 primarily on young stages of euphausiids and larval nototheniids (Kellermann 1990; La Mesa et
40 al. 2011). Although most channichthyids are demersal-benthic as adults, larvae and postlarvae
41 are typically pelagic. The most common channichthyid within the pelagic communities of the
42 Ross and Dumont D’Urville Sea are larval and juvenile *Chionodraco* sp. (Granata et al. 2002;
43 North 1988). The genus *Chionodraco* includes *C. hamatus*, *C. myersi*, and *C. rastrospinosus*,
44 with *C. hamatus* and *C. myersi* previously identified from the Dumont d’Urville Sea (Koubbi et
45 al. 2010). As the taxonomic identification of larval stages of *Chionodraco* sp. is still unclear
46 (Kellermann 1990), most authors base larval identification on the co-occurrence of adults in the

47 same area (Hubold 1990; Moteki and Ishimaru 2008). In the Dumont d'Urville Sea, adult *C.*
48 *hamatus* are overwhelmingly more common than adult *C. myersi* (Koubbi et al. 2009), and some
49 barcoded larvae have been identified as *C. hamatus* (Dettai, pers. comm.). Therefore, larvae of
50 the genus *Chionodraco* are referred to as *C. hamatus* in this study.

51 The life history and biology for early life stages of *C. hamatus* remain poorly understood.
52 This species has been reported to spawn during summer in the Ross Sea (La Mesa et al. 2003;
53 Vacchi et al. 1996) and demonstrates nesting behavior (Ferrando et al. 2014). Hatching time is
54 not known, although presumably occurs in summer/autumn because few reproductively active
55 females have been observed in the coastal zone near the Dumont d'Urville station in January
56 (Koubbi, pers. comm.).

57 In polar regions, lipids and their constituent FA play major roles in growth, movement,
58 buoyancy, and reproduction, and also represent the main energy reserves of many polar species
59 (Sargent et al. 2002). Lipid class dynamics reflect the ability of fish larvae to withstand
60 starvation events and can be used to determine a lipid-based condition index (Fraser 1989;
61 Giraldo et al. 2012; Håkanson 1989). The lipid condition index is based on the principal
62 assumption that larval condition in many marine organisms is dependent upon lipid energy
63 reserves, which typically correspond to triacylglycerol (TAG) content. TAG content is dependent
64 on larval size or body mass and must be standardized by cholesterol (Chol) content; Chol is a
65 membrane lipid that is correlated with larval size but is independent of nutritional condition
66 because it is not catabolized during starvation (Fraser 1989).

67 The relationship between the storage-class lipids (TAG) and the structural membrane
68 lipids (polar lipids, PL) to total lipids (TL) also reflects the main metabolic strategy of larvae and
69 the tradeoff between energy allocation toward growth and/or lipid storage. Further, FA

70 composition of the TAG fraction directly reflects FA composition of the diet, and differences in
71 FA composition between different organisms or developmental stages therefore reflect dietary
72 similarities/differences (Dalsgaard et al. 2003). In contrast, FA composition of the PL fraction is
73 under genetic control (i.e. independent of diet) and can be used to determine ontogenetic changes
74 within an organism (Giraldo et al. 2015a).

75 In this study, the lipid composition and dynamics of *C. hamatus* are analyzed to (1)
76 determine lipid composition and the role of lipids in early life strategies of *C. hamatus*, and (2)
77 provide an overview of the lipid class-specific FA composition of *C. hamatus* that can be used to
78 determine trophic pathways in the East-Antarctic pelagic ecosystem.

79 **Materials and Methods**

80 *a. Sampling*

81 Field sampling was conducted in the Dumont d'Urville Sea (East Antarctica) during the austral
82 summer 2010-2011 as part of the French IPEV-ICO²TA program (Integrated Coastal Ocean
83 Observations in Terre Adélie) (Koubbi et al. 2011). Larval fish samples were collected from the
84 RV "*L'Astrolabe*" using an Isaacs-Kidd midwater trawl (IKMT) at four stations along transects
85 oriented from nearshore to across the continental shelf located from the Mertz Glacier Tongue to
86 the Adélie Bank. All samples ($n = 26$) were immediately frozen in liquid nitrogen (-196°C) and
87 stored at -80°C until further analysis. Back to our laboratory, samples were thawed on ice,
88 weighed (degree of precision 0.01 mg) and measured to the nearest 0.1 mm with a digital caliper
89 (standard length, SL) before analysis. Two larval developmental stages were differentiated based
90 on flexion and corresponded to specimens smaller (pre-flexion, $n = 16$) and larger (post-flexion,
91 $n = 10$) than 25mm. Preflexion larvae were defined as having a straight notochord with depleted
92 yolk reserves. The second group corresponded to postflexion larvae and was characterized by an

93 angled notochord with partially developed anal and dorsal fins. These two distinct larval stages
94 were subsequently separated for further lipid analysis.

95 *b. Lipid analysis*

96 Lipid extraction followed the method of Bligh and Dyer (1959) as modified by Mayzaud
97 et al. (2007). Samples were mechanically homogenized and twice-extracted with a one-phase
98 solvent mixture of methanol:chloroform:water (2:1:0.8 v/v/v). Phases were separated overnight
99 by addition of chloroform and NaCl 0.7 % (w/v) to a final solvent ratio of 2:2:1.8
100 methanol:chloroform:water (v/v/v). The total extract was vacuum concentrated using a rotary
101 evaporator and stored under nitrogen at -80°C in the laboratory.

102 TL content was determined gravimetrically. Lipid classes were quantified using a
103 chromatographic separation coupled with FID (Flame Photometry Detection) detection on an
104 Iatroscan MK V TH 10. TL extracts were applied to SIII chromarods using a SAS A4100
105 autospotter programmed to deliver 1 μl of chloroform extract per rod. Analyses were performed
106 in triplicate. Lipid classes were separated by chromatography using a double development
107 procedure with the following solvent systems: n-hexane:benzene:formic acid 80:20:1 (v/v/v)
108 followed by n-hexane:diethyl ether:formic acid 97:3:1.5 (v/v/v). The FID was calibrated for each
109 compound class using commercial standards. For FA analysis, lipid classes were isolated by thin
110 layer chromatography with the hexane:diethyl ether:acetic acid 170:30:2.5 (v/v/v), and the band
111 of PL was then scraped off from the origin and eluted. Lipid classes were visualized using
112 dichlorofluorescein and identification was achieved by comparison with standard mixtures.
113 Following identification, the TAG fraction was then scraped off and eluted. FA from PL and
114 TAG were subsequently converted into methyl esters with 7% boron trifluoride in methanol

115 (Morrison & Smith 1964). A control thin layer chromatography was performed to verify the
116 efficiency of the trans methylation procedure.

117 Gas chromatography (GC) of all FA methyl esters (FAME) was carried out on a 30 m
118 (length) x 0.32 mm (width) internal diameter quartz capillary column coated with Famewax
119 (Restek) in a Perkin-Elmer XL Autolab GC equipped with FID. The column was operated
120 isothermally at 185°C for FAME. Helium was used as carrier gas at 7 psig. Injector and detector
121 were maintained at 250°C. Individual components were identified by comparing retention time
122 data with those obtained from laboratory standards (capelin:menhaden oils, 50:50). In addition,
123 FAME samples were hydrogenated to confirm FA determination. The level of accuracy was $\pm 3\%$
124 for major components, 1–9% for intermediate components, and up to $\pm 25\%$ for minor
125 components ($< 0.5\%$ of total FA). In order to have enough material for GC analysis, two to three
126 preflexion larvae were pooled together according to their TAG:Chol ratio. Postflexion larvae
127 were analyzed individually.

128 *c. Statistics*

129 Linear regression of log-transformed values was used to assess the relationship between
130 TL, WW and SL. Contribution of main lipid classes (i.e. Chol, PL and TAG) to TL was assessed
131 using linear regression on standardized values (μg lipid class per mg WW). Correspondence
132 analysis (CA) (Benzécri et al. 1973) has been widely applied to analyze ecological data (Giraldo
133 et al. 2015b) and was chosen here to describe the total inertia in the multi-dimensional FA data
134 as a sample of fewer dimensions that best visualizes patterns in the data. The FA matrix was
135 transformed to relative frequencies and scaled such that each row (or column) can be viewed as a
136 row (or column) of conditional probability distribution. Distances between profiles were

137 computed with X^2 metrics. This distance gives symmetry to the 2 sets of data such that each
138 factorial axis of the cloud of variables corresponds to a factorial axis of the cloud of
139 observations. Thus, it was possible to represent both descriptors and observations on the plane
140 defined by the factorial axes. The percent variance explained is given for each analysis. Symbol
141 size is proportional to the cosine², illustrating the quality of representation for each point.
142 Computations were performed in the statistical software package R ver. 3.1.0 (R Team Core
143 2012). Data were transformed to normalize (Zar 1999).

144 **Results**

145 *Size, weight and lipid components*

146 The SL of *C. hamatus* (n = 26) ranged from 19.3 to 35.1 mm with WW from 31 to 249
147 mg. The regression between WW and SL was described by a log-log function (Eq. 1):

$$148 \quad (1) \log (WW) = -2.1 + 2.9 * \log (SL), F = 100.4, df= 24 p < 0.001, R^2 = 0.80$$

149 TL content varied from 1.1 to 2.1% (of WW) and was positive correlated with WW and SL, as
150 described by the following equations (Eq. 2 & Eq. 3):

$$151 \quad (2) \log (TL) = -2.0 + 1.1 * \log (WW), F = 584.4, df=24, p < 0.001, R^2 = 0.96$$

$$152 \quad (3) \log (TL) = -4.3 + 3.2 * \log (SL), F = 76.2, df= 24, p < 0.001, R^2 = 0.75$$

153 Chol and PL content were used to indicate the mass of an individual. A relatively good linear fit
154 (Fig. 1) shows that these lipid components are indeed indicative of larval weight (Eq. 4 & Eq. 5):

$$155 \quad (4) \log (Chol) = -1.70 + 1.59 * \log (WW), F = 69.1, df = 24, p < 0.001, R^2 = 0.73$$

$$156 \quad (5) \log (LP) = 0.36 + 1.39 * \log (WW), F = 205.8, df = 24, p < 0.001, R2 = 0.89$$

157 PL were the major constituent in both larval stages ($96.2 \pm 1.7\%$ and $94.1\% \pm 2.5\%$ for
158 pre-flexion and post-flexion, respectively) followed by Chol ($1.96 \pm 0.6\%$ and $2.70 \pm 1.1\%$) and
159 TAG ($1.5 \pm 0.2\%$ and $3.0 \pm 1.5\%$). In some samples free FA and diacylglycerols were identified
160 but represented less than 1% of TL. Wax esters were not present.

161 *Lipid dynamics*

162 The contribution of the main lipid classes (i.e. PL, Chol and TG) to TL content was
163 analyzed by standardizing lipids (μg) by WW (mg). In preflexion larvae, PL and Chol were the
164 dominant constituent influencing changes in TL (*Linear regression* $F = 24470$ and 30.84 ,
165 *respectively*; $df = 14$, $p < 0.001$), while TAG levels were low relative to other lipid fractions and
166 did not contribute significantly to TL content (*Linear regression*, $F = 0.55$, $df = 14$, $p = 0.46$)
167 (Fig. 2). Similarly, PL dominated TL in postflexion larvae, but all lipid classes contributed
168 significantly to changes in TL (*Linear regression* $F = 2039$, 37.15 , 34.6 for PL, Chol and TAG
169 *respectively*, $df = 8$, $p < 0.001$) (Fig. 3).

170 *Condition index TG:Chol*

171

172 Although there was a slightly better fit between PL and WW than between Chol and
173 WW, Chol was used to standardize TAG content because PL can be mobilized during starvation
174 and might therefore be less stable. The TAG:Chol ratio varied between 0.18 to 1.74 in preflexion
175 larvae and from 0.22 to 2.20 in postflexion larvae. No significant differences were detected for
176 TAG:Chol ratios (*Wilcoxon test*, $W = 45$, $p > 0.05$) between the two larval stages.

177 *Fatty acid signature*

178

179 *Polar lipids*

180 Overall, saturated (~26%) and polyunsaturated FA (PUFA, ~45%) dominated the FA
181 composition of the PL fraction of each larval stage (Table 1). For all developmental stages,
182 saturated FAs were dominated by palmitic acid (16:0) and, to a lesser extent, by stearic acid
183 (18:0). Monoenoic acids (~23%) were dominated by oleic (18:1n-9), vaccenic (18:1n-7) and
184 palmitoleic (16:1n-7), while PUFA were dominated by EPA (20:5n-3) and DHA (22:6n-3).
185 Correspondence analysis explained 52% of the variance between the FA of preflexion and
186 postflexion larvae. Individuals were distributed around the centroid of the analysis with no clear
187 differences between the two stages (Fig 4).

188 *Triacylglycerols*

189 Monoenoic (~28%) and PUFA (~36%) dominated the TAG fraction of both preflexion
190 and postflexion larvae (Table 1). For all developmental stages, saturated FAs were dominated by
191 palmitic acid (16:0), monoenoic acids were dominated by oleic (18:1n-9), palmitoleic (16:1n-7)
192 and vaccenic acid (18:1n-7), and PUFA were dominated by EPA (20:5n-3) and DHA (22:6n-3).
193 Correspondence analysis explained 73.49% of variance in FA signature of the TAG fraction of
194 preflexion and postflexion larvae. However, all samples fell within the centroid of the analysis,
195 indicating no marked differences in FA composition between the two larval stages.

196 **Discussion**

197
198 Larval development in many marine organisms is largely dependent upon energy
199 reserves, which typically correspond with TAG content. Starvation and predation represent
200 major causes of mortality in larval fishes, particularly once yolk reserves are depleted and larvae
201 must switch to deriving energy from exogenous sources (Leggett and Deblois 1994). Predation
202 risk is lower in individuals with larger body size, and fish larvae are therefore confronted with a

203 tradeoff between allocating energy reserves to optimize growth, reduce predation risk and
204 increase the opportunity to consume larger prey items, versus storing TAG to increase the
205 likelihood of survival during starvation events. In this study, the dominance of polar structural
206 lipids (PL) compared to TAG content in preflexion larvae (< 25 mm) of *C. hamatus* indicates
207 that small individuals primarily allocate energy reserves toward somatic growth. Conversely, the
208 important contribution of both TAG and PL to TL dynamics of older individuals (> 25 mm,
209 postflexion larvae) suggests an ability to allocate energy toward both growth and lipid storage
210 reserves because the benefits of allocating energy toward growth decrease with increase in body
211 size. Overall, the results of this study highlight a marked ontogeny of energy allocation that
212 likely decreases predation risk for small larvae and favors lipid storage in postlarval *C. hamatus*.

213 Ratios of TAG:Chol suggested no significant differences in condition factor of pre- and
214 postflexion larvae, indicating that both stages were in good condition and that prey availability
215 during the summer 2011 was sufficient to meet the basal requirements of *C. hamatus* individuals
216 from this study.

217 PL are known to be strongly regulated and appear to be directly related to membrane
218 requirements and specific energetic pathways (reviewed by Sargent et al., 2002 and Dalsgaard et
219 al., 2003). Although the lipid class dynamics of preflexion and postflexion *C. hamatus* larvae
220 were different, neither of these developmental stages exhibited any detectable ontogeny in the
221 FA pattern of PL and TAG fractions. High levels of DHA with a mean EPA: DHA ratio of $0.6 \pm$
222 0.05 reflects the role of polyunsaturated n-3 FA in the maintenance of biological membranes in
223 *C. hamatus* larvae. In contrast to PL, the FA composition of TAG is related to trophic
224 interactions in marine organisms (Dalsgaard et al. 2003; Mayzaud et al. 2011). In this study,
225 there were no significant differences between the pattern of FA trophic markers for pre- and

226 post-larval *C. hamatus*, indicating similar diet across larval stages. Specifically, early life stages
227 of *C. hamatus* were characterized by low contribution of *Calanus*-type copepod markers
228 ($\Sigma C20:1$, $C22:1$) and a relatively high value of the ratio $C18:1n-9/C18:1n-7$, a typical carnivory
229 index in marine trophic ecology (Hagen et al. 2000). This finding is consistent with previous
230 work demonstrating that young stages of euphausiids (furcilia to juveniles) and fish larvae
231 constitute the most important food source for channichthyids larvae (Kock 2005).

232 Early life stages of the pelagic fish, *Pleuragramma antarctica* (Antarctic Silverfish), one
233 of the most important key species of Antarctica (along with the krill *Euphausia superba*)
234 (Corsolini et al. 2002) may be of particular importance in the diet of *C. hamatus*. Early life stages
235 of *C. hamatus* have been previously reported as specialized predators in the Ross Sea, feeding on
236 a relatively narrow niche width, with *P. antarctica* larvae as their overwhelmingly dominant prey
237 (La Mesa et al. 2011). Compared to the carnivory index previously described for *P. antarctica*
238 larvae (1.34 and 1.06) (Mayzaud et al. 2011, Tavernier et al. 2012), the relative high value (1.93)
239 of the ratio $C18:1n-9/C18:1n-7$ reported for *C. hamatus* is in good agreement with previous
240 studies. Moreover, stable nitrogen signatures ($\delta^{15}N$), mainly used to establish trophic
241 relationships, have been reported as 10.5 ‰ for *C. hamatus* larvae (SL= 31-38 mm) (Cherel et al.
242 2011) and 6.7 ‰ for larval *P. antarctica* (Giraldo et al. 2011). Considering that, on average, a
243 ~3‰ enrichment in $\delta^{15}N$ values accompanies each trophic step, these results also support the
244 hypothesis that larval *P. antarctica* could be the main prey item for *C. hamatus* larvae. The
245 hatching time of *C. hamatus* and *P. antarctica* are thought to coincide. Further, *C. hamatus* and
246 *P. antarctica* co-occur spatially and have a similar geographic distribution in the western Ross
247 Sea (La Mesa et al. 2010) and offshore of the Antarctic Peninsula (White and North 1987).
248 Future studies could use FA as dietary biomarkers to test the hypothesis that survival of larval *C.*

249 *hamatus* is closely linked to spatial and temporal dynamics of young stages of euphausiids and *P.*
250 *antarctica* larvae.

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256 **References**

- 257 Benzécri JP, Benzécri F, Birou A, Blumenthal S, De Bœck A (1973) L'analyse de données Vol. 2:
258 L'analyse des correspondances. Dunod, Paris
- 259 Bligh EG, Dyer WJ (1959) A rapid method of total lipid extraction and purification. *Can J Biochem Phys*
260 37(8):911-917
- 261 Cherel Y, Koubbi P, Giraldo C et al (2011) Isotopic niches of fishes in coastal, neritic and oceanic waters
262 off Adélie Land, Antarctica. *Polar Sci* 5:286-297
- 263 Corsolini S, Romeo T, Ademollo N, Greco S, Focardi S (200) POPs in key species of marine Antarctic
264 ecosystem. *Microchem J* 73(1):187-93
- 265 Dalsgaard J, St John M, Kattner G, Müller-Navarra D, Hagen W (2003) Fatty acid trophic markers in the
266 pelagic marine environment. *Adv Mar Biol* 46:225-340
- 267 Efremenko V (1987) Species composition and distribution of mesopelagic fish eggs and larvae in the
268 Ross Sea. Biological and oceanographic investigations of the Pacific sector of Antarctica 186-193
- 269 Ferrando S, Castellano L, Gallus L, Ghihiotti L, Masini MA, Pisano E., Vacchi M (2014) A
270 Demonstration of Nesting in Two Antarctic Icefish (Genus *Chionodraco*) Using a Fin
271 Dimorphism Analysis and Ex Situ Videos. *PLoS ONE* 9(3): e90512.
272 doi:10.1371/journal.pone.0090512
- 273 Fraser AJ (1989) Triacylglycerol Content as a Condition Index for Fish, Bivalve, and Crustacean Larvae.
274 *Can J Fish Aquat Sci* 46:1868-1873
- 275 Giraldo C, Cherel Y, Vallet C, Mayzaud P, Tavernier E, Moteki M, Hosie G, Koubbi P (2011) Ontogenic
276 changes in the feeding ecology of the early life stages of the Antarctic silverfish (*Pleuragramma*
277 *antarcticum*) documented by stable isotopes and diet analysis in the Dumont d'Urville Sea (East
278 Antarctica). *Polar Sci* 5(2):252-63
- 279 Giraldo C, Cherel Y, Vallet C et al (2012) Lipid components as a measure of nutritional condition in fish
280 larvae (*Pleuragramma antarcticum*) in East Antarctica. *Marine Biol* 160:877-887
- 281 Giraldo C, Mayzaud P, Tavernier E, Boutoute M, Penot F, Koubbi P (2015a) Lipid dynamics and trophic
282 patterns in *Pleuragramma antarctica* life stages. *Antarctic Sci* 27(5):429-438
- 283 Giraldo C, Stasko A, Choy ES, Rosenberg B, Majewski A, Power M, Swanson H, Loseto L, Reist JD
284 (2015b) Trophic variability of Arctic fishes in the Canadian Beaufort Sea: a fatty acids and stable
285 isotopes approach. *Polar Biol* 1-6. doi:10.1007/s00300-015-1851-4
- 286 Granata A, Cubeta A, Guglielmo L, et al (2002) Ichthyoplankton abundance and distribution in the Ross
287 Sea during 1987–1996. *Polar Biol* 25:187-202
- 288 Hagen W, Kattner G, Friedrich C (2002) The lipid compositions of high-Antarctic notothenioid fish
289 species with different life strategies. *Polar Biol* 23(11):785-91

290 Håkanson JL (1989) Analysis of lipid components for determining the condition of anchovy larvae,
 291 *Engraulis mordax*. Marine Biol 102:143-151

292 Hubold G (1990) Seasonal Patterns of Ichthyoplankton Distribution and Abundance in the Southern
 293 Weddell Sea. In: Kerry KR, Hempel G (eds) Antarctic Ecosystems. Springer Berlin Heidelberg,
 294 pp 149-158

295 Kellermann A (1990) Catalogue of early life stages of Antarctic notothenioid fishes. Ber Polarforsch
 296 67:45-136

297 Kellermann A, Schadwinkel S (1991) Winter aspects of the ichthyoplankton community in Antarctic
 298 Peninsula waters. Polar Biol 11:117-127

299 Kock K-H (2005) Antarctic icefishes (Channichthyidae): a unique family of fishes. A review, Part I Polar
 300 Biol 28:862-895

301 Koubbi P, Duhamel G, Hecq JH et al (2009) Ichthyoplankton in the neritic and coastal zone of Antarctica
 302 and Subantarctic islands: A review. J Mar Syst 78:547-556

303 Koubbi P, Ozouf-Costaz C, Goarant A et al. (2010) Estimating the biodiversity of the East Antarctic shelf
 304 and oceanic zone for ecoregionalisation: example of the ichthyofauna of the CEAMARC
 305 (Collaborative East Antarctic Marine Census) CAML surveys. Polar Sci 4:115-133

306 Koubbi P, O'Brien C, Loots C, Giraldo C, Smith M, Tavernier E, Vacchi M, Vallet C, Chevallier J,
 307 Moteki M (2011) Spatial distribution and inter-annual variations in the size frequency distribution
 308 and abundances of *Pleuragramma antarcticum* larvae in the Dumont d'Urville Sea from 2004 to
 309 2010. Polar Sci 5(2):225-38

310 La Mesa M, Ashford J (2008) Age and growth of ocellated icefish, *Chionodraco rastrispinosus* DeWitt
 311 and Hureau, 1979, from the South Shetland Islands. Polar Biol 31:1333-1342

312 La Mesa M, Caputo V, Rampa R, Vacchi M (2003) Macroscopic and histological analyses of gonads
 313 during the spawning season of *Chionodraco hamatus* (Pisces, Channichthyidae) off Terra Nova
 314 Bay, Ross Sea, Southern Ocean. Polar Biol 26:621-628

315 La Mesa M, Catalano B, Greco S (2011) Larval feeding of *Chionodraco hamatus* (Pisces,
 316 Channichthyidae) in the Ross Sea and its relation to environmental conditions. Polar Biol 34:127-
 317 137

318 La Mesa M, Catalano B, Russo A, Greco S, Vacchi M, Azzali M (2010) Influence of environmental
 319 conditions on spatial distribution and abundance of early life stages of Antarctic silverfish,
 320 *Pleuragramma antarcticum* (Nototheniidae), in the Ross Sea. Antarct Sci 22:243-254

321 Leggett WC, Deblois E (1994) Recruitment in marine fishes: Is it regulated by starvation and predation in
 322 the egg and larval stages? Neth J Sea Res 32:119-134

323 Loeb VJ, Kellermann AK, Koubbi P, North AW, White MG (1993) Antarctic larval fish assemblages: a
 324 review. B Mar Sci 53:416-449

325 Mayzaud P, Boutoute M, Perissinotto R, Nichols P (2007) Polar and neutral lipid composition in the
 326 pelagic tunicate *Pyrosoma atlanticum*. Lipids 42(7):647-57

327 Mayzaud P, Chevallier J, Tavernier E, Moteki M, Koubbi P (2011) Lipid composition of the Antarctic
 328 fish *Pleuragramma antarcticum*. Influence of age class. Polar Sci 5:264-271

329 Morrison WR, Smith LM (1964) Preparation of fatty acid methyl esters and dimethylacetals from lipids
 330 with boron fluoride-methanol. J Lipid Res 5(4):600-8

331 Moteki M, Ishimaru T (2008) Development of feeding and swimming functions in larvae of *Chionodraco*
 332 *rastrispinosus* (Channichthyidae). Cybium 32:247-251

333 Moteki M, Koubbi P, Pruvost P, Tavernier E, Hulley P-A (2011) Spatial distribution of pelagic fish off
 334 Adélie and George V Land, East Antarctica in the austral summer 2008. Polar Sci 5:211-224

335 North A (1988) Distribution of fish larvae at South Georgia: horizontal, vertical, and temporal
 336 distribution and early life history relevant to monitoring year-class strength and recruitment
 337 SCCAMLR, SeL Sci Pap 4:1987

338 R Team Core (2012) R: A language and environment for statistical computing

339 Sargent JR, Tocher DR, Bell JG (2002) The lipids. Fish nutrition 3:181-257

- 340 Tavernier E, Mayzaud P, Boutoute M, Vallet C, Koubbi P (2012) Lipid characterization of
341 *Pleuragramma antarcticum* (Nothoteniidae) larvae off East Antarctica (139 E–145.10 E) during
342 summer. *Polar Biol* 35(6):829-40
- 343 Vacchi M, Williams R, La Mesa M (1996) Reproduction in three species of fish from the Ross Sea and
344 Mawson Sea. *Antarct Sci* 8:185-192
- 345 Vallet C, Labat J-P, Smith M, Koubbi P (2011) Interannual variations in euphausiid life stage distribution
346 in the Dumont d'Urville Sea from 2004 to 2008. *Polar Sci* 5:166-178
- 347 White MG, North AW (1987) Postlarval Notothenioides and midwater fish collected during the SIBEX
348 cruise by British Antarctic Survey, 1985. In *Proc Congr Europ Ichthyol, Stockholm Vol*
349 *1985:405-411*)
- 350 Zar JH (1999) *Biostatistical Analysis* (4th Edition) Prentice Hall, Englewood Cliffs, New Jersey
- 351

- 352 Figure 1: Linear regression on log-transformed membrane lipids (Chol: cholesterol, PL: polar lipids, μg)
353 and wet weight (WW).
- 354 Figure 2: Contribution of the main lipid classes (PL: Polar Lipids, TAG: Triacylglycerol, Chol:
355 Cholesterol) to the total lipid (TL) content of preflexion larvae *C. hamatus*.
- 356 Figure 3: Contribution of the main lipid classes (PL: Polar Lipids, TAG: Triacylglycerol, Chol:
357 Cholesterol) to the total lipid (TL) content of postflexion larvae of *C. hamatus*.
- 358 Figure 4: Correspondence Analysis of the fatty acid signature of the polar lipid fraction for preflexion
359 larvae (L1-6) and postflexion larvae (P1-10) of *C. hamatus*.

Table 1: Fatty acid composition of the triacylglycerol and polar lipid fraction in pre-flexion and post-flexion larvae. Minor fatty acids (<1%) common for all individuals are not shown. Data is reported as means \pm standard deviation.

Fatty acid/Stage	Triacylglycerol		Polar Lipids	
	Pre - flexion	Post - flexion	Pre - flexion	Post - flexion
C14	2.49 \pm 0.64	2.60 \pm 0.54	0.96 \pm 0.19	0.97 \pm 0.19
C15	0.47 \pm 0.22	0.30 \pm 0.04	0.18 \pm 0.02	0.18 \pm 0.01
ISO17	0.76 \pm 0.12	0.84 \pm 0.11	0.53 \pm 0.08	0.55 \pm 0.07
ANT17	0.20 \pm 0.06	0.21 \pm 0.06	0.14 \pm 0.05	0.10 \pm 0.05
C16	12.88 \pm 0.77	11.82 \pm 0.37	20.39 \pm 0.49	20.21 \pm 1.37
C17	2.27 \pm 0.36	2.88 \pm 0.23	0.26 \pm 0.03	0.25 \pm 0.04
C18	3.11 \pm 0.34	2.79 \pm 0.22	3.70 \pm 0.25	3.72 \pm 0.29
Σ Saturates	23.17 \pm 1.27	22.15 \pm 0.86	26.43 \pm 0.43	26.27 \pm 1.62
C16:1n7	7.32 \pm 0.56	7.02 \pm 0.47	3.91 \pm 0.16	3.95 \pm 0.35
C16:1n5	0.81 \pm 0.15	0.85 \pm 0.15	1.03 \pm 0.11	1.00 \pm 0.10
C18:1n9	13.98 \pm 1.28	14.11 \pm 1.29	7.21 \pm 0.24	7.92 \pm 0.71
C18:1n7	7.75 \pm 1.33	7.28 \pm 0.95	8.08 \pm 0.50	7.83 \pm 1.01
C18:1n5	0.95 \pm 0.03	0.97 \pm 0.19	0.75 \pm 0.05	0.79 \pm 0.08
C20:1n9	1.09 \pm 0.24	0.90 \pm 0.32	1.10 \pm 0.11	1.09 \pm 0.11
C20:1n7	0.36 \pm 0.42	0.21 \pm 0.03	0.16 \pm 0.03	0.17 \pm 0.03
C24:1n9	0.23 \pm 0.10	0.20 \pm 0.09	0.16 \pm 0.03	0.21 \pm 0.05
Σ Monoenes	33.72 \pm 1.78	32.56 \pm 1.61	22.73 \pm 0.28	23.29 \pm 1.57
C18:2n7	0.30 \pm 0.24	0.37 \pm 0.29	0.11 \pm 0.03	0.13 \pm 0.03
C18:2n6	2.28 \pm 0.22	2.42 \pm 0.10	1.15 \pm 0.11	1.34 \pm 0.13
Σ Dienes	2.79 \pm 0.13	3.06 \pm 0.39	1.51 \pm 0.15	1.76 \pm 0.20
C16:3n6	0.54 \pm 0.17	0.64 \pm 0.11	0.32 \pm 0.06	0.38 \pm 0.07
C16:3n3	0.43 \pm 0.04	0.42 \pm 0.02	0.25 \pm 0.05	0.27 \pm 0.05
C18:3n6	1.41 \pm 0.78	0.57 \pm 0.13	0.17 \pm 0.06	0.14 \pm 0.07
C18:3n3	0.98 \pm 0.37	1.23 \pm 0.13	0.40 \pm 0.13	0.37 \pm 0.14
Σ Trienes	3.46 \pm 0.76	2.97 \pm 0.26	1.22 \pm 0.22	1.21 \pm 0.21
C16:4n3	0.37 \pm 0.08	0.36 \pm 0.11	0.36 \pm 0.05	0.37 \pm 0.06
C18:4n3	1.93 \pm 0.66	2.77 \pm 0.35	0.49 \pm 0.14	0.58 \pm 0.09
C20:4n6	0.62 \pm 0.11	0.63 \pm 0.09	1.36 \pm 0.14	1.35 \pm 0.10
Σ Tetraene	3.36 \pm 0.69	4.14 \pm 0.36	2.41 \pm 0.08	2.44 \pm 0.11
C20:5n3	13.6 \pm 0.69	14.85 \pm 0.59	16.77 \pm 0.89	16.26 \pm 1.23
C22:5n3	0.71 \pm 0.06	0.68 \pm 0.08	0.76 \pm 0.07	0.60 \pm 0.04
C22:6n3	18.58 \pm 1.03	19.24 \pm 1.34	28.02 \pm 1.09	28.03 \pm 2.16
Σ PUFA	33.51 \pm 1.90	35.12 \pm 1.74	45.55 \pm 0.64	44.89 \pm 2.97

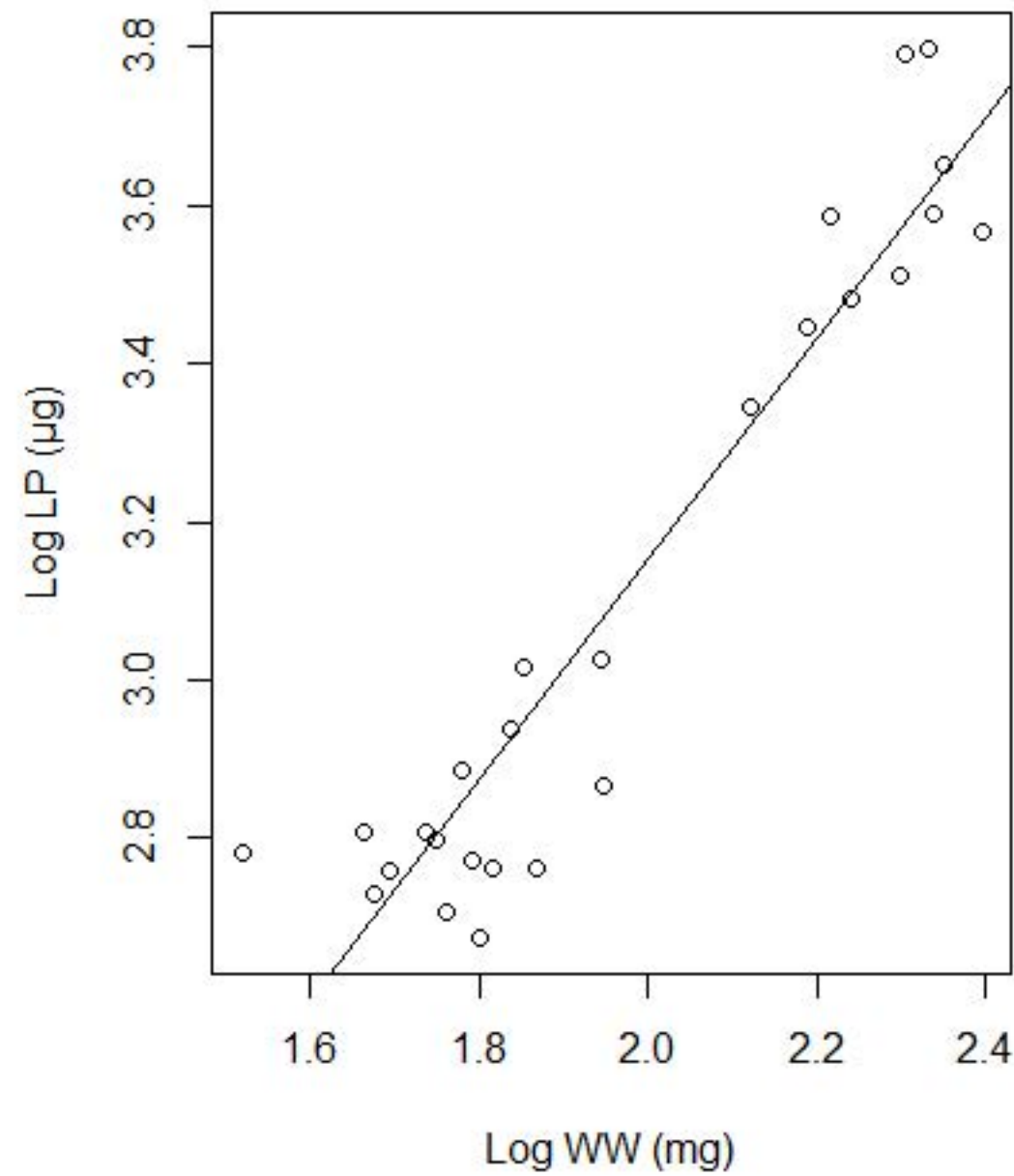
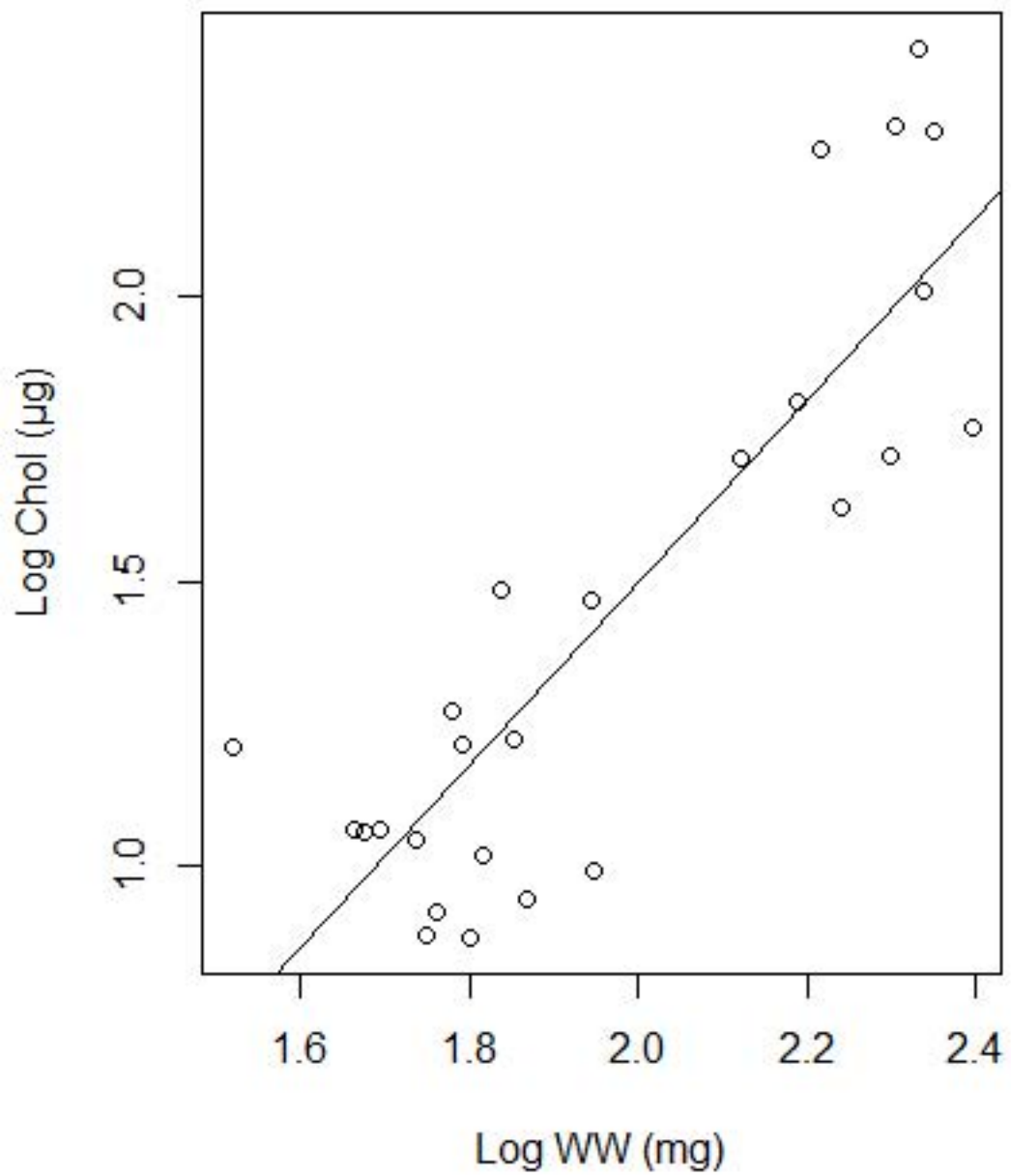
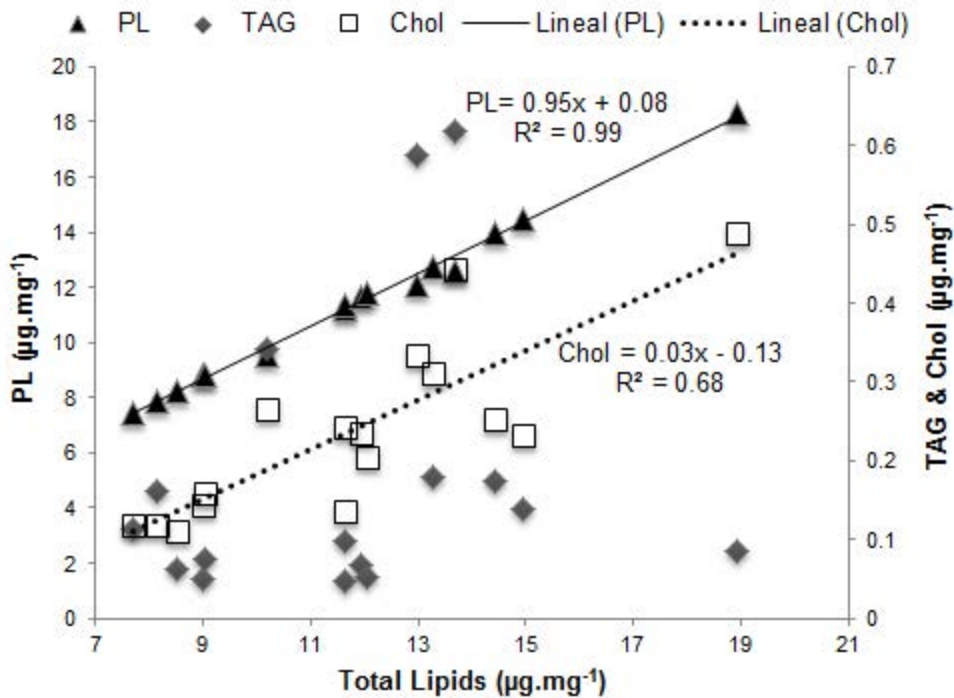


Figure 1



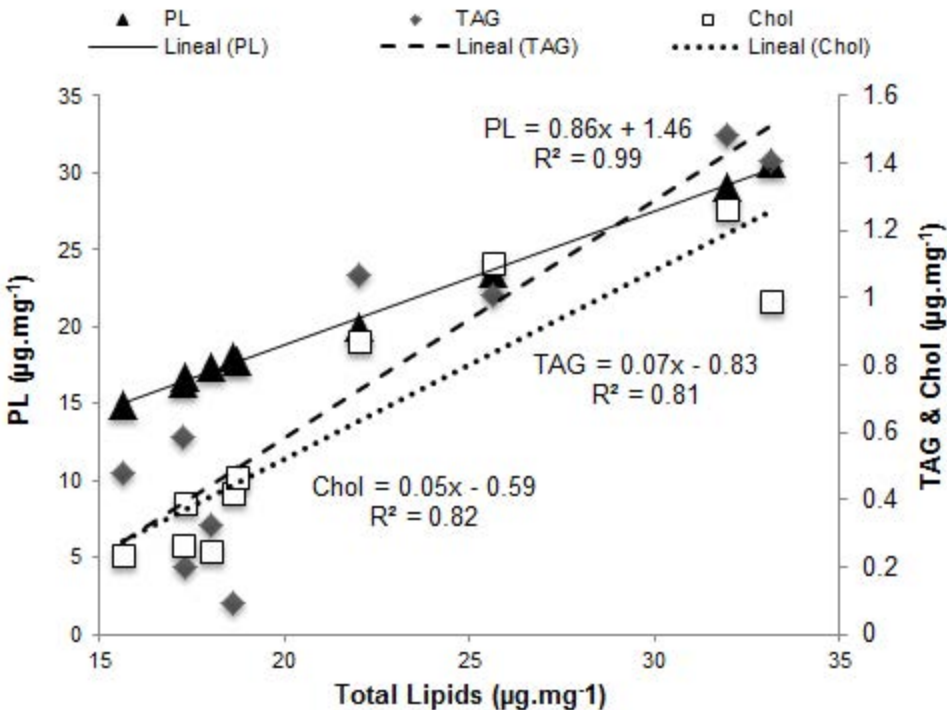


Figure 3

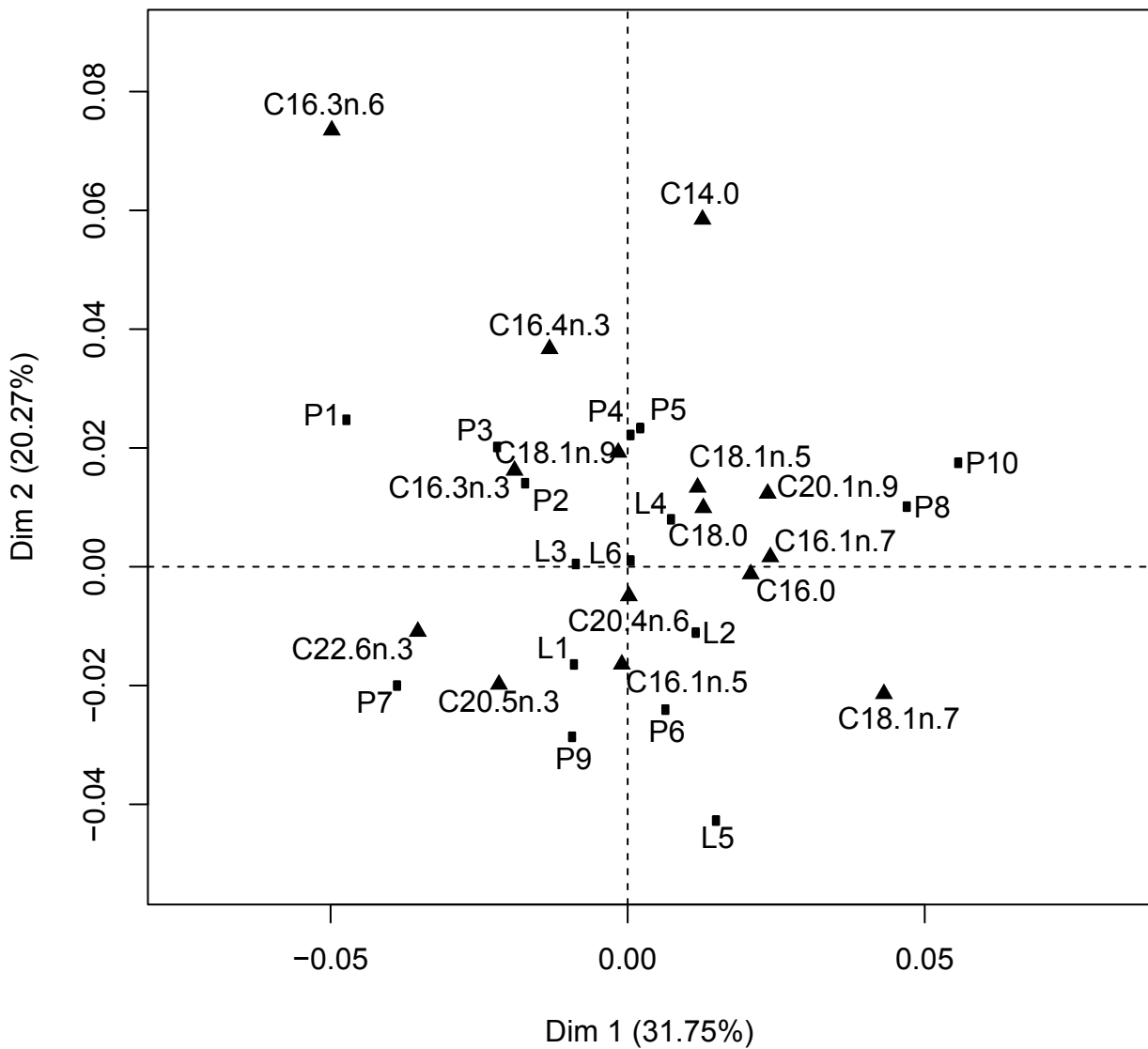


Figure 4