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1 **Hg concentrations and related risk assessment in coral reef crustaceans,**
2 **molluscs and fish from New Caledonia**

3

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28

29 **Abstract**

30

31 There is a dramatic lack of data on Hg levels in marine organisms from tropical areas,
32 and in particular from New Caledonia. For the first time, this study reports the total Hg
33 concentrations in the tissues of several marine taxa from the New Caledonian lagoon. Seafood
34 from both wild and farmed populations was considered. Hg concentrations varied over 3
35 orders of magnitudes according to factors including species, age (size/weight), trophic level,
36 lifestyle and geographical origin. Taking into account the edible tissues, estimations of the
37 amount of flesh that should be consumed by a 60-kg person to reach the Hg Provisional
38 Tolerable Weekly Intake (PTWI) reveal acceptable risk for Human health in general.
39 However, a risk was clearly identified in one site of the lagoon (i.e. Grande Rade) where high
40 Hg concentrations were measured. These concentrations were higher than values reported in
41 the current literature.

42

43

44 **Capsule:** This work reports the first assessment of Hg levels in edible organisms from the
45 New Caledonian lagoon and the associated risk linked to their consumption by Human.

46

47

48 *Keywords:* Tropical environment; Metal; Marine products; Seafood; Risk assessment; PTWI

49

50 **1. Introduction**

51

52 Among heavy metals, Hg is of particular concern in marine environmental studies
53 because it has both natural and anthropogenic sources, has no known biological function and
54 is toxic to all living organisms (for a review, see Eisler, 1987). In the marine environment, Hg
55 is naturally released in the water and then in the atmosphere through erosion of the sediments
56 where it is present as sulphide salts (Salomon et al., 1987). However, about 30% of the total
57 Hg emissions in the atmosphere are of anthropogenic origins. Moreover, these anthropogenic
58 atmospheric emissions are ten times greater than direct inputs to water, contributing to a
59 widespread contamination which is difficult to assess (Hylander, 2001). These emissions are
60 mainly originating from industrial and domestic incineration (Cossa et al., 1990).

61 In the marine environment, Hg is mainly found under organic forms. Among organic Hg
62 species, methyl-Hg is the most stable form in the marine environment; it is primarily
63 produced by microorganisms in sediments. Methyl-Hg is also the most toxic form to
64 organisms (WHO, 1990). Finally, Hg and methyl-Hg have the particularity to be
65 bioaccumulated by marine organisms and to biomagnify along the food chain (Zizek et al.,
66 2007). Therefore, the consumption of marine products represents a non negligible exposure
67 pathway to Hg and, thereby, a risk for Human health (e.g. Buzina et al., 1989; Svensson et al.,
68 1992). This is particularly the case for fish, since virtually 100% of the total Hg in fish
69 muscles (edible tissues) are present as methyl-Hg (e.g. Bloom, 1992, Holsbeck et al. 1997),
70 and is thus highly bioavailable for Human consumers and other predators.

71 In New Caledonia, coastal waters are subjected to large inputs of metals, mainly due to
72 intense mining activities (especially Ni production), but also due to natural erosion of the soils
73 associated with tropical rainfall, urban development and lack of efficient wastewater
74 treatment (Ambastian et al., 1997). Surprisingly, few studies have been conducted to assess
75 the marine contamination status of New Caledonia by metals (Labrosse et al., 2000).

76 Available studies are generally limited to Ni and its mining by-products and to a narrow range
77 of species (Monniot et al., 1994; Bustamante et al., 2000; Hédouin et al., 2007, 2008; Metian
78 et al., 2008a). To the best of our knowledge, data published on Hg in marine organisms from
79 New Caledonia are limited to a single study on pelagic marine mammals (Bustamante et al.,
80 2003), and so far none is available on non mammalian organisms from the lagoon.

81 The aim of the present study was therefore to provide baseline information on the Hg
82 contamination status of the New Caledonia coastal marine environment. A wide range of
83 species including Bivalves, Cephalopods and Teleosts from different locations were analysed
84 for their Hg concentrations. Special emphasis was given to species that have already been
85 recognised as valuable bioindicator species (i.e. the tumid venus *Gafrarium tumidum* and the
86 radula scallop *Comptopallium radula*; Hédouin et al., 2007, 2008; Metian et al., 2008a), and
87 to those that are major seafood for local consumption or exportation. The investigated
88 organisms were collected either from the wild (i.e. scallops, clams, cockles, cephalopods and
89 fish) or from mariculture farms (e.g. the Pacific blue shrimp *Litopenaeus stylirostris* and the
90 Pacific cupped oyster *Crassostrea gigas*). Differences in Hg bioaccumulation among body
91 compartments of a given species, within and among taxonomic groups, and among sites were
92 tested. Size and weight were also taken into account as driving parameters. Finally, this paper
93 provides a site-specific preliminary risk assessment for Hg consumption along with seafood.

94

95 **2. Materials and methods**

96

97 *2.1. Sampling and sample preparation*

98

99 Organisms belonging to 32 taxa (Table 1) were collected in March and October 2007
100 along the coast of New Caledonia (Fig. 1, Table 2), either by SCUBA diving (fish), by hand
101 picking at low tide (bivalves), or bought on the central market of Noumea City (shrimp,

102 oysters, cephalopods and some fish). The sampling sites were selected because they were
103 reported to have contrasting contamination status (Hédouin et al., 2008; Metian et al., 2008a;
104 Warnau and Bustamante unpublished results): Grande Rade, Grande Rade-SLN, Koutio Bay,
105 the edge of Noumea harbour, Sainte Marie Bay, Ouano Bay (which included 3 sub-sampling
106 sites from the shore -S1- to open waters -S3), Maa Bay, Unia and Tomo (Fig. 1, Table 2). The
107 geographical origin of the organisms bought on the Noumea central market was obtained
108 from the selling fishermen: Bassin de La Foa, Dumbea Bay, southern and northern lagoon
109 (Fig. 1, Table 2).

110 Grande Rade is subjected to anthropogenic inputs from the Ducos industrial zone,
111 whereas Grande Rade-SLN is directly subjected to those of the metallurgic factory “Société
112 Le Nickel” (SLN). Due to these anthropogenic inputs, Grande Rade sediments were shown to
113 display high concentrations in several elements (Hédouin et al., 2008). Koutio Bay is
114 characterised by the presence of an important rubbish dump and is influenced by inputs of
115 domestic wastes from Noumea City. Sainte Marie Bay is located to the East of Noumea City
116 and receives important sewage sludge and terrigenous inputs coming from the Coulée River.
117 Dumbea Bay is also subjected to terrigenous inputs from the Dumbea River (Ambastian et al.,
118 1997). In contrast, Unia (East coast), southern and northern lagoon, Maa Bay and Ouano Bay
119 are preserved from important anthropogenic inputs. Finally, the Tomo site is located near the
120 international airport of New Caledonia, between Ouano Bay and Noumea City, whereas the
121 site of Bassin de La Foa is located near a shrimp farm on the West coast of New Caledonia.

122 All collected organisms were weighed (wet wt) and measured (total length for fish and
123 shrimp, height and length of the shells for bivalves, and mantle length for cephalopods) upon
124 return to the laboratory. Characteristics (origin, number of individuals, length and weight,
125 sampling date) of each of the 32 species collected are given in Table 1. This table also
126 indicates the trophic level (i.e. filter feeder, grazer/scavenger, predator of invertebrates,

127 predator of invertebrates and small fish, predator of small fish) and the water-column
128 distribution (benthic, nectobenthic and neritic) for every species.

129 Organisms were dissected to collect specific body compartments. A piece of muscle
130 (edible tissue) was taken from fish, shrimp and cephalopods. For fish, the liver was also
131 collected. In cephalopods (*Sepioteuthis lessoniana*, *Sepia latimanus* and *Octopus cyanea*), the
132 digestive gland and branchial hearts were collected whenever possible. In the case of
133 Pectinidae (*Comptopallium radula* and *Mimachlamys gloriosa*), the edible tissues (muscle +
134 gonads) were separated from the remaining soft tissues. For all other bivalves, the soft parts
135 were considered as a whole. After dissection, the samples were weighed (wet wt) and
136 immediately placed in individual plastic bags, frozen at -25°C , freeze-dried, and weighed
137 again (dry wt). Freeze-dried tissues were then ground and stored in individual plastic vials
138 until further metal analysis.

139

140 2.2. Total Hg analysis

141

142 Total Hg analyses were carried out with an Advanced Mercury Analyser (ALTEC AMA
143 254), on dried tissue aliquots ranging from 4 to 50 mg, weighed to the nearest 0.01 mg. For
144 Hg determination, the metal was evaporated by progressive heating up to 800°C , then held
145 under oxygen atmosphere for 3 minutes, and finally amalgamated on a gold net. Afterwards,
146 the net was heated to liberate the collected Hg, which was measured by atomic absorption
147 spectrophotometry. Mercury analyses were run according to a thorough quality control
148 programme including the analysis of a NRC reference material (lobster hepatopancreas
149 TORT-2; National Research Council, Canada). Standard aliquots were treated and analysed
150 according to the same conditions as the samples. The results were in good agreement with the
151 certified values, with an average recovery rate of 105%. Detection limit was 5 ng g^{-1} dry wt.
152 All total Hg concentrations in tissues further reported are expressed in ng g^{-1} dry wt.

153

154 *2.3. Data analysis*

155

156 All data submitted to statistical tests were first checked for normality (Shapiro-Wilk test)
157 and for homogeneity of variances (Bartlett test). When these conditions were satisfied,
158 parametric tests were used in the subsequent analyses; otherwise, non-parametric analogues
159 were used. Pearson or Spearman correlation coefficient test was used to analyse the
160 correlations between size or weight and total Hg concentration in edible tissues in each
161 species. Differences in Hg concentrations between tissues in species for which different body
162 compartments were dissected were tested by Student *t*-test or Wilcoxon test for paired
163 samples. To assess whether trophic levels (see Table 1) could influence Hg concentrations in
164 fish (among the collected organisms, this taxa was the only one to display different diets;
165 Table 1), analysis of covariance (ANCOVA) was performed, using length of individuals as
166 covariable. Finally, species with a minimum of two individuals collected per different
167 location were considered to test differences in Hg concentrations among sampling locations
168 (Table 4), using a one-way analysis of variance (ANOVA) followed by the post-hoc Tukey
169 test. In the case of species for which a correlation between size or weight and Hg
170 concentration was previously revealed, ANCOVA was performed instead of ANOVA, using
171 size or weight as covariable. One-way ANOVA and ANCOVA were performed on log-
172 transformed Hg concentrations and length or weight values. When appropriate, the variability
173 explained by each factor and their interaction was derived from the sum of squares (Warnau
174 et al., 1996, 1998). The levels of significance for statistical analyses was always set at $\alpha =$
175 0.05.

176

177

178

179 2.4. Risk assessment for Human consumers

180

181 To prevent Human health impairments by Hg originating from dietary sources, the Joint
182 FAO/WHO Expert Committee on Food Additives (JECFA) allocated a Provisional Tolerable
183 Weekly Intake (PTWI) for total Hg and methyl-Hg of 5000 and 1600 ng kg⁻¹ wk⁻¹,
184 respectively (WHO, 2003). In this study, we calculated a “Maximum Safe Weekly
185 Consumption” (MSWC), i.e. the weight of edible tissue (muscle for shrimp, cephalopods and
186 fish, muscle + gonads or whole soft parts for bivalves) that should be consumed by a 60 kg
187 adult to reach the PTWI. For this, mean Hg concentrations in ng g⁻¹ dry wt were first
188 converted to wet wt, taking into account the dry wt/wet wt ratios measured in all samples.
189 These ratios indicated a mean moisture content of 80% for bivalve flesh, shrimp and
190 cephalopod muscle, and of 75% for fish muscle, which matched well those previously
191 published for the same taxonomic groups (e.g. Trombini et al., 2003; Bustamante and
192 Miramand, 2005). Then, the PTWI (ng kg⁻¹ wk⁻¹) multiplied by the consumer body weight (60
193 kg) was divided by the Hg concentration (ng g⁻¹ wet wt) in the considered seafood to obtain
194 the MSWC (g wet wt). The latter value (g) was finally converted in kg (Tables 3 and 4). In
195 the particular cases of the fish *Plectropomus leopardus* and the bivalves *Comptopallium*
196 *radula*, *Gafrarium tumidum* and *Anadara scapha*, the MSWC was also calculated for each
197 given site (Table 4). Finally, the MSWC was calculated for total-Hg and methyl-Hg, taking a
198 75% ratio of Me-Hg/T-Hg for shrimp muscle (Riisgard and Famme, 1986), a 80% ratio of
199 Me-Hg/T-Hg for cephalopod muscle (Bustamante et al., 2006), and a 100% ratio for fish
200 muscle (Bloom, 1992). MSWC for methyl-Hg was not calculated in bivalves, due the great
201 variability of the ratio MeHg/T-Hg found in the literature (ranging from 20 to 95%),
202 depending on species, age, season and location (Mohlenberg and Riigard, 1988; Kawaguchi et
203 al., 1999; Otchere et al., 2003; Trombini et al., 2003).

204

205 3. Results

206

207 3.1. Concentrations and tissue distribution

208

209 Total Hg concentrations in edible tissues varied greatly within and among species groups
210 (i.e. fish, crustaceans, mollusc cephalopods, mollusc bivalves). They ranged from 26 to 2063
211 ng g^{-1} dry wt in fish, from 128 to 297 ng g^{-1} dry wt in crustaceans (i.e. *Litopenaeus*
212 *stylirostris*), from 40 to 218 ng g^{-1} dry wt in cephalopods, and from 73 to 2531 ng g^{-1} dry wt
213 in bivalves (see Table 3). Even within a single species, the variability was sometimes quite
214 important, e.g. for *Mimachlamys gloriosa*, Hg concentrations ranging from 244 to 890 ng g^{-1}
215 dry wt. As it could be expected the variability was even greater when animals of a single
216 species were sampled in different sites. Indeed, Hg concentrations ranged from 173 to 2063
217 ng g^{-1} dry wt in *Plectropomus leopardus*, from 73 to 1015 ng g^{-1} dry wt in *Anadara scapha*,
218 and from 104 to 2531 ng g^{-1} dry wt in *Gafrarium tumidum*. In a single sampling location, Hg
219 concentrations varied greatly among species of the same taxonomic group. For example in
220 Grande Rade, average Hg concentrations were significantly different (Kruskal-Wallis test,
221 $p < 0.01$) among the three bivalves *C. radula*, *A. scapha* and *G. tumidum*: 234 ± 24 , 723 ± 414
222 and 1633 ± 565 ng g^{-1} dry wt, respectively (Table 4). Interestingly, this pattern *C. radula* < *A.*
223 *scapha* < *G. tumidum* was also observed in Koutio and Maa bays, even though the differences
224 among species were significant only in Maa Bay (Kruskal-Wallis test, $p < 0.01$).

225 In Ouano Bay (S3), average Hg concentrations in the fish muscles were significantly
226 different (Kruskal-Wallis test, $p < 0.01$) among *Kyphosus vaigiensis*, *Priacanthus hamrur* and
227 *Plectropomus leopardus*, with 55 ± 22 , 188 ± 58 and 856 ± 330 ng g^{-1} dry wt, respectively
228 (Tables 3 and 4).

229 With very few exceptions, total Hg concentrations in fish were always higher in the liver
230 (detoxification organ) than in the muscle (edible tissue) (Fig. 2). Moreover, this difference

231 was statistically significant for most of the species (t or Wilcoxon tests for paired samples,
232 $p < 0.05$). In contrast, in cephalopods, there was no significant difference in Hg concentrations
233 between muscles and detoxification tissues, i.e. the digestive gland for the squid *Sepioteuthis*
234 *lessoniana* (t -test for paired samples, $p > 0.05$) and the branchial hearts for the octopus *Octopus*
235 *cyanea* (Wilcoxon tests for paired samples, $p > 0.05$) (Fig. 3). However, in this latter species,
236 the concentrations recorded in the digestive gland of one specimen was far higher those of the
237 branchial hearts and muscle (Fig. 3). In *Sepia latimanus*, Hg concentrations followed the
238 decreasing order: branchial hearts $>$ digestive gland $>$ muscle (Fig. 3). Finally, for the
239 Pectinidae (i.e. *Comptopallium radula* and *Mimachlamys gloriosa*), Hg concentrations were
240 significantly lower (Wilcoxon test, $p < 0.05$) in the edible tissues (muscle + gonads) than in the
241 remaining tissues (Fig. 4).

242

243 3.2. Influence of size, weight and trophic level

244

245 Correlations between Hg concentrations in edible tissues and individual size or weight
246 were established for each species, considering all sites together. Few Spearman correlations
247 were significant and Hg levels only varied positively with size for 2 out of the 32 species
248 collected: in the muscles of the fish *P. leopardus* ($r = 0.773$, $p < 0.001$) and in the muscle +
249 gonad of the pectinid *C. radula* ($r = 0.422$, $p = 0.040$). Interestingly, Hg concentrations in whole
250 soft parts of *C. radula* were also correlated significantly with size ($r = 0.472$, $p = 0.020$).
251 Positive correlations with the individual weight were significant for 3 out of the 32 species: in
252 the muscles of *P. leopardus* ($r = 0.782$, $p < 0.001$), and in the whole soft tissues of the bivalves
253 *G. tumidum* and *Periglypta chemnitzii* ($r = 0.239$, $p = 0.024$ and $r = 0.663$, $p = 0.037$, respectively).

254 Differences in Hg concentrations among trophic levels in fish are shown in Fig. 5. The
255 ANCOVA revealed that trophic level, length and their interaction were all factors affecting
256 significantly Hg concentrations ($p < 0.005$). Trophic level was the most important factor

257 explaining ca. 60% of Hg concentration variability, followed by length (15%) and their
258 interaction (6%). The remaining 19% of the variability were due to other factors (residual
259 term). It was not possible to perform ANCOVA with the sites or species as covariable, as was
260 done for trophic levels, because the residuals did not satisfy normality and/or
261 homoscedasticity pre-requisites.

262

263 3.3. Differences among sampling sites

264

265 Table 4 displays the comparison among Hg concentrations measured in different sites of
266 New Caledonia for four species, i.e. the fish *P. leopardus* and the bivalves *A. scapha*, *C.*
267 *radula* and *G. tumidum*. As it was previously found for the first 3 species that a significant
268 positive correlation occurred between Hg concentrations and size or weight, the appropriate
269 factor was used as covariable in the ANCOVA performed to test the differences among sites.

270 For all the four species, Hg concentrations in the edible tissues displayed significant
271 differences among sampling sites ($p_{\text{ANCOVA or ANOVA}}$ always <0.001). Post-hoc Tukey test also
272 showed that for all species, the highest Hg concentrations were always measured in Grande
273 Rade. With respect to *A. scapha* and *G. tumidum*, relatively low Hg values were found for
274 individuals collected in Ouano Bay sites (ranging from 73 to 492 ng g⁻¹ dry wt). In contrast,
275 the fish collected in the latter bay displayed quite high Hg concentration (from 590 to 1338 ng
276 g⁻¹ dry wt in muscles). Koutio, Maa and Sainte Marie Bays were generally characterized by
277 intermediate values for the three bivalves, and by the lowest values for the fish (Table 4).
278 Regarding the clam *G. tumidum*, Hg concentrations were the lowest in Unia, whereas they
279 were relatively high in Tomo (154 ± 38 and 497 ± 124 ng g⁻¹ dry wt respectively).
280 Nevertheless, values in Tomo were significantly lower than those measured in Grande Rade
281 (Table 4). At a smaller geographic scale, possible difference between Grande Rade and
282 Grande Rade-SLN and among the sub-stations in Ouano Bay (S1, S2, S3) could be

283 investigated for 2 out of the 4 species: *A. scapha* and *G. tumidum*. For *G. tumidum*, Hg
284 concentrations were significantly higher ($p < 0.001$) in Grande Rade than in Grande Rade-
285 SLN, whereas no significant difference was detected for *A. scapha*. In Ouano Bay, no
286 significant difference could be detected among the three sampling sites (Table 4).

287

288 3.4. Risk assessment for Human consumers

289

290 The “Maximum Safe Weekly Consumption” (MSWC, in kg wet wt) of edible flesh was
291 estimated taking into account the “Provisional Tolerable Weekly Intake” (PTWI)
292 recommended by JECFA (WHO, 2003) for total Hg and methyl-Hg. MSWC values are given
293 on a species basis in Table 3 (for the species collected in more than one site, the MSWC is
294 thus an average value taking into account the different sampling sites), and on a site-specific
295 basis in Table 4 (for the four species that were collected in sufficient quantity in several sites).
296 The amount of shrimp muscle (*L. stylirostris*) from Bassin de La Foa (i.e. a shrimp farm)
297 which should be eaten by a 60-kg person to reach the PTWI for total Hg ($5000 \text{ ng kg}^{-1} \text{ wk}^{-1}$)
298 would be ca. 7.5 kg. For the oyster *Crassostrea gigas* from Dumbea Bay, this amount would
299 be about 13.5 kg of oyster flesh. Regarding cephalopods from the southern and northern
300 lagoon, the MSWC for total Hg ranged from 10 kg of edible flesh (muscle) for the squid
301 *Sepioteuthis lessoniana* to 36.7 kg per week for the cuttlefish *Sepia latimanus* (Table 3). With
302 respect to fish consumption, the MSWC for total Hg was between ca. 1 kg of flesh for some
303 carnivorous species from Grande Rade (*Plectorhinchus chaetodonoides*, *P. flavomaculatus*)
304 to more than 32 kg per week for some herbivorous species coming from Ouano Bay (*Naso*
305 *unicornis*, *Scarus microrhinos*, *S. rivulatus*, *S. schlegeli*) (Tables 3 and 4). In Grande Rade, a
306 60 kg person should eat 6.4 kg, 2.1 kg and 920 g wet wt per week of flesh of *C. radula*, *A.*
307 *scapha* and *G. tumidum*, respectively, to reach the PTWI in total Hg (Table 4). In the same
308 site, the MSWC for total Hg was 830 g of edible flesh of the *P. leopardus* fish. In all cases,

309 MSWCs for methyl-Hg were far lower than those computed for total Hg, especially in fish
310 (Tables 3 and 4). For example, a 60 kg person should eat about 260 g wet wt of flesh of *P.*
311 *leopardus* from Grande Rade to reach the PTWI in methyl-Hg (vs. the aforementioned 830 g
312 for total Hg).

313

314 **4. Discussion**

315

316 The whole dataset of the present study provides substantial baseline information of major
317 importance for future investigations on Hg contamination status in New Caledonia as well as
318 for the evaluation of the risk related to local seafood consumption. Indeed, despite the well-
319 known toxicity of Hg to marine organisms and its potential effects on Human health, this
320 metal has been poorly investigated in this tropical zone, with only one published study
321 reporting Hg measurements in tissues of two marine mammals (Bustamante et al., 2003). So
322 far, there are no published data on Hg levels in invertebrate or vertebrate species used as food
323 by local populations, whether they are fished from the wild or cultured in artificial (shrimp) or
324 natural (oysters) environments.

325 In species for which several tissues were examined, the lowest concentrations were
326 almost always recorded in the muscles (see Figs 2 to 4). In cephalopods, the digestive gland
327 and the branchial hearts are actually known to be major sites for concentrating metals, among
328 which Hg, compared to muscles (e.g. Miramand and Bentley, 1992; Bustamante et al., 2000,
329 2006). The digestive gland is generally supposed to play a major role in the storage and
330 detoxification of many essential and non essential elements such as Ag, Cd, Cu or Zn
331 (Miramand and Bentley, 1992; Bustamante et al., 2000, 2002, 2006). Concerning the
332 Pectinidae family, the digestive gland and the kidneys have been identified for their storage
333 and detoxification function for many elements (e.g. Bustamante and Miramand, 2004, 2005;
334 Metian et al., 2008a), especially in the case of Hg (Metian et al., 2008b). This explains the
335 higher Hg values that we measured in the “remaining soft tissues” body compartment of *C.*

336 *radula* and *M. gloriosa* (Fig. 4) as this compartment comprises all tissues and organs other
337 than the adductor muscle and the gonad (i.e. it includes both the kidneys and the digestive
338 gland). Finally, in fish, hepatic levels of Hg are generally reported to be higher than the
339 muscular ones (e.g. Storelli et al., 2005; Kojadinovic et al., 2007), probably due to the
340 demethylation process that has been suggested to occur in fish liver, as indicated by the
341 occurrence of almost only inorganic Hg in this organ (Oliveira Ribeiro et al., 1996; Maury-
342 Bachet et al., 2006). In our study, liver was similarly found to be the major organ for Hg
343 storage in fish. Pertaining to edible tissues, Hg concentrations varied greatly in some bivalves
344 collected from different sites in the New Caledonia lagoon. Hg levels ranged from 73 to 1015
345 and from 104 to 2531 ng g⁻¹ dry wt in the whole soft parts of *A. scapha* and *G. tumidum*,
346 respectively. In fish, *P. leopardus*, which was also collected in several sites, displayed
347 muscular Hg concentrations ranging from 173 to 2063 ng g⁻¹ dry wt. On the other hand, in
348 some species of fish (i.e. *Scarus sp.*, *Lutjanus monostigma*, *Kyphosus vaigiensis*), Hg
349 concentrations were very low (<60 ng g⁻¹ dry wt) for most of the individuals collected (Table
350 3). Similarly, Hg concentrations measured in the cultured species did not exceed 105 and 297
351 ng g⁻¹ dry wt for the oyster *C. gigas* and the shrimp *L. stylirostris*, respectively.

352 Comparison with other tropical areas (i.e. NE coast of Australia, Thailand, and Gulf of
353 Oman) indicates that the total Hg concentrations reported in similar organisms were generally
354 below the mean values that we obtained in this study. Indeed, in bivalves from Thailand, total
355 Hg in the clam *Paphia undulate*, the blood cockle *Anadara granosa* and the oyster
356 *Crassostrea commercialis* never exceeded 100 ng g⁻¹ dry wt (Phillips and Muttarasin, 1985)
357 whereas in the Gulf of Oman, Hg concentrations were below 315 ng g⁻¹ dry wt for the clam
358 *Circentia callipyga*, the spiny oyster *Spondylus sp.* and the oyster *Saccostrea cucullata* (de
359 Mora et al., 2004). Regarding fish, relatively low concentrations were reported for species
360 from the NE coast of Australia with Hg levels ranging from 120 to 760 ng g⁻¹ dry wt in
361 muscle of *Acanthopagrus berda*, *Cymbacephalus nematophthalmus*, *Lutjanus carponotatus*,

362 *L. sanguineus* and *Plectorhynchus flavimaculatus* (Denton and Breck, 1981). However, de
363 Mora et al. (2004) found relatively high values in fish from the Gulf of Oman, i.e. ranging
364 from 343 to 522 and from 498 to 2350 ng g⁻¹ dry wt in *Lethrinus nebulosus* and *Epinephelus*
365 *coicoides*, respectively. Also, Denton and Breck (1981) reported values from 250 to 1250 ng
366 Hg g⁻¹ dry wt in muscles of cephalopods (*Loligo sp.* and *Sepia sp.*), and a Hg concentration of
367 ca. 1000 ng g⁻¹ dry wt for the tumid venus *Gafrarium tumidum*. Moreover, in chronically
368 polluted, non tropical areas (i.e. Western Limfjord, Denmark and Lavaca Bay, Texas, USA),
369 Hg concentrations ranging from 414 to 2517 ng g⁻¹ dry wt were reported in the cockle
370 *Cardium sp.* and from 430 and 10 100 ng g⁻¹ dry wt in several other species of bivalves
371 (Mohlenberg and Riigard, 1988; Locarnini and Presley, 1996). In our study, some values
372 recorded in the edible *A. scapha* and *G. tumidum* from Grande Rade were thus on the same
373 order of magnitude than those reported in well known Hg-contaminated areas. Hence, along
374 with our data on Hg levels in fish muscles, the former comparisons indicate that New
375 Caledonia may suffer Hg contamination to some extent and that additional studies would be
376 necessary for further assessing the contamination status in Hg of the New Caledonia lagoon.
377 Nonetheless, the assessment of the risk for Human consuming marine products from this
378 lagoon appeared of particular concern, particularly for the Grande Rade area.

379 From a global health standpoint, Hg concentrations measured in the investigated
380 organisms of this study did not reveal excessive risk for Humans consuming seafood in New
381 Caledonia. Indeed, even in the most contaminated site (Grande Rade), the amount of bivalve
382 flesh to be eaten on a weekly basis by a 60 kg person for a given species to reach the PTWI
383 for total Hg was relatively elevated: 920 g, 2.1 kg and 6.4 kg wet wt for *G. tumidum*, *A.*
384 *scapha* and *C. radula*, respectively (Table 4). Also, regarding the fish *P. leopardus* in the
385 same location, a 60 kg person should eat more than 830 g of fish muscle to exceed the PTWI
386 in total Hg. Hence, except in local Human groups where sea products constitute the main food
387 source, the former quantities of fish or bivalves are not very likely to be reached over a one-

388 week period, as far as total Hg is considered. However, if we assume that ca. 100% of total
389 Hg in fish muscle is occurring as methyl-Hg as it is typically the case in this group (e.g.
390 Bloom, 1992; Holsbeek et al., 1997), the PTWI in methyl-Hg would be reached with the
391 consumption of approximately 260 g wet wt of edible flesh of *P. leopardus* from Grande
392 Rade. Such a low quantity of flesh can be easily consumed during a single meal. Indeed, in
393 New Caledonia, fish consumption is particularly high, varying between 23 to 50
394 kg/inhabitant/year, i.e. between 0.5 to 1 kg per week (Labrosse et al., 2006). Moreover, the
395 “Maximum Safe Weekly Consumption” (MSWC) for methyl-Hg assessed for the other fish
396 species collected in Grande Rade (i.e. *Plectorhinchus chaetodonoides*, *P. flavomaculatus* and
397 *Bodianus perditio*) were similarly quite low and always below 400 g wet wt of flesh per week
398 for a 60-kg consumer (Table 3). Although these low MSWC values are of concern, they were
399 only found in the single area of Grande Rade.

400 As for other metals, Hg concentrations in marine organisms may vary with biological and
401 environmental factors such as age (size/weight), trophic level, lifestyle and geographical
402 origin (e.g. Monteiro et al., 1992; Otchere et al., 2003; Burger et al., 2007; Zizek et al., 2007).
403 Size has been reported as a factor to which Hg concentrations are well correlated in fish
404 (Monteiro and Lopes, 1990; Mathieson and McLusky, 1995; Adams, 2004; Kojadinovic et al.,
405 2006), due to the continuous bioaccumulation of Hg in muscular tissues all along their life
406 (Braune, 1987; Burger and Gochfeld, 2007). However, among the fish species examined in
407 the present study, only *P. leopardus* displayed a positive correlation with length and weight.
408 The lack of positive correlation for the other fish investigated may be due to the small number
409 of individuals within those species, or, alternatively to the fact that the sampled individuals
410 were of about the same age (Braune, 1987; Mathieson and McLusky, 1995).

411 In cephalopods, it is also generally admitted that Hg concentrations are positively
412 correlated with size (Rossi et al., 1993; Bustamante et al., 2006; Pierce et al., 2008). However,

413 no correlation was found either for *Sepioteuthis lessoniana* or for *Octopus cyanea*, probably
414 because of the too narrow size range of the individuals examined.

415 Hg concentrations were found to differ among species, and notably among species
416 belonging to the same taxonomic group. Interestingly, for a given sampling location (Grande
417 Rade, Koutio Bay, Maa Bay), the three species of bivalves (*C. radula*, *A. scapha* and *G.*
418 *tumidum*) did not bioaccumulate Hg to the same extent. The increasing order of
419 concentrations (*C. radula* < *A. scapha* < *G. tumidum*) always occurred in each site, the clam
420 and the cockle concentrating Hg much more than the scallop. These three species were of
421 very different sizes: average length was 77 ± 14 mm for *C. radula*, 58 ± 9 mm for *A. scapha*
422 and 38 ± 5 mm for *G. tumidum*. It is well-established that metal uptake efficiency can
423 decrease with organism size increase (e.g. Swaileh and Adelung, 1995; Warnau et al., 1995;
424 Hédouin et al., 2006). This trend is generally explained by the decreasing surface/volume
425 ratio of an organism with increasing body size, the decreasing metabolic activity in older
426 individuals, and/or by the dilution of the metal in larger organisms (e.g. Braune, 1987;
427 Swaileh and Adelung, 1995; Warnau et al., 1995). Moreover, different species of bivalves
428 may have different diet and filtration rates. Although further studies are needed to better
429 explain the differences in Hg bioaccumulation among marine bivalves from New Caledonia,
430 it is effectively well-known that scallops have a quite elevated filtration rate compared to
431 other bivalves (Meyhöfer, 1985). As they displayed lower values of Hg than other bivalves in
432 this study, it could be suggested that diet composition could be a major factor in Hg
433 bioaccumulation in bivalves. This is in accordance with the few evidences available in the
434 related literature (e.g. Wang and Wong, 2003; Metian et al., 2008b). This apparently also
435 holds true in fish, for which the trophic level clearly appeared to affect Hg concentrations in
436 the investigated species (see Fig. 5). Indeed, grazers/scavengers displayed the lowest values
437 of Hg in their muscular tissues, whereas predators of small fish displayed the highest ones.

438 These observations are in good agreement with the Hg biomagnification process occurring in
439 marine food webs (e.g. Burger et al., 2007; Zizek et al., 2007).

440 Species, size or weight and trophic level as factors of variation for Hg concentrations
441 were also well illustrated by the case of the three fish species collected in Ouano Bay S3.
442 Indeed, they displayed significant differences in their mean muscle values of total Hg,
443 according to the following order: *Kyphosus vaigiensis* < *Priacanthus hamrur* < *Plectropomus*
444 *leopardus*. Actually, *K. vaigiensis* and *P. hamrur* are similar in size, but the former is a grazer
445 whereas the second is a predator of invertebrates and small fish; as for *P. leopardus*, it is
446 much heavier and is a predator of small fish, and displayed thus, as could be expected, the
447 highest Hg concentrations among the three species.

448 Finally, there were clear differences in Hg concentrations among sites for a given species,
449 the site factor explaining between 68 and 85% of the variability in the performed ANCOVA.
450 In the three bivalve species *A. scapha*, *C. radula* and *G. tumidum*, and in the fish *P.*
451 *leopardus*, individuals from Grande Rade always displayed the highest concentrations in Hg.
452 Considering the concentrations of several metals in the sediment and in the clam *G. tumidum*,
453 Grande Rade is regarded as a highly contaminated station (Hédouin et al., 2008). As this area
454 is subjected to industrial inputs, it was not surprising to find high concentrations of Hg in the
455 organisms living there. However, there was a spatial heterogeneity for bivalves from the
456 Grande Rade area, with Hg concentrations in *G. tumidum* from Grande Rade-SLN that were
457 surprisingly much lower than that from Grande Rade (individuals from both locations were of
458 similar size). Very intense exposure to Ni and to Ni-ore co-occurring metals in Grande Rade-
459 SLN lead to very high concentrations on these elements in the tissues of *G. tumidum* (>10 µg
460 Cr g⁻¹, >90 µg Ni g⁻¹, >300 µg Mn g⁻¹; Hédouin et al., 2008) which could interfere with other
461 elements such as Hg. However, the lack of similar trends in Hg concentrations for the other
462 bivalve also collected in both sites (*A. scapha*) does not support this hypothesis. Further
463 investigations are thus necessary to explain this peculiar observation in *G. tumidum*.

464

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466

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477

478 **References**

479

- 480 Adams, D.H., 2004. Total mercury levels in tunas from offshore waters of the Florida Atlantic
481 coast. *Marine Pollution Bulletin* 49: 659-667.
- 482 Ambastian, P., Fernex, F., Bernat, M., Parron, C., Lecolle, J., 1997. High metal inputs to
483 closed seas: the New Caledonia lagoon. *Journal of Geochemistry Exploration* 59: 59-74.
- 484 Bloom, N.S., 1992. On the chemical form of mercury in edible fish and marine invertebrate
485 tissue. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 1010-1017.
- 486 Braune, B.M., 1987. Mercury accumulation in relation to size and age of Atlantic Herring
487 (*Clupea harengus harengus*) from the Southwestern Bay of Fundy, Canada. *Archives*
488 *Environmental Contamination and Toxicology* 16: 311-320.

- 489 Burger, J., Gochfeld, M., 2007. Risk to consumers from mercury in Pacific cod (*Gadus*
490 *macrocephalus*) from the Aleutians: Fish age and size effects. *Environmental Research*
491 105: 276-284.
- 492 Burger, J., Gochfeld, M., Jeitner, C., Burke, S., Stamm, T., Snigaroff, R., Snigaroff, D.,
493 Patrick, R., Wetson, J., 2007. Mercury levels and potential risk from subsistence foods
494 from the Aleutians. *Science of the Total Environment* 384: 93-105.
- 495 Bustamante, P., Cosson, R.P., Gallien, I., Caurant, F., Miramand, P., 2002. Cadmium
496 detoxification processes in the digestive gland of cephalopods in relation to accumulated
497 cadmium concentrations. *Marine Environmental Research* 53: 227-241.
- 498 Bustamante, P., Garrigue, C., Breau, L., Caurant, F., Dabin, W., Greaves, J., Dodemont, R.,
499 2003. Trace elements in two odontocete species (*Kogia breviceps* and *Globicephala*
500 *macrorhynchus*) stranded in New Caledonia (South Pacific). *Environmental Pollution* 124:
501 263-271.
- 502 Bustamante, P., Grigioni, S., Boucher-Rodoni, R., Caurant, F., Miramand, P., 2000.
503 Bioaccumulation of 12 trace elements in the tissues of the nautilus *Nautilus macromphalus*
504 from New Caledonia. *Marine Pollution Bulletin* 40: 688-696.
- 505 Bustamante, P., Lahaye, V., Durnez, C., Churlaud, C., Caurant, F., 2006. Total and organic
506 Hg concentrations in cephalopods from the North Eastern Atlantic waters: Influence of
507 geographical origin and feeding ecology. *Science of the Total Environment* 368: 585-596.
- 508 Bustamante, P., Miramand, P., 2004. Interspecific and geographical variations of trace
509 element concentrations in Pectinidae from European waters. *Chemosphere* 57: 1355-1362.
- 510 Bustamante, P., Miramand, P., 2005. Subcellular and body distributions of 17 trace elements
511 in the variegated scallop *Chlamys varia* from the French coast of the Bay of Biscay.
512 *Science of the Total Environment* 337: 59-73.

- 513 Buzina, R., Suboticaneć, K., Vukusić, J., Sapunar, J., Antonic, K., Zorica, M., 1989. Effect of
514 industrial pollution on seafood content and dietary intake of total and methylmercury.
515 Science of the Total Environment 78: 45-57.
- 516 Cossa, D., Thibaud, Y., Roméo, M., Gnassia-Barelli, M., 1990. Le mercure en milieu marin.
517 Biogéochimie et écotoxicologie. Rapports scientifiques et techniques de l'IFREMER, No.
518 19, Brest.
- 519 de Mora, S., Fowler, S.W., Wyse, E., Azémard, S., 2004. Distribution of heavy metals in
520 marine bivalves, fish and coastal sediments in the Gula of Oman. Marine Pollution Bulletin
521 49: 410-424.
- 522 Denton, G.R.W., Breck, W.G., 1981. Mercury in tropical marine organisms from North
523 Queensland. Marine Pollution Bulletin 12: 116-121.
- 524 Eisler, R., 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S.
525 Fish and Wildlife Service Biological Report 85(1.10).
- 526 Hédouin, L., Metian, M., Teyssié, J-L., Fowler, S.W., Fichez, R., Warnau, M., 2006.
527 Allometric relationships in the bioconcentration of heavy metals by the edible tropical
528 clam *Gafrarium tumidum*. Science of the Total Environment 366: 154-163.
- 529 Hédouin, L., Pringault, O., Metian, M., Bustamante, P., Warnau, M., 2007. Nickel
530 bioaccumulation in bivalves from the New Caledonia lagoon: seawater and food exposure.
531 Chemosphere 66: 1449-1457.
- 532 Hédouin, L., Bustamante, P., Churlaud, C., Pringault, O., Fichez, R., Warnau, M., 2008.
533 Trends in concentrations of selected metalloids and metals in two bivalves from the SW
534 lagoon of New Caledonia. Ecotoxicology and Environmental Safety, in press
535 doi:10.1016/j.ecoenv.2008.04.004.
- 536 Holsbeek, L., Das, K., Joiris, C.R., 1997. Mercury speciation and accumulation in Bangladesh
537 freshwater and anadromous fish. Science of the Total Environment 198: 201-210.

- 538 Hylander, L.D., 2001. Global mercury pollution and its expected decrease after a mercury
539 trade ban. *Water, Air, and Soil Pollution* 125: 331-344.
- 540 Kawaguchi, T., Porter, D., Bushek, D., Jones, B., 1999. Mercury in the American oyster
541 (*Crassostrea virginica*) in South Carolina, USA, and public health concerns. *Marine*
542 *Pollution Bulletin* 38: 324-327.
- 543 Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R.P., Bustamante, P., 2006. Mercury
544 content in commercial pelagic fish and its risk assessment in the Western Indian Ocean.
545 *Science of the Total Environment* 366: 688-700.
- 546 Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R.P., Bustamante, P., 2007.
547 Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean.
548 *Environmental Pollution* 146: 548-566.
- 549 Labrosse, P., Ferraris, J., Letourneur, Y., 2006. Assessing the sustainability of subsistence
550 fisheries in the Pacific: The use of data on fish consumption. *Ocean Coastline Management*
551 49: 203–221.
- 552 Labrosse, P., Fichez, R., Farman, R., Adams, T., 2000. New Caledonia, in: Sheppard, C.R.C.
553 (Ed.), *Seas at the Millenium: an environmental evaluation*. Elsevier Science, Amsterdam,
554 pp. 723-736.
- 555 Locarnini, S.J.P., Presley, B.J., 1996. Mercury concentrations in benthic organisms from a
556 contaminated estuary. *Marine Environmental Research* 41: 225-239.
- 557 Maury-Brachet, R., Durrieu, G., Dominique, Y., Boudou, A., 2006. Mercury distribution in
558 fish organs and food regimes: significant relationships from twelve species collected in
559 French Guiana (Amazonian basin). *Science of the Total Environment* 368: 262-270.
- 560 Mathieson, S., McLusky, D.S., 1995. Inter-species variation of mercury in skeletal muscle of
561 five fish species from inshore waters of the Firth of Clyde, Scotland. *Marine Pollution*
562 *Bulletin* 30: 283-286.

- 563 Metian, M., Bustamante, P., Hédouin, L., Warnau, M., 2008a. Accumulation of trace
564 elements in the tropical scallop *Comptopallium radula* from coral reefs in New Caledonia.
565 Environmental Pollution 152: 543-552.
- 566 Metian, M., Warnau, M., Cosson, R.P., Bustamante, P., 2008b. Bioaccumulation of Hg and
567 detoxification processes in the king scallop *Pecten maximus*: field and laboratory
568 investigations. Submitted.
- 569 Meyhöfer, E., 1985. Comparative pumping rates in suspension-feeding bivalves. Marine
570 Biology 85: 137-142.
- 571 Miramand, P., Bentley, D., 1992. Concentration and distribution of heavy metals in tissues of
572 two cephalopods, *Eledone cirrhosa* and *Sepia officinalis*, from the French coast of the
573 English Channel. Marine Biology 114: 407-14.
- 574 Mohlenberg, F., Riisgard, H.U., 1988. Partitioning of inorganic and organic Mercury in
575 cockles *Cardium edule* (L.) and *C. glaucum* (Bruguère) from a chronically polluted area:
576 influence of size and age. Environmental Pollution 55: 137-148.
- 577 Monniot, F., Martoja, R., Monniot, C., 1994. Cellular sites of iron and nickel accumulation in
578 ascidians related to the naturally and anthropic enriched New Caledonian environment.
579 Annales de l'Institut Océanographique 70: 205-216.
- 580 Monteiro, L.R., Lopes, H.D., 1990. Mercury content of Swordfish, *Xiphias gladius*, in
581 relation to length, weight, age and sex. Marine Pollution Bulletin 21: 293-296.
- 582 Monteiro, L.R., Porteiro, F.M., Gonçalves, J.M., 1992. Inter- and intra-specific variation of
583 mercury levels in muscle of cephalopods from the Azores. Archipelago 10: 13-22.
- 584 Oliveira Ribeiro, C.A., Guimaraes, J.R.D., Pfeiffer, W.C., 1996. Accumulation and
585 distribution of inorganic mercury in a tropical fish (*Trichomycterus zonatus*).
586 Ecotoxicology and Environmental Safety 34: 190-195.

- 587 Otchere, F.A., Joiris, C., Holsbeek, L., 2003. Mercury in the bivalves *Anadara (Senilis)*
588 *senilis*, *Perna perna* and *Crassostrea tulipa* from Ghana. *Science of the Total Environment*
589 304: 369-375.
- 590 Phillips, D.J.H., Muttarasin K., 1985. Trace metals in bivalve molluscs from Thailand. *Marine*
591 *Environmental Research* 15: 215-234.
- 592 Pierce, G.J., Stowasser, G., Hastie, L.C., Bustamante, P., 2008. Geographic, seasonal and
593 ontogenetic variation in cadmium and mercury concentrations in squid (Cephalopoda:
594 Teuthoidea) from UK waters. *Ecotoxicology and Environmental Safety* 70: 422-432.
- 595 Riisgard, H.U., Famme, P., 1986. Accumulation of inorganic and organic mercury in shrimp,
596 *Crangon crangon*. *Marine Pollution Bulletin* 17: 255-257.
- 597 Rossi, A., Pellegrini, D., Belcari, P., Barghigiani, C., 1993. Mercury in *Eledone cirrhosa* from
598 the Northern Tyrrhenian Sea: contents and relations with life cycle. *Marine Pollution*
599 *Bulletin* 26: 683-686.
- 600 Salomons, W., de Rooij, N.M., Derdijk, H., Bril, J., 1987. Sediments as a source for
601 contaminants? *Hydrobiologia* 149: 13-30.
- 602 Storelli, M.M., Giacomini, R., Storelli, A., Marcotrigiano, G.O., 2005. Accumulation of
603 mercury, cadmium, lead and arsenic in Swordfish and Bluefin tuna from the Mediterranean
604 Sea: a comparative study. *Marine Pollution Bulletin* 44: 281-288.
- 605 Svensson, B.G., Schütz, A., Nilsson, A., Akesson, I., Akesson, B., Skerfving, S., 1992. Fish
606 as a source of exposure to mercury and selenium. *Science of the Total Environment* 126:
607 61-74.
- 608 Swaileh, K.M., Adelung, D., 1995. Effect of body size and season on the concentrations of
609 Cu, Cd, Pb and Zn in *Diastylis rathkei* (Kröyer) (Crustacea: Cumacea) from Kiel Bay,
610 Western Baltic. *Marine Pollution Bulletin* 31: 103-107.

- 611 Trombini, C., Fabbri, D., Lombardo, M., Basura, I., Zavoli, E., Horvat, M., 2003. Mercury
612 and methylmercury contamination in surficial sediments and clams of a coastal lagoon
613 (Pialassa Baiona, Ravenna, Italy). *Continental Shelf Research* 23: 1821-1831.
- 614 Wang, W-X., Wong, R.C.K., 2003. Combined effects of food quantity and quality on Cd, Cr,
615 and Zn assimilation to the green mussel, *Perna viridis*. *Journal of Experimental Marine*
616 *Biology and Ecology* 290: 49-69.
- 617 Warnau, M., Biondo, R., Temara, A., Bouquegneau, J.M, Jangoux, M., Dubois, P., 1998.
618 Distribution of heavy metals in the echinoid *Paracentrotus lividus* (Lmk) from the
619 Mediterranean *Posidonia oceanica* ecosystem: seasonal and geographical variations.
620 *Journal of Sea Research* 39: 267-280.
- 621 Warnau, M., Ledent, G., Temara, A., Alva, V., Jangoux, M., Dubois, P., 1995. Allometry of
622 heavy metal bioconcentration in the echinoid *Paracentrotus lividus* (Echinodermata).
623 *Archives of Environmental Contamination and Toxicology* 29: 393-399.
- 624 Warnau, M., Teysssié, J-L., Fowler, S.W., 1996. Biokinetics of selected heavy metals and
625 radionuclides in two marine macrophytes: the seagrass *Posidonia oceanica* and the alga
626 *Caulerpa taxifolia*. *Marine Environmental Research* 41: 343-362.
- 627 WHO, 1990. Methylmercury. *Environmental Health Criteria* 101: 1-80.
- 628 WHO, 2003. Joint FAO/WHO Expert Committee on Food Additives and Contaminants,
629 Sixty-first Meeting. Summary and Conclusions. Web access at
630 <ftp://ftp.fao.org/es/esn/jecfa/jecfa61sc.pdf>.
- 631 Zizek, S., Horvat, M., Gibicar, D., Fajon, V., Toman, M.J., 2007. Bioaccumulation of
632 mercury in benthic communities of a river ecosystem affected by mercury mining. *Science*
633 *of the Total Environment* 377: 407-415.
- 634

635 Captions to figures

636

637 Fig. 1. Map of the sampling stations in the South of New Caledonia and in the vicinity of

638 Noumea City. GR: Grande Rade; GR-SLN: Grande Rade-SLN.

639

640 Fig. 2. Relationship between total Hg concentrations (T-Hg; ng g⁻¹ dry wt) in liver and muscle

641 in fish species from New Caledonia.

642

643 Fig. 3. Total Hg concentrations (T-Hg; mean ± SD, ng g⁻¹ dry wt) in the digestive gland,

644 branchial hearts and muscles of three cephalopod species from New Caledonia.

645

646 Fig. 4. Total Hg concentrations (T-Hg; mean ± SD, ng g⁻¹ dry wt) in the muscle + gonad and

647 in the remaining tissues of two scallop species from New Caledonia.

648 * reconstructed data

649

650 Fig. 5. Comparison of total Hg concentrations (T-Hg, ng g⁻¹ dry wt) in the muscles of fish

651 from New Caledonia according to their trophic level. GS = grazer / scavenger (*n* = 10); PI =

652 predator of invertebrates (*n* = 5); PISM = predator of invertebrates and small fish (*n* = 23);

653 PSM = predator of small fish (*n* = 24).

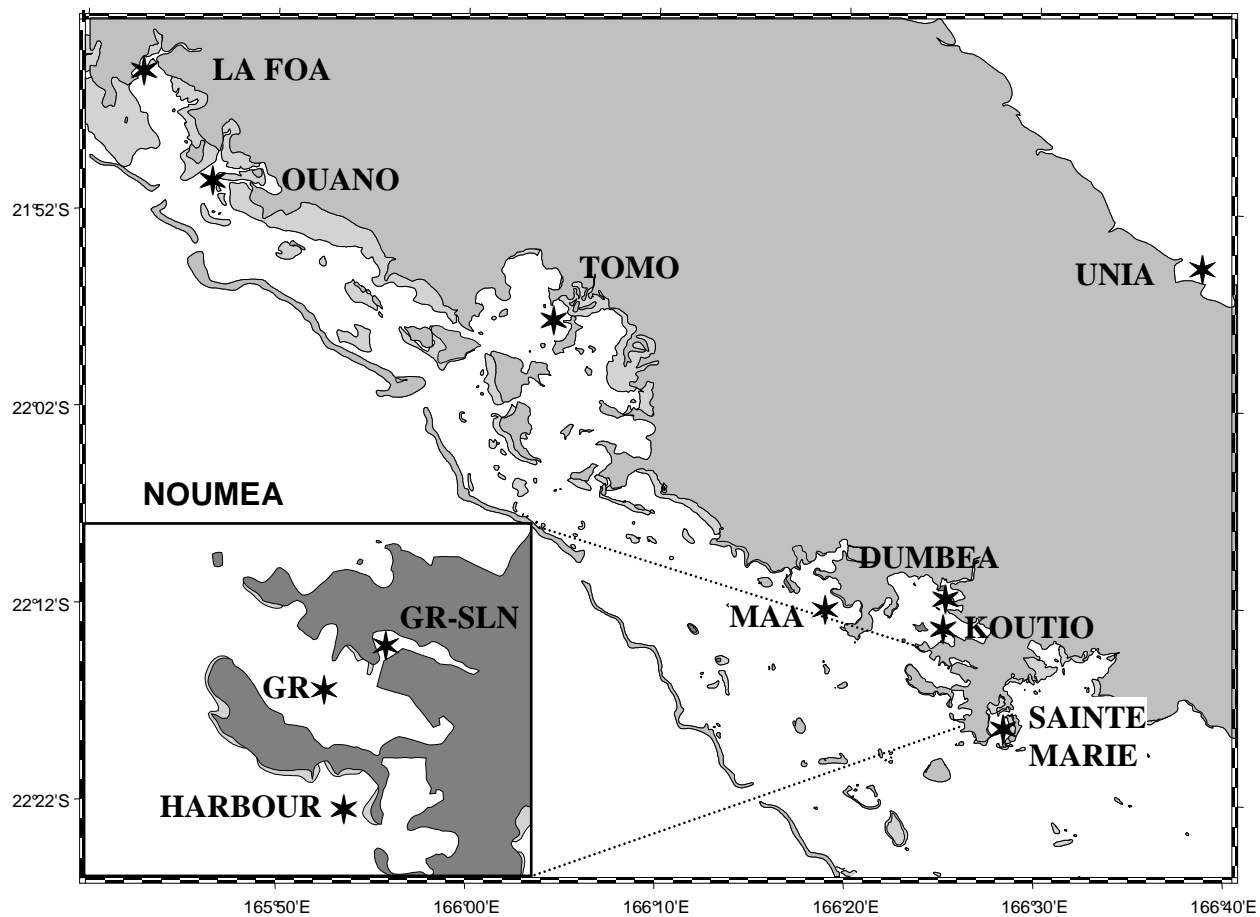


Figure 1

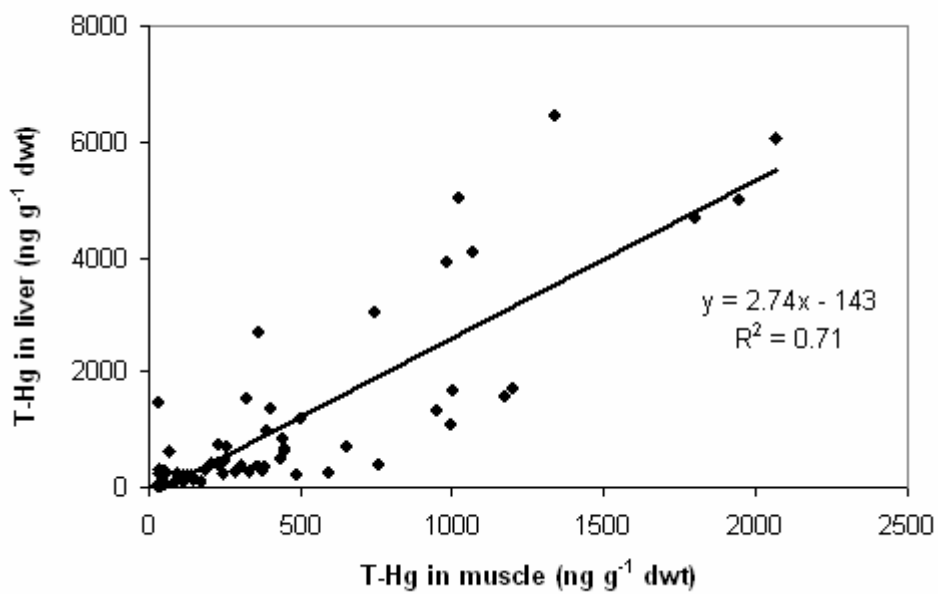


Figure 2

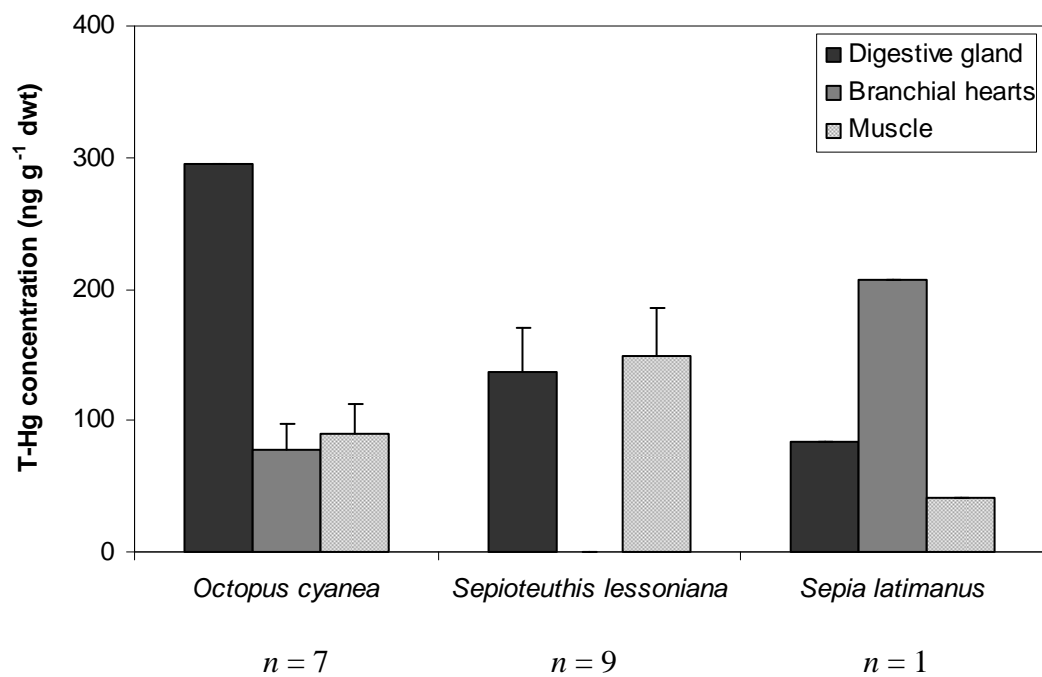


Figure 3

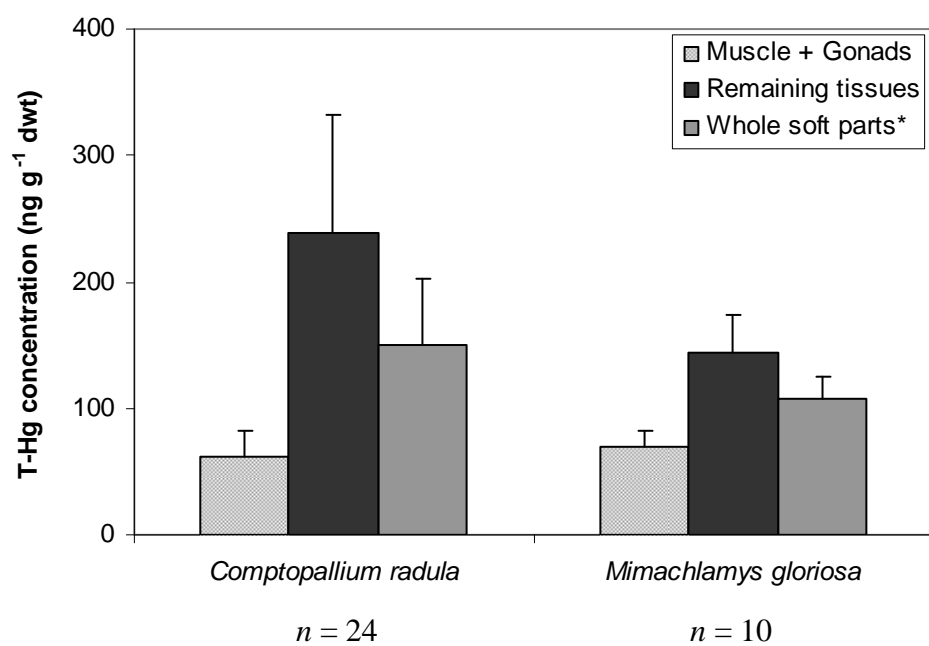


Figure 4

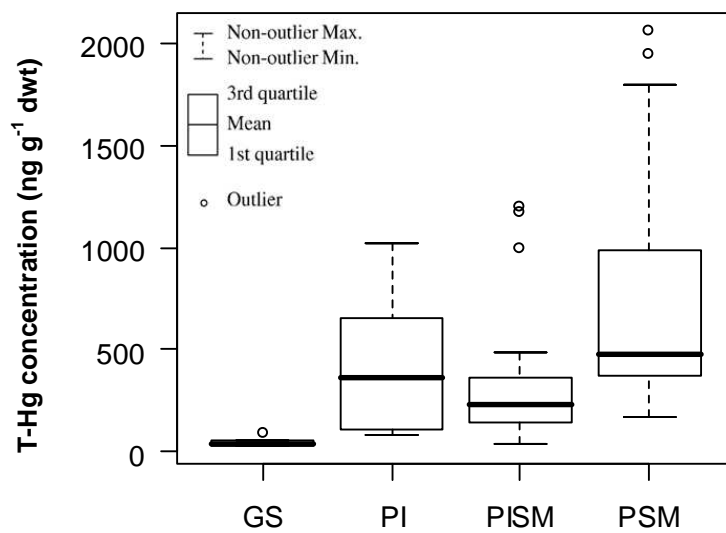


Figure 5

Table 1
Characteristics of the organisms collected and analysed

| Family and Scientific Name | Common Name | <i>n</i> | Length (mm) Mean \pm SD (Range) | Wet wt (g) Mean \pm SD (Range) | Sampling date | Sampling site(s) | Trophic level | Life style |
|---------------------------------|-----------------------|----------|--|--|----------------------|---|--------------------|--------------|
| Crustaceans | | | | | | | | |
| Penaeidae | | | | | | | | |
| <i>Litopenaeus stylirostris</i> | Pacific blue shrimp | 5 | 155 \pm 4 (155 – 160) | 21.5 \pm 1.3 (20.2 – 23.3) | Mar 2007 | Bassin de La Foa | Grazer / Scavenger | Benthic |
| Mollusc Bivalves | | | | | | | | |
| Arcidae | | | | | | | | |
| <i>Anadara scapha</i> | Antique ark | 28 | 58.4 \pm 8.8 (28 – 70) | 60.8 \pm 20.5 (9 – 101) | Mar 2007 Oct 2007 | Grande Rade, Koutio, Ouano (S1, S2), Maa, Sainte Marie Grande Rade-SLN | Filter feeder | Benthic |
| Ostreidae | | | | | | | | |
| <i>Crassostrea gigas</i> | Pacific cupped oyster | 5 | 86.0 \pm 4.7 (80 – 93) | 62.0 \pm 7.1 (54 – 73) | Mar 2007 | Dumbea | Filter feeder | Benthic |
| Pectinidae | | | | | | | | |
| <i>Comptopallium radula</i> | Radula scallop | 24 | 77.3 \pm 14.3 (44 – 99) | 70.6 \pm 28.4 (19.6 – 115) | Mar 2007 Oct 2007 | Grande Rade, Koutio, Maa, Sainte Marie Noumea harbour | Filter feeder | Benthic |
| <i>Mimachlamys gloriosa</i> | Tropical scallop | 10 | 72.6 \pm 6.4 (63 – 80) | 55.8 \pm 14.9 (38 – 80) | Oct 2007 | Noumea harbour | Filter feeder | Benthic |
| Veneridae | | | | | | | | |
| <i>Gafrarium tumidum</i> | Tumid venus | 89 | 37.6 \pm 4.6 (29 – 45) | 22.3 \pm 6.4 (11.3 – 35.8) | Mar 2007 Oct 2007 | Grande Rade, Grande Rade-SLN, Koutio, Ouano (S1, S2, S3), Maa Unia, Tomo | Filter feeder | Benthic |
| <i>Periglypta chemnitzii</i> | Chemnitz Venus | 10 | 60.6 \pm 2.8 (56 – 65) | 111 \pm 26.3 (73 – 172) | Oct 2007 | Unia | Filter feeder | Benthic |
| Mollusc Cephalopods | | | | | | | | |
| Loliginidae | | | | | | | | |
| <i>Sepioteuthis lessoniana</i> | Big fin reef squid | 9 | 215 \pm 34 ^a | 441 \pm 185 | Oct 2007 | Southern Lagoon | Predator | Neritic |
| Octopodidae | | | | | | | | |
| <i>Octopus cyanea</i> | Big blue octopus | 7 | 113 \pm 16.3 ^a (82 – 131) ^a | 1521 \pm 671 (700 – 2900) | Oct 2007 | Northern Lagoon | Predator | Benthic |
| Sepiidae | | | | | | | | |
| <i>Sepia latimanus</i> | Broad club cuttlefish | 1 | 240 ^a | 1300 ^a | Oct 2007 | Southern Lagoon | Predator | Nectobenthic |

^a Mantle length (not total length)

Table 1 (continued)

| Family and Scientific Name | Common Name | <i>n</i> | Length (mm) Mean \pm SD (Range) | Wet wt (g) Mean \pm SD (Range) | Sampling date | Sampling site(s) | Trophic level | Life style |
|--------------------------------------|------------------------|----------|---|--|----------------------|--|---|------------|
| Fish | | | | | | | | |
| Acanthuridae | | | | | | | | |
| <i>Naso unicornis</i> | Bluespine unicornfish | 1 | 435 | 1600 | Mar 2007 | Ouano (S3) | Grazer / Scavenger | Neritic |
| Haemulidae | | | | | | | | |
| <i>Plectorhinchus albovittatus</i> | Two-striped sweetlips | 1 | 405 | 1300 | Mar 2007 | Ouano (S3) | Predator (invertebrates) | Neritic |
| <i>P. chaetodonoides</i> | Harlequin sweetlips | 1 | 351 | 900 | Mar 2007 | Grande Rade | Predator (invertebrates and small fish) | Neritic |
| <i>P. flavomaculatus</i> | Lemon sweetlips | 1 | 485 | 1600 | Mar 2007 | Grande Rade | Predator (crustaceans and small fish) | Neritic |
| <i>Diagramma pictum</i> | Painted sweetlips | 1 | 451 | 1160 | Oct 2007 | Ouano (S3) | Predator (invertebrates and small fish) | Neritic |
| Kyphosidae | | | | | | | | |
| <i>Kyphosus vaigiensis</i> | Brassy chub | 5 | 317 \pm 50 (260 – 370) | 718 \pm 330 (380 - 1100) | Mar 2007 | Ouano (S3) | Grazer / Scavenger | Neritic |
| Labridae | | | | | | | | |
| <i>Bodianus perditio</i> | Golden-spot hogfish | 1 | 343 | 800 | Mar 2007 | Grande Rade | Predator (invertebrates) | Neritic |
| <i>Cheilinus chlorourus</i> | Floral wrasse | 1 | 290 | 450 | Mar 2007 | Koutio | Predator (invertebrates) | Neritic |
| Lethrinidae | | | | | | | | |
| <i>Lethrinus laticaudis</i> | Grass emperor | 3 | 266 \pm 11 (256 – 277) | 376 \pm 45 (331 – 420) | Mar 2007 | Southern Lagoon | Predator (crustaceans and small fish) | Neritic |
| <i>Monotaxis grandoculis</i> | Humpnose big-eye bream | 2 | 261 \pm 7 (256 – 266) | 420 \pm 21 (405 – 434) | Mar 2007 | Southern Lagoon | Predator (invertebrates) | Neritic |
| Lutjanidae | | | | | | | | |
| <i>Lutjanus argentimaculatus</i> | Mangrove red snapper | 5 | 449 \pm 63 (348 – 510) | 1345 \pm 494 (625 – 1900) | Mar 2007 | Grande Rade, Ouano (S3), Maa | Predator (crustaceans and small fish) | Neritic |
| <i>L. monostigma</i> | Onespot snapper | 2 | 249 \pm 37 (223 – 275) | 475 \pm 177 (350 – 600) | Mar 2007 | Ouano (S3), Maa | Predator (crustaceans and small fish) | Neritic |
| Platycephalidae | | | | | | | | |
| <i>Cymbacephalus beauforti</i> | Crocodile fish | 2 | 510 \pm 99 (440 – 580) | 1425 \pm 530 (1050 – 1800) | Oct 2007 | Southern Lagoon | Predator (small fish) | Benthic |
| Priacanthidae | | | | | | | | |
| <i>Priacanthus hamrur</i> | Moontail bullseye | 7 | 307 \pm 21 (285 – 340) | 454 \pm 96 (360 – 600) | Mar 2007 | Ouano (S3) | Predator (invertebrates and small fish) | Neritic |
| Scaridae | | | | | | | | |
| <i>Scarus ghobban</i> | Blue-barred parrotfish | 1 | 247 | 245 | Mar 2007 | Koutio | Grazer / Scavenger | Neritic |
| <i>S. microrhinos</i> | Blunt-head parrotfish | 1 | 508 | 3000 | Mar 2007 | Ouano (S3) | Grazer / Scavenger | Neritic |
| <i>S. rivulatus</i> | Rivulated parrotfish | 1 | 355 | 900 | Mar 2007 | Ouano (S3) | Grazer / Scavenger | Neritic |
| <i>S. schlegeli</i> | Yellowband parrotfish | 1 | 249 | 400 | Mar 2007 | Ouano (S3) | Grazer / Scavenger | Neritic |
| Serranidae | | | | | | | | |
| <i>Plectropomus leopardus</i> | Leopard coralgroupier | 21 | 413 \pm 110 (265 – 615) | 1294 \pm 1051 (300 – 3800) | Mar 2007 Oct 2007 | Grande Rade, Koutio, Ouano (S3), Maa, Sainte Marie Grande Rade, Ouano (S3), Southern Lagoon | Predator (small fish) | Neritic |
| <i>Epinephelus coeruleopunctatus</i> | Whitespotted grouper | 1 | 470 | 1500 | Oct 2007 | Southern Lagoon | Predator (crustaceans and small fish) | Neritic |
| <i>E. maculatus</i> | Highfin grouper | 1 | 340 | 480 | Mar 2007 | Ouano (S3) | Predator (invertebrates and small fish) | Neritic |
| Sparidae | | | | | | | | |
| <i>Acanthopagrus berda</i> | Picnic seabream | 1 | 278 | 600 | Mar 2007 | Ouano (S2) | Predator (invertebrates and small fish) | Neritic |
| | | 1 | 271 | 500 | Oct 2007 | Maa | | |

Table 2
Latitude and longitude coordinates of the sampling stations in the New Caledonia Lagoon

| Sampling site | Geographical coordinates | |
|----------------------|---------------------------------|------------------|
| | Latitude | Longitude |
| Northern Lagoon | 19°57 S | 163°58 E |
| Bassin La Foa | 21°45 S | 165°43 E |
| Ouano Bay S1 | 21°51 S | 165°50 E |
| Ouano Bay S2 | 21°49 S | 165°46 E |
| Ouano Bay S3 | 21°52 S | 165°49 E |
| Tomo | 21°57 S | 166°04 E |
| Maa Bay | 22°12 S | 166°19 E |
| Dumbea Bay | 22°12 S | 166°24 E |
| Koutio Bay | 22°13 S | 166°25 E |
| Grande Rade | 22°16 S | 166°25 E |
| Grande Rade-SLN | 22°15 S | 166° 26 E |
| Noumea harbour | 22°17 S | 166°25 E |
| Sainte Marie Bay | 22°18 S | 166°28 E |
| Unia | 21°55 S | 166°38 E |
| Southern Lagoon | 22°25 S | 166°53 E |

Table 3

Total Hg concentrations (T-Hg; mean \pm SD, ng g⁻¹ dry wt) in the edible tissues of the species collected, correlations with individual size and weight, and estimate of the “Maximum Safe Weekly Consumption” (MSWC) for total Hg (T-Hg) and methyl-Hg (Me-Hg) (kg of flesh wet wt)

| Species | Tissue | n | T-Hg concentration (ng g ⁻¹ dry wt) | | MSCW (kg) | |
|--------------------------------------|-------------------------------|----|---|------------|-----------|-------|
| | | | Mean \pm SD | (Range) | T-Hg | Me-Hg |
| Crustaceans | | | | | | |
| <i>Litopenaeus stylirostris</i> | muscle | 5 | 201 \pm 62 | 128 – 297 | 7.5 | 3.2 |
| Cephalopods | | | | | | |
| <i>Sepioteuthis lessoniana</i> | muscle | 9 | 150 \pm 36 | 113 – 218 | 10 | 4 |
| <i>Octopus cyanea</i> | muscle | 7 | 90 \pm 23 | 69 – 139 | 16.7 | 6.7 |
| <i>Sepia latimanus</i> | muscle | 1 | 41 | - | 36.7 | 14.7 |
| Bivalves | | | | | | |
| <i>Comptopallium radula</i> | muscle + gonad | 24 | 62 \pm 20 | 30 – 108 | 24.3 | - |
| <i>C. radula</i> | whole soft parts ^a | 24 | 150 \pm 53 | 84 – 261 | 10 | - |
| <i>Mimachlamys gloriosa</i> | muscle + gonad | 10 | 70 \pm 12 | 55 – 91 | 21.5 | - |
| <i>M. gloriosa</i> | whole soft parts ^a | 10 | 107 \pm 18 | 90 – 142 | 14 | - |
| <i>Anadara scapha</i> | whole soft parts | 28 | 297 \pm 226 | 73 – 1015 | 5.1 | - |
| <i>Crassostrea gigas</i> | whole soft parts | 5 | 111 \pm 15 | 92 – 105 | 13.5 | - |
| <i>Gafrarium tumidum</i> | whole soft parts | 89 | 418 \pm 466 | 104 – 2531 | 3.6 | - |
| <i>Periglypta chemnitzii</i> | whole soft parts | 10 | 407 \pm 222 | 244 – 890 | 3.7 | - |
| Fish | | | | | | |
| <i>Naso unicornis</i> | muscle | 1 | 32 | - | 38 | 12.1 |
| <i>Plectorhinchus albobittatus</i> | muscle | 1 | 650 | - | 1.8 | 0.59 |
| <i>P. chaetodonoides</i> | muscle | 1 | 1200 | - | 1 | 0.32 |
| <i>P. flavomaculatus</i> | muscle | 1 | 1173 | - | 1 | 0.33 |
| <i>Diagramma pictum</i> | muscle | 1 | 329 | - | 3.6 | 1.2 |
| <i>Kyphosus vaigiensis</i> | muscle | 5 | 55 \pm 22 | 36 – 92 | 22 | 7 |
| <i>Bodianus perditio</i> | muscle | 1 | 1020 | - | 1.2 | 0.38 |
| <i>Cheilinus chlorourus</i> | muscle | 1 | 362 | - | 3.3 | 1.1 |
| <i>Lethrinus laticaudis</i> | muscle | 3 | 165 \pm 55 | 125 – 228 | 7.3 | 2.3 |
| <i>Monotaxis grandoculis</i> | muscle | 2 | 99 \pm 18 | 87 – 112 | 12.1 | 3.9 |
| <i>Lutjanus argentimaculatus</i> | muscle | 5 | 430 \pm 325 | 403 – 994 | 2.8 | 0.89 |
| <i>L. monostigma</i> | muscle | 2 | 51 \pm 23 | 35 – 67 | 23.6 | 7.5 |
| <i>Cymbacephalus beauforti</i> | muscle | 2 | 1022 \pm 62 | 979 – 1066 | 1.2 | 0.38 |
| <i>Priacanthus hamrur</i> | muscle | 7 | 188 \pm 58 | 113 – 258 | 6.4 | 2 |
| <i>Scarus ghobban</i> | muscle | 1 | 53 | - | 22.7 | 7.3 |
| <i>S. microrhinos</i> | muscle | 1 | 30 | - | 39.5 | 12.6 |
| <i>S. rivulatus</i> | muscle | 1 | 26 | - | 46.1 | 14.8 |
| <i>S. schlegeli</i> | muscle | 1 | 37 | - | 32.2 | 10.3 |
| <i>Plectropomus leopardus</i> | muscle | 21 | 738 \pm 576 | 173 – 2063 | 1.6 | 0.52 |
| <i>Epinephelus coeruleopunctatus</i> | muscle | 1 | 439 | - | 2.7 | 0.87 |
| <i>E. maculatus</i> | muscle | 1 | 389 | - | 3.1 | 0.99 |
| <i>Acanthopagrus berda</i> | muscle | 2 | 368 \pm 168 | 249 – 486 | 3.2 | 1 |

^a reconstructed data

Table 4

Comparison of total Hg concentrations (T-Hg; mean \pm SD, ng g⁻¹ dry wt) in the whole soft parts of the bivalves *Comptopallium radula*, *Anadara scapha* and *Gafrarium tumidum* and in the muscle of the fish *Plectropomus leopardus* collected from different sites in New Caledonia. MSWC is the estimate of the “Maximum Safe Weekly Consumption” for total Hg (T-Hg) and methyl-Hg (Me-Hg) (kg of flesh wet wt) from each site

| Species | Site | n | T-Hg concentration (ng g ⁻¹ dry wt) | | Group | | | | MSCW (kg) | |
|------------------------------------|------------------|----|---|------------|---|---|---|---|-----------|-------|
| | | | Mean \pm SD | Range | 1 | 2 | 3 | 4 | T-Hg | Me-Hg |
| Bivalves (whole soft parts) | | | | | | | | | | |
| <i>Anadara scapha</i> | | | | | | | | | | |
| | | | | | One-way ANOVA and Tukey test ^a | | | | | |
| | Ouano Bay S2 | 5 | 103 \pm 39 | 73 – 169 | | | | | 14.6 | - |
| | Ouano Bay S1 | 3 | 146 \pm 20 | 130 – 169 | | | | | 10.3 | - |
| | Koutio Bay | 5 | 230 \pm 111 | 129 – 354 | | | | | 6.5 | - |
| | Maa Bay | 5 | 304 \pm 165 | 164 – 588 | | | | | 4.9 | - |
| | Sainte Marie Bay | 5 | 337 \pm 145 | 224 – 279 | | | | | 4.4 | - |
| | Grande Rade-SLN | 3 | 515 \pm 290 | 184 – 724 | | | | | 2.9 | - |
| | Grande Rade | 2 | 723 \pm 414 | 430 – 1015 | | | | | 2.1 | - |
| <i>Comptopallium radula</i> | | | | | | | | | | |
| | | | | | ANCOVA (cov.: length) and Tukey test ^a | | | | | |
| | Noumea harbour | 3 | 99 \pm 13 | 84 – 108 | | | | | 15.2 | - |
| | Maa Bay | 6 | 116 \pm 19 | 93 – 144 | | | | | 12.9 | - |
| | Sainte Marie Bay | 7 | 125 \pm 16 | 103 – 145 | | | | | 12.0 | - |
| | Koutio Bay | 4 | 199 \pm 29 | 173 – 231 | | | | | 7.6 | - |
| | Grande Rade | 4 | 234 \pm 24 | 203 – 261 | | | | | 6.4 | - |
| <i>Gafrarium tumidum</i> | | | | | | | | | | |
| | | | | | ANCOVA (cov.: weight) and Tukey test ^a | | | | | |
| | Unia | 10 | 154 \pm 38 | 111 – 224 | | | | | 9.7 | - |
| | Ouano Bay S3 | 10 | 193 \pm 45 | 146 – 281 | | | | | 7.8 | - |
| | Ouano Bay S2 | 10 | 197 \pm 68 | 106 – 295 | | | | | 7.6 | - |
| | Grande Rade-SLN | 10 | 253 \pm 107 | 143 – 495 | | | | | 5.9 | - |
| | Koutio Bay | 10 | 299 \pm 143 | 104 – 614 | | | | | 5.0 | - |
| | Ouano Bay S1 | 10 | 310 \pm 98 | 198 – 492 | | | | | 4.8 | - |
| | Maa Bay | 10 | 344 \pm 194 | 113 – 741 | | | | | 4.4 | - |
| | Tomo | 10 | 497 \pm 124 | 291 – 658 | | | | | 3.0 | - |
| | Grande Rade | 9 | 1633 \pm 565 | 894 – 2531 | | | | | 0.92 | - |
| Fish (muscle) | | | | | | | | | | |
| <i>Plectropomus leopardus</i> | | | | | | | | | | |
| | | | | | ANCOVA (cov.: length) and Tukey test ^a | | | | | |
| | Koutio Bay | 4 | 336 \pm 49 | 286 – 380 | | | | | 3.6 | 1.1 |
| | Maa Bay | 4 | 353 \pm 82 | 245 – 445 | | | | | 3.4 | 1.1 |
| | Sainte Marie Bay | 3 | 629 \pm 280 | 436 – 950 | | | | | 1.9 | 0.61 |
| | Ouano Bay S3 | 4 | 856 \pm 330 | 591 – 1338 | | | | | 1.4 | 0.45 |
| | Grande Rade | 5 | 1451 \pm 697 | 449 – 2063 | | | | | 0.83 | 0.26 |

^a According to the results of ANOVA or ANCOVA followed by Tukey test, means which do not differ significantly within each species are joined by vertical bars (|)