Impact of toxic cyanobacteria on gastropods and microcystin accumulation in a eutrophic lake (Grand-Lieu, France) with special reference to Physa (= Physella) acuta

Emilie Lancé, Luc Briët, Alexandre Carpentier, Anthony Acou, Loïc Marion, Myriam Bormans, Claudia Gérard

⁎ Corresponding author. Tel.: +33 2 23 23 50 37; fax: +33 2 23 23 50 54.
Email addresses: emilie.lancé@live.fr (E. Lancé), luc.briet@univ-rennes1.fr (L. Briët), alexandre.carpentier@univ-rennes1.fr (A. Carpentier), anthony.acou@nmnh.fr (A. Acou), loic.marion@univ-rennes1.fr (L. Marion), myriam.bormans@univ-rennes1.fr (M. Bormans), claudia.gerard@univ-rennes1.fr (C. Gérard).

1. Introduction

Cyanobacterial microcystins (MCs) have been shown to accumulate with acute and subacute effects in various organisms of the freshwater food web (for reviews, see Wiegand and Pflugmacher, 2005; Malbrouk and Kestemont, 2006; Ibelings and Chorus, 2007). Gastropods, including Pulmonata and Prosobranchia, are generally common in fresh waters where they can comprise a substantial part of invertebrate biomass (Hadjija et al., 1995). As primary consumers, they constitute an important link between primary producers (e.g., potentially toxic cyanobacteria) and higher consumers (e.g., crayfish, fish, and waterfowl; Dillon, 2000). Gastropods may uptake MCs either via feeding on MC-producing cyanobacteria or particles to which MCs have been adsorbed or via absorption of MCs dissolved in the surrounding water. In the field, positive relationships between MC concentrations in phytoplankton and gastropods suggest that they are primarily intoxicated by the consumption of toxic cyanobacteria (Kotak et al., 1996; Zurawell et al., 1999; Ozawa et al., 2003; Chen et al., 2005). Nevertheless, in the prosobranch B. aeruginosa MC accumulation can be correlated with both intracellular and extracellular MCs (Zhang et al., 2007).

During laboratory investigations, the pulmonate L. stagnalis and the prosobranch P. antipodarum showed varying responses to intoxication pathways in terms of MC accumulation...
The consumption of toxic cyanobacteria was the major intoxication pathway for *L. stagnalis*, whereas both intracellular and extracellular MC exposures equally intoxicated *P. antipodarum*. In addition, according to field (Zurawell et al., 1999; Ozawa et al., 2003; Chen et al., 2005; Gkelis et al., 2006; Zhang et al., 2007; Gérard et al., 2009) and laboratory (Gérard et al., 2005; Lance et al., 2006, 2008) studies, MC accumulation is higher in pulmonates (compared to prosobranchs). Therefore, impact of cyanobacteria proliferations on natural populations of gastropods may probably vary depending on species due to differences in feeding habits, ecology, and physiology. Recently, the decline of a gastropod community was demonstrated over a 10-year study in a lake due to recurrent MC-producing cyanobacteria proliferations (Gérard et al., 2008). In other sites, significant changes in the structure of molluscan communities were related to the MC-producing cyanobacteria contamination level of the medium, and pulmonates (compared to prosobranchs and bivalves) were dominant in waters with high cyanobacteria densities (Gérard et al., 2009).

The aim of this field study was to investigate the impact of MC-producing cyanobacteria occurrence on the structure and composition of natural gastropod communities. The study site is the protected Grand-Lieu Lake, the oldest natural French plain lake and one of the European freshwater ecosystems harbouring high biodiversity (Marion and Brient, 1998, 2000). It became increasingly eutrophic in the 1960s and since the 1980s, the large beds of floating leafy plants have almost completely disappeared while turbidity dramatically increased due to yearly cyanobacterial blooms (Vézie et al., 1998; Paillisson and Marion, 2002). Three stations presenting different cyanobacteria proliferation intensities and thus MC contamination level were monthly investigated during one year. We expected both lower abundance and richness of gastropods concomitant to a higher MC tissue concentration at stations with the highest MC-producing cyanobacteria densities. Moreover, *L. stagnalis* and *P. antipodarum* were caged at the three stations in order to confirm their differences in MC accumulation demonstrated in laboratory experiments (Gérard et al., 2005; Lance et al., 2006, 2007, 2008), and to compare with the MC uptake of gastropods inhabiting the lake. Results are discussed in terms of the negative impact of toxic cyanobacteria on the composition of gastropod communities, gastropod survival, and MC accumulation based on species.

2. Material and methods

2.1. Study site

Grand-Lieu Lake is a shallow eutrophic natural floodplain system in western France (47°05′N, 1°39′W), covering 4000 ha during summer and expanding to 6300 ha during the winter when the lake floods the adjacent peaty marsh grasslands (Fig. 1). The permanent flooded area is mostly covered from April to October by extensive beds (1000 ha) of

![Fig. 1. The Grand-Lieu Lake and the three sampling stations: Malgogne, Sénaigerie, and Capitaine (adapted from Paillisson J.-M.).]
floating-leaved macrophytes; the water level fluctuates from 0.70 to 2.20 m (Marion and Brient, 1998; Paillisson and Marion, 2002). During summer, half of the lake is composed of peat fen and the water level falls by 0.40 m. Three shoreline stations varying in cyanobacteria densities and intracellular MC concentrations were chosen for both the natural field study and the caging experiment (Fig. 1): Malgogne, Sénaiagerie, and Capitaine. Cyanobacteria have rarely occurred at Malgogne during the last 10 years, whereas the water at both Sénaiagerie and Capitaine was contaminated by recurrent toxic blooms with respective cell densities ≤250,000 and 1,000,000 cells mL⁻¹ and intracellular MCs ≤2.9 and 8 µg L⁻¹ (L. Brient, unpubl. data).

2.2. Water and phytoplankton samplings and analyses

Water and phytoplankton were sampled monthly from March 2006 to February 2007 (except in December 2006) and fortnightly in May, June, August, September and October 2006 (n = 16 per station). Samples were collected from the uppermost part of the water column with a 1 m integrated vertical tube. Cyanobacteria species were identified and counted (density in cells per mL⁻¹) in a 50 µL-Nageotte chamber (Brient et al., 2008). Frequency of occurrence (FO) was calculated as the percentage of samplings in which each cyanobacteria species was present. Concentrations of dissolved MCs in water and of intracellular MCs in cyanobacteria were determined using HPLC with diode array detection (HPLC-DAD) and a variable-wavelength UV detector operating at 238 nm as described in Lance et al. (2006). Briefly, before HPLC, cells harvested by filtration (nylon cloth, 2 µm pore size) were suspended in 0.5 mL of 85% methanol and centrifuged at 7000 g for 7 min. A total of 20 µl of supernatant was injected into the HPLC. The separation was performed on a microsphere C18 reverse-phase column (3 µm) under isocratic conditions with a mobile phase HPLC. The separation was performed on a microsphere C18 reverse-phase column (3 µm) under isocratic conditions with a mobile phase HPLC. The nearest 0.01 µg L⁻¹ (Gilroy et al., 2000). MCs were extracted with 2 mL of 100% methanol, as described in Lance et al. (2006), and MC contents in gastropods were expressed in MC-LReq ug dry weight⁻¹ (DW).

2.3. Gastropod samplings and analyses

Gastropods were sampled monthly from March 2006 to February 2007 (except in December at each station by using a pond-net (nylon mesh: 1 mm, square aperture: 0.5 × 0.5 m). The water column was swept during 3 min in a littoral area of 10 m in length by 2 m in width, and with a maximum depth of 2 m. All collected gastropods were identified (Glöer and Meier-Brook, 1994) and measured (height for conic shells, diameter for discoid shells) using the Pegase Pro Software (precision: 0.1 mm). The descriptors used to characterize the gastropod species occurring at all three stations) and caged gastropods. When necessary, multiple pairwise comparisons were made using the Post-hoc Bonferroni test. Analyses were performed using STATISTICA 5.5. Differences were regarded as significant when P ≤0.05. Percentages are reported as mean ± standard error (SE).

3. Results

3.1. Cyanobacteria occurrence, abundance and MC concentrations

3.1.1. Inter-station variations in cyanobacteria occurrence and abundance

During the one-year study, cyanobacteria represented 48.20 ± 8.31% and 71.08 ± 4.90% and 75.22 ± 5.11% of the phytoplankton density at Malgogne, Sénaiagerie and Capitaine, respectively. The other species of phytoplankton were primarily chlorophytes and diatoms. Cyanobacteria were recorded in each of the 16 samples per station except in May (two samples) and February at Malgogne. The ANOVA results (FStudent = 7.44, pairwise Bonferroni comparison, P <0.05) indicated that both the mean and maximum cyanobacteria densities were lower at Malgogne (71,288 ± 26,343 with a maximum of 318,000 cells mL⁻¹) than at Sénaiagerie (218,649 ± 47,684 with a
maximum of 616,000 cells mL$^{-1}$) and Capitaine (489,593 ± 171,762 with a maximum of 2,236,901 cells mL$^{-1}$).

Among the 21 cyanobacteria species recorded, seven species were potentially producing MCs: Anabaena flos-aquae, Anabaena spiroides, Microcystis aeruginosa, Microcystis wesenbergii, Oscillatoria sp., and Plankthotrix agardhii (Table 1). The species with the highest frequency of occurrence was P. agardhii (FO = 58.33 ± 7.12%), followed by A. spiroides (50.00 ± 7.22%), and Aphanocapsa sp. (picoplankton) (7.12%), followed by Microcystis wesenbergii (3350 ± 3350, 6.25 ± 0.65), Merismopedia sp. (3048 ± 2127, 25.00 ± 10.83), and Aphanizomenon gracile (1885 ± 1368, 25.00 ± 10.83). A total of 2592 gastropods belonging to 23 species were sampled at Malgogne (five species) compared to 100% at Sénagerie (seven species) and Capitaine (six species) respectively, with a mean density of 18,492 ± 11,951, 5600 ± 1691, and 75,000 ± 10,831, respectively; Fig. 2.

Species potentially producing MCs were detected in 43.75 ± 12.40% of the samplings at Malgogne (seven species) and Capitaine (six species) compared to 20% at Sénagerie (seven species) and Capitaine (six species). Among them, P. agardhii had lower densities at Malgogne than at Sénagerie and Capitaine (ANOVA, F$_{2,45}$ = 9.71, pairwise Bonferroni comparison, P < 0.05), whereas the contrary was observed for A. spiroides (ANOVA, F$_{2,45}$ = 3.85, pairwise Bonferroni comparison, P > 0.05).

3.1.2. Extra- and intracellular MC concentrations

Extracellular dissolved MCs were not detected at Malgogne and were only detected in May and August at Sénagerie (4.20 ± 0.90 and 2.00 ± 0.06 µg L$^{-1}$, respectively), and in May, August and November at Capitaine (4.20 ± 0.14, 2.10 ± 0.10 and 5.60 ± 0.29 µg L$^{-1}$, respectively). Intracellular MCs were detected in 18.75 ± 9.76, 62.50 ± 12.10 and 50.00 ± 12.50% of phytoplankton samples at Malgogne, Sénagerie, and Capitaine, respectively, with mean concentrations of 0.16 ± 0.08, 0.71 ± 0.23 and 1.00 ± 0.66 µg L$^{-1}$ during the year (Fig. 2). At Malgogne, the intracellular MC maxima occurred in July (1.28 µg L$^{-1}$). MC concentrations increased with increasing abundance of potentially MC-producing cyanobacteria (R$^2$ = 0.97, n = 16, P < 0.001). In contrast, intracellular MC maxima occurred in November at both Sénagerie (2.95 µg L$^{-1}$) and Capitaine (7.16 µg L$^{-1}$). P. agardhii represented 97.11% of the potentially MC-producing species at the two stations, respectively. However, no significant relationship between intracellular MC concentrations and abundance of potentially MC-producing cyanobacteria was observed at either Sénagerie or Capitaine (P > 0.05).

3.2. Structure of the gastropod community, spatial and temporal fluctuations

A total of 2592 gastropods belonging to 23 species were sampled over a one-year period (Table 2). Pulmonates occurred at higher frequencies (84.85 ± 6.24%), and were more abundant (82.56 ± 0.73%) and diverse (16 species among Ancylidae, Lymnaeidae, Physidae, and Planorbidae) than prosobranchs (34.55 ± 8.67%, 17.44 ± 0.75%; seven species among Bithyniidae, Hydrobiidae, Valvatidae, and Viviparidae). The Planorbidae family was the best represented (39.16 ± 0.96% of the total gastropod abundance, 10 species), followed by Physidae, which was only represented by Physa acuta (27.51 ± 0.88%). P. acuta was both the most abundant and frequently occurring species (84.85 ± 6.24%), as well as the only one recorded at all three stations. Three other species were both abundant (> 10%) and occurred at higher frequencies (> 20%): Planorbus planorbis, Radix ovata and Valvata cristata, in decreasing order, and were present at Malgogne and Sénagerie (Table 2).
Table 2

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>Malgogne</th>
<th>Sénagère</th>
<th>Capitaine</th>
<th>All sampling stations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>F (%)</td>
<td>FO (%)</td>
<td>A</td>
<td>F (%)</td>
</tr>
<tr>
<td>Bithyniidae</td>
<td>Bithynia leachi</td>
<td>12</td>
<td>2.05 ± 0.35</td>
<td>27.27 ± 13.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bithynia tentaculata</td>
<td>24</td>
<td>0.31 ± 0.14</td>
<td>36.36 ± 14.50</td>
<td></td>
</tr>
<tr>
<td>Hydrobiidae</td>
<td>Marstoniopsis scholzii</td>
<td>20</td>
<td>1.24 ± 0.28</td>
<td>18.18 ± 11.63</td>
<td></td>
</tr>
<tr>
<td>Valvatidae</td>
<td>Valvata cristata</td>
<td>192</td>
<td>11.93 ± 0.81</td>
<td>72.73 ± 13.43</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td>Valvata piscinalis</td>
<td>62</td>
<td>3.85 ± 0.48</td>
<td>63.64 ± 14.50</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Valvata pulchella</td>
<td>32</td>
<td>1.99 ± 0.35</td>
<td>54.55 ± 15.01</td>
<td></td>
</tr>
<tr>
<td>Viviparidae</td>
<td>Viviparus viviparus</td>
<td>2</td>
<td>0.22 ± 0.15</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td>Ancylidae</td>
<td>Ancylus fluviatilis</td>
<td>33</td>
<td>2.05 ± 0.35</td>
<td>27.27 ± 13.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ferrisia waustleri</td>
<td>40</td>
<td>2.49 ± 0.30</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td>Lymnaeidae</td>
<td>Lymnaea stagnalis</td>
<td>23</td>
<td>0.44 ± 0.16</td>
<td>27.27 ± 13.43</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Lymnaea stagnalis</td>
<td>95</td>
<td>5.90 ± 0.59</td>
<td>36.36 ± 14.50</td>
<td>234</td>
</tr>
<tr>
<td></td>
<td>Radix ovata</td>
<td>2</td>
<td>0.12 ± 0.09</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td>Planorbidae</td>
<td>Planorbarius corneus</td>
<td>1</td>
<td>0.06 ± 0.06</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>16</td>
<td>0.99 ± 0.25</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>58</td>
<td>3.60 ± 0.46</td>
<td>36.36 ± 14.50</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>11</td>
<td>0.68 ± 0.21</td>
<td>27.27 ± 13.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>122</td>
<td>7.58 ± 0.66</td>
<td>54.55 ± 15.01</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>65</td>
<td>4.04 ± 0.49</td>
<td>63.64 ± 14.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>4</td>
<td>0.25 ± 0.12</td>
<td>18.18 ± 11.63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>39</td>
<td>2.42 ± 0.38</td>
<td>45.45 ± 15.01</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Planorbarius corneus</td>
<td>1</td>
<td>0.06 ± 0.06</td>
<td>9.09 ± 8.67</td>
<td></td>
</tr>
<tr>
<td>Prosobranchia</td>
<td>Physa acuta</td>
<td>367</td>
<td>22.81 ± 1.05</td>
<td>100.00 ± 0.00</td>
<td>284</td>
</tr>
<tr>
<td>Prosobranchia</td>
<td>Physa acuta</td>
<td>1809</td>
<td>100.00 ± 0.00</td>
<td>100.00 ± 0.00</td>
<td>921</td>
</tr>
<tr>
<td>Prosobranchia</td>
<td>Physa acuta</td>
<td>344</td>
<td>21.38 ± 1.02</td>
<td>91.91 ± 8.67</td>
<td>108</td>
</tr>
<tr>
<td>Prosobranchia</td>
<td>Physa acuta</td>
<td>1265</td>
<td>78.62 ± 1.02</td>
<td>100.00 ± 0.00</td>
<td>813</td>
</tr>
</tbody>
</table>
Species richness and abundance of gastropods differed significantly between the three stations during the year (ANOVA, respectively $F_{2,30} = 21.03$ and $8.11, P < 0.05$), and were higher at Malgogne than at Sénaigerie and Capitaine (Tukey's HSD, $P = 0.05$). The mean values were: $9 \pm 2$ species and $268 \pm 64$ individuals at Malgogne, $3 \pm 1$ species and $153 \pm 52$ individuals at Sénaigerie, and $1 \pm 0$ species and $10 \pm 2$ individuals at Capitaine. Over the year, $62.08 \pm 0.95\%$ of the gastropods were sampled at Malgogne ($22$ species), $35.53 \pm 0.94\%$ at Sénaigerie ($11$ species), and $2.39 \pm 0.30\%$ at Capitaine (one species; Table 2). Furthermore, the frequency of occurrence for gastropods was higher at Malgogne ($100\%$ of occurrence) than at either Sénaigerie ($81.82 \pm 11.63\%$) or Capitaine ($72.73 \pm 13.43\%$; Table 2). When considering each taxa, similar patterns of inter-station variations were observed for prosobranchs (ANOVA, $F_{2,30} = 21.62$ and $14.47, P < 0.05$) and pulmonates (ANOVA, $F_{2,30} = 18.00$ and $5.90, P < 0.05$). Indeed, regardless of the station, pulmonates were always more diverse and abundant than prosobranchs, and also occurred at higher frequencies (Table 2).

Temporal fluctuations in species richness and abundance showed a peak in June: $16$ species and $715$ individuals at Malgogne, nine species and $586$ individuals at Sénaigerie compared to one species and $14$ individuals at Capitaine. This corresponds to the breeding period for most gastropods (Russel-Hunter, 1978; Calow, 1978; Dillon, 2000).

Concerning $P. acuta$, two peaks of abundance were observed, irrespective of the station, corresponding to the main breeding period in June (with a concomitant decrease in mean shell size) and a minor one in autumn (October–November; Fig. 3a and b) (Gonzales-Solis and Ruiz, 1996; Gérard, 2001). $P. acuta$ abundance decreased with the increasing intracellular MC concentration across the three sites ($R^2 = 0.81, n = 12, P < 0.05$). A total of $367, 284$ and $62$ individuals were collected at Malgogne, Sénaigerie and Capitaine, respectively, with a mean of $33 \pm 17, 26 \pm 13$ and $5 \pm 2$ snails per monthly sample (Table 2, Fig. 3a).

3.3. MC tissue concentration in gastropods

Gastropod MC tissue concentration ranged from $0$ to $4.32 \mu g$ g$^{-1}$ (maximum in $P. acuta$ at Sénaigerie in November) and varied according to the stations and gastropod species (Fig. 4). Mean MC tissue concentration was significantly lower at Malgogne ($0.01 \pm 0.00 \mu g$ g$^{-1}$) than at Sénaigerie ($0.01 \pm 0.06 \mu g$ g$^{-1}$) and Capitaine ($0.02 \pm 0.03 \mu g$ g$^{-1}$) (ANOVA, $F_{2,112} = 37.03$, pairwise Bonferroni comparison, $P < 0.001$). At Malgogne, MCS were detected in $43.1 \pm 1.89\%$ of tissue samples and only in three species ($V. cristata, Valvata pulchella$, and $P. acuta$) among the $20$ analysed (Fig. 4). At Sénaigerie, MCS were detected in all species (nine) corresponding to $94.12 \pm 3.29\%$ of the MC-analyses. These species were also present at Malgogne, i.e., two MC-intoxicated species ($V. cristata$ and $P. acuta$) and seven species that were MC-negative (Fig. 4). At Capitaine, $100\%$ of the tissue samples were MC-positive, corresponding to the single species recorded, $P. acuta$ (Fig. 4).

Concerning $P. acuta$, the same patterns of inter-station variation were observed for both the frequency of MC occurrence in tissues and the MC concentration. MCS occurred in tissues for $20.51 \pm 6.47, 96.30 \pm 3.63$ and $100.00 \pm 0.00\%$ of the analyses at Malgogne, Sénaigerie and Capitaine, respectively (i.e. $84$ total analyses: $39$ at Malgogne, $27$ at Sénaigerie, and $18$ at Capitaine). In terms of MC concentration, these numbers were significantly lower at Malgogne ($0.04 \pm 0.01 \mu g$ g$^{-1}$) than at Sénaigerie ($1.26 \pm 0.24 \mu g$ g$^{-1}$) and Capitaine ($0.95 \pm 0.25 \mu g$ g$^{-1}$) (ANOVA, $F_{2,24} = 7.36$, pairwise Bonferroni comparison, $P < 0.05$). Temporal fluctuations in mean MC tissue concentration (Fig. 3c) showed a maximum in August at Malgogne ($0.29 \pm 0.04 \mu g$ g$^{-1}$) and in November at both Sénaigerie ($3.92 \pm 0.39 \mu g$ g$^{-1}$) and Capitaine ($2.95 \pm 0.23 \mu g$ g$^{-1}$), after which $P. acuta$ was not recorded again at either of these two stations (Fig. 3a).

3.4. MC tissue concentration in caged $P. antipodarum$ and $L. stagnalis$

Due to snail deaths in September, the caging experiment lasted only four months (May–August 2006) at each station. Among the $48$ analyses performed by species, $P. antipodarum$ and $L. stagnalis$ were MC-positive for six and $34$ analyses, respectively. MCS were only detected in caged $P. antipodarum$ at Sénaigerie in July ($0.02 \pm 0.00 \mu g$ g$^{-1}$) and August ($0.01 \pm 0.00 \mu g$ g$^{-1}$). In contrast, MCS were found in $L. stagnalis$ caged in all three stations ($12.5\%$ of analyses for Malgogne compared to $100\%$ for Sénaigerie and
Capitaine) with a mean value significantly lower at Malgogne (0.02 ± 0.00 µg g DW⁻¹) than at Sénaièrge and Capitaine (0.26 ± 0.05 and 0.19 ± 0.03 µg g DW⁻¹, respectively; Fig. 5) (ANOVA, F₄.₅₇ = 21.23, pairwise Bonferroni comparison, P < 0.05). During the caging experiment, the mean concentration of intracellular MCs in cyanobacteria was 0.21 ± 0.18 (Malgogne), 0.44 ± 0.20 (Sénaièrge), and 0.48 ± 0.27 (Capitaine) µg L⁻¹ and extracellular dissolved MCs were detected only in May and August at Sénaièrge and Capitaine (Fig. 2). For comparison, among the four MC-analyses carried out on L. stagnalis sampled in the field, MCs were detected only in the June sample at Sénaièrge with a concentration of 0.32 µg g DW⁻¹ (vs. 0.11 µg g DW⁻¹ in caged L. stagnalis).

4. Discussion

Our one-year field investigation at Grand-Lieu Lake demonstrates that both abundance and MC tissue concentrations of gastropods vary greatly according to the occurrence of MC-producing cyanobacteria. Seven MC-producing cyanobacteria have been sampled: A. flos-aquae, A. spiroides, M. aeruginosa, M. flos-aquae, M. wesenbergii, Oscillatoria sp., and P. agardhii (Chorus and Bartram, 1999). MCs were always detected from April to November 2006 at the stations Sénaièrge and Capitaine, but only in July at Malgogne. Spatiotemporal variations in the cyanobacteria communities measured at stations located between 3 and 6 km apart from each other may be due to nutrient input. Indeed, Capitaine and Sénaièrge receive flows from agricultural landscapes and Malgogne from unexploited grasslands (Vézie et al., 2006, 2008). Such differences may be attributed to differences in i) proportion of detritus, diatoms, green algae, bacteria, and mineral particles; occurrence of a pedal ciliary feeding as for several species of Physa, Lymnaea and Planorbis (Russel-Hunter, 1978; Reavell, 1980), ii) degree of readaptation to aquatic life (e.g., in pulmonates development of neomorphic gill-lobes and cutaneous respiration; McMahan, 1983) and ii) MC metabolism abilities and life history strategies (e.g., energy trade-offs between detoxification and life history traits) as suggested by Lance et al. (2007).

Toxic cyanobacteria proliferations are therefore expected to indirectly influence competitive interactions by favouring the most resistant or tolerant gastropods, to the detriment of the most sensitive ones. Among the 23 gastropod species collected in the Grand-Lieu Lake (indicative of a high species richness in France (e.g., Costil, 1994; Marion and Brient, 1998). Moreover, MC concentrations may influence competitive interactions by favouring the most resistant or tolerant gastropods, to the detriment of the most sensitive ones (e.g., Capitaine and Sénaigerie receive different inputs from agricultural landscapes and Malgogne from unexploited grasslands (Vézie et al., 2006, 2008), as well as in the laboratory (Lance et al., 2006, 2008), MC tissue concentration tends to be lower in prosobranchs (from 0.05 to 10 µg g DW⁻¹) than in pulmonates (from 3.46 to 140 µg g DW⁻¹). In various organisms (i.e., plants, invertebrates, and vertebrates), accumulated MCs can be metabolized into less harmful compounds after conjugation with glutathione via glutathione-S-transferase, resulting in MC excretion or physiological degradation (Pflugmacher et al., 1998). Prosobranchs have probably less MC accumulation capacities approximating the tolerance limit over the range of ambient concentrations. MC metabolization capacities of gastropods would require further investigations.

Fig. 5. Mean microcystin (MC) tissue concentration (± SE; µg g DW⁻¹) in Lymnaea stagnalis caged from May to August 2006 at the three stations of the Grand-Lieu Lake (Malgogne in white, Sénaièrge in grey, and Capitaine in black). Significant differences between sampling times are indicated with an *.

Over the division between prosobranchs and pulmonates, MC accumulation as well as detrimental effects on gastropods also depends on species and on developmental stage [with a higher MC accumulation in juveniles compared to adults as previously demonstrated (Gérard and Poullain, 2005; Gérard et al., 2005; Lance et al., 2006, 2008)]. Such differences may be attributed to differences in uptake routes due to feeding habits and food composition (e.g., proportion of detritus, diatoms, green algae, bacteria, and mineral particles; occurrence of a pedal ciliary feeding as for several species of Physa, Lymnaea and Planorbis (Russel-Hunter, 1978; Reavell, 1980), ii) degree of readaptation to aquatic life (e.g., in pulmonates development of neomorphic gill-lobes and cutaneous respiration; McMahan, 1983) and ii) MC metabolism abilities and life history strategies (e.g., energy trade-offs between detoxification and life history traits) as suggested by Lance et al. (2007).
Based on these results, the gastropod species in the present study (up to 4.32 µg gDW$^{-1}$) and among gastropods and bivalves inhabiting different MC-contaminated hydrosystems according to Gérard et al. (2009) (up to 3.25 µg gDW$^{-1}$). On this basis, P. acuta seems less sensitive to MCs than other molluscs, at least over the range of ambient concentrations. Therefore, P. acuta deserves to be further investigated since i) it might represent a sentinel species, i.e., a biological monitor that accumulates other molluscs, at least over the range of ambient concentrations. Therefore, P. acuta deserves to be further investigated since i) it might represent a sentinel species, i.e., a biological monitor that accumulates }

References


Marion L, Brient L. Measures of a wetland's effect on water quality input–output studies of suspended particulate matter, nitrogen (N) and phosphorus (P) in the main plain lake, Grand-Lieu. Hydrobiologia 1998;373/374:217–35.