A Comparison of Organochlorine Contaminant Levels
in the Zebra Mussel, *Dreissena polymorpha*,
versus its Unionid Attachment, *Elliptio complanata*,
in the Rideau River, Ontario

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Organochlorine contaminant levels were compared between the native unionid *Elliptio complanata* and the exotic zebra mussel, *Dreissena polymorpha*, at four sites along the Rideau River near Ottawa in 1995. Overall, the two taxa exhibited similar bioaccumulation patterns. PCB congeners, treated individually or as classes, showed strong positive and significant correlations between the two taxa. Additionally, the ratios DDD/ΣDDT, DDE/ΣDDT and DDT/ΣDDT were not significantly different between the two taxa. Mean concentrations of ΣPCB, ΣDDT, and Σchlordane were 65.8, 14.0, 1.2 and 227.9, 10.6, 1.8 ng/g soft tissue dry weight in *E. complanata* and *D. polymorpha*, respectively. These three organochlorine groupings accounted for 98.2 and 98.7% of the organochlorine soft tissue dry weight burden in *E. complanata* and *D. polymorpha*, respectively. However, while the bioaccumulation patterns were similar in *E. complanata* and *D. polymorpha*, the ΣPCB concentration was significantly higher in *D. polymorpha*. The organochlorine dry weight burden was 2.0 to 5.6 times greater in *D. polymorpha* compared to that in *E. complanata* and this was mostly attributable to differences in ΣPCB. This difference may be explained in part by the relative lipid content in *D. polymorpha* being 1.8 times greater on average than in *E. complanata*. We conclude that *D. polymorpha* is a good alternative freshwater biomonitor for *E. complanata*.

Key words: organochlorine pesticides, PCBs, zebra mussel, unionid, Rideau River

Introduction

In North America, native unionid mussels have long been used as biomonitors of organochlorine contaminants in the freshwater environment (Bedford et al. 1968; Curry 1977–78; Kauss et al. 1983; Kauss and Hamdy 1985; Pugsley et al. 1985; Koenig and Metcalfe 1990; Renaud et al. 1995). The exotic Eurasian zebra mussel, *Dreissena polymorpha*, on the other hand, has only recently been used for this purpose in North America (Brieger and Hunter 1993; Comba et al. 1996b; Robertson and Lauenstein 1998; Willman et al. 1999; Metcalfe and Charlton 1990; Renaud et al. 1995). The exotic Eurasian zebra mussel, *Dreissena polymorpha*, on the other hand, has only recently been used for this purpose in North America (Brieger and Hunter 1993; Comba et al. 1996b; Robertson and Lauenstein 1998; Willman et al. 1999; Metcalfe and Charlton 1990; Renaud et al. 1995). However, while the bioaccumulation patterns were similar in *E. complanata* and *D. polymorpha*, the ΣPCB concentration was significantly higher in *D. polymorpha*. The organochlorine dry weight burden was 2.0 to 5.6 times greater in *D. polymorpha* compared to that in *E. complanata* and this was mostly attributable to differences in ΣPCB. This difference may be explained in part by the relative lipid content in *D. polymorpha* being 1.8 times greater on average than in *E. complanata*. We conclude that *D. polymorpha* is a good alternative freshwater biomonitor for *E. complanata*.
Materials and Methods

Sample Preparation

*D. polymorpha* (*n* = 203 specimens) and Eastern elliptio, *E. complanata* (*n* = 35 specimens) were collected by hand using SCUBA from four sites along the Rideau River in the fall of 1995 (Fig. 1, Table 1). *D. polymorpha* was almost entirely taken from *E. complanata* to which they were attached. In those few cases (9 specimens out of 203) where they were taken from other substrates (a twig and a rock), they were nevertheless closely associated with the sediments. Specimens of either mollusc species were chosen at random into two replicates per site (Table 1). The shell lengths of both bivalve species were measured to the nearest 0.1 mm. A non-*D. polymorpha*-infested control sample of *E. complanata* was also collected in the fall of 2002 in the Rideau River at Edmonds Lock (Fig. 1). The live *D. polymorpha* and *E. complanata* specimens were shucked open with a scalpel, drained of any excess water, blotted and their soft tissues removed. These were then placed in aluminum foil, previously rinsed with acetone, prior to freezing. The frozen mollusc tissue samples were weighed to four significant figures, freeze-dried and then re-weighed. The difference between frozen weight and freeze-dried weight was used to calculate percent moisture in tissues. The freeze-dried mollusc tissues were mixed with 10 g of previously fired sodium sulfate at 500°C for 12 h and extracted for 6 h using Soxhlet and 350 mL of dichloromethane (DCM). Final extracts were dried through 30 g of sodium sulfate previously fired at 500°C for 12 h, and concentrated to 2 mL.

The concentrated extracts were eluted through 2.5-cm internal diameter x 40 cm columns of (200–400 mesh) SX-3 Bio-Beads7 with 1:1 (v/v) DCM/hexane. The first 100-mL fraction contained lipid and was evaporated to constant weight to determine the percent lipid in dried tissue. The second 100-mL fraction was concentrated to 2 mL (in hexane) and fractionated using 8 g of fully activated silica gel (heated at 350°C for 8 h). The 60-mL hexane fraction contained aldrin, o,p'-DDE, p,p'-DDE (85%), heptachlor (80%), hexachlorobenzene, pentachlorobenzene, mirex and PCBs. The 50-mL 1:1 (v/v) DCM/hexane fraction contained chlordane, DDDs, p,p'-DDE (15%), DDTs, dieldrin, endrin, endosulfans, heptachlor (20%) and heptachlor epoxide. The fractions eluted from the silica gel column were quantitatively concentrated to 1 mL and analyzed using a Hewlett-Packard (HP) 5890 gas chromatograph, equipped with dual electron-capture detectors. Two 30-m high performance fused silica cap-
illary columns; one coated with dimethylpolysiloxane gum—100% methyl (HP-1), and the other with diphenyldimethylsilicone fluid—5% diphenyl (HP-5) were used (Comba et al. 1996a). Initial column temperatures were 65°C for 2 min, temperature-programmed to 90°C at 10°/min, and temperature-programmed to 280°C at 2.5°/min. The carrier gas was hydrogen at a head pressure of 60 kPa. Injector and detector temperatures were 250 and 350°C, respectively. The carrier gas had electronic flow pressure control.

Twenty-one organochlorine pesticides and 128 PCB congeners grouped in 98 congener-congener combinations were assayed. The procedure of Mullin (1985) was used to identify PCB congeners. Method performance was described by Swackhamer (1988) as determined by the separation of congener pairs 16–32, 28–31, 66–95, 105–153, 118–149 and 199-mirex on one or both columns. The National Water Research Institute, Neashore-Offshore Interactions Project PCB standard (NOIPCB) was used to quantify individual congeners. The standard is a mixture of Aroclors® 1016, 1221, 1242, 1254 and 1262 (Supelco 4-8701, 4-8705, 4-8706, 4-8707, 4-4810) reconstituted in hexane at a ratio of 1:1:1:1:1. The NOIPCB standard was prepared at a concentration of 2972 ng/mL. For each chromatographic capillary column, the elution order and concentration of each PCB congener in the NOIPCB standard were determined using relative response factors and retention indices for pure individual PCB congener standards. All 209 PCB congeners were purchased as certified analytical standards from AccuStandard Inc. New Haven, Conn., U.S.A. Physical, spectral and chromatographic properties of each congener were described by Bolgar et al. (1995).

Method recovery and performance was monitored using internal surrogates of 1,3-dibromobenzene (1,3-DB) and octachloronaphthalene (OCN). Recoveries of 1,3-DB were 39 to 69% with mean 48.9 and SD 11.0 for *E. complanata* samples and 21 to 90% with mean 56.1 and SD 27.9 for *D. polymorpha* samples. Recoveries of OCN were 59 to 96% with mean 73.9 and SD 13.8 for *E. complanata* samples and 65 to 135% with mean 90.6 and SD 30.5 for *D. polymorpha* samples. While the recoveries were substantially better for OCN than 1,3-DB, and both standards had better recoveries with *D. polymorpha* than with *E. complanata*, all results were within acceptable limits. Two organochlorine pesticide method standards and three method blanks were analyzed. No detectable amounts of organochlorine pesticides were found in method blanks and the average recovery of organochlorine pesticides was 89 ± 9.5%. Two PCB method standards and three method blanks were analyzed. Reagent blanks were found to be highly satisfactory and the average recovery of PCB was 107 ± 4.8%. Recovery of individual PCB congeners was well within the uncertainty of the method. No corrections were made for recovery efficiencies.

Method detection limits were based on a 95% confidence interval for spiked replicates. Typically, values lower than 10 times noise were not reported. For statistical purposes, values below the detection limit were treated as zeros.

### Data Presentation and Statistical Analyses

Organochlorine residue concentrations are presented on a dry weight of soft tissue basis, one of two normalization methods (the other one was soft tissue wet weight concentration). Table 1 provides the collection data for the samples of introduced *Dreissena polymorpha* and native *Elliptio complanata* from the Rideau River, Ontario.

<table>
<thead>
<tr>
<th>Site</th>
<th>Collection date</th>
<th>Species</th>
<th>N</th>
<th>Shell length, mm</th>
<th>Dry weight/wet weight</th>
<th>Lipid weight/dry weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kars</td>
<td>11 Nov. 1995</td>
<td><em>D. polymorpha</em></td>
<td>18</td>
<td>24.4 ± 3.5 (15.9–28.6)*</td>
<td>0.14</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>E. complanata</em></td>
<td>16</td>
<td>22.8 ± 4.8 (14.4–28.4)</td>
<td>0.22</td>
<td>12.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>95.0 ± 5.0 (90.6–103.5)</td>
<td>0.16</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>89.7 ± 8.9 (78.0–102.6)</td>
<td>0.16</td>
<td>5.4</td>
</tr>
<tr>
<td>Long Island</td>
<td>9 Nov. 1995</td>
<td><em>D. polymorpha</em></td>
<td>36</td>
<td>23.7 ± 2.0 (19.6–27.1)</td>
<td>0.17</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>E. complanata</em></td>
<td>41</td>
<td>23.0 ± 1.6 (19.6–27.6)</td>
<td>0.16</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>91.7 ± 5.1 (87.1–98.8)</td>
<td>0.12</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>88.5 ± 17.4 (69.0–111.3)</td>
<td>0.15</td>
<td>4.1</td>
</tr>
<tr>
<td>Black Rapids</td>
<td>11 Nov. 1995</td>
<td><em>D. polymorpha</em></td>
<td>28</td>
<td>22.0 ± 3.2 (15.6–26.9)</td>
<td>0.15</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>E. complanata</em></td>
<td>3</td>
<td>101.3 ± 4.2 (96.5–104.4)</td>
<td>0.17</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>95.2 ± 3.8 (91.2–100.0)</td>
<td>0.19</td>
<td>3.9</td>
</tr>
<tr>
<td>Moone’s Bay</td>
<td>27 Sept. 1995</td>
<td><em>D. polymorpha</em></td>
<td>30</td>
<td>23.4 ± 3.0 (19.1–31.6)</td>
<td>0.13</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>E. complanata</em></td>
<td>34</td>
<td>22.7 ± 1.8 (17.9–28.3)</td>
<td>0.14</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>79.3 ± 4.8 (71.9–83.5)</td>
<td>0.14</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>72.2 ± 10.4 (61.4–88.7)</td>
<td>0.14</td>
<td>4.7</td>
</tr>
</tbody>
</table>

*Data for shell length represent the mean ± standard deviation and range (in parentheses).
basis) recommended by Metcalfe-Smith et al. (2002), as being both precise and accurate for D. polymorpha. The reason for this is that moisture content in D. polymorpha is very consistent and both of these methods yield similar results. Lipid content, on the other hand, varies considerably with reproductive status and condition of D. polymorpha, and therefore, varies considerably among locations, seasons and years. In their study comparing various methods of expressing contaminant concentrations, Metcalfe-Smith et al. (2002) found that the concentrations expressed on a lipid basis yielded inconsistent results and advised against using these in isolation.

Organochlorine residues were grouped based on their chemical relatedness in order to reduce the effects due to metabolism and degradation. These groupings were expressed as total (Σ) values; i.e., Σaldrin = aldrin, dieldrin and endrin; ΣCB = hexachlorobenzene and pentachlorobenzene; Σchlor dane = α- and γ-chlordane, heptachlor and heptachlor epoxide; ΣDDT = o,p’- and p,p’-DDT, p,p’-DDE, o,p’- and p,p’-DDT; Σendosulfan = α- and β-endosulfan; and ΣHCH = α-, β- and γ-HCH. ΣPCB refers to the sum of individual congeners. PCB congener class distributions were determined based on the designation of PCB compounds given by Ballschmitter and Zell (1980). Congeners from different classes that co-eluted, were distributed based on measured proportions in the NOICB standard and in the case of PCB congener combination 176(130) following Mullin (1985).

Parametric (t) or nonparametric (Mann-Whitney U or Kruskal-Wallis) statistical tests were used to make several comparisons. Nonparametric tests were chosen whenever the data were tested and found to be either not normally distributed (Lilliefors test) and/or heteroscedastic (Levene’s test). Ratios were transformed to arcsine values. Tests were two-tailed and the chosen level of significance was P ≤ 0.05.

Results

The mass ratio (whole mass of attached D. polymorpha/whole mass of E. complanata) for the 35 individuals of E. complanata collected in 1995 was 0.00 (only byssal threads left behind post detachment) to 1.83 with mean 0.55 and SD 0.65. Forty percent of the E. complanata were carrying at least half of their mass as attached D. polymorpha. In order to determine whether D. polymorpha in this study had already produced a physiological impact on E. complanata, thereby potentially influencing organochlorine concentrations in the latter, the ratios of dry weight to wet weight in the eight E. complanata composite samples (N = 3–5 specimens/sample) from the Rideau River (Table 1) were compared with the ratios of a control sample also from the Rideau River (i.e., sample of E. complanata not carrying D. polymorpha). The E. complanata samples (61.4–111.3 mm shell length) with the attached D. polymorpha and collected between 27 September and 11 November 1995 had dry weight to wet weight ratios of 0.12 to 0.19 with mean 0.15 and SD 0.02. The control sample consisted of 12 E. complanata specimens (70.0–86.6 mm shell length) free of D. polymorpha and collected on 1 November 2002 in the Rideau River at Edmonds Lock, 53 km upstream from Kars (Fig. 1). The dry weight to wet weight ratios of those E. complanata were 0.14 to 0.24 with mean 0.17 and SD 0.02. Dry weight to wet weight ratios in the recently fouled E. complanata samples (1995) versus the D. polymorpha-free control E. complanata sample (2002) showed no significant difference (t-test, P = 0.17).

Shell lengths (Table 1) differed significantly among sites for E. complanata (Kruskal-Wallis test, P = 0.0003), but not for D. polymorpha. A t-test showed that dry weight to wet weight ratios between the two molluscs were not significantly different (Fig. 2A). Lipid content, expressed on a dry weight basis, was significantly higher in D. polymorpha compared to E. complanata (P = 0.0003) (Fig. 2B).

The E. complanata sample dry weights were 5.06 to 17.94 g with mean 10.65 and SD 4.54 and for D. polymorpha, 0.95 to 2.10 g with mean 1.65 and SD 0.45. These dry weight recoveries were considered reliable because the wet weight samples they came from, 35.25 to 109.35 g in the former and 6.44 to 13.32 g in the latter, exceeded the 5-g wet weight threshold level recommended by Honeycutt et al. (1995).

PCBs represented by far the most important component of the organochlorine body burden, contributing 72.0 to 86.6% of that burden in E. complanata and 89.0 to 97.4% in D. polymorpha (Table 2, Fig. 4). The pesticides β-HCH, mirex and PCB congener 207 were not detected (i.e., below quantitation limit) in E. complanata; endrin and PCB congener combination 54(29) were not detected in D. polymorpha and aldrin, γ-chlordane, o,p’-DDE, o,p’-DDT, p,p’-DDT and PCB congener combination 12(13) were not detected in either E. complanata or D. polymorpha. Mirex was detected at 0.07 ng/g dry weight in a single sample replicate of D. polymorpha (n = 18) from Kars (Fig. 1).

The dry weight concentrations of the various contaminant groups (Table 2) were compared using Kruskal-Wallis tests and showed no significant differences among sites for either E. complanata or D. polymorpha. The data from all sites were therefore combined for each of the molluscs. A comparison of the dry weight concentrations of the various contaminant groups in the E. complanata versus D. polymorpha showed a significant difference for ΣPCB only (Mann-Whitney test, P = 0.02), being about 3.5 times higher in D. polymorpha (Table 3).

The DDD/ΣDDT and DDE/ΣDDT ratios in D. polymorpha versus E. complanata samples were not significantly different in both cases (t-tests, P > 0.05).
DDT/ΣDDT ratios were not tested because, as noted above, neither o,p’-DDT nor p,p’-DDT were detected in any of the samples of either bivalve species.

The relative concentrations of each PCB congener class, expressed in percentages, in the *D. polymorpha* versus *E. complanata* samples (Fig. 3) showed a significantly higher value in *D. polymorpha* for tetra-chlorobiphenyls (Mann-Whitney test, P = 0.02). In contrast, values were significantly higher in *E. complanata* for di-(P = 0.02), hepta- (P = 0.005) and deca-chlorobiphenyls (P = 0.04). The cumulative percentage of mono- to penta-chlorobiphenyl congeners amounted to 75.0% for *D. polymorpha* versus 69.4% for *E. complanata* and the percentage of hexa- to deca-chlorobiphenyl congeners amounted to 25.0% for *D. polymorpha* versus 30.5% for *E. complanata*. The Spearman rank correlations of the mean concentrations of the 10 PCB congener classes and 98 PCB congener combinations between *D. polymorpha* versus *E. complanata* samples were 0.96 (P < 0.001) and 0.91 (P < 0.001), respectively. Based on a best fit analysis with Aroclor compositions given by Mullin (1985), the congener class profile in *D. polymorpha* approximated a 10:58:29:1:1:1 mixture of Aroclors 1221:1248:1254:1260:1262:1268 and the one in *E. complanata* approximated a 5:43:38:2:6:1 mixture of Aroclors 1221:1232:1248:1254:1260:1262:1268 (Fig. 3).

ΣPCB, ΣDDT and Σchlordane accounted for 98.2 and 98.7% of the organochlorine dry weight burden in *E. complanata* and *D. polymorpha*, respectively. At any given site, the organochlorine dry weight burden was 2.0 to 5.6 times higher in *D. polymorpha* than in *E. complanata* (Fig. 4).

**Discussion**

The absence of a significant difference between the dry weight to wet weight ratios in the recently fouled *E. complanata* samples (1995) versus the *D. polymorpha*-free Organochlorines in Rideau River Zebra Mussel and Unionid 87

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**Fig. 2.** Comparisons between 1995 *D. polymorpha* versus *E. complanata* samples from the Rideau River, Ontario. A. Dry weight to wet weight ratios; B. Lipid weight to dry weight ratios. Error bars represent ± 1 SD.

**TABLE 2.** Organochlorine contaminant concentrations in ng/g soft tissue dry weight in the unionid *Elliptio complanata* (U) versus the zebra mussel, *Dreissena polymorpha* (Z) at four sites along the Rideau River, Ontario, in 1995

<table>
<thead>
<tr>
<th>Contaminant group</th>
<th>Kars</th>
<th>Long Island</th>
<th>Black Rapids</th>
<th>Mooney’s Bay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>U</td>
<td>Z</td>
<td>U</td>
<td>Z</td>
</tr>
<tr>
<td>Σaldrin</td>
<td>0.2 ± 0.1 (0.2–0.3)</td>
<td>0.0 ± 0.0 (0.0–0.0)</td>
<td>0.4 ± 0.4 (0.0–0.7)</td>
<td>0.5 ± 0.7 (0.0–1.0)</td>
</tr>
<tr>
<td>ΣCB</td>
<td>0.4 ± 0.1 (0.3–0.4)</td>
<td>0.4 ± 0.0 (0.4–0.4)</td>
<td>0.5 ± 0.2 (0.3–0.7)</td>
<td>0.2 ± 0.0 (0.2–0.2)</td>
</tr>
<tr>
<td>Σchlordane</td>
<td>0.9 ± 0.0 (0.9–1.0)</td>
<td>2.0 ± 1.8 (0.8–3.3)</td>
<td>1.0 ± 0.2 (0.9–1.2)</td>
<td>1.8 ± 0.1 (1.7–1.9)</td>
</tr>
<tr>
<td>ΣDDT</td>
<td>4.8 ± 1.8 (3.5–6.1)</td>
<td>8.2 ± 0.6 (7.7–8.6)</td>
<td>8.3 ± 4.7 (5.0–11.6)</td>
<td>13.7 ± 0.2 (13.6–13.8)</td>
</tr>
<tr>
<td>Σendosulfan</td>
<td>0.3 ± 0.1 (0.2–0.4)</td>
<td>0.6 ± 0.8 (0.0–1.1)</td>
<td>0.5 ± 0.3 (0.3–0.8)</td>
<td>0.8 ± 0.9 (0.2–1.4)</td>
</tr>
<tr>
<td>ΣHCH</td>
<td>0.4 ± 0.0 (0.0–0.6)</td>
<td>0.3 ± 0.4 (0.4–0.6)</td>
<td>0.5 ± 0.1 (2.0–2.5)</td>
<td>2.3 ± 0.4 (0.2–6.6)</td>
</tr>
<tr>
<td>ΣPCB</td>
<td>33.2 ± 3.3 (30.9–35.6)</td>
<td>216.5 ± 64.4 (170.9–262.1)</td>
<td>73.0 ± 27.3 (53.7–92.3)</td>
<td>155.2 ± 4.5 (152.0–158.4)</td>
</tr>
</tbody>
</table>

*Data represent the mean ± standard deviation and range (in parentheses). All values were based on two replicates except for Z from Black Rapids.
control sample (2002) suggested that the 1995 samples had not yet been physiologically compromised by the *D. polymorpha* attached to them.

A comparison of organochlorine contaminant concentrations in *D. polymorpha* from various locations with *D. polymorpha* from the Rideau River showed that the latter had amongst the lowest levels encountered. Land use along the stretch of river where the samples were collected and upstream is predominantly agricultural, with urban use in the Mooney’s Bay area. Average levels of ΣDDT in mixed samples of *D. polymorpha* and quagga mussel, *D. bugensis*, of unknown proportions and collected in 1992 to 1994 from 21 sites along the American shores of lakes Michigan, Huron, Erie and Ontario varied from 9.8 to 274.2 ng/g dry weight (Robertson and Lauenstein 1998). Of these, only two sites, Anchor Bay in Lake St. Clair and Black River Canal in Lake Huron, both collected in 1992, had the low levels (9.8–12.1) found in the Rideau River (5.7–14.7). In the same study, comparison of mean concentrations of other contaminants revealed equally high levels relative to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites. ΣAldrin and Σchlordane were, respectively, 13.4 and 9.0 ng/g dry weight for the 21 sites combined (Robertson and Lauenstein 1998) in marked contrast to the Rideau River sites.

Conversion of the overall organochlorine burdens from dry weight to lipid weight in the *E. complanata* from the Rideau River, Ontario (this study) allowed a comparison with the same species (n = 5 non-gravid specimens; 77.6–99.1 mm shell length) from the Châteauguay River, St. Lawrence River basin, Québec, and collected 28 August 1990 (Renaud et al. 1995). The Châteauguay River site is situated in the upper reaches of the river and land use in the area is predominantly agricultural. *E. complanata* from the four Rideau River sites had by far the lower organochlorine lipid burdens, varying between 814 and 2266 ng/g lipid compared with 25,245 in the Châteauguay River, a value 11 to 31 times higher than those of the Rideau River sites. Metcalfe-Smith et al. (2002) have shown that lipid content in *D. polymorpha* varies considerably between seasons, localities and from year to year and this likely applies to *E. complanata* also (see Muncaster et al. 1989). The lipid content on a dry weight basis for the Rideau River *E. complanata* samples was 3.9 to 5.5% compared with 0.2% in the Châteauguay sample. The latter corresponds to a 19.5 to 27.5 times lower lipid content, and therefore, probably accounts for the differences observed in organochlorine lipid burdens between the two localities. The pesticides

![Fig. 3. Distribution of PCB congener classes, expressed as percentages, in *D. polymorpha* versus *E. complanata* samples collected in 1995 from the Rideau River, Ontario, relative to mixtures of commercial Aroclors.](https://iwaponline.com/wqrj/article-pdf/39/2/83/229163/wqrjc0390083.pdf)
aldrin and β-HCH and PCB congener combination 12(13) were not detected in *E. complanata* from the Châteauguay River (Renaud et al. 1995), nor were they detected in *E. complanata* from the Rideau River.

Assuming 90% moisture content in unionids (Renaud et al. 1995), the data in Bedford et al. (1968) and Curry (1977–78) were converted from a wet weight to a dry weight basis. Bedford et al. (1968) found ΣDDT mean concentrations of 210 to 8520 ng/g dry weight in three unionids, *Anodonta grandis*, *Lampsilis silquoidea* and *L. ventricosa*, collected from five sites along the Red Cedar River, Michigan, between 30 June and 3 October 1966. This is considerably higher than what was found in the Rideau River *E. complanata* (14 ng/g dry weight). Curry (1977–78) also found a higher mean concentration of ΣDDT (70 ng/g dry weight) in *E. complanata* from Balsam Lake, Ontario, introduced to the mouth of the Humber River, Ontario, for a month in July 1977. According to Pugsley et al. (1985), the *E. complanata* in Kauss et al. (1983) had a moisture content of 82%. Therefore, using a multiplication factor of 5.6, we determined that Kauss et al. (1983) found ΣPCB mean concentrations of 129 to 532 ng/g dry weight in *E. complanata* transplanted from Balsam Lake to three sites along the Niagara River, Ontario/New York, for 16 days in August 1980. Kauss and Hamdy (1985) also used *E. complanata* specimens from Balsam Lake and introduced them to the St. Clair and Detroit rivers, Ontario/Michigan, for a three-week period from 16 August to 9 September 1982. The mean ΣPCB that they found at three sites along the St. Clair River was 150 to 275 ng/g dry weight and at 14 sites along the Detroit River was 125 to 2194 ng/g dry weight. Koenig and Metcalfe (1990) introduced *E. complanata* from Buckhorn Lake, Ontario, to six sites along the Otonabee River basin, Ontario, for an eight-week period starting 28 September 1988. Assuming a 90% moisture content, we converted their mean ΣPCB concentrations based on wet weight, giving 190 to 610 ng/g dry weight. The Rideau River ΣPCB mean value (66 ng/g dry weight) for *E. complanata* falls well below the four above ranges. In October 1985, Metcalfe and Charlton (1990) collected *E. complanata* and *Lampsilis radiata* from 17 sites in the St. Lawrence River between Lake Ontario and Trois-Rivières, and three sites along the Ottawa River. The highest ΣPCB concentration that they found in these unionids was 4920 ng/g dry weight at the mouth of the Grass River, at the inlet from Lake Ontario. Levels in lakes Saint-François, Saint-Louis and Saint-Pierre were at least 10 times lower (490 ng/g dry weight) and in the Ottawa River about 100 times lower (49 ng/g dry weight). The latter value is very close to the one found in the Rideau River (66 ng/g dry weight).

Using shell length annual external growth ring regressions from two previous studies on *E. complanata* from the St. Lawrence River (Lac des Deux Montagnes and Lac Saint-Louis; Magnin and Stańczykowska 1971) and from Mirror Lake, New Hampshire (Strayer et al. 1981), we estimated the age range for the *E. complanata* used in this study at ca. 7 to 18 years. The age range for *D. polymorpha* (shell length range: 14.4–31.6 mm) was estimated at 1 to 3 years old (see study by Neumann et

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**Fig. 4.** Comparison of organochlorine burdens, on a soft tissue dry weight basis, in *D. polymorpha* versus *E. complanata* at four sites along the Rideau River, Ontario, in 1995.
TABLE 3. Organochlorine contaminant concentrations in ng/g soft tissue dry weight in the unionid *Elliptio complanata* (U) versus the zebra mussel *Dreissena polymorpha* (Z) for the four sites combined along the Rideau River, Ontario, in 1995

<table>
<thead>
<tr>
<th>Contaminant group</th>
<th>U</th>
<th>Z</th>
<th>Significance (P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΣAldrin</td>
<td>0.2 ± 0.1</td>
<td>0.5 ± 0.8</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>(0.0–0.7)</td>
<td>(0.0–1.6)</td>
<td></td>
</tr>
<tr>
<td>ΣCB</td>
<td>0.5 ± 0.1</td>
<td>0.3 ± 0.1</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>(0.3–0.9)</td>
<td>(0.1–0.4)</td>
<td></td>
</tr>
<tr>
<td>ΣChlordane</td>
<td>1.2 ± 0.3</td>
<td>1.8 ± 1.5</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(0.9–2.1)</td>
<td>(0.0–4.7)</td>
<td></td>
</tr>
<tr>
<td>ΣDDT</td>
<td>14.0 ± 8.9</td>
<td>10.6 ± 4.3</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td>(3.5–26.2)</td>
<td>(5.7–15.2)</td>
<td></td>
</tr>
<tr>
<td>ΣEndosulfan</td>
<td>0.4 ± 0.1</td>
<td>0.6 ± 0.4</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>(0.1–0.8)</td>
<td>(0.0–1.4)</td>
<td></td>
</tr>
<tr>
<td>ΣHCH</td>
<td>0.4 ± 0.2</td>
<td>1.8 ± 1.5</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>(0.0–0.6)</td>
<td>(0.0–4.2)</td>
<td></td>
</tr>
<tr>
<td>ΣPCB</td>
<td>65.8 ± 27.3</td>
<td>227.9 ± 65.9</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>(30.9–116.2)</td>
<td>(152.0–315.2)</td>
<td></td>
</tr>
</tbody>
</table>

aData represent the mean ± standard deviation and range (in parentheses).

Therefore, the average period of exposure was approximately six times less in *D. polymorpha* compared to *E. complanata* and yet the former bioaccumulated much greater levels of contaminants. The answer probably lies, at least in part, in the higher lipid content in *D. polymorpha* relative to *E. complanata*. Notwithstanding the problem raised by Metcalfe-Smith and Green (1992), that ages determined by counting external rather than internal rings in unionids were often unreliable, particularly for specimens over 10 years of age, it is clear that *E. complanata* was considerably older than *D. polymorpha*.

Kryger and Riisgård (1988) determined that at 20°C the filtration rate per unit gill area (mL/min·cm$^2$) of four European unionid species (*Anodonta anatina*, *Unio crassus*, *U. pictorum*, *U. tumidus*), was nearly identical with that of *D. polymorpha*, being 1.2 to 1.7 and 1.4 to 1.9, respectively. The dry weights for individual unionids used in their study (2.42–3.14 g) were comparable to those of *E. complanata* (1.01–3.59 g) used in the present investigation. The same was true for *D. polymorpha* (0.06 g in Kryger and Riisgård [1988] and 0.03–0.13 g with a mean of 0.06 in this study). Hence, it is reasonable to assume that in the present study, the filtration rates of *E. complanata* and *D. polymorpha* per unit gill area were similar. Also, the daily period of pumping activity in *D. polymorpha* and in the unionid *Anodonta cygnea* is identical at 16.8 h (Walz 1978; De Bruin and Davids 1970). Walz (1978) determined that assimilation efficiency in *D. polymorpha* did not vary with body size and was about 40% at 15°C and a food concentration of 2 mg/L, whereas Lewandowki and Stańczykowska (1975) determined that the assimilation efficiencies in the unionids *Anodonta piscinalis* and *Unio tumidus* were 79.6%, double that recorded for *D. polymorpha*. However, in order to determine if these two assimilation efficiencies are comparable, an experiment would need to be conducted where all the parameters would be the same for both *D. polymorpha* and the unionids and this cannot be established from the two papers. In summary, and based on the available data, it appears that unionids and *D. polymorpha* are similar in terms of their uptake characteristics.

The fact that no significant differences were found in the grouped organochlorine body burdens in *E. complanata*, despite there being a significant difference in their shell lengths among sites, suggests that these bivalves had reached an equilibrium once they had attained a certain size.

Brieger and Hunter (1993), Nalepa et al. (1993), Comba et al. (1996b) and Willman et al. (1999) reported lipid contents in *D. polymorpha* of 8.8 to 10.8, 6.4 to 17.7, 11 and 5.0 to 11.5% dry weight, respectively, and these are comparable to the range of values (5.3–12.1%) measured for this species in this study. On average, the lipid content in *D. polymorpha* was 1.8 times greater than that in *E. complanata* (this study). Brieger and Hunter (1993) reported lipid percentage in *D. polymorpha* being about five times greater than in the unionid *Lampsilis siliquoidea*. The difference between the two studies may be attributable to species differences and/or differences in the state of maturity and/or condition of the unionids.

Brieger and Hunter (1993) reported PCB levels in *D. polymorpha* from Lake St. Clair being approximately 10 times greater than in *Lampsilis siliquoidea*, its unionid attachment. They suggested that the five-fold greater lipid percentage in *D. polymorpha* compared to *L. siliquoidea* could explain in part the difference in PCB concentration. Likewise, we suggest that the 1.8 times greater lipid percentage in *D. polymorpha* compared to the unionid attachment, *E. complanata*, explains in part the 2.1 to 6.5 times greater ΣPCB concentration in the former relative to the latter (this study). Furthermore, Bruner et al. (1994) have shown that *D. polymorpha* with greater lipid content (mean = 13.5% lipid on a dry weight basis) exhibit significantly higher levels of PCBs, particularly the highly hydrophobic hexachlorobiphenyls, than ones with lower lipid content (mean = 5.9% lipid on a dry weight basis). Willman et al. (1999) likewise showed that *D. polymorpha* with a higher lipid content (mean = 11.5% on a dry weight basis) exhibited ΣPCBs of 1047.1 to 1434.8 ng/g dry weight compared with only 386.6 to 405.6 ng/g dry weight in *D. polymorpha* with lower lipid content (mean = 5.0% on a dry weight basis). The two major types of PCB found in the two molluscs in the Rideau River were Arochlor 1248 and 1254. These collec-
tively represented 87 and 81% of the total PCB constituents in *D. polymorpha* and *E. complanata*, respectively. This indicates that the major sources of PCB contaminants were the same for both.

**Conclusions**

This study shows that *E. complanata* and *D. polymorpha* in the Rideau River exhibit similar organochlorine bioaccumulation patterns. Higher concentrations in ΣPCB in *D. polymorpha* appear to be related to their higher lipid content. We conclude therefore that *D. polymorpha* could serve as an alternative to *E. complanata* as a biomonitor. However, the organochlorine pollution status of the river needs to be determined in order to evaluate whether the concentrations found in the two bivalves reflect the situation in the environment, and hence, their usefulness as biomonitors. Comparative data of organochlorine burdens in *E. complanata* and in *D. polymorpha* from the Laurentian Great Lakes and St. Lawrence River basins showed that in the Rideau River these taxa had amongst the lowest levels encountered. Since organochlorine concentrations are linked, not only to the pollution status of the environment, but also to the lipid content of the organisms being used as biomonitors, it is critical to take seasonal variations in lipid content into account when comparing biomonitoring sites.

**Acknowledgements**

Our thanks to Diane Pathy, Health Canada, Alison Murray and intern Nick Van Lankveld, Canadian Museum of Nature (CMN) for assistance in the field and in preparing samples. Volunteer SCUBA divers Manfred Kühnapfel, Dan Spooner, Nancy Binnie and François Mainville helped with the collecting. Co-op student J. Richardson performed the sample preparation and cleanup and Virginia S. Palabrica, National Water Research Institute (NWRI), conducted the organochlorine assays. Noel Alfonso, CMN, helped with statistical analyses and Paul Hamilton, CMN, freeze dried the samples. K. Klein provided valuable comments on the manuscript. This study was funded in part through grants in 1995 to 1996 to CBR and ALM from the Regional Municipality of Ottawa-Carleton and the Canadian Museum of Nature.

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Received: July 22, 2003; accepted: March 29, 2004.