Bibliography of Dreissena polymorpha (Zebra Mussels) and Dreissena rostriformis Bugensis (QUAGGA Mussels): 1989 to 2011

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BIBLIOGRAPHY OF DREISSENA POLYMORPHA (ZEBRA MUSSELS) AND DREISSENA ROSTRIFORMIS BUGENSIS (QUAGGA MUSSELS): 1989 TO 2011

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ABSTRACT  Dreissenid mussels invaded and colonized waters of the Laurentian Great Lakes during the late 1980s. Their colonization and resulting impact have been characterized as one of the most important ecological changes in freshwater systems in North America. The need for information on dreissenid mussels has grown during the past 2 decades, which has prompted the compilation of this bibliography. Two previous bibliographies of dreissenid mussels indicate average publication rates were 6 publications/year between 1971 and 1964 (1,180 in 194 y) and 30 publications/year between 1964 and 1993 (885 in 30 y). In the current bibliography, the average rate of publication doubled during the past 23 y (1989 to 2011) to 66 publications/year based on a total of 1,502 publications. These rates may be biased by increased numbers of researchers and journals over time but, at a minimum, these rates indicate continued interest and concern by humans about the impact of dreissenid mussels on water availability and the expanding range of dreissenids throughout the world. The current bibliography has a 94% efficiency rate for subject and 100% efficiency for title search criteria when compared with references in published studies of dreissenid mussels in 2011. In addition to publications, we included 206 student theses and 225 chapters in 26 books including 6 books devoted solely to dreissenid mussels. A vast majority of student theses were about dreissenid mussels in North America, especially in the Laurentian Great Lakes. The 6 books devoted to dreissenid mussels contained a variety of chapters that described biology, impact, control, and ecology of dreissenid mussels in both Europe (published in 1992 and 2010) and North America (1993, 1994, 1997, and 2000). In addition, there is a 7th book devoted solely to dreissenid mussels that is near completion.

KEY WORDS: zebra mussels, quagga mussels, dreissenid, bibliography, databases, Dreissena polymorpha, Dreissena rostriformis bugensis

INTRODUCTION  

In the late 1980s, zebra mussels, Dreissena polymorpha, and quagga mussels, Dreissena rostriformis bugensis (Fig. 1), were transported from the European continent and became established in the Laurentian Great Lakes of North America (Hebert et al. 1989). Zebra mussels quickly became abundant enough to become a social menace because of their visibility and ability to attach to and foul structures, which caused water withdrawal problems for drinking-water facilities, electric power plants, marinas, and industries (Nalepa & Schloesser 1993). In addition, mussels colonized the surfaces of all solid structures in the water, which created nuisances for boaters, fishermen, beach visitors, and water navigators (Nalepa & Schloesser 1993). During the early 1990s, shortly after zebra mussels became generally known to the public, quagga mussels were recognized to have similar nuisance abilities as zebra mussels but greater ecological impact than zebra mussels. These 2 mussels, together, have been called one of the most important ecological threats to freshwater in North America (Pollick in press).

The need for scientific information about the biology, impact, control, and ecology of zebra mussels in North America was evident during the early 1990s. In response to this need, Schloesser et al. (1994) compiled a bibliography of Dreissena polymorpha (885 between 1964 to 1993) in waters of Europe and Russia. Compilation of this bibliography was difficult and, although valuable, had limited use because many publications were not in English and had been based on studies of dreissenid mussels in Europe and Russia (Schloesser et al. 1994). However, this 1994 bibliography was much more accessible by English-speaking researchers and managers than earlier bibliographies published in Russian by Limanova in 1964 (1,180 between 1971 to 1964) and translated into English in 1968, and another bibliography by Limanova in 1978 (unknown number), which is believed to be available only in Russian (Schloesser et al. 1994). All 3 of these bibliographies undoubtedly contained large amounts of information that could be valuable to researchers and managers who want to understand and control dreissenid mussels.

As predicted 20 y ago, the need to obtain information about zebra mussels in North America has increased (Schloesser et al. 1994). This need to understand and control zebra mussels increased dramatically during the early 2000s, when a genetically similar dreissenid mussel, the quagga mussel (Dreissena rostriformis bugensis), impacted the ecology of the Laurentian Great Lakes dramatically and spread to the western half of the United States (Benson in press). In addition, the need for regional impact studies became evident because dreissenid mussels in North America exhibited different behavior than those in Europe and Russia.

The current bibliography includes publications between 1989 and 2011 and was compiled to provide researchers, managers, and water users with a bibliography to help understand and manage dreissenid mussels, especially in North America. The temporal overlap (1989 to 1993) between the bibliography of Schloesser et al. (1994) (1964 to 1993) and the current bibliography (1989 to 2011) was included primarily because the first publication to include zebra mussels found in North America was published in 1989, but was not included in the bibliography of European and Russian literature compiled by Schloesser et al. (1994) (Hebert et al. 1989). Although the current bibliography emphasizes studies published in English about dreissenid mussels in North America, a few non-English-language publications may be included because it is not always evident in which language the main body of text is printed based on electronic searches.
RESULTS

This bibliography is a compilation of several literature searches in pertinent computerized databases of companies that index thousands of scholarly journals, books, reports, proceedings, and open-access journals that meet strict criteria (Testa 2011). Scientific and common names of both species and dreissenid mussels, in various configurations, were searched in title fields to ensure the resulting references would contain substantial information about dreissenid mussels. The focused search of names in titles was done to reduce inclusion of many publications that only mention dreissenid mussels in an introduction and/or discussion. For example, the focused search allowed elimination of studies that only mentioned dreissenid mussels as responsible agents of observed changes (e.g., reduction of phytoplankton) and often contained no data about dreissenid mussels. Searches for listings spanned a period of 23 y, 1989 to 2011, except for theses, which included the years 1950 through 2011. Student theses were obtained from title searches of a commercial theses database and from the database of a worldwide library cooperative.

Figure 1. Typical shell morphology of zebra mussels, *Dreissena polymorpha* (left), and quagga mussels, *Dreissena rostriformis bugensis* (right). from Pavlova (in press) and the U.S. Geological Survey.

Results of searches were reviewed for content and duplication. References that contained obvious errors were deleted (e.g., duplications attributed to abbreviated journal titles vs. nonabbreviated journal titles, full author names vs. abbreviated author names). Databases can detect duplication of exact records but not inaccuracies in basic information such as variations of spelling and abbreviations. In addition, manual searches of books and personal records (e.g., D. W. S.) were included, and a call for missed publications was extended to researchers knowledgeable about dreissenid literature (e.g., book contributors to Nalepa and Schloesser (in press)). Studies that contained substantial information on dreissenid mussels were included as a result of this method, but they accounted for about 5% of compiled listings.

The current bibliography contains few references from online-only publications. At the time of this compilation, not many online-only journals meet the high standards of companies that produce electronic databases (e.g., Testa 2011). Although we recognize electronic publication as a growing source of scientific information, we did not attempt to include exhaustively electronic-only journals because indexing companies add past journal articles slowly to databases. For example, searches of 1 database based on total and processed/included dates indicated that in 1 y, about 4% more publications, published in earlier years, were added to the database. This 4% represents older publications that had been added to the database. When databases include more older publications, and a greater number of online-only journals establish prominence in online databases, we believe a bibliography needs to be compiled with inclusion of digital-object identifier numbers.

Efficiency of this bibliography was evaluated by comparing the occurrence of references in published studies and their occurrence as listings in the bibliography. Seven publications with dreissenid mussels in the title were used to check the efficiency of the current bibliography. Individual publications occurred in 7 individual journals published in 2011. Publications were read and references used to cite studies of dreissenid mussels were cross-checked against the current bibliography to determine the number of references found in publications and this bibliography. Only studies published between 1989 and 2011 were included in reference searches of the 7 publications.
RESULTS AND CONCLUSIONS

The current bibliography contains 1,932 listings. Of these listings, 1,502 were published studies comparable with previous bibliographies by Schloesser et al. (1994) and Limanova (1964). In addition, our search included 206 student theses and 225 chapters in 26 books. Of the 26 books, 6 were devoted solely to zebra mussels. In addition, but not included in the current bibliography, there is a 7th book in press (Nalepa and Schloesser) that includes 44 chapters on zebra and quagga mussels. Previous bibliographies did not, for the most part, include theses and books that are included in the current bibliography.

Based on the current bibliography, we believe the rates of publication about dreissenid mussels increased after their discovery and spread in North America. Although an extensive effort to overcome language and publication methods of earlier listings is needed to verify this theory, bibliographies indicate that the annual rate of publication between 1771 and 1964 was about 6 publications/year (1,180 in 194 y), between 1964 and 1993 was about 32 publications/year (885 in 30 y), and between 1989 and 2011 was about 66 publications/year (1,502 in 23 y) (Limanova 1964, Schloesser et al. 1994). These rates may be biased by increased numbers of researchers and journals during the past 250 y. However, at a minimum, these rates indicate continued interest and concern by humans about water availability and the expanding range of dreissenids throughout the world.

Efficiency of the current bibliography to include references of dreissenid mussels in 7 published studies in 2011 was relatively high (Table 1). Overall, 162 of 172 (94%) references in the 7 publications were included in the bibliography. Only 10 of 172 (3%) references about dreissenid mussels were not found in the current bibliography. Of the 10 references not found in this bibliography, 7 were not about dreissenid mussels, but contained information about mussels the authors used to relate to the subject of the study (e.g., plankton impacted by dreissenid mussels). The 3 remaining references not found in the bibliography were expected to be in the bibliography because they contained reference to mussels (not specifically dreissenid mussels) in the titles. However, these articles did not contain the search words used to compile the bibliography. Instead, the articles used the words “filter feeding mussels,” which did refer to dreissenid mussels. As a result of this careful evaluation, we believe the current bibliography has a 94% efficiency to detect references to the subject of dreissenid mussels and 100% efficiency to detect key words contained in title searches.

In addition to published studies, our search included 206 student theses and 225 chapters in 26 books. Of the 206 theses (1950 to 2011), 195 were published between 1989 and 2011 (99%), and a large majority (74%) of them were from schools located adjacent to a shore of the Laurentian Great Lakes, whereas only 21% were from institutions not located adjacent to a shore of the Great Lakes. Only 5% of these were from institutions in Europe. Of the 26 books, 6 books were devoted solely to zebra mussels and they contained 173 chapters; 1 book in 1992 (20 chapters), 1 book in 1993 (47 chapters), 2 books in 1994 (16 chapters and 7 chapter, respectively), and 1 book in 1997 (42 chapters) and 2010 (41 chapters). The first 2 books (Neumann & Jenner 1992, Nalepa & Schloesser 1993) contained a total of 67 chapters devoted to zebra mussels and were published shortly after zebra mussels were discovered in the Great Lakes in 1988 (Hebert et al. 1989). The only nonedited book, written by Claudi and Mackie (1994), was also published shortly after zebra mussels were found in the Great Lakes and is the only book devoted to the control of mussels in water facilities. Three other books devoted to zebra mussels contain 99 chapters devoted primarily to the ecology of mussels in the Great Lakes (Staroborgatov 1994, D’Itri 1997) and Europe (van der Velde et al. 2010). In addition, there were 46 chapters in a total of 15 other books not devoted to zebra mussels that included data about mussels. No books published before 1992 were devoted specifically to dreissenid mussels. These results indicate that the majority of theses, books, and book chapters about zebra mussels were written after mussels colonized the Laurentian Great Lakes.

The abundance of publications about dreissenid mussels in the Great Lakes undoubtedly occurred because of the impact these mussels had on water users and ecology in the Great Lakes (Nalepa & Schloesser 1993). Although there are a few large studies of dreissenid mussels (e.g., Morton 1969) in the 203-y published history before they invaded the Great Lakes, it appears their occurrence in North America during the late 20th century; their impact on human, plant, and animal communities of the Great Lakes; their spread throughout the United States; and the ease at which information can now be exchanged have resulted in popular as well as scientific interest in these exotic mussels.

The current bibliography does not contain information about dreissenid mussels found in traditional gray literature (abstracts, conference proceedings, reports, memoranda, and so forth). For example, there were several thousand abstracts written for international conferences devoted to dreissenid mussels during the first decade of their occurrence in North America. As electronic databases continue to grow, it is likely that traditional gray literature will be included in searched databases and the number of listings from past studies will increase, especially non-English–language listings from Europe and Russia. In addition, old and future studies, of which there are and are likely to be many, will find their way into databases for easy access and use. Currently, the need for information about dreissenid mussels appears to be increasing and paralleling the human need for freshwater as dreissenid mussels continue to expand their range and impact water users in North America and elsewhere throughout the world.

### Table 1.
Numbers of references (1993 to 2011) based on the subject of dreissenid mussels present and not present in 7 scientific journals published in 2011.

<table>
<thead>
<tr>
<th>Journal</th>
<th>In bibliography (n)</th>
<th>Not in Bibliography (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquatic Ecosystem Health and Management</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>Canadian Journal of Fisheries and Aquatic Sciences</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>Ecosphere</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Toxicology and Chemistry</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Freshwater Biology</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>Journal of Great Lakes Research</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Journal of the North American Benthological Society</td>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>162</td>
<td>10</td>
</tr>
</tbody>
</table>
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We thank numerous researchers who contributed information in response to our call for references to help compile this bibliography. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. government. This article is contribution number 1717 of the U.S. Geological Survey Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI.

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