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Economic Impacts of Zebra Mussels on Drinking Water Treatment and Electric Power Generation Facilities

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Abstract Invasions of nonnative species such as zebra mussels can have both ecological and economic consequences. The economic impacts of zebra mussels have not been examined in detail since the mid-1990s. The purpose of this study was to quantify the annual and cumulative economic impact of zebra mussels on surface water-dependent drinking water treatment and electric power generation facilities (where previous research indicated the greatest impacts). The study time frame was from the first full year after discovery in North America (Lake St. Clair, 1989) to the present (2004); the study area was throughout the mussels' North American range. A mail survey resulted in a response rate of 31% for electric power companies and 41% for drinking water treatment plants. Telephone interviews with a sample of nonrespondents assessed nonresponse bias; only one difference was found and adjusted for. Over one-third (37%) of surveyed facilities reported finding zebra mussels in the facility and almost half (45%) have initiated preventive measures to prevent zebra mussels from entering the facility operations. Almost all surveyed facilities (91%) with zebra mussels have used control or mitigation alternatives to remove or control zebra mussels. We estimated that 36% of surveyed facilities experienced an economic impact. Expanding the sample to the population of the study area, we estimated $267 million (BCa 95% CI = $161 million–$467 million) in total economic costs for electric generation and water treatment facilities through late 2004, since 1989. Annual costs were greater ($44,000/facility) during the early years of zebra mussel infestation than in recent years ($30,000). As a result of this and other factors, early predictions of the ultimate costs of the zebra mussel invasion may have been excessive.

Keywords Aquatic nuisance species · Economic impacts · Invasive species · Zebra mussels

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Introduction

Invasions of nonnative species are one of the leading mechanisms of global environmental change, especially in freshwater ecosystems (Garcia-Berthou and others 2005). Human-mediated introductions are among the most important impacts affecting ecosystems (Mack and others 2000). Damage can be both ecological and economic, with zebra mussels and quagga mussels (*Dreissena polymorpha* and *Dreissena bugensis*) serving as excellent examples (for the purposes of this paper, the two species of dreissenids are hereafter referred to generically as ''zebra mussels''). While ecological impacts are being debated elsewhere (e.g., Raikow 2004, Strayer and others 2004, Winkler and others 2005), economic impacts of zebra mussels have not been examined in detail since the mid-1990s, although predictions have ranged as high as $1 billion per year (Pimentel 2005).

Zebra mussels were first observed in North America in June 1988 (O'Neill and MacNeill 1989). The zebra mussel can now be found in 23 states (AL, AR, CT, IL, IN, IO, KS, KY, LA, MI, MN, MO, MS, NE, NY, OH, OK, PA, TN, VA, VT, WI, WV) and two Canadian provinces (Ontario [ON], Quebec). All five of the Great Lakes are infested, as well as Lakes St. Clair and Champlain and inland lakes in Michigan, Missouri, New York, Ohio, Oklahoma, Pennsylvania, Vermont, Wisconsin, and Ontario. The Allegheny, Arkansas, Cumberland, Detroit, Genesee, Hudson, Illinois, Niagara, Mississippi, Missouri, Mohawk, Monongahela, Ohio, Oswego, Rideau (ON), St. Clair, St. Lawrence, Susquehanna, Tennessee, Vertigris (OK), and Wabash rivers are also home to zebra mussel populations. It is likely that they will continue to spread into additional rivers and inland lakes (Ram and McMahon 1996) that are currently uninfested but within the range of the invasion. GARP (genetic algorithm for rule-set production) analysis of the current distribution of zebra mussels in North America based on 11 important environmental and geological variables indicates that much of New England that is currently uninfested, as well as some areas of the Southeast and the West Coast, may be at considerable risk; however, much of the American West will likely be uninhabitable for zebra mussels (Drake and Bossenbroek 2004).

Zebra mussels have affected surface water-dependent electric power generation and drinking water treatment facilities since their arrival in North America by fouling intake pipes and other equipment, resulting in severely impeded flows of water into these facilities (MacIsaac 1996). Such infestations, once discovered, must be remediated and measures taken to prevent future fouling. This can involve construction of new intakes, physical removal of mussel accumulations, and/or chemical treatments of affected intake components. Preventive actions are possible as well; these generally include physical barriers, chemical treatments, and educational programs for recreational boaters to prevent introduction of mussels to new waters.

The economic impact of zebra mussels was studied most comprehensively in 1995 by two groups of researchers. A study conducted by Ohio Sea Grant estimated zebra mussel impacts in the Great Lakes Basin at $120 million for 1989 to 1994 (Park and Hushak 1999). That study was limited to municipal water plants, electric generation facilities, and other industries using surface water from the Great Lakes or its tributaries. A more comprehensive study, undertaken by New York Sea Grant for the National Zebra Mussel Information Clearinghouse (now the National Aquatic Nuisance Species Clearinghouse), covering the entire North American range of the mussels at that time (Great Lakes plus other water bodies), estimated zebra mussel-related expenditures in excess of $69 million for the period 1989 to 1995 (O'Neill 1997). The latter study included additional water uses beyond drinking water and electric generation, such as navigation locks, and institutional uses such as at universities, golf courses, and fish hatcheries. These uses, although affected negatively by zebra mussels, did not suffer economically to the extent experienced by municipal/industrial water users (O'Neill 1997). Both of these studies relied on small sample sizes, thus explaining the difference in estimates between the two. Extrapolations to overall population estimates should be considered tentative at best. No comprehensive study of the economic impact of zebra mussels in terms of control and prevention costs and lost production costs has been conducted since 1995. The New York Sea Grant coauthor, however, extrapolated forward the 1995 results, positing a cumulative impact from 1989 through 2005 of approximately $1 billion (taking into account additional infested waters, additional impacted facilities, and additional years of treatment expenses) (unpublished data).

The purpose of this study was to quantify the annual and cumulative economic impact of zebra mussels, from the first full year after their introduction (1989) to the present (2004) throughout the mussels' North American range, on surface water-dependent drinking water treatment and electric power generation facilities (as these were the facilities most impacted previously). (The study does not estimate other economic impacts of the invasion, such as on fisheries and recreational boating.) Research questions addressed included comparisons with the previous New York Sea Grant study to examine how closely current estimates match past estimates and predictions. With the expansion of the zebra mussels range, have costs expanded proportionally? Also, are there differences in the impacts on drinking water treatment and electric power generation facilities? Are there differences in costs as facility size increases? Given the importance of this species for water resources management throughout the central United States, an updated, comprehensive economic assessment of zebra mussel impacts was needed to inform decision making.

Methods

We used a mail questionnaire to gather information on the costs of implementing zebra mussel control or prevention measures as well as estimates of the economic value of lost production. We sought information for the period beginning in 1989, the first full year of possible infestation, to the fall of 2004, when the survey was implemented. We also obtained information on the history of infestation and the types of prevention and control measures used. We designed the questionnaire so that results would be comparable with those of the 1995 New York Sea Grant survey (O'Neill 1997).

We surveyed all identifiable electric generation and drinking water treatment companies which might use surface water in U.S. states and Canadian provinces within the range where zebra mussels were known to be present. We developed a list of 708 electric generation companies from Platts

2003 UDI Directory of Electric Power Producers and Distributors (Giles and Brown 2003) and a list of 876 drinking water treatment providers from EPA listings and contacts at health departments in states where zebra mussels exist. Identifying raw water intake from surface water was important because zebra mussels might be present in surface water sources and not groundwater. We generated a listing of water treatment facilities with surface water sources from the EPA records, but water source information was not known in advance for electric generation facilities.

We sent the mail questionnaire to all identified companies (1584) in the fall of 2004. We used the standard three follow-up reminder process advocated by Dillman (2000) to encourage response. We were aware that electric companies in particular might be reluctant to provide economic data, so we emphasized confidentiality in our correspondence. We conducted nonrespondent telephone interviews with 50 electric and 50 water companies to assess differences between respondents and nonrespondents.

Because companies could be responsible for more than one facility, we asked mail survey respondents to photocopy the questionnaire and respond for each facility for which they were responsible. In the nonrespondent telephone survey, we asked interviewees how many facilities they were responsible for but asked them to provide answers for the one facility they knew best. From this information we estimated the number of facilities in the study area.

We entered data on the computer and analyzed it using SPSS. Chi-square and *t*-tests were used to test for statistical differences between respondents and nonrespondents and between drinking water and electric generation facilities. To calculate a 95% confidence interval for the estimate of economic costs, the bootstrap bias-corrected accelerated (BCa) interval using 5000 resamples in S-PLUS was used because the distribution was not normal (Hesterberg and others 2006).

We conducted site visits at five facilities of different types to allow for a more in-depth examination of prevention and control methods used. During the site visit the questionnaire filled out previously by the facility manager was discussed in more detail to determine how he or she developed estimates of costs. This information was used to help interpret the findings from the mail survey.

Results

Response Rates and Population Size

Of the 708 electric generation companies contacted, 61 questionnaires were undeliverable and 81 responded, for an adjusted response rate of 13%. Of the 876 drinking water treatment companies contacted, 70 questionnaires were undeliverable and 321 responded, for an adjusted response rate of 40%. However, during the survey process (mail and telephone follow-up), we found that many companies, particularly those providing electric power generation, did not obtain their raw water from surface water but used wells and groundwater instead (Table 1). From the mail survey process we found that 34% of electric generation companies that contacted us either by responding to the questionnaire or via e-mail were using groundwater. These companies were not part of the intended population for the study and, therefore, were removed from our estimates of population size and response rate. We also assumed that mail survey nonrespondents we contacted via telephone were representative of all nonrespondents, and we removed nonrespondents according to the percentage not using surface water (66% for electric, 2% for water). The result is an estimated population of 259 electric and 787 drinking water companies that use surface water. The effective response rate, therefore, based on surface water users, was 31% for electric and 41% for drinking water.

Assuming that we began with a complete list of all electric and drinking water companies in the study area, we estimated that the population of companies that used surface water was 1046 and they were responsible for 1297 facilities. Our data were collected on a facility basis (n = 447 facilities), so we report data by facility and multiply by 2.9 to expand our estimates to population estimates reflecting the total costs borne by all companies and all facilities.

Nonresponse Bias

Nonrespondents contacted by phone (n = 100) did not differ from respondents (n = 447) on most variables compared. Nonrespondents were just as likely as respondents to have zebra mussels in their facility. The year when zebra mussels arrived at the specific facility did not differ between respondents and nonrespondents. The mussels were equally likely to have caused problems in the facility for respondents and nonrespondents. Nonrespondents were just as likely as respondents to have engaged in prevention and control of zebra mussels. Based on past research in which nonrespondents were found to be less interested in the topic being studied (Connelly and Knuth 2002), we expected nonrespondents would be less likely to have zebra mussels in their facility, but this was not the case.

The only variable for which we could detect a difference between respondents and nonrespondents was the percentage experiencing an economic impact due to zebra mussels. Almost half (46%) of the respondents spent money or had an economic loss, compared to one-third (31%) of nonrespondents. Estimates of economic impact discussed later are adjusted for this bias. The sample size

Table 1 Estimating the population of electric generation and drinking water treatment companies using surface water as their raw water source

	Electric generation companies	Drinking water treatment companies
Initial population	708	876
Undeliverable questionnaires	61	70
Responded ''Not using surface water''	42	10
Responded to mail questionnaire	81	321
Nonrespondents to mail questionnaire	524	475
% ''not using surface water'' (based on nonrespondent phone interviews)	66%	2%
Nonrespondents using surface water	178	466
Estimated population using surface water	259	787

for nonrespondents reporting an economic impact was too small (n = 9) for comparison of average impacts experienced by nonrespondents in 2003 or 2004 vs. impacts experienced by respondents.

Facility Characteristics

Most responding facilities (76%) primarily provided public drinking water. These were sufficient in number to permit data analysis by facility size (as measured by million gallons per day of drinking water produced). A similar number of facilities (37% and 38%, respectively) produced ≤ 1 million or 2 million–10 million gallons per day; the remaining 25% produced ≥11 million gallons per day. Fifteen percent of facilities surveyed provided electric generation, with just over half (58%) being publicly owned as opposed to privately or investor-owned. Most of these facilities generated energy using fossil fuels (63%), followed by hydroelectric (32%) and nuclear (5%). The remaining facilities (9%) were some combination of drinking water, electric generation, and industrial facilities.

We received responses from facilities in 19 states and 2 Canadian provinces, thus covering almost the entire range of zebra mussels in North America. The top 10 water bodies used as a raw water source by respondents were (in descending order) Lake Michigan, Lake Erie, St. Lawrence River, Ohio River, Lake Superior, Lake Ontario, Tennessee River, Lake Champlain, Mississippi River, and Lake Huron.

Zebra Mussel Prevention and Control Activities

Over one-third of responding facilities reported finding zebra mussels in their facility (Table 2). Most discoveries occurred between 1989 and 1998, but some occurred in every year from 1989 to 2004. Most respondents thought the zebra mussels had been in the facility 6 months to 1 year before discovery. Only one-fifth of responding facilities had preventive measures in place prior to their discovery. About half are currently monitoring for zebra mussels. Over two-fifths have a plan in place for prevention and/or control. No significant differences were found between drinking water and electric power generation facilities for any of these comparisons.

Almost half of responding facilities have initiated preventive measures to prevent zebra mussels from entering the facility operations (Table 2). This was more often the case for drinking water facilities than for electric power generation facilities. The most commonly used preventive measures included sand filtration, restricting access to the water source, and oxidizing chemicals such as sodium hypochlorite, chlorine gas, and potassium permanganate.

The vast majority of surveyed facilities with zebra mussels have used control or mitigation alternatives to remove or control zebra mussels (Table 2). Proportionately fewer electric power generation facilities had used such alternatives, but their sample size was too small to support statistical comparisons. The most commonly used control measures included mechanical removal by divers and the use of oxidizing chemicals such as sodium hypochlorite, chlorine gas, and potassium permanganate. The chemicals were viewed as the most effective control measures.

Economic Impact of Zebra Mussels

About half (46%) of the responding facilities had some expenditures between 1989 and 2004 for controlling/preventing zebra mussels or had suffered lost production and revenues due to zebra mussels. The percentage reporting expenditures was lower for electric power generation facilities (32%) than for drinking water facilities (49%) (χ^2 = 5.5, df = 1, p = 0.02). Adjusting for nonresponse bias in the percentage of facilities reporting a loss, we estimate that 36% of surveyed facilities (or a total of 468) experienced an economic impact. Each of these facilities indicated total mean expenditures or costs of $500,000 between 1989 and the time they completed the questionnaire in October or November 2004. (These numbers were not

Table 2 Zebra mussel occurrence, prevention, and control in responding facilities.

Characteristic	Overall	Electric generation facilities	Drinking water treatment facilities
Facilities with zebra mussels	37%	41%	37%
Monitoring for zebra mussels	47%	47%	49%
Plan in place for prevention and/or control	44%	39%	46%
Preventive measures in place[a]	45%	50%	20%
Of those with zebra mussels			
Preventive measures in place prior to discovery	22%	37%	19%
Control measures in place[b]	91%	76%	94%

[a] Statistically significant difference between electric generation facilities and drinking water treatment facilities, $\chi^2 = 19.9$, df = 1, $p < 0.01$

[b] The sample size for electric generation facilities was too small for statistical comparisons with drinking water treatment facilities

adjusted for inflation, because of our desire to compare them with the results of other studies.) Expanding the sample to the population of the study area, we estimated $267 million in total economic costs for electric generation and water treatment facilities through late 2004. Using bootstrap methods, we estimated the BCa 95% confidence interval to be $161 million to $467 million. Costs were greater during the early years of zebra mussel infestation than in recent years (Table 3).

Analysis of expenditures by category (e.g., prevention, retrofit, chemical treatment) shows that most costs were associated with prevention efforts (Table 4). Lost production and revenues contributed significantly to the overall estimate of impacts. Expenditures for facilities producing electricity appeared to be greater than for those providing drinking water treatment, but the sample size for electric-only facilities was too small to support statistical comparisons.

As facility size increased, so did costs related to zebra mussels (Table 5). Affected facilities that produce ≤ 10 million gallons of drinking water per day spent on average $100,000 to $150,000 between 1989 and 2004, compared with $500,000 for affected facilities that produced >10 million gallons per day. The average expenditures for prevention, planning, and filtration were particularly high for larger facilities compared with those producing ≤ 10 million gallons.

Table 3 Mean and total economic impacts caused by zebra mussels by year

Year of expenditure	Mean per facility with some type of expenditures	Estimated total for study area
1989–1995	$312,424 ($52,070/yr)	$146,214,432
1996–2000	$144,984 ($28,996/yr)	$67,852,512
2001	$26,493	$12,398,724
2002	$29,106	$13,621,608
2003	$33,673	$15,758,964
2004 to date (Oct.–Nov.)	$24,328	$11,385,504
Total	$571,009	$267,232,212

Future Concerns

In response to an open-ended question about emerging issues for their facility, over one-third (37%) indicated at least one issue, most commonly algal blooms (32%) and taste and odor concerns (30%). Other topics mentioned by more than 10% of these respondents were toxic bacteria, disinfectant by-products, and possible new species or threats of which they were not yet aware.

Discussion

This study attempted to identify all surface water-dependent drinking water treatment and electric generation facilities within the current range of zebra mussels in North America. Using state/provincial lists, we included some facilities outside the zebra mussels' current range, choosing to err on the side of being inclusive rather than exclusive in our list of facilities. Thus, not all of the facilities surveyed had zebra mussels. However, many of these facilities anticipate problems in the future and are monitoring or taking preventive actions. Approximately one-third of all facilities had spent money on prevention or control measures.

The methodology used in this study gives us confidence in our estimate of the number of facilities affected. However, a caution about the lower response rate for electric power generation facilities is in order. With the advent of deregulation, many electric power generation facilities experienced a large turnover in staff and an increased concern for confidentiality of financial information. Although we went to greater lengths than usual in our survey implementation to assure respondents of the confi-

Table 4 Mean and total economic impacts caused by zebra mussels, 1989–2004 by expenditure category

Expenditure category	Mean per facility with some type of expenditures	Estimated total for study area
Prevention efforts	$186,557	$87,308,676
Lost production and revenues	$124,110	$58,083,480
Chemical treatment	$63,049	$29,506,932
Planning, design, and engineering	$58,459	$27,358,812
Retrofit and/or reconstruction	$48,314	$22,610,952
Filtration or other mechanical exclusion	$22,061	$10,324,548
Monitoring and inspection	$21,398	$10,014,264
Mechanical removal	$13,897	$6,503,796
Nonchemical treatment	$9,786	$4,579,848
Research and development	$4,208	$1,969,344
Personnel training	$2,976	$1,392,768
Customer education	$1,831	$856,908
Other	$14,360	$6,720,480

Table 5 Mean economic impacts caused by zebra mussels, 1989–2004 by expenditure category, for drinking water treatment facilities with different capacities

Expenditure category	Mean per facility with some type of expenditures		
	≤ 1 MGD	2–10 MGD	≥ 11 MGD
Prevention efforts	$17,078	$59,144	$152,468
Lost production and revenues	$0	$1,453	$0
Chemical treatment	$26,618	$21,981	$64,736
Planning, design, and engineering	$17,429	$13,140	$85,934
Retrofit and/or reconstruction	$20,989	$30,283	$53,916
Filtration or other mechanical exclusion	$2,893	$2,906	$47,352
Monitoring and inspection	$17,615	$11,387	$27,388
Mechanical removal	$2,956	$4,567	$19,179
Nonchemical treatment	$211	$0	$0
Research and development	$11	$0	$8,173
Personnel training	$911	$1,780	$3,036
Customer education	$3,571	$94	$3,443
Other	$0	$0	$39,836

Note. MGD, million gallons per day

dentiality of their responses, it is likely that our lower response rates for these facilities can be attributed to this change in management culture. Thus, our findings (particularly economic impacts) regarding electric power generation facilities are more limited than for water treatment plants.

Based on our estimate of the total number of facilities affected, we estimated a cumulative economic impact to drinking water treatment and electric generation facilities in North America of $267 million between 1989 and 2004. The 95% confidence interval ($161 million to $467 million) was large primarily because of the wide range of estimates of economic costs. This $267 million estimate does not account for all costs related to the zebra mussel invasion because it does not include costs associated with other infrastructure impacts on industry and navigation, natural resources impacts such as those to fisheries, or economic impacts related to recreational boating and tourism.

The average costs per facility have remained steady in recent years at approximately $30,000 per year. This differs from costs in the early years, which were roughly $44,000 per facility per year. Since none of the estimates have been adjusted for inflation, the disparity between early years and more recent times is even greater. It is probable that more money was spent in earlier years cleaning out facilities that were infested and developing control procedures than in more recent years, in part because staff at many facilities have learned from earlier experiences at other facilities what to do and how to be more proactive. From discussions with

Table 6 Comparison of mean economic impacts caused by zebra mussels in 1989–1995 overall and by expenditure category for drinking water treatment facility respondents who responded to the 1995 survey vs. 2004 respondents

Expenditure category	Mean per facility with expenditures in that category	
	2004 survey respondents	1995 survey respondents[a]
Total	$261,311	$214,356
Prevention efforts	$248,306	IS
Lost production and revenues	IS	IS
Chemical treatment	$39,476	$194,421
Planning, design, and engineering	$76,883	$113,263
Retrofit and/or reconstruction	$93,776	$182,445
Filtration or other mechanical exclusion	IS	IS
Monitoring and inspection	$12,922	$11,435
Mechanical removal	IS	IS
Nonchemical treatment	IS	IS
Research and development	IS	IS
Personnel training	IS	$4,257
Customer education	IS	IS
Other	IS	IS
Avg. production capacity (MGD)	36.8	56.8

Note. IS, insufficient sample; MGD, million gallons per day.

[a] Source: O'Neill (unpublished data)

electric generation facility managers outside the context of this study, we learned that after the initial early years of trial and error control implementation, managers found that continuous chemical treatment was not needed to control zebra mussels, only periodic treatment. This would decrease the costs for those facilities. However, continuous chemical treatment still would be used in drinking water treatment facilities because the chemicals served other purposes besides zebra mussel control.

We found no difference in the rate of infestation of electric power generation versus drinking water treatment facilities but did find that drinking water treatment facilities were more likely to be implementing preventive measures and spending some money on control. Perhaps this is another case of electric power generation facilities being reluctant to report financial information. However, among facilities reporting spending money, it appears that electric power generation facilities were spending more per facility than drinking water treatment plants (but we could not substantiate this statistically due to small sample sizes for electric power generation facilities).

We also found that as facility size increases, so do costs. We demonstrated this by comparing drinking water treatment plants that produced more versus less than 10 million gallons per day. Larger plants' costs were three to five times greater than those of smaller facilities.

Comparisons of data from the current study for the time period 1989–1995 with data collected from the same time period by O'Neill (1997) show the current estimates ($146 million) to be much larger than previous estimates ($69 million). The difference is similar when comparing mean expenditures per facility for drinking water treatment plants (Table 6). (Comparisons could not be made for electric power generation facilities due to insufficient sample sizes.) Even though current survey respondents on average are associated with smaller facilities than 1995 survey respondents, the average cost per facility during the 1989–1995 time period was greater for current survey respondents. Some differences in the opposite direction appear by expenditure category; expenditures for 1995 survey respondents were greater than for 2004 survey respondents (Table 6). The differences in these numbers may be explained by the more complete listing of facilities obtained for the current study compared with the lists available in 1995.

Early predictions of the ultimate costs of the zebra mussel invasion may have been overblown (e.g., Roberts [1990] estimated $4 billion over 10 years in the Great Lakes, including impacts to sportfishing). Using data from the 1995 Sea Grant study (O'Neill 1997), our Sea Grant coauthor predicted impacts of approximately $1 billion, well in excess of the $267 million estimate from this study (and its associated confidence interval of $161 million–$467 million). Several reasons may explain this difference. First, as suggested earlier and borne out by our data, facilities infested in the early years had to spend more money cleaning out their facilities and developing control procedures than facilities that were infested later. Second, facility staff may have learned what to do from the earlier infested facilities and are being more proactive now and therefore spending less than originally anticipated. For example, an unanticipated cost savings came in the change from continuous to periodic chemical treatments for electric generation facilities. Third, zebra mussels did not expand into new waters, particularly smaller inland lakes, as rapidly as anticipated.

The discrepancy between the predictions of costs and the current estimates also may be explained by information gathered in the site visits. Interviewees noted how difficult it was to separate costs associated with zebra mussels from other costs as they completed the questionnaire. For example, chlorine is used to kill zebra mussels at many intake pipes. However, chlorine is used normally as a disinfectant even without concerns about zebra mussels, perhaps not at the mouth of the intake but at some point in the treatment process. Interviewees indicated that they did their best when completing the questionnaire, but the difficulties reported in distinguishing specific costs attributable to zebra mussels suggests uncertainty about the magnitude of ongoing maintenance costs that should be attributed to zebra mussels vs. other operational requirements.

The focus of research efforts on costs and control may now naturally shift to new invasive species. Clearly more are on the way (Mack and others 2000; Roberts 1990). Facility operators expressed concern about them, how they would control them, and what the costs will be. This analysis suggests that costs will most likely be highest in the beginning years of dealing with a new invader, then level off over time, and perhaps be incorporated as part of the ongoing maintenance budget for normal operations.

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