OHSU-TS-042
as a result of Ohio Sea Grant
Project R/ZM-012

Costs of Alternative Zebra Mussel Control Strategies: The Case of Great Lakes Surface Water Users. Proceedings Seventh International Zebra Mussel and Aquatic Nuisance Species Conference, January 28-31, 1997, Radisson Hotel, New Orleans, LA, co-hosted by Ontario Hydro and U.S. Army Corps of Engineers, Waterways Experiment Station.

DP0191

TS-042

Costs of Alternative Zebra Mussel Control Strategies: The Case of Great Lakes Surface Water Users

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proceedings from
7th International
ZM + ANS conference
Jan 28-31 1997
Radisson Hotel New Orleans LA

INTRODUCTION

In this study we assess the economic cost effectiveness of alternative zebra mussel control technologies and the level of damages remaining to (or the level of control achieved by) Great Lakes surface water users (municipal water treatment plants, electric generating utility or power plants and industrial facilities). As part of this assessment, we examined the cost of replacing chlorine with alternative control technologies to address environmental concerns about increased chlorine use. In addition, a sensitivity analysis of rates of return to zebra mussel research was conducted to examine returns to future zebra mussel research. Survey data obtained from surface water users in the Great Lakes basin, i.e., those drawing water from a Great Lake, a Great Lake tributary or an unconnected body of water within the basin, and researchers for 1989-94 provided the data base.

Economic methods of cost-benefit analysis comparing benefit streams over time and productivity of damage control inputs are relevant in estimating the potential productivity of new or improved zebra mussel control strategies. Empirical studies provide evidence supporting the contribution of research and development (R&D) to productivity improvement in both industry and agriculture (Norton & Davis, 1981, Mairese & Sassenou, 1991, Griliches, 1979, 1994). The Cobb-Douglas production function is usually the basic analytical framework for modeling the impact of R&D on productivity. A measure of R&D is treated similarly to the usual factors of production such as labor and capital. R&D investments contribute not only to increases of output but also to changes in cost of production. R&D may be cost-reducing or demand-stimulating through product quality improvement (Voon & Edwards, 1992, Unnevehr, 1986, Stranahan & Shonkwiler, 1986). Thus, the benefits of R&D can be evaluated in terms of cost savings.

In many empirical studies of pesticide productivity, pesticides have been treated as regular production inputs. The possible overestimate of pesticide productivity due to misspecification of the crop-pest function in these studies led Lichtenberg and Zilberman (LZ, 1986) to introduce the abatement function of the damage control input. LZ suggest that actual (realized) output is a combination of two components; potential output (the maximum quantity of a product obtainable from any given combination of inputs) and losses caused by damaging agents present in the environment. Then the productivity of damage control agents should be defined in terms of their contributions to damage abatement services. Damage control inputs act through an indirect mechanism on output. The benefit of pest control is to reduce output losses rather than to increase output.

Empirical studies of the damage abatement concept show that pesticide productivity has been overestimated in the past (Carrasco-Tauber & Moffitt, 1992, Babcock et al., 1992). Using a dual representation, Chambers and Lichtenberg (1994) generalize the concept of damage control technology in a multi-output model. The fact that damage control agents act indirectly through the damage abatement function on output and other inputs ensures that the control agents are separable from other inputs. Thus, the cost control function of damage control agents can be treated separably from output and other inputs It is this concept of damage abatement that we apply to estimating the effectiveness and efficiency of zebra mussel control technologies.

SURVEY DATA BASE

Two surveys provide the data base for this study: a survey of all water users we were able to identify in the Great Lakes water basin and a survey of a sample research investigators studying the zebra mussel and zebra mussel control.

Water user survey. Questionnaires seeking information about zebra mussel damages and zebra mussel control strategies were mailed to 1494 facilities with water intakes in the Great Lakes basin during November 1994. The initial mailing was followed up with two mailings, a reminder letter and a then second questionnaire with cover letter. Finally, a selected subset of facilities we identified as "probably infested" received a fourth mailing. Of these, 1412 were deliverable from which 420 surface water user respondents make up the data base (30%). An additional 165 respondents (12%) use water from wells or purchase water and are not used in the analysis.

A telephone follow-up of 100 non-respondents resulted in 70 contacts; the remaining 30 percent may no longer exist. The contacted facilities showed 79% surface water users compared to 72% of respondents, 44% electric power generating and municipal water compared to 57% of respondents, and 76% located on a Great Lake or Great Lake tributary compared to 82% of respondents. Reduction of the non-respondent base by 30% reduces the sample to 1164, and yields an adjusted response rates of 36% for surface water users and 14% for other water users, for a total response rate of 50%.

One hundred sixty respondents reported detecting zebra mussels at their facilities, of which 142 reported zebra mussel monitoring and control expenses of $60.2m during the period 1989-94. 86% of expenditures were reported by facilities located on a Great Lake. A simple projection to non-respondents based on the 50% response rate yields total monitoring and control expenditures of $120.4m during 1989-94.

Additional information was obtained through a telephone survey of 109 water users who did zebra mussel control. They were asked about their exact daily water usage, quantity of water treated, prices of control agents, the feeding rate of chemicals or cost per million gallons of water treated, and the contribution of each control technology to zebra mussel control if more than one control method was used.

Investigator survey. Using the zebra mussel reports prepared by Ohio Sea Grant, the abstracts of the 4th International Zebra Mussel Conference and other sources, 276 zebra mussel research investigators were identified and received a research questionnaire in early 1995. Each investigator received two additional mailings, a reminder letter followed by a second questionnaire with cover letter. Information was requested about research expenditures and new discoveries affecting zebra mussel control strategies. A total of 87 responses were received for a response rate of 32%. Of these 72 reported a research program.

Reported research project budgets totaled $18.7m, with 2 projects extending into 1998. The average project had a budget of $96,000 and a duration of 2.4 years. The typical investigator spent about 30% of their time on zebra mussel research. Based on the area of research and the goals stated by the investigators, we estimated that 58% of the research budget was devoted to basic research and 42% to application or testing of zebra mussel control technologies.

Zebra mussel research expenditures reported in 1994 totaled $3.6m, and investigator time totaled 18 person years (pys). We assume that average investigator compensation was $40,000/year and that no investigator time was compensated in the reported research budgets. This implies investigator costs of $0.77m, and total reported expenditures of $4.4m. For the cost-benefit sensitivity analysis reported in the last section, we assume that our respondent reports are 50% of the total work conducted in 1994, yielding a total 1994 research budget of $8.8m.

MODEL

The use of damage control inputs, such as pesticides, is widespread in agriculture and forestry. Since the late 1960s economists have made assessments of benefits of agricultural pest control. Pesticides have traditionally been treated as standard inputs and their productivity derived from standard production theory models (McCarl, 1981)

LZ's economic framework for estimating pesticide technologies recognizes the biological role of pesticides as damage-control agents. They consider both biological and physical processes with damage control agents. The distinctive role of damage control agents is in their ability to increase the share of potential output that producers realize by reducing damage from both natural and human causes. LZ's concept of damage abatement has two important implications for theoretical and empirical work. First, traditional production function specifications overestimate the productivity of damage control inputs. This upward bias is due to a misspecification of the shape of the marginal factor productivity curve of damage control inputs which decreases more rapidly in the economic range than the standard specification implies. Second, this specification offers more plausible explanations for changes in damage control agent productivity over time, such as the observed increase in pesticide use.

LZ proposed a damage abatement function $G(z)$ defined as the proportion of the destructive capacity of the damaging agent eliminated e.g., target pest population killed, by the application of a level of control agent z. They hypothesize that $G(z)$ will possess the properties of a cumulative probability distribution in the interval $(0,1)$: $G(z) = 1$ denotes complete eradication of the destructive capacity and $G(z) = 0$ denotes zero elimination of damages. $G(z)$ is monotonically increasing and $G(0) > 0$ implies that destruction is not necessarily total when $z = 0$. The derivative of $G(z)$ with respect to z, i.e., $g(z)$, represents marginal damage control effectiveness or marginal productivity. It is the density of $G(z)$. The output Q can be specified as a function of direct inputs, X, and damage abatement $G(z)$. The production function $F(.)$ is assumed to possess the standard properties of concavity in (X,G).

Duality of Damage Abatement

Chambers and Lichtenberg (CL, 1994) generalize LZ's damage-control technology to a multioutput technology. The generalized LZ model's dual representation is then derived and applied to aggregate U.S. agricultural data. They suggest that the dual representation with the indirect profit function permits the specification of a more flexible representation of the damage-control technology and show that the dual is conditionally additive in the price of abatement activities and other prices, a property that is critical to this study given the limited data on zebra mussel control cost, prices of control agents, facility revenues and facility characteristics.

LZ's specification of damage abatement requires that the damage control agent act indirectly through the damage abatement function on output and thus on other inputs. In the dual presentation it requires that the effects of perturbations in pesticide prices manifest themselves on outputs and other inputs only through adjustments in abatement $g(z)$. Also, changes in output prices and input prices only manifest themselves on pesticides input as induced adjustments to changes in abatement.

The survey provides limited data on zebra mussel control costs, prices of control agents, water volume, revenues and facility characteristics. Data on quantities and prices of output and other inputs were not obtained. The dual indirect cost function allows a flexible specification of factor demand for control agents and a flexible specification of the cost function of zebra mussel control by including prices of control agents. The separability of the control agents from other inputs is ensured by LZ's damage abatement specification and CL's dual representation of LZ's dual abatement technology. For purposes of this study, we must assume that firms use similar production technology with constant returns to scale. Of four functional specification of G(z) suggested by LZ, we choose the exponential function as the only function which does not overestimate pesticide productivity and as the only function which is empirically tractable with the data from the survey.

In the statistical damage abatement model, zebra mussel control cost is a nonlinear function of 1) prices of control agents, 2) share of each control agent in damage abatement, 3) facility revenues, and 4) whether chlorine was used before zebra mussels, where control cost is the average of the sum of physical cleaning and thermal costs, chemical costs, and annual depreciation expenses of associated equipment for 1992, 1993 and 1994; prices are the costs of chemicals ($/lb) (for physical and thermal it is the cost divided by volume of water treated); the shares are the percent contribution of each control agent to the total control costs of zebra mussels with a sum equal to one; facility revenues are actual revenues for electric utilities and industrial facilities (for water plants revenues are estimated as the product of water volume and a single average price calculated from price per unit volume data obtained for selected facilities); and a dummy variable m = 1, if chlorine was used prior to zebra mussel infestation, and = 0 otherwise (Deng, 1996 pp. 49-61).

Sensitivity Analysis of Research Returns

Given the short experience with the zebra mussel, it is not possible to compile an empirical data base on changes in zebra mussel control costs over time and conduct a fully-developed cost-benefit study. Instead, a sensitivity analysis on potential returns to zebra mussel research was conducted on a series of if-then alternatives using a cost-benefit framework. We estimate annual zebra mussel control costs for Great Lakes basin water users and apply reasonable parameters for discount rate, time horizon, and expected annual cost to estimate the discounted present value of alternative scenarios.

RESULTS

Costs of Zebra Mussel Control

Cost functions of zebra mussel control, using the damage abatement concept developed for estimating the effectiveness of agricultural pesticides and herbicides, were estimated for a subgroup of water treatment plants and a subgroup of electric utility and industry plants that were zebra mussel infested. From the survey data and a telephone follow-up with 109 responding facilities to obtain more accurate data on water capacity and per unit chemical prices, we assembled data bases for 62 water treatment plants and 47 utility and industry plants. The average water treatment plant had water revenues of $47.4m and zebra mussel control costs of $25,500, while the utility and industry plants had average revenues of $229.3m and control costs of almost $105,000.

Water treatment plants were using three treatment technologies: physical cleaning, chlorine and potassium permanganate (PP). Electric utility and industry plants were using physical cleaning (including two cases of thermal), chlorine, biocides and bromine (three cases of sodium bisulfate were not included in the model).

The simulated cost of replacing chlorine by PP in water treatment plants was $13,258 per facility if the plant was using chlorine prior to the zebra mussel infestation and purchased PP explicitly to control zebra mussels. Most of the plants using chlorine were using it prior to arrival of the zebra mussel and the marginal or additional cost of using chlorine to kill zebra mussels was very small. If such a plant wanted to use PP for zebra mussel control but retain chlorine for water purification, the cost of PP is substantial. For water plants which adopted chlorine explicitly to kill zebra mussels, the cost of using PP as an alternative resulted in small simulated savings of $1,612 per facility.

For electric utilities and industry, biocides or bromine were the primary alternatives to chlorine. Replacing chlorine by biocides or bromine resulted in lower simulated control costs of $21,792 and $26,067 per facility, respectively. If chlorine control were replaced entirely by physical cleaning, simulated costs increased by $3,774 per facility. In both subgroups, the results are subject to the caution that the substitute technologies may not be feasible at a particular facility.

The significant conclusion from these simulated cost function estimates is that elimination of chlorine for zebra mussel control will not impose high costs on surface water using facilities.

The cost function estimates also showed that both subgroups of surface water users had achieved very high levels of damage abatement, which is necessary for an effective control strategy. The percent damage, which is also equal to output loss, was estimated at 0.013% for water treatment plants and 0.0045% for electric utilities and industry, implying abatement levels of 99.987% for water and 99.9955% for utility and industry. Further abatement of zebra mussel damages in these facilities would be costly. Zebra mussel research on alternative control cost reduction technologies is expected to be more beneficial. In other words, current technologies kill nearly all zebra mussels in a facility. The biggest gains will come from new ways to kill them in less costly ways, and not from finding ways to kill a larger percent of them.

Potential Research Returns

For the sensitivity analysis, estimates of annual zebra mussel control costs and annual research expenditures were needed. For Great Lakes facilities, annual zebra mussel control costs of $30m were estimated for 1992, 1993 and 1994. It is assumed that this is a maximum cost level from which control expenditure reductions due to research occur. Cost reductions can occur either from more efficient use of existing technologies or from new less costly technologies.

Zebra mussel research expenditures are estimated at $8.8m for 1994, and assumed to remain at that level into the future. Discount (interest) rates of 3% and 6% and time horizons of 10 and 20 years are used. Annual control cost reductions of 2, 3 and 5% are tested. The sensitivity analysis focuses on the annual percent reduction in zebra mussel control costs required to justify annual research expenditures of $8.8m into the future.

To calculate the present value of the $8.8m research expenditures, we incorporate the information that 58% of the research budget was for basic research and 42% for testing of control technologies. We assume that there is a 5-year lag for basic research to be incorporated into control technologies while applied research results are utilized with a one-year lag (Stranahan and Shonkwiler, 1986, Griliches, 1994). This compounding of basic research costs 5 years into the future results in the present value of the $8.8m research expenditures with a 3% discount rate of $9.68m (Table 1), and with a 6% discount rate of $10.70m (Table 2).

At a 3% discount rate and a 20-year time horizon, a 3% annual zebra mussel control cost reduction for Great Lakes basin surface water users will justify continuing research expenditures of $8.8m for 11 years (Table 1). The estimated annual zebra mussel control cost is lowered to an estimated $21.43m. At 5 percent control cost reduction per year, research expenditures of $8.8m ($9.68m present value) are justified for 17 years, while at 2 percent they are not justified for any period.

If inclusion of inland surface water user control costs should double annual control costs to $60m (this is a guess), then a 2% annual control cost reduction justifies the current level of research expenditures using a 6% discount rate and 20-year time horizon for at least 17 years (a higher discount rate results in a smaller present value of the stream of cost savings over the 20-year period), see Table 2. The remaining annual zebra mussel control cost is lowered to $43.5m. At 3 percent and 5 percent annual cost reductions, research expenditures of $8.8m ($10.7m present value) are justified for more than 20 years.

Table 1: Discounted annual present value of the benefit stream for base control cost = $30 million, discou rate = 3 percent, and 20-year time horizon for 2%, 3% and 5% cost reductions per year, and the annu cost of zebra mussel control remaining, for selected years.

Yr.	2% Red.	Cost Remaining	3% Red.	Cost Remaining	5% Red.	Cost Remaining	Research Cost
1	9.19		13.79		22.98		9.68
5	8.58	27.11	12.26	25.73	18.70	23.2	9.68
10	7.82	24.50	10.43	22.10	14.55	17.96	9.68
11			9.81	21.43			9.68
15	7.05	22.15	9.04	18.99	11.19	13.90	9.68
17					10.11	12.54	9.68
20	6.28	20.05	7.66	16.31	8.73	10.75	9.68

Table 2: Discounted annual present value of the benefit stream for base control cost = $60 million, discount rate = 6 percent, and 20-year time horizon for 2%, 3% and 5% cost reductions per year, and the annual cost of zebra mussel control remaining, for selected years.

Yr.	2% Red.	Cost Remaining	3% Red.	Cost Remaining	5% Red.	Cost Remaining	Research Cost
1	14.59		21.88		36.47		10.70
5	13.62	54.22	19.45	51.46	29.67	46.44	10.70
10	12.40	49.00	16.55	44.20	23.10	35.92	10.70
15	11.19	44.30	14.35	37.98	17.75	27.80	10.70
17	10.70	43.54					10.70
20	9.97	40.10	12.16	32.62	13.86	21.50	10.70

CONCLUSIONS AND IMPLICATIONS

Four primary conclusions of this study can be drawn. First, for water systems and electric utility and industry surface water users, effective and cost efficient zebra mussel control strategies exist. Second, effective and cost efficient non-chlorine zebra mussel control strategies exist for both municipal water and utility and industry. Potassium permanganate, where it can be used, provides effective zebra mussel control. In addition, other treatment technologies which can be used by water systems have come on the market since this data base was collected. Biocides are effective for the electric utility industry. Third, the average level of control achieved by zebra mussel control strategies exceeds 99.98% for both groups of facilities. This result is important because it provides further support that zebra mussel control technologies are effective. It further suggests that future research focus on less costly ways to kill zebra mussels; current technologies kill nearly all of them in cost effective ways.

Finally, simulation of reasonable annual cost reductions in zebra mussel control from further research supports future zebra mussel control research at current levels if this were the only benefit of the research. I recommend that zebra mussel research and outreach funds be focused on basic research to further understand the zebra mussel and its effects on the ecosystems it invades. While further cost reductions to surface water users are valuable, these results suggest that more efficient use of current technologies will be marginally profitable at best, and that major reductions in control costs are more likely to emerge from better understanding of the biology of the zebra mussel. In addition, research on emerging ecological impacts of the zebra mussel, such as 1) increased growth of blue-green algae which affect the taste of water, 2) changes in fish community structures which will affect recreational fishing, and 3) other changes in water quality, is likely to generate larger research payoffs than a focus on killing zebra mussels in power plants, water systems and industrial cooling water.

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