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Understanding the Importance of Dreissenid Mussel Mitigation in South Dakota

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UNDERSTANDING THE IMPORTANCE OF DREISSENID MUSSEL MITIGATION IN SOUTH DAKOTA

by

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ABSTRACT

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Since 2014, dreissenid mussels have been established in South Dakota, spreading throughout the state. These invasive mussels can be vastly detrimental to an environment and completely disrupt the balance natural systems they invade. In South Dakota, a state that relies heavily on land and resource use for some of the state's major economic drivers, such as agriculture, hydropower, and tourism, the issue could be incredibly harmful if left uncontrolled. The mussel's impacts reach from increasing rash-causing bacteria in lakes and rivers to damaging critical infrastructure within dams. To understand the importance of the issue further, this paper explores the potential impact the infestation of the mussel may have to different stakeholders by using developed surcharges based on current observed costs and the use of USGS data. After examining the potential costs and impacts to industries around the state, this paper explores the current spread of dreissenid mussels in South Dakota, current policies, and government responses around invasive mussel mitigation throughout the region.

KEYWORDS: dreissenid mussel, zebra mussels, South Dakota, invasive species, economic impact

The members of the Honors Thesis Committee appointed

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INTRODUCTION

Invasive species can have profound effects on the environment they inhabit. The disruption of the balance of an ecosystem due to an invasive species can cause wreckage within the environment, harming the organisms around them. This can happen through changes in the food chain, the introduction of new diseases, and crowding out native life. However, the impact can extend beyond the systems that have first contact with the species. Every year, invasive species cost billions of dollars to economies across the world, with some estimates putting the cost as high as $1.288 trillion over the last 50 years (Zenni, R.D. et al. 2021). This cost accumulates in many different ways. One example is direct damage, such as degrading infrastructure, and another example is just the cost that accompanies measures taken to control and mitigate the species. Though invasive species are a major threat to biodiversity, their impact is far-reaching in our economies, especially in areas where reliance on land-used-based activities, such as agriculture and tourism, is high (Zenni R.D. et al. 2021).

South Dakota derives a high amount of the state's economic output from agriculture, with a report from the governor attributing about 32.1 billion to the economy or about 30% of total output coming from agricultural industries (South Dakota Governor, 2022). Environmental disruptions that would impede agricultural land use would negatively impact the farmers and ranchers that cover the state and contribute to this output, not to mention the many businesses that provide services to support agricultural operations, such as veterinarians, grain elevators, and mechanical services. Additionally, South Dakota relies on environmental resource use for energy generation, with hydroelectric power generation being a large proportion of total energy creation and consumption in the state (US EIA, 2023). Through these disruptions, the importance of protecting our environment from invasive species stretches beyond ecological concerns and establishes cause for economic concern.

This study will focus on the dreissenid mussel, sometimes called the zebra mussel, which is an invasive species in South Dakota. They are small, fingernail-sized mollusks that were originally found on the continent in Michigan during the late 1980s, likely arriving on ships from Eastern Europe. With the ability to produce up to one million new mussels per year and no natural predators in the domestic waters they infest, their spread across North America has been rapid (New Hampshire Department of Environmental Services, 2019). When waterfowl or watercraft enter a body of water infested with the mussels, the mussels can attach themselves to the structure. When attaching to a structure, the mussel secretes fibers which allow them to securely bind to materials like stone, wood, iron, plastic, PVC, and more. From there, they can form hard layers which can get several feet thick. The veligers (larva) may be harbored in any extra water retained on a watercraft, such as in live wells or engine cooling water. If the contaminated structure is to enter into another body of water, it risks transporting the rapidly reproducing species and furthering the spread (New Hampshire Department of Environmental Services, 2019).

This thesis aims to look at how a dreissenid mussel invasion might impact areas of a regional economy by using USGS data and an understanding of the costs associated with typical mussel mitigation strategies. The threat of dreissenid mussel invasion is of concern to many different groups, some of which will face adverse economic impacts with continued infestation. Understanding the impact that invasive species can have on economies and providing the information needed to make data-based decisions is helpful to those in charge of forming strategies going forward, such as policymakers or land management agencies. Though the nature of environmental issues can be complicated, as they are not strictly bound by geographical boundaries, region-wide estimates can help to encourage local action as well as collaboration between stakeholders (Crystal-Ornela, R. et al. 2021).

BACKGROUND

Invasive dreissenid mussels were first detected in South Dakota in 2014 in the Lewis and Clark Lake located near Yankton. This was unsurprising, as bordering states had been fighting to slow the spread of the mussels for some time before the initial detection in South Dakota. In response, South Dakota's Department of Game, Fish, and Parks increased both the number of staff stationed near bodies of water and their testing rates. Soon after, it was reported that the mussels had spread from the first point of detection up the Missouri River, hitting Gavin's Point Dam and McCook Lake (Detres, 2021). Most recently, there have been detections in the Big Sioux River and the Pactola Reservoir, which is in the Black Hills of South Dakota, over 300 miles from their state origin point (Thompson, 2022).

Estimates about the potential damages caused by an invasive species can create a clear picture of the financial implication of nonaction. This can further help inform what course of action is appropriate and how it will be delivered. Decision makers can weigh the costs and benefits and then choose which paths delivers the most value to stakeholders. Further, estimates can highlight how resources to address an issue should be allocated by identifying key industries among given stakeholders in order to maximize effectiveness or order of control. Cost estimates are also the first step to informing proper planning and budgeting, making sure that future projects have a criterion to create timelines and constraints. This is important for long term management plans, accounting for immediate and future costs for an issue that isn't a one-time fix. Estimates can even inform areas of uncertainty, acting as a financial compass for fiscally responsible choices (Ryder et al., 2009).

Concerning dreissenid mussels the importance becomes even more prevalent. Knowing what the costs may be can impact performance measures like boat inspections and other methods used to control the spread of the mussel, as opposed to accepting the much higher annual costs once established. Examining the potential damage to infrastructure, such as in fisheries and power generators, there is further justification for control efforts which is important for South Dakota state government officials, who seek to spend taxpayer money responsibly while also protecting their interests (South Dakota Governor, 2022). Additionally, as will be explored in the report, different mitigation methods come with different expenditures. The tradeoffs between mitigation methods like chemical and physical removal are different and are appropriate for different situations (Nelson, 2019, Nelson, 2022). The importance of resource intensive industry in South Dakota makes the threat of dreissenid mussel invasion of importance to many across the state (South Dakota Governor, 2022). Knowing the potential costs of the mussel could inspire public advocacy or grassroots initiatives.

This project looks to evaluate what the possible costs of dreissenid mussel mitigation will be given an identified set of stakeholders. The initial model, Nanette

Nelson's 2019 study titled, "Enumeration of Potential Economic Costs of Dreissenid Mussel Infestation in Montana," estimated costs by looking at water withdrawals and assuming high levels of infestation, as is seen in the Great Lakes in Michigan. This study pulled on existing knowledge of reported mussel mitigation rates from areas that handle the issue to develop a per Mgal surcharge rate. However, this model overestimated actual costs in South Dakota because of discrepancies in the dispersion of the mussels, the chosen mitigation strategies, and the scale of facilities in existing reports. A follow-up study by Nelson developed a survey to acquire additional data from South Dakota Stakeholders to understand actual infestation levels and mitigation practices (Nelson, 2022). This allowed for a more accurate picture of dreissenid mussel mitigation with numbers informed by actual practices. In this report, these informing case studies as well as information from current knowledge about dreissenid mussels are examined, such as how they may impact recreation and tourism. Documentation of dreissenid mussel spread in South Dakota and the current policies in place to manage the issue are explored to further understand what is most at risk by the continued spread of dreissenid mussels.

DATA & METHODS

To measure the impact that dreissenid mussel colonization could have through the use of surface water, stakeholders were identified through USGS water withdrawals in South Dakota. These were further divided by county to understand the impacts on both east and west of the river in South Dakota, who's varying resources mean differing importance of stakeholders. The United States Geological Survey (USGS) system gathers water-use information in the United States every five years, with the most recent data available being from 2015. This data is also available individually by state and county which can work to create a complete picture of our water use. Water withdrawals can be from either ground or surface water sources and can be used for a variety of different reasons. Since dreissenid mussels cannot infest groundwater, only surface water withdrawals are relevant to this paper. Categories in this data include public supply, irrigation, livestock, thermoelectric, mining, industrial, and aquaculture (USGS, 2015). These are our identified stakeholders. It is worth noting that this data is only helpful for consumptive uses of water, meaning once the water has been used no other parties can use it. However, there are ways that water contributes to our economy without leaving the system, such as enhancing property value, fishing, tourism, and property tax revenue (Nelson, 2019).

A study by Nanette Nelson in 2019 examined the potential costs of dreissenid mussels in Montana by compiling data from regions facing infestation and mitigation of mussels in given USGS categories to understand how current applications operate and what the associated costs are. This data was based on the assumption that dreissenid mussels would colonize all exposed water bodies in Montana at the highest observed level. More specifically, these levels were drawn from observations of population levels in the Great Lakes. This structure emulated a "worst case scenario," with the situation reaching its height (Nelson, 2019). South Dakota's reliance on agricultural output brings a higher importance to this data, as opposed to states with a non-water-intensive industry (Zenni R.D. et al. 2021). The design of Nelson's study allowed other states to easily use their respective water use data to estimate potential costs (Nelson, 2022). This is due to the "per volume" organization of the data, allowing for the generalization of both location and scale.

South Dakota's Department of Game, Fish, and Parks tested the economic model and found that dreissenid mussel colonies were localized along the Missouri River, not throughout the length of the state. This led to the resolution that the worst-case scenario model would be sub-optimal for management decisions going forward (Nelson, 2022). In a 2022 report titled, "Ground Truthing Assumptions Used in Developing an Economic Damages Model of Dreissenid Mussels," Nelson collected additional data to understand how the magnitude of facilities and operations may impact the costs of mitigating mussels. Because the condition of mussel infestation can range from only veligers to adult mussels, and then in a range of concentrations, this adds additional complications in estimating costs. The report developed a survey to understand the state of mitigation strategies among irrigation and water treatment facility information, level of infestation, and presently incurred costs. These were then sent to appropriate stakeholder groups provided by South Dakota's ANS coordinator.

By adding more information to the first model, it was found that issues like the lack of mussel cost tracking, varying facility size, and dispersion among stakeholder groups add layers to estimating the cost of dreissenid mussel mitigation. The worst-case scenario model had cost estimates higher than what stakeholders are currently incurring, however, the structure of the original study held true, and the application of locating stakeholders and creating a per-volume estimate are maintained (Nelson, 2022). The responses allowed for more information about the current presence of the mussels and the actual application of mitigation methods explored in Nelson's 2019 report to shape more accurate predictions of costs. The data used in this paper uses the adjustments that the 2022 report provided, giving a more accurate picture of the costs associated with dreissenid mussel mitigation.

Public supply, thermoelectric, mining, industrial, and aquaculture all have the same surcharge rate, \$26 per million gallons. This was developed by annualizing the reported costs to water treatment plants and their average daily water withdrawal. The number includes the cost of increased chemical use, as controlling the mussel means using more chemicals overall, sometimes at multiple steps of the treatment process. Some water treatment plants also used a copper ion generator, which put costs at \$27 per million gallons, but the lower number was used for the offshoot categories of public supply. Irrigation and livestock numbers were generated from the reported costs to irrigators because the same equipment is used for both stakeholders. It was found that they used manual labor to physically unclog their sprinklers or pump systems or install screens and the estimated costs were about \$1.85 in lost labor per acre feet of water, or \$5.67 per million gallons. Currently, no operations in South Dakota are using chlorine to control mussel in irrigation systems. Unlike the other explored categories, hydroelectric power does not use USGS data. Instead, it was found using annualized costs per generator taken from the increased costs to maintenance and costs of control methods, like strainers and foul release coating, amounting to \$61,574 per generator from reporting facilities (Nelson, 2022). Hydroelectric plants also face more unplanned outages and downtime, which have lost revenue associated with it. To estimate this, a 2% and 10% reduction of the total hydropower energy generation in 2013 were multiplied by the average market price of a MWh of energy (Nelson, 2019). Because methods and strategies aiming to mitigate dreissenid mussels are tailored according to the situation at hand, potential specific mitigation procedures are described further in their correlated section.

Case studies about the potential economic impact of an invasive species on various stakeholders can help to provide information for those looking to make decisions based on informed benefit-cost analyses. In the case of dreissenid mussels, the way in which water is used for the stakeholders given through USGS data provides a relatively straightforward investigation, allowing those looking to understand the impact of an invasive species through a broad economic lens to capture a picture of an issue that requires state attention. A broad, even national, investigation can lead to valuable information about how surveys or models should be designed (Crystal-Ornela, R. et al. 2021). This can be supplemented with other significant local data to narrow parameters, such as identifying key economic sectors, patterns of water use, or size. However, the issue can also vary based on the biological specifications of a region, which may be expressive of the initial rejection of Nelson's 2019 study by South Dakota's Department of Game, Fish, and Parks.

Table 1. Total Average Daily Surface Water Withdrawals

	Withdrawal (Mgal/d)		
Category	Statewide	East River	West River
Irrigation	71.2	51.4	19.8
Thermoelectric	2.4	2.4	0
Public Supply	24	11.4	12.6
Livestock	28.6	19.2	9.4
Mining	5.1	1.3	3.8
Aquaculture	24.9	8.5	16.4
Industrial	6	6	0
Domestic Self Supply	0	0	0
Total	162.2	100.2	62

RESULTS

PUBLIC SUPPLY

South Dakota only sees about 9,000 million gallons of surface water withdrawn each year for public supply use. This is because the vast majority of water treatment plants in South Dakota draw on groundwater. However, there are two plants that report encountering dreissenid mussels in their surface water withdrawals (Nelson, 2022). Should dreissenid mussels contaminate a water treatment facility, they can attach to pipes and restrict flow, as well as damage screens, pumps, and valves, disrupting normal operations (Chakraborti et al., 2016). Further, the mussel can alter the color or smell of treated water, calling for additional treatment for aesthetic purposes. To avoid these issues, facilities can use chemical and physical mitigation strategies or both, which were theorized to be about $44-$56 per million gallons annually. This was based on data collected from ten, 1-Mgal/d, water treatment plants who are actively managing the mussel, aiming to calculate the annual costs from both chemical injection and additional operation and maintenance costs (Chakraborti et al., 2016, Nelson, 2019). However, because the reporting plants in South Dakota are almost three times the size of the facilities examined in that study (average of 3-3.23 Mgal/d), they incurred lower costs as the scale and capacity were larger (Nelson, 2022). This is reflected in the table below.

Presently, not many water treatment plants in South Dakota utilize surface water withdrawals for public water supply purposes. However, legislation from 2024 indicates that numbers may increase due to the growing demand for water in the southeast part of the state, which will be supplemented by water taken from the Missouri River. A Senate

Joint Resolution approves the Lewis and Clark Regional Water System to take an additional 19,121 acre-feet each year (Senate Joint Resolution 502, 2024).

Table 2. Potential Annual Mitigation Costs to Water Treatment Plants Using Copper Ion Generators

	Annual Withdrawals (Mgal/year)	Mussel Mitigation Cost (per Mgal)	Annual Costs
State Total	8749.05	$26.00	$227,475.30
East River	4168.3		$108,375.80
West River	4580.75		$119,099.50

Table 3. Potential Annual Mitigation Costs to Water Treatment Plants Using Chemical Injection

	Annual Withdrawals (Mgal/year)	Mussel Mitigation Cost (per Mgal)	Annual Costs
State Total	8749.05	$27.00	$236,224.35
East River	4168.3		$112,544.10
West River	4580.75		$123,680.25

IRRIGATION AND LIVESTOCK

In 2015 there were 71.2 million gallons per day (or 79,807 acre-feet per year) in surface water withdrawals for the purpose of irrigation. This is likely largely for agriculture purposes, however, the figure could also include irrigation for the purpose of maintaining other green spaces, such as golf courses. Mussels can damage the efficiency of, or preclude the work of, pumps, pipelines, sprinklers, emitters, gates, pipe and siphon tubes, and stock watering systems (BC Ministry of Water, Land and Resource Stewardship, 2023). The settlement of mussels in pumps could increase overall wear and require more frequent maintenance or replacement of the system. These issues also impact ranchers who use similar systems to draw water out for the purpose of maintaining livestock (Nelson, 2019). Withdrawal for this purpose totaled 28.6 million gallons per day or 32,057 acre-feet per year. In the Coachella Valley Water District, which provides water for irrigation purposes in California, chlorine is added to the water stock to prevent the mussels from colonizing and damaging irrigation infrastructure. This allows them to manage them from the source point relative to the pumps and other equipment and is considered the most suitable. This additional maintenance causes Coachella Valley Water District to administer a mussel mitigation surcharge to their users, which has ranged from around $2.78 to $5.75 (Nelson, 2019). Given the different types of irrigation methods available, such as flood irrigation strategies which would call for physical methods of removal, there is a range of costs that could incur depending on the proportion of irrigation strategies in South Dakota (Nelson, 2019).

The reported costs derived from the survey administered to irrigators across South Dakota in Nanette Nelson's 2022 report, titled, "Ground Truthing Assumptions Used in Developing an Economic Damages Model of Dreissenid Mussels," assert that, presently, the actual costs incurred do not come from chemical mitigation (the use of chlorine). They are derived from the time spent plugging and unplugging sprinklers and the installation of screens. This lowered the predicted costs of $2.78 to $5.75 to around $1.85 per acre-foot or $5.67 per million gallons. This, combined with USGS data, is expressed in the graph below.

Table 4. Potential Annual Mitigation Costs to Farmers Using Sprinkler Irrigation Systems

	Annual Withdrawls (acre feet/year)	Mussel Mitgation Rate (Per acre feet, b)	Potential Costs
State total	79,807.1	$1.85	$147,643.14
East River	57,613.6		$106,585.16
West River	22,193.6		$41,058.16

Table 5. Potential Annual Mitigation Costs to Ranchers

	Annual Withdrawals (Mgal)	Mussel Mitigation Rate (per Mgal)	Potential Costs
State Total	10439	$5.67	$59,189.13
East River	7008		$39,735.36
West River	3431		$19,453.77

THERMOELECTRIC, MINING, INDUSTRIAL, AND AQUACULTURE

Because they are likely to have similar mitigation methods and strategies, these categories are reviewed together. Thermoelectric energy creation includes the boiling of water to spin a turbine after which water is used for cooling purposes (Nelson, 2019). USGS data marks 872 million gallons as withdrawn in South Dakota for this purpose. Coal, natural gas, or oil are burned in the initial process, which together are responsible for about 15% of total electricity generation in South Dakota as of 2021 (U.S. Energy Information Administration, 2023). 1,846 million gallons were withdrawn for use in the mining process, the specifics of which vary depending on the substance being mined. There are several active mines in South Dakota, the majority being for sand and gravel mining, and many claims/permits have been filed for future mining opportunities in the state (South Dakota Department of Agriculture and Natural Resources, 2024). Industry use of water was 2,204 million gallons during the data period and could be used for any number of reasons, including the production of wood products. Aquaculture facilities provide fish for either stocking or consumptive purposes. There are three active fish farms in South Dakota operated by either state or private entities (North Central Regional Aquaculture Center, 2022). In total, 9,084 million gallons of surface water were used for aquaculture purposes in South Dakota during 2015 (USGS, 2015). Because of the likely similar use of chemical methods, and higher operation and maintenance costs, the costs used in estimating these potential economic damages were the same as used by Nanette Nelson in her 2019 study concerning the economic impact of dreissenid mussels in Montana to determine the damage to water treatment plants (Nelson, 2019). The survey which added local data to her original model helped adjust the numbers to $26-$27, as was discussed above (Nelson, 2022). The $26 per Mgal cost is reflected in the graphs below.

It is worth noting that it was uncovered in the survey administered in Nelson's 2022 report that the costs between these categories do seem to vary. Though intake and use look relatively the same for these categories, as they rely on water treatment plants, the categorization and tracking of dreissenid mussel mitigation strategies looks different. For example, respondents for aquaculture were reporting incurring up to $57 per Mgal for the purposes of mussel mitigation while reporting industrial facilities cited $2 per Mgal. This variation could be the result of many different reporting errors, such as the fact that many steps taken to mitigate the mussels become a part of regular maintenance costs as time goes on (Nelson, 2022). To avoid this, more collaboration and documentation could be useful to track how the issue is managed over time.

Table 6. Potential Annual Mitigation Costs to Thermoelectric Facilities

	Annual Withdrawals (Mgal)	Average Cost (per Mgal)	Annual Costs
State Total	872.35		$22,681
East River	872.35	$26	$22,681
West River	0		0

Table 7. Potential Annual Mitigation Costs to Mining Operations

	Annual Withdrawals (Mgal)	Average Cost (per Mgal)	Annual Costs
State Total	1846.9		$48,019
East River	456.25	$26	$11,863
West River	1390.65		$36,157

Table 8. Potential Annual Mitigation Costs to Industrial Facilities

	Annual Withdrawals (Mgal)	Average Cost (per Mgal)	Annual Costs
State Total	2204.6		$57,320
East River	2204.6	$26	$57,320
West River	0		0

Table 9. Potential Annual Mitigation Costs to Aquaculture

	Annual Withdrawals (Mgal)	Average Cost (per Mgal)	Annual Costs
State Total	9084.85		$236,206
East River	3087.9	$26	$80,285
West River	5996.95		$155,921

HYDROELECTRIC POWER

There are five hydropower facilities in South Dakota with 28 generators between them, four of which are major facilities along the Missouri River (US EIA, 2023). The fifth is a small facility located in Spearfish, South Dakota (Consumer Energy Alliance, 2019). Together, they produced 29% of South Dakota's electricity in 2022 (US EIA, 2023). Because of the placement of these dams, it makes more sense to talk about them as a group rather than divided by East and West River. Among other equipment, the intake structures, gates and valves, cooling water systems, service and domestic water systems of hydroelectric plants are at risk of damage from mussel colonization (Boyd, 2016). According to the Army Corps of Engineers, since the discovery of mussels in several hydroelectric facilities, they have clogged up, "powerhouse raw water systems, generator air cooler and thrust bearing oil coolers," and due to this, "the dam must take frequent outages in order to rid the raw water system of the invasive species. These increased outages result in decreased power generating potential" (Detres, 2021).

The costs associated with the implementation of ultraviolet light to address internal components by a facility along with the use of foul-release coating are reflected in Table 10, using both estimates derived from reports of estimated from Davis and Hoover Dam, confirmed by information from responses to the survey (Nelson, 2019, Nelson, 2022). These methods are known to be used in some capacity at both the Gavin's Point Dam and the Big Bend Dam. It is worth noting that the number of generators has been found to be a poor predictor of mussel control costs (Detres, 2021, Pucherelli et al., 2021). However, neither of these methods considers the lost revenue from the time taken to perform physical mitigation methods, operation, and maintenance. In 2013, there were about 10 million megawatt hours of hydroelectric power generated in South Dakota (National Hydropower Association, 2013). The average price for a MWh for hydropower electricity was $45 in 2020 according to the US Department of Energy (Uria Martinez, 2023). In Table 11, the revenue lost during the time the hydropower generation is stopped is estimated at an assumed reduction of two percent and ten percent, providing a snapshot for potential losses from the hydroelectric power generation industry.

Table 10. Annualized Mitigation Costs for Hydropower Facilities

Total Capital Costs ($)	Total O & M Costs ($)	Total Annualized Costs ($)	Total Annualized Costs per Generator	Potential Costs for South Dakota Generators (x28)
$67,326-$1,305,000	$0-$269,000	$35,934-$402,852	$4,492-$134,284	$125,776-$3,759,952

Table 11. Potential Annual Mitigation Costs for Hydropower Facilities from Additional Generator Downtime

	2013 Net Electric Generation (million MWh)	Reduction in Energy Generation (MWh)	Market Price (MWh)	Lost Revenue
Lower Bound Estimate -2% reduction in generation				
State Total	10.4	207,159	$45	$ 9,322,155.00
Upper Bound Estimate -10% reduction in generation				
State Total	10.4	1,035,795	$45	$ 46,610,775.00

COST SUMMARY

The table below outlines the costs determined from stakeholders evaluated through this paper. The total potential cost of dreissenid mussel mitigation in South Dakota could be roughly $10 to $50 million annually. Though each stakeholder will incur costs, the largest areas are water treatment, aquaculture, and hydroelectric facilities, particularly concerning lost revenue. Possible dispersion of USGS water withdrawals across the state may also change how these results are viewed; for instance, though there are only $23 thousand potential costs to thermoelectric facilities, this might directly impact only one or two businesses. Some stakeholder groups had more information available than others, and this has no doubt expressed costs correlated with specific mitigation options. The results have been broken down between East River and West River through the paper to understand the costs at a more local level, possibly informing distribution of costs and recognizing agricultural patterns. Actual costs could depend on factors not accounted for in this report, such as operating conditions or scale, choice of mitigation strategy, and complexity of the invasion. Further, the impact on recreation, tourism, and property values has not yet been explored. These will likely play a large part in estimating the worth of preventing dreissenid mussel spread (Nelson, 2019).

Table 12. Summary of Potential Damage Costs for Dreissenid Mussels Statewide

Stakeholder Group	Annual Mitigation Costs
Water Treatment	$227,000-$236,000
Irrigation	$148,000
Livestock	$59,000
Thermoelectric	$23,000
Mining	$48,000
Industrial	$57,000
Aquaculture	$236,000
Hydroelectric	$9,448,000-$50,371,000
Mitigation Costs Total	$10,246,000-$51,178,000

Table 13. Summary of Potential Damage Costs for Dreissenid Mussels East River

East River Stakeholder Group	Annual Mitigation Costs
Water Treatment	$108,000-$113,000
Irrigation	$107,000
Livestock	$40,000
Thermoelectric	$23,000
Mining	$12,000
Industrial	$57,000
Aquaculture	$80,000
Mitigation Costs Total	$427,000- $431,000

Table 14. Summary of Potential Damage Costs for Dreissenid Mussels West River

West River Stakeholder Group	Annual Mitigation Costs
Water Treatment	$119,000- $124,000
Irrigation	$41,000
Livestock	$19,000
Thermoelectric	$0
Mining	$36,000
Industrial	$0
Aquaculture	$156,000
Mitigation Costs Total	$372,000- $376,000

COSTS UNACCOUNTED FOR: RECREATION, TOURISM, PROPERTY VALUES

Water adds value to our economy without leaving the system. This type of water use, nonconsumptive, is not captured by USGS data. For instance, continued infestation may impact recreation via boating and fishing. The impact that dreissenid mussels may have on a boat happens through the attachment to hulls, motors, and trailers, as well as the ability of veligers to enter into the engine and grow within the interior of the motors. This can result in complications with boat operation, and the attachment of mussels could decrease fuel efficiency and ruin the aesthetics of the boat's exterior. These damages could be avoided by proper compliance with South Dakota state policies regarding mussel mitigation, and drying out the boat between uses to ensure both proper care of the boat and reduced spread. Estimates from Lake Tahoe fall from about $200 to $400 per year per boat (USACE, 2009). However, because South Dakota watercraft operators do not see year-round use, and are likely winterized and stored for half the year, they are likely to incur the lower side of costs (Nelson, 2019). It is unclear how dreissenid mussel infestation in a lake may alter fish composition in a waterbody, or if there are changes to which fish can inhabit. This partially depends on how much dreissenid mussel introduction alters the ecology of a waterbody and what kind of fish already inhabit the area (Higgins and Vander Zanden, 2010). For example, if the fish feed on the edges of the lake (littoral species) they will be very impacted by the change in their food ability. However, if the fish feed in the open water they may not be as impacted by the introduction by way of food availability (Nelson, 2019).

In 2022, South Dakota hosted about 14.4 million visitors. Together they spent about $4.7 billion directly on transportation, recreation, retail, food/beverage, and lodging, and further generated $7.6 billion for the state. Tourism is the 7th largest employment sector in the state, employing nearly 40,000 people (Tourism Economics, 2022). There are no ways to differentiate the motivations of tourists from traveling for water-based recreation or non-water-based activities. However, should dreissenid mussel permeation impact fishing, boating, and aesthetics of South Dakota’s water features, there could be a reduction in visitation. This could even include reductions in casual water recreation activities, like swimming, kayaking, or paddle boarding. Communities across the state rely on tourism and the many services that support them may struggle to maintain business. Given the stated numbers prepared in a report for the South Dakota Office of Tourism, even a 2% reduction in tourism would result in a loss of $94 million in direct visitor spending and $152 million in total economic impact. Many features of dreissenid mussel development heavily impact the aesthetics of a lake. Their shells can cover the shores of the beaches they inhabit which can cut the feet of humans or pets. The mussel also only feeds on certain algae, and leaves others, like cyanobacteria alone. This can increase the population of this species, which is harmful for humans, causing increases in skin rashes and gastrointestinal illnesses (Nelson, 2019, Knoll et al., 2008). These adverse changes could also lower the surrounding property values.

Dreissenid mussels have been called “ecosystem engineers” because of their impacts on ecosystems (Jones, Lawton, & Shachak, 1994). Aside from damage caused to structures, dreissenid mussels can completely alter the environment they inhabit. The changes they make can be physical, chemical, and biotic. The species’ ability to filter feed can remove needed particles in the water, including algae which feeds many other aquatic organisms. This can cause a chain reaction in the body they have invaded (Kozak, 2021). This damage, though it may not directly impact economic industries in the state, is harmful for non-use value which contributes to human welfare. Maintaining fully functional ecosystems for the sake of knowing they are there (existence value) and to leave for future generations (bequest value) are not included in attempts to find the market value of ecosystems (Nelson, 2019). It is difficult and labor-intensive to attempt to put a price on the intrinsic value of our regional water bodies. There is no arguing that the effects dreissenid mussels have on the “economic surface level” have far-reaching impacts that have not been fully captured through this paper and cannot easily be assigned economic worth (Rea & Munns, 2017).

DISCUSSION

In terms of total impact, the cost of dreissenid mussel infestation in South Dakota could be \$10 to \$50 million annually. The areas facing the most loss are hydroelectric power generation and water treatment. Hydropower faced the biggest potential loss from dreissenid mussel mitigation by far, with most of the overall costs being attributed to this area. Lost revenue from generator downtime is the largest contributor. Dreissenid mussels can damage water treatment infrastructure, requiring increased operation and maintenance costs or require additional treatment processes. Although most water treatment facilities in South Dakota use groundwater, there are indications that with growing urbanization there could be an increasing reliance on surface water resources (Senate Joint Resolution 502, 2024). Issues in this area also impact various water uses, including aquaculture, thermoelectric facilities, mining, and industrial facilities, furthering the importance.

According to the results, East River will incur more costs than West River. This is in part because there are some USGS categories that site no water withdrawals for West River, including thermoelectric and industrial. East River also incurs much higher total cost in irrigation and livestock categories, probably because of higher agricultural output East River. In the areas of water treatment, mining, and aquaculture, West River will incur more costs. However, the largest cost category, hydroelectric power, was not divided into these regions because of the dams' placement along the river, these costs will be incurred by both.

Standard policy for dreissenid mussel containment in the United States uses a few different steps, outlined in a national framework, to form an approach that is enforceable for state land management agencies. This includes first and foremost, educating the public about the issue. To accomplish this, a state may provide signage and interpretive opportunities at relevant sites, such as hardware stores, lakes, and state parks. This allows the public to understand the species, how to recognize it, and allows them, if necessary, to do their own research. Procedures put into place to decontaminate watercraft are an imperative part of preventing the spread from lake to lake. As has been established, the attachment of mussels or veligers to watercraft is one of the main avenues dreissenid mussel spread takes. Decontamination includes draining the boat in whatever ways are applicable and washing the boat using clean water and possibly a chemical disinfectant (National Park Service, 2007). Many states, including South Dakota, have set up washing stations for boats coming in and out of infested waters. To ensure the public is compliant with this, screening stations at the entrance and exit of state lakes help to ensure that boaters, especially frequent boaters, are following the procedure correctly.

South Dakota has adopted this policy, and the slogan "Clean, Drain, Dry;" however, the simple policy may struggle to effectively address and protect South Dakota's water, energy, and economic systems. With just short of 10,000 waterbodies and 500 watercraft ramps statewide, critics say that the state legislature and other elected leadership have failed to allocate sufficient resources, specifically financially, to state land management agencies. South Dakota's Department of Game, Fish, and Parks is the body in charge of enforcing and informing laws meant to stop the spread of the invasive species but bar a 2020 legislative act that broadened their authority, there have been almost no signs of progression in either policy depth or enforcement since the years following the initial detection. Recent statements from South Dakota's Aquatic Invasive Species (AIS) coordinator say that compliance with "Clean, Drain, Dry," is at 96%, and any issues with continued spread and enforcement of prevention methods are due to a lack of available labor in the job market, not lack of finances (Whitney, 2023).

The outlined approach to dreissenid mussel mitigation is one that other states are seeing success with. Montana, which uses similar containment strategies to South Dakota, has even been able to "delist" positive waterbodies after strict enforcement of policies and consecutive years of negative tests (Kusnierz, 2020). After the initial detection of the mussels in Montana, the governor declared an emergency and increased funding for water protection programs. Ridding state waters of invasive mussels is a priority to Montana state lawmakers in part because of their anticipated impact on economic output in the state. Even though reservoirs across the state are consistently testing negative for invasive mussels, officials want to make sure enforcement and state involvement stay rigorous. The Chief of Montana's AIS Bureau urges surrounding states to ensure their own policies are working towards managing the species, as threats from across state lines may undermine Montana's efforts (Kuglin, 2022).

South Dakota's policy regarding preventing the spread of the mussels has been the same since their detection (Scott, 2019). However, the invasion has now reached the far corners of our state and does not seem to be slowing. Officials from Wyoming and Montana, as well as advocates from South Dakota itself, are calling for a change in South

Dakota's prevention methods, further citing a lack of enforcement of boat inspections. The opinion of officials in surrounding state governments is that South Dakota has taken a "hands-off" approach. Josh Leonard, the Aquatic Invasive Species Coordinator of Wyoming, claims that if South Dakota were to do its part in preventing the spread, the surrounding states would not have to work as hard (Whitney, 2023). When aquatic invasive species efforts are placed into context with surrounding states, South Dakota's methods do seem to fall short of a satisfactory contribution to collective efforts to reduce the spread. Though reports from Game, Fish, and Parks may say otherwise, it seems that state allocations and priorities do not match regional standards. As of 2024, the state of Wyoming has yet to have any instate dreissenid mussel detections. However, their budget for managing the issue is over two times the size of South Dakota's, while Montana and Minnesota's budgets are roughly ten and twenty times the size, respectively. This is in part because South Dakota does not delegate any state funding towards the issue, relying on piecemeal funding from federal grants and community partnerships (Whitney, 2023). Further, other states have prioritized control and mitigation of the methods to avoid the potential losses from the mussel and to protect their industries such as tourism and recreation. This also helps to ensure the industries can continue to grow and the states are attractive to business investments. In 2019, the Minnesota Invasive Species Council released a report indicating a $230 million loss due to dreissenid mussel invasions, and a similar study in the same year by Nanette Nelson estimated costs for Montana ranging from around $480 million to over $730 million. South Dakota leadership has so far resisted similar impact evaluations (Whitney, 2023).

Interestingly, South Dakota has much higher costs concerning potential losses of revenue from hydropower generator downtime. Surrounding state's impact studies do not lose nearly as much in energy generation as they do not rely as much on the resource. This strain could cause upward pressure on energy costs for consumers and businesses served by the dam energy systems. Should South Dakota continue to lose power due to mussel infestation they make have to look at alternative resources to fill the gap, losing what has historically been a clean and constant source of energy for the state (US EIA, 2023). The U.S. Army Corps of Engineers explored different ways to combat the issue at dam locations, but strategies like the installation or copper ion generators and mechanical removal of the mussels, but these do nothing to slow the spread and ease the situation for the future (Detres, 2021).

Though the progression of dreissenid mussels throughout the state of South Dakota is relatively well cataloged, the importance of mitigation is underexplored. Advocacy groups, such as the Lakes and Streams Association believe this is in part due to a failure by elected officials to weigh the potential impact that continued spread and invasion could have on state tourism, agricultural systems, and ecosystems (Whitney, 2023). The lack of motivation to establish a starting point for the ability to provide benefit-cost analysis information could lead to long-term damage through uninformed management strategies. Because of the expressed importance of land-use based economic activity, as well as the impact this could have to tourism and recreation, this could be catastrophic for South Dakota citizens. Individual stakeholders may independently gather data on how the issue will impact their investments, but as a state, the picture is proving insufficient to shape policy and inform decision-makers. The threat of additional unintentional species introduction is a serious concern for both our environment and critical infrastructure, which will undoubtedly have economic impacts (Scott, 2019, Nelson, 2019). Studies that seek to examine the potential economic impacts of dreissenid mussel infestation can help advise policymakers on the state, local, and federal levels to make the appropriate decisions to protect the interests of our state. The data provided in this report is a small proportion of the total possible damages from invasive dreissenid mussels in South Dakota and displays concerning potential costs to South Dakota businesses and citizens.

A large part of dreissenid mussel spread concerns the biological traits of the environment they inhabit. This was brought to the attention of Nanette Nelson in her survey report when concentrations of dreissenid mussel locations did not correlate with the reporting facilities experiencing issues with dreissenid mussels (Nelson, 2022). This could be attributed to many biological variables, of which just a few are water currents, substrate type, temperature, or pH balance (Cohen, 2005). To predict economic damages in South Dakota accurately, more biological information will be needed. Ecosystem conditions can help add information about how dreissenid mussels establish themselves and to what degree (Cohen, 2005). Since South Dakota's Department of Game, Fish, and Parks cited the worst-case scenario model to not be optimal for informing their decisions and strategies going forward, more information about the biological characteristics of dreissenid mussels could help in creating predictive models to best aid prevention efforts at high-risk sites.

REFERENCES

Advancing Agriculture. (2022). South Dakota Governor, Kristi Noem. https://governor.sd.gov/ priorities/advancing-agriculture.aspx

Boyd, D. (2016). Mussel-Related Impacts and Costs at Hoover, Davis, and Parker Dams (Lower Colorado Dams Office Facilities) (No. ST-2016-1608) (pp. 1–25). Bureau of Reclamation.

Chakraborti, R. K., Madon, S., & Kaur, J. (2016). Costs for controlling Dreissenid mussels affecting drinking water infrastructure: Case studies. Journal - American Water Works Association, 108, E442–E453. http://doi.org/10.5942/jawwa.2016.108.0104

Cohen, A. N. (2005). A review of zebra mussels' environmental requirements. California Department of Water Resources. https://www.sfei.org/documents/review-zebra-mussels-environmental-requirements

Consumer Energy Alliance. n.d. "Hydro in Our State." South Dakota Hydro. Retrieved from https://consumerenergyalliance.org/the-power-of-water/south-dakota/south-dakota-hydro

Crystal-Ornelas, R., Hudgins, E. J., Cuthbert, R. N., Haubrock, P. J., Fantle-Lepczyk, J., Angulo, E., Kramer, A. M., Ballesteros-Mejia, L., Leroy, B., Leung, B., López-López, E., Diagne, C., & Courchamp, F. (2021). Economic costs of biological invasions within North America. NeoBiota (67, 485–510). doi: 10.3897/neobiota.67.58038. https://neobiota.pensoft.net/article/58038/

Detres, Ferdinand Jr. (2021). "U.S. Army Corps of Engineers moves to eradicate invasive species." Northwest Division Website. U.S. Army Corps of Engineers. Retrieved from https://www.nwd.usace.army.mil/Media/News-Stories/Article/2487150/us-army-corps-of-engineers-moves-to-eradicate-invasive-species/

Environmental Fact Sheet, Zebra Mussels. (2019). New Hampshire Department of Environmental Services. https://www.des.nh.gov/sites/g/files/ehbemt341/files/documents/2020-01/bb-17.pdf

Higgins, S. N., & Vander Zanden, M. J. (2010). What a difference a species makes: a metaanalysis of dreissenid mussel impacts on freshwater ecosystems. Ecological Monographs, 80(2), 179-196.

Invasive Mussels, Control Measures. (2020). US Bureau of Reclamation. https://www.usbr.gov/mussels/control/index.html#:~:text=A%20variety%20of%20management%20techniques,in%20the%20West%20are%20limited.

Jones, C. G., Lawton, J. H., & Shackak, M. (1994) Organisms as ecosystem engineers. In Ecosystem Management (pp. 130-147). New York, NY: Springer.

Knoll, L. B., Sarnelle, O., Hamilton, S. K., Kissman, C. E. H., Wilson, A. E., Rose, J. B., & Morgan, M. R. (2008). Invasive zebra mussels (Dreissena polymorpha) increase cyanobacterial toxin concentrations in low-nutrient lakes. Canadian Journal of Fisheries and Aquatic Sciences, 65(3), 448– 455. http://doi.org/10.1139/f07-181

Kozak, Julia. (2021). "Back to Basics: This is What Zebra Mussels Do to a Lake." International Institute for Sustainable Development, Experimental Lakes Area. https://www.iisd.org/ela/blog/this-is-what-zebra-mussels-do-to-a-lake/

Kuglin, Tom. (2022). "Montana Waters Set to Move to Mussel-Free Designation."

Helena Independent Record. https://helenair.com/news/state-and-regional/govt-and-politics/ montana-waters-set-to-move-to-mussel-free-designation/article_7a778f9f-5a79-58cc-99be-75f323839e2e.html

Kusnierz, Paul. (2020). "Montana AIS Partner Updates: Protect our Waters." Avista.

Economic Impact of Tourism in South Dakota. (2022). Tourism Economics. Oxford Economics Company. Prepared for South Dakota Office of Tourism. https://sdvisit.com/sites/default /files/2023-01/22EcoImp_Tourism_Economics.pdf

Manalo, King. (2024). "Electricity Rates in South Dakota." Find Energy. Retrieved from https://findenergy.com/sd/

Ministry of Water, Land, and Resource Stewardship. (2023). "Potential Economic Impact of Zebra and Quagga Mussels in B.C" https://www2.gov.bc.ca/assets/gov/environment/ plants-animals-and-ecosystems/invasive-species/invasive-mussels/zqm_economic_report_2023_05_26_final.pdf

National Hydropower Association. (2013). "Midwestern U.S. Hydro Generation Profile, 2013." National Hydropower Association. Retrieved from https://www.hydro.org/waterpower/why-hydro/available/hydro-in-the-states/midwest/.

National Park Service. (2007). Quagga/Zebra Mussel Information Prevention and Response Planning Guide. U.S. Department of the Interior. Retrieved from https://invasivemusselcollaborative.net/wp-content/uploads/2018/11/QuaggaPlanningGuide_ext.pdf.

Nelson, Nanette M. (2022). “Ground Truthing Assumptions Used in Developing an Economic Damages Model of Dreissenid Mussels.” Flathead Lake Biological Station, University of Montana.

Nelson, Nanette M. (2019). “Enumeration of Potential Economic Costs of Dreissenid Mussels Infestation in Montana.” https://edit.doi.gov/sites/doi.gov/files/uploads/dnrc_economic_ cost_dreisseid_mussels_0119. pdf

North Central Regional Aquaculture Center. (2022). Introduction to Aquaculture in the North Central Region. https://www.ncrac.org/files/publication/ncracfs129-introduction_to_a quaculture_in_the_north_central_region.pdf.

Pucherelli, S., Claudi, R., Prescott, T., Willett, L., & OOstrom, T. V. (2021). Case studies: Impact and control of invasive mussels at hydropower plants (ST-2020-1876-01; p. 68). Bureau of Reclamation, U.S. Department of the Interior. https://www.usbr.gov/research/projects/index.html

Rea, A. W., & Munns, W. R., Jr (2017). The value of nature: Economic, intrinsic, or both?.Integrated environmental assessment and management, 13(5), 953–955. https://doi.org/10.1002/ieam.1924. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5790155/.

Ryder, H. F., McDonough, C., Tosteson, A. N., & Lurie, J. D. (2009). Decision Analysis and Cost-effectiveness Analysis. Seminars in spine surgery, 21(4), 216–222. https://doi.org/10.1053/j.semss.2009.08.003.

Senate Joint Resolution 502. (2024). 99th South Dakota Legislature. https://sdlegislature.gov/Session/Bill/24747/264178.

Scott, David. (2019). “New Zebra Mussel Infestations Found In South Dakota Lakes.” SDPBR Radio. South Dakota Public Broadcasting. https://listen.sdpb.org/news/2019-11-01/ new-zebra-mussel-infestations-found-in-south-dakota-lakes

South Dakota Department of Agriculture and Natural Resources. (2024). Sand, Gravel, and Construction Aggregate Mining. Retrieved from https://sdbit.maps.arcgis.com/apps/ webappviewer/index.html?id=4046cfb6c4c24087831e18c6255466ae

Thompson, Nathan. (2022). “Zebra Mussels Discovered in Pactola Reservoir.” Rapid City Journal. https://rapidcityjournal.com/news/local/zebra-mussels-discovered-in -pactola-reservoir/article_b53866e5-1821-5cdd-874c-43c82c686f84.html

U.S. Army Corp of Engineers [USACE]. (2009). Lake Tahoe Region Aquatic Invasive Species Management Plan, California - Nevada. Report prepared for U.S. Army Corp of Engineers and the California Tahoe Conservancy.

U.S. Energy Information Administration. (2021). South Dakota State Profile and Energy Estimates: Profile Analysis. Retrieved from https://www.eia.gov/state/analysis.php?sid=SD.

U.S. Geological Survey [USGS]. (2015). USGS Water Use Data for South Dakota. Retrieved from https://waterdata.usgs.gov/sd/nwis/wu.

Uria-Martinez, R. & Johnson, M. M. (2023). U.S. Hydropower Market Report (2023 Edition). Author. Retrieved from https://www.energy.gov/sites/default/files/2023-09/ U.S.%20Hydropower%20Market%20Report%202023%20Edition.pdf

Whitney, Stu. (2023). “Critics say South Dakota governor and Legislature falling short in preventing spread of invasive zebra mussels." South Dakota News Watch. https://news.sd.gov/news?id=news_kb_article_view&sysparm_article=KB0029912&sys_kb_id=65e9d5c41b1c69506e4aa97ae54bcbee&spa=1

Zenni, R. D., Essl, F., García-Berthou, E., & McDermott, S. M. (2021). The economic costs of biological invasions around the world. NeoBiota (67, 1–9). doi: 10.3897/neobiota.67.69971. https://neobiota.pensoft.net/article/69971/