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Brief Report

An Initial Survey of Unionid Mussels in Lakes East of the Missouri River in South Dakota, USA

Riley E. Henderson [1], Katherine M. Wollman [2], Chelsey A. Pasbrig [3] and Michael E. Barnes [1,*]

[1] South Dakota Game, Fish and Parks, McNenny State Fish Hatchery, 19619 Trout Loop, Spearfish, SD 57783, USA
[2] Independent Researcher, 6708 East 76th Street, Tulsa, OK 74133, USA
[3] South Dakota Game, Fish and Parks, 523 East Capitol Avenue, Pierre, SD 57501, USA; chelsey.pasbrig@state.sd.us
* Correspondence: mike.barnes@state.sd.us; Tel.: +1-605-642-6920

Abstract: This study surveyed freshwater mussels (family Unionidae) in 116 lakes and reservoirs east of the Missouri River in South Dakota, USA, during 2017. Using two-person–hour/site timed searches, evidence of a total of 1789 mussels, including 1053 live mussels, was obtained from 50 waters. Nine species, from two different orders, were found in lakes and reservoirs throughout five of the six major river drainages east of the Missouri River. The native species observed included Giant Floater *Pyganodon grandis*, Fatmucket *Lampsilis siliquoidea*, Threeridge *Amblema plicata*, White Heelsplitter *Lasmigona complanata*, Wabash Pigtoe *Fusconaia flava*, Deertoe *Truncilla truncata*, and Pink Heelsplitter *Potamilus alatus*. Giant Floater was the most widespread and abundant species observed, representing 63.3% of the live mussels sampled. Two non-native species, Zebra Mussel *Dreissena polymorpha* and Chinese Basket Clam *Corbicula fluminea*, were also documented from three water bodies in the lower Missouri River drainage. Overall, mussel abundance was negatively correlated with lake water conductivity and positively correlated with turbidity. No significant correlations were observed between species abundance and water temperature, pH, dissolved oxygen, or substrate particle size.

Keywords: lake; unionid; eastern South Dakota; survey; mussels

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1. Introduction

Unionid mussels are found in all continents, excluding Antarctica [1–3]. North America contains 294 of the 820 known Unionid species, with several of these mussel species considered some of the most threatened aquatic fauna [1,3–5].

In the state of South Dakota, USA, information about freshwater mussel (family Unionidae) distributions has been limited and almost entirely focused on flowing water in streams and rivers. In the early 1900s, the first, albeit small, surveys reporting mussel abundance in South Dakota were conducted [6]. The authors of [7] conducted the next mussel survey. Several other surveys have subsequently occurred, again primarily focusing on rivers and wadable streams [8–21]. Overall, these surveys recorded 30 Unionid species, whose NatureServe ranking system conservation status [22] ranges from global and state imperiled (G1 and S1, respectively) to global and state secure (G5 and S5). In addition, prior surveys included three mussel species listed as endangered under the United States Endangered Species Act: Higgins Eye *Lampsilis higginsii*, scaleshell *Potamilus leptodon*, and Winged Mapleleaf *Quadrula fragosa*.

Because of the limited information on Unionid distributions and abundance in South Dakota, additional information is needed. Information is particularly lacking on mussel populations in lakes and reservoirs. Thus, the objective of this study was to document freshwater mussel occurrence and abundance in eastern South Dakota lakes.

2. Materials and Methods

2.1. Study Area

The landscape of eastern South Dakota was formed by melted ice deposits during the late Wisconsin glaciation, creating large numbers of lake basins of varying sizes [23]. The northern glaciated plains comprise most of eastern South Dakota. The large numbers of glacial lake basins are affected by row crop agriculture and, to a lesser degree, livestock grazing. Within eastern South Dakota, lakes are drained by six major river drainages: Big Sioux, James, Minnesota, Missouri, Red, and Vermillion [23,24]. Most of the natural lakes and reservoirs are characterized as either eutrophic or hypereutrophic because of intensive agricultural practices [24]. Approximately 70% of the publicly owned and managed lakes in South Dakota are man-made reservoirs, while 30% are natural lakes [25].

2.2. Field Surveys

Eastern South Dakota lakes were surveyed for freshwater mussels in from 7 May to 9 August 2017. Lakes and reservoirs were selected from the South Dakota Department of Environmental Natural Resources lakes data set, using a similar protocol as Faltys' [21]. Sample sites (n = 116) were proportionally and randomly assigned to publicly owned waterbodies within each of the six major river drainage basins east of the Missouri River based upon basin size. If permission was not obtained to access a lake or if water levels were not optimal for mussel surveying, that lake was randomly replaced with a different lake or reservoir within the same river drainage basin.

Two-person–hour timed searches were performed at each lake or reservoir survey site [26]. Each search effort started at the nearest lake access point or most optimal habitat (i.e., avoiding cattail-dominated shorelines). Because of low visibility in the shallow, turbid, eutrophic-to-hypereutrophic waters in eastern South Dakota, tactile searches using a zig-zag motion parallel to the shoreline in water up to 1.5 m deep were performed. The two-person–hour search was divided into two equal intervals to allow for specimens from the two surveyors to be combined and properly recorded [27]. GPS coordinates were taken at the start, middle, and end location of the search area to calculate the total length and mussel location within the search area. All live mussels and shells from recently dead mussels were collected and identified following taxonomy by the Freshwater Mussel Conservation Society [28]. Two vouchers of each species were collected at each site and, along with photo documentation, taken to the South Dakota Aquatic Invertebrate Collection located at South Dakota State University in Brookings, South Dakota, USA. Dissolved oxygen, conductivity, and temperature were recorded from each lake or reservoir site using a multiparameter sonde (YSI Incorporated, Yellow Springs, OH, USA). In addition, substrate particle size was recorded using a gravelometer (Wildco, Yulee, FL, USA), and turbidity was recorded using a Secchi disc. Water depth was also recorded at each site.

2.3. Analysis

Mussel distribution, species occurrence, abundance, and richness were assessed based on river drainage and lake type (natural lake or reservoir). Abundance was based on the number of live and dead mussels sampled per hour or catch per unit effort (CPUE). Richness included both live and dead mussels. Mussel distribution was based on the presence and absence of species within each natural lake or reservoir, represented by both live and recently dead shells. Relative abundance was calculated using the total counts of each species relative to all species. Species richness was calculated based on river drainage and basin type. Spearman rank correlations were conducted using Statistix statistical software (version 10.0/2013, Analytical Software, Tallahassee, FL, USA) to evaluate relationships between mussel abundance and abiotic factors.

3. Results

A total of 1789 freshwater mussels were collected, including 1053 (59%) live specimens and 736 (41%) recently dead shells (Figure 1). Evidence of mussels was found in 50 lakes

(43%), with live mussels found in 41 lakes (35%). A total of nine species, from two different orders, were found in lakes and reservoirs throughout five of the six major river drainages (Table 1). Native species included Giant Floater *Pyganodon grandis*, Fatmucket *Lampsilis siliquoidea*, Threeridge *Amblema plicata*, White Heelsplitter *Lasmigona complanata*, Wabash Pigtoe *Fusconaia flava*, Deertoe *Truncilla truncata*, and Pink Heelsplitter *Potamilus alatus*. Two non-native species, Zebra Mussel *Dreissena polymorpha* and Chinese Basket Clam *Corbicula fluminea*, were also documented from three waters within the lower Missouri River drainage. Mussel species richness across all sites ranged from zero to four (mean = 0.58 ± 0.08 SE). The number and species of mussels found in each lake or reservoir are detailed in Table 2.

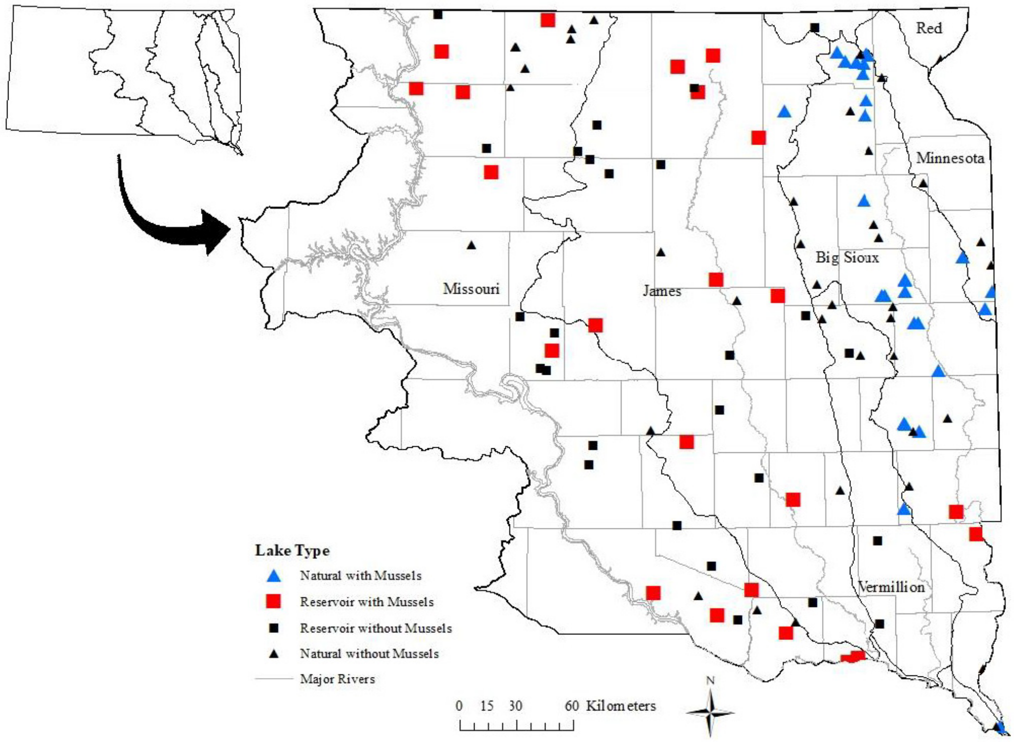

Figure 1. Map of mussel survey locations within the natural lakes and reservoirs of the six major river basins of eastern South Dakota (*n* = 116). Triangles indicate natural lakes and squares indicate reservoirs. Black triangles or squares indicate the absence of mussels.

Abiotic factors varied greatly among the lake sites. Dissolved oxygen ranged from 5.3 to 21.1 mg/L, conductivity ranged from 352 to 4096 µS/cm, water temperature ranged from 10.6 to 31.7 °C, and pH ranged from 7.66 to 10.05. Turbidity ranged from 16 to 120 cm, substrate particle size ranged from 1 to 17.8 mm. and water depth ranged from 18 to 1500 mm.

No evidence of mussel presence was found in the Red River drainage. In the other five eastern drainages, giant floater was the most abundant and widely distributed species, found in 48.4% of the Big Sioux River drainage sites, 45.5% of the James River drainage sites, 16.7% of the Minnesota River drainage sites, 32.4% of the Missouri River drainage sites, and 14.3% of the Vermillion River drainage sites (Figure 2). Fatmucket was the second most abundant and widely distributed species, occurring in 19.4% of the Big Sioux sites, 6.1% of the James River sites, 16.7% of the Minnesota, 2.7% of the Missouri sites, and absent from the Vermillion River drainage sites. White Heelsplitter only occurred at sites within three drainages, including the Big Sioux (3.2%), James (9.1%), and Missouri (2.7%) River drainages. Threeridge occurred in a single lake from within the Big Sioux River drainage, Wabash Pigtoe and Deertoe each were sampled from single lakes from within the James River drainage. Pink Heelsplitter had a low occurrence in single lakes within both the James and Missouri River drainages. Other than Giant Floater and Fatmucket, the other native mussel species sampled represented less than 1% of all mussels sampled from all lakes sampled.

Table 1. Mussel species collected during a 2017 survey of eastern South Dakota lakes and reservoirs in the six river drainages. Numbers in parentheses after drainage name indicate the number of sites sampled. "L" indicates species found live and "-" indicates that the species was not found. CPUE = catch per unit effort (number of live mussels/h). Relative abundance is reported as the number of live mussels for an individual species divided by the total number of live mussels collected. Fish host use was determined following Haag [29], where "G" indicates fish host generalist and "S" indicates fish host specialist. Life history strategies were determined following Haag [29], where "O" indicates opportunistic, "P" indicates periodic, and "E" indicates equilibrium. Conservation rankings were obtained from the NatureServe Explorer database [22], where "G5" indicates secure, "S2" indicates imperiled, "S3" indicates vulnerable, and "E" indicates exotic.

Species	Fish Host	Life History Strategy	Global Conservation Ranking	State Conservation Ranking	Eastern Drainages						All Sampled Sites				Natural Lakes			Reservoirs		
					Big Sioux (20)	James (20)	Minnesota (6)	Missouri (26)	Red (2)	Vermillion (7)	Number Live and Dead	Number Live	CPUE	Relative Abundance (%)	Number Live and Dead	Number Live	Relative Abundance (%)	Number Live and Dead	Number Live	Relative Abundance (%)
Unionida																				
Unionidae																				
Pyganodon grandis	G	O	G5	S5	L	L	L	L	-	L	1357	667	2.88	63.3	546	198	36.0	811	469	93.2
Lampsilis silquoidea	S	P	G5	S4	L	L	L	-	-	-	351	340	1.47	32.3	351	340	61.8	0	0	0
Lasmigona complanata	G	O	G5	S5	L	L	-	-	-	-	16	7	0.03	0.7	2	1	0.2	14	6	1.2
Truncilla truncata	S	O	G5	S2	-	L	-	-	-	-	4	4	0.02	0.4	0	0	0	4	4	0.8
Potamilus alatus	S	O	G5	S3	-	L	-	L	-	-	4	3	0.01	0.3	2	1	0.2	2	2	0.4
Fusconaia flava	S	E	G5	S2	-	L	-	-	-	-	2	2	0.01	0.2	0	0	0	2	2	0.4
Amblema pliacta	G	E	G5	S3	L	-	-	-	-	-	1	1	0	0.1	1	1	0.2	0	0	0
Veneroida																				
Cyrenidae																				
Corbicula fluminea	-	-	G5	E	-	-	-	-	L	-	45	20	0.09	1.9	0	0	0	45	20	4.0
Myida Dreissenidae																				
Dreissena ploymorpha	-	-	G5	E	-	-	-	L	-	-	9	9	0.04	0.9	9	9	1.6	0	0	0
Drainage Richness					4	6	2	4	0	1										
Total											1789	1053		100	911	550	100	878	503	100

Table 2. Unionid mussel species counts from eastern South Dakota natural lakes or reservoirs, referenced by county and drainage. Species include *Pyganodon grandis* (Pg), *Lasmigona siliquoidea* (Ls), *Amblema plicata* (Ap), *Lasmigona complanata* (Lc), *Fusconaia flava* (Ff), *Truncilla truncata* (Tt), *Potamilus alatus* (Pa), *Dreissena polymorpha* (Dp), and *Corbicula fluminea* (Cf).

Water	County	Drainage	Species								
			Pg	Ls	Ap	Lc	Ff	Tt	Pa	Dp	Cf
Natural Lakes											
Bourne Slough	Lake	Big Sioux	1								
Buffalo North	Marshall	James	2								
Campbell	Brookings	Big Sioux	2	6	1						
Clear	Deuel	James	2	24							
Clear	Marshall	Missouri	53	16							
Dry	Codington	Big Sioux	12								
Dry	Hamlin	Big Sioux	6								
Enemy Swim	Day	Big Sioux	10	1							
Fish	Deuel	Minnesota		17							
Florence	Hamlin	Big Sioux	45								
Greys	Marshall	James	35								
Lost	Minnehaha	Vermillion	1								
Madison	Lake	Big Sioux	1								
Mary	Hamlin	Big Sioux	1								
McCook	Union	Missouri	1						2	9	
Mud	Marshall	James	37								

Table 2. *Cont.*

Water	County	Drainage	Species								
			Pg	Ls	Ap	Lc	Ff	Tt	Pa	Dp	Cf
Norden	Hamlin	Big Sioux		3							
Oak	Brookings	Minnesota	155								
Oakwood East	Brookings	Big Sioux	3								
Oakwood West	Brookings	Big Sioux	13								
Pickerel	Day	Big Sioux		3							
Pierpont	Day	James	29								
Poinsett	Hamlin	Big Sioux	1								
Round	Lake	Minnesota	3			2					
Roy	Marshall	James	8	281							
Sarah	Marshall	James	24								
Six Mile	Marshall	James	35								
Reservoirs											
Alvin	Lincoln	Big Sioux	32								
Campbell	Campbell	Missouri	66								
Columbia	Brown	James				1					
Covell	Minnehaha	Big Sioux	1								
Dakotah	Hand	James	39								
Dudley	Spink	James	33								
Elm #1	Brown	James	238			11	2	4			
Elm #4	Brown	James				2			2		
Fraser Dam	Aurora	James	1								
Geddes	Charles Mix	Missouri	9								
Hanson	Hanson	James	3								
Hiddenwood	Walworth	Missouri	100								
Molstad	Walworth	Missouri	1								
Peno	Hyde	Missouri	35								
Pigors	Brown	James	6								
Simon	Potter	Missouri	8								
Straum	Beadle	James	181								
Tripp	Hutchinson	Missouri	10								
Tyndall	Bon Homme	Missouri	23								
Wagner	Charles Mix	Missouri	25								
Westside	Yankton	Missouri									8
Wolff	McPherson	Missouri	66								
Yankton	Yankton	Missouri									37

Of the live mussels found in eastern South Dakota lakes, Giant Floater comprised 63.3% of the relative abundance and had a catch per unit effort (CPUE) of 2.88 mussels/h. Fatmucket was the second most abundant species, comprising 32.3% of the relative abundance and having a CPUE of 1.47 mussels/h. All other native mussels had a relative abundance less than 1 and CPUE of less than 0.03 mussels/h. Non-native Zebra Mussels were only found within the lower Missouri River drainage in Union County (McCook Lake), and Chinese Basket Clam were only found in Yankton County (Yankton Lake and Westside Community Fishing Pond).

Mussel species richness and abundance was highest within the James River drainage (six species). Species richness by site within the James River drainage ranged from 0 to 4 (mean richness/site = 0.7 $\pm$ 0.2), and the abundance present ranged from 0 to 316/site (mean CPUE = 20.5 $\pm$ 7.4 SE). Sixty-one percent of the total mussels sampled were collected from lakes within the James River drainage. The Missouri River drainage ranked second in species richness (four species) and abundance. Species richness by site within the Missouri River drainage ranged from 0 to 4 (mean richness/site = 0.5 $\pm$ 0.1), and the abundance present ranged from 0 to 136/site (mean CPUE = 6.5 $\pm$ 2.4 SE). Just under 23 percent of the total mussels sampled were collected from lakes within the Missouri River drainage.

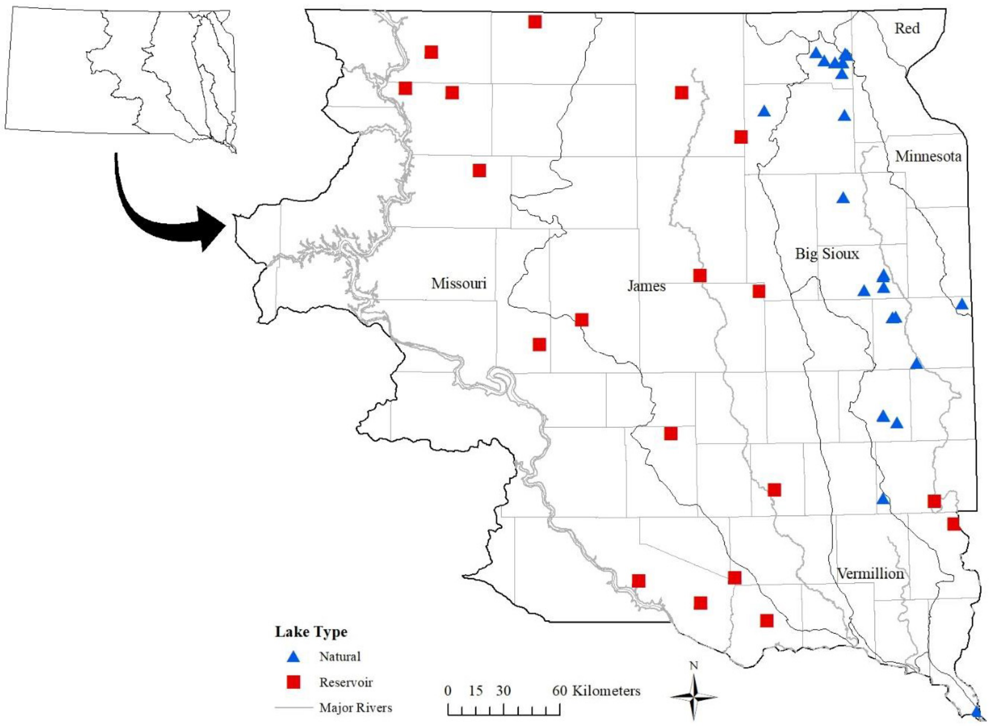

Figure 2. Locations of natural lakes and reservoirs in eastern South Dakota with evidence of *Pyganodon grandis* (n = 42). Triangles indicate natural lakes and squares indicate reservoirs.

Six species were found in both natural lakes and reservoirs. The catch per unit effort was greater in reservoirs where abundance ranged from 0 to 158/site (mean CPUE = 12.1 ± 4.4 SE). In natural lakes, the CPUE was lower where abundance ranged from 0 to 144/site (mean CPUE = 7.7 ± 2.7 SE).

Conductivity was significantly negatively correlated with mussel abundance (r = −0.37, p = 0.0001), and lake turbidity was significantly positively correlated with abundance (r = 0.23, p = 0.014; Table 3). Dissolved oxygen, temperature, pH, depth, and substrate particle size were not correlated with mussel abundance.

Table 3. Correlation co-efficients and *p*-values for abiotic factors in relation to lake and reservoir mussel abundance.

Factor	r	*p*
Dissolved oxygen	0.03	0.779
Conductivity	−0.36	0.010
Temperature	0.07	0.415
pH	−0.14	0.137
Transparency	0.23	0.014
Depth	−0.02	0.727
Substrate	−0.15	0.101

4. Discussion

This study is the first comprehensive survey of Unionid mussels in South Dakota lakes. Because prior research of Unionid abundance and distribution in South Dakota has been mostly limited to streams and rivers, it is difficult to document historical changes in lake mussel species composition, range, or abundance [11–18,20]. However, the 7 species of Unionid mussels and two nonnative Veneroid mussels observed in this study are far fewer than the 30 Unionid species previously reported in all South Dakota waters. Of the seven species, four are considered fish host specialists [29]. However, most of the total abundance (63.3%) was comprised of giant floater, a fish host generalist and opportunistic life strategist. Additionally, giant floater was the dominant species in all drainages that observed mussel presence.

Coker and Southall [6] reported that 90% of the Unionids from the James River basin were Threeridge. Although a fish host generalist, Threeridge favor an equilibrium life strategy which are characterized by a long-life span, late maturity, and stable, productive habitats [29]. Although the current survey only examined lakes and reservoirs, Threeridge were not sampled in the lakes and reservoirs from within the James River drainage. Compared to the 12 mussel species previously reported in the James River drainage and its tributaries by Coker and Southall [6], the current survey documented 6 species. Giant Floater comprised 77.9% of all mussels sampled within the lakes and reservoirs within the James River drainage. Giant Floater was also the most common in all lake sites samples during this study. Giant Floater has an opportunistic life strategy which exhibits fast, growth, a short life-span, and early maturity, which are adaptations for rapid colonization and persistence in disturbed and unstable habitats [29,30]. As a habitat generalist, Giant Floater tends to survive at much higher rates than most Unionid species [30]. This species is tolerant of turbid and silty sediments, conditions that frequently occur in South Dakota lakes and reservoirs [5,31]. Perkins and Backlund [13] reported that Giant Floater was commonly found within the muddy substrate in the backwaters of Missouri River tributaries, which is a similar environment to many prairie pothole lakes in eastern South Dakota.

The conservation ranking of all of the native mussels surveyed in this study is secure (G5) globally [22]. However, within South Dakota, Threeridge and Pink Heelsplitter are considered vulnerable (S3), and Wabash Pigtoe and Deertoe are considered imperiled (S2). The South Dakota imperiled or vulnerable species are either fish host specialists or have equilibrium life histories (or both in the case of Wabash Pigtoe) [29]. The state rankings are not surprising, given the less-than-ideal typical lake and reservoir environmental conditions and fluctuating fish populations in eastern South Dakota that can be stressful for many mussel species, especially non-generalist or non-opportunistic species [25,31].

High conductivity and turbidity are indicators of lake eutrophication [32,33]. Many of the lakes surveyed in this study are highly turbid and either eutrophic or hypereutrophic [25,34]. Thus, the positive correlation of turbidity with mussel abundance observed in this study is likely the result of the enhanced primary production and resuspension of sediment from the bottom of shallow South Dakota prairie lakes. Likewise, eutrophication likely explains the negative correlation between conductivity and abundance [35,36]. These nutrient-laden South Dakota lakes typically experience blue-green algae blooms during the warmer summer months, which may impede mussel filter feeding. As these blooms die off and/or rebloom, oxygen deficits likely also stress gill-breathing mussels.

While the number of mussel species was similar in natural lakes and reservoirs, the CPUE was much greater in reservoirs. Fatmucket were predominantly found in natural lakes, indicative of their inability to adapt to canal or reservoir habitats [37]. Fatmucket are a fish host specialist that exhibit a periodic life history strategy. The periodic strategy for mussels is characterized by moderate to high growth rates, low to intermediate life spans, age at maturity, and fecundity. These are strategies that allow species to persist in unproductive habitats or habitats that are subject to stress [29]. The infrequent occurrence of Wabash Pigtoe, Deertoe, White Heelsplitter, and Pink Heelsplitter in eastern South Dakota lakes and reservoirs observed in this study is similar to that reported previously [30,38,39].

There were few mussels surveyed in the natural lakes west of the Vermillion River basin. This likely occurred because of the low number of natural lakes present in this area, resulting in considerable geographic isolation. The glaciated region of far eastern South Dakota contains most of the natural lakes present in the entire state [40] and is also where most of the lake-dwelling mussels were detected during the present survey.

This survey documented the presence of the non-native mussels *Dreissena polymorpha* and *Corbicula fluminea* in three lakes of eastern South Dakota. These non-native species have high fecundity and rapid dispersal rates, compete effectively for food resources, and effect recreational practices, and although they filter large amounts of water, they leave harmful metals in water systems [41–43]. Recording the presence of non-native mussels within lakes is needed to determine how quickly they are spreading, as well as to enact measures to help prevent their further dispersal into new water bodies [44].

It is possible that the sampling design and techniques used in this study may have missed some mussel species. Species may not have been sampled because of the locations sampled, sample timing, effort expended (time allotted for sampling), sediment depths, high turbidity, and other factors [45–47]. It is also possible that some of the mussels were misidentified because the cryptic nature of freshwater mussels can make identification difficult [48,49].

5. Conclusions

In conclusion, this initial Unionid mussel survey in eastern South Dakota lakes provides the current status of mussel populations in lakes. It also provides a baseline for future studies to determine temporal changes. When used in conjunction with a mussel monitoring program, the information in this study can provide information on the distributions and population estimates of mussel species [50]. Given the relative paucity of information on freshwater mussels in South Dakota, more research and surveys are needed [51]. Future research could also involve habitat suitability modeling and eDNA to help focus future sampling efforts.

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