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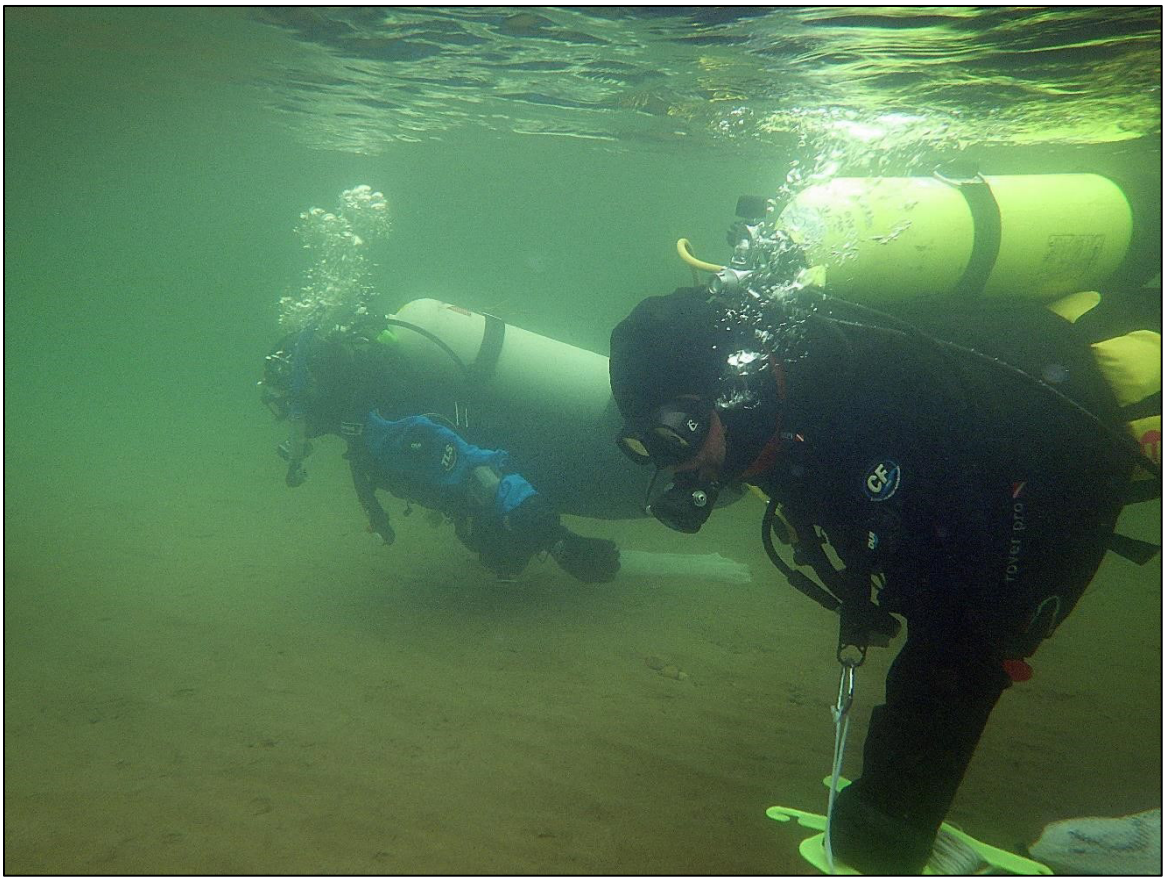
Zebra Mussel (*Dreissena polymorpha*) Distribution in Apostle Islands National Lakeshore: SCUBA-based Search and Removal Efforts

2019–2020

Natural Resource Report NPS/APIS/NRR—2022/2379



ON THE COVER

Brenda Moraska Lafrancois (*left*) and Toben Lafrancois surveying for invasive and native mussels in Outer Island lagoon, 17 September 2019.

Zebra Mussel (*Dreissena polymorpha*) Distribution in Apostle Islands National Lakeshore: SCUBA-based Search and Removal Efforts

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Natural Resource Report NPS/APIS/NRR—2022/2379

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Abstract

Invasive zebra mussels (*Dreissena polymorpha*) were first observed *in situ* at Apostle Islands National Lakeshore (APIS) in 2015. This report builds on 2018 SCUBA surveys and Environmental Protection Agency (EPA) veliger sampling to: 1) determine whether shoals on APIS borders act as sentinel sites to corroborate veliger drift hypotheses about invasion pathways, 2) evaluate ongoing hand-removal of zebra mussels from easily identified structures, and 3) continue efforts to assess native unionid mussel populations, particularly where zebra mussels are also present.

Standard catch per unit effort survey methods by SCUBA teams were used to determine the distribution and relative abundance of zebra or quagga mussels (dreissenids) and native mussels (unionids). Zebra mussels were present at densities between 3 and 42 n/diver/hr (number of mussels per diver per hour), while native unionids were present at densities between 5 and 72 n/diver/hr. Shoal surveys (Eagle Island shoal, Sand Island shoal, York Island shoal, Bear Island shoal, Oak Island shoal, and Gull Island shoal) showed zebra mussels were more abundant on the west side of APIS and absent on the easternmost shoal (Gull Island), corroborating veliger work by the EPA that suggested drift from the Twin Ports of Duluth, Minnesota, and Superior, Wisconsin, is one pathway of invasion. Our results support the use of shallow shoals along the periphery of the park as sentinel sites gauging zebra mussel immigration and population dynamics.

Zebra mussel densities in the central islands showed no obvious spatial pattern, and this survey cannot determine whether currents or human transport (or both) are invasion vectors. Given the mussels' continued presence at heavily used mooring areas and docks where there are no zebra mussels on nearby natural features (e.g., Rocky Island dock, Stockton Island mooring areas), our findings are consistent with multiple invasion pathways (drift from the Twin Ports and anthropogenic sources at mooring areas).

SCUBA search and removal of zebra mussels from docks was confirmed to be an effective method for significantly lowering the risk of zebra mussels reproducing and dispersing from these locations. We caution that this work is being done on what look like initial invasions at low densities. Repeated removal of zebra mussels by divers reduced numbers to zero at some sites after one year (South Twin docks, Stockton Island NPS docks, and the *Ottawa* wreck) or decreased numbers by an order of magnitude (Rocky Island docks). Dreissenid densities were more persistent on the *Sevona* wreck and longer-term work is required to evaluate removal versus recruitment (local and/or veliger drift). Given the size of the wreck, we have tracked detailed survey maps to guide future efforts.

Zebra mussels were again observed attached to native mussels near Stockton Island and South Twin Island. Their continued presence on sensitive native species is of concern. Native unionid mussels were more widely distributed in the park than previously known, with new beds found near Oak and Basswood Islands. The work reported here will form the basis for continued efforts to determine the optimal frequency of zebra mussel removal for effective control, as well as evaluate impacts on native species.

Acknowledgments

Constraints associated with the COVID-19 pandemic limited work in 2020, but we safely completed our research objectives thanks to the extra efforts of the many good people involved in this project. We thank the talented and dedicated National Park Service staff including those at Apostle Islands National Lakeshore, the Great Lakes Inventory and Monitoring Network, and the Midwest Region aquatic scientists. In particular, we thank D. Cooper for logistical support and diver assistance, B. Lafrancois and D. VanderMeulen for study planning and field assistance with mussel collection, the National Park Service Great Lakes and Big Rivers Dive Team, T. Gostomski for assistance with manuscript layout and editing, A. Kirschbaum for map composition, and K. Cullen Bartnick for helping to archive samples. The support of Apostle Islands National Lakeshore maintenance and law enforcement staff made this work possible. The National Park Service funded this project.

Introduction

Zebra and quagga mussels can have severe impacts on the ecological and economic health of freshwater systems (Strayer 2009). Most of Lake Superior was thought to be unsuitable habitat for these dreissenids, but in 2015 zebra mussels (*Dreissena polymorpha*) were discovered by National Park Service (NPS) divers in the Apostle Islands National Lakeshore (APIS or park) on the *Sevona* wreck near Sand Island (Kaeding 2018, Lafrancois et al. 2019). Quagga mussels (*D. bugensis*) were found near Michigan Island in an Environmental Protection Agency (EPA) dredge sample (Trebitz et al. 2019), but they have yet to be observed by divers.

In contrast, native mussels of the family Unionidae are sentinel species associated with good water quality, and world-wide they are one of the most endangered groups of freshwater organisms (Graf and Cummings 2007, Lopes-Lima et al. 2018). These filter feeders are tightly bound to bottom-up ecological processes, and they are associated with healthy fish populations because they have a juvenile symbiote stage with a host fish. Unionid mussels are highly sensitive to zebra and quagga mussel invasion (Schloesser and Nalepa 1994, Strayer and Malcom 2007, Ozgo et al. 2020).

In 2017, we performed SCUBA surveys at APIS following methods of a 1991 NPS mussel survey (Doolittle 1991), with the addition of sites based on our novel zebra mussel observations (Lafrancois et al. 2019). Native mussel beds forming three distinct community types were found in APIS. Several native mussel beds showed evidence of population growth and recruitment, while other locations, specifically Red Cliff and Raspberry Bays, showed marked declines in diversity from the 1991 survey. Three species historically present were not found in 2017. Zebra mussels were found in low densities but at an alarmingly broad distribution across APIS: at nearly all sites searched by SCUBA with the exception of Long Island. In 2017, the EPA found veligers in almost half of 100 sites in or near APIS (Trebitz et al. 2019). During training dives in 2018, NPS divers found zebra mussels on Oak Island shoal as well as two large, previously unknown native mussel beds near Oak and Basswood Islands, where EPA visually detected zebra mussels using a remote camera (T. Lafrancois, personal observation submitted to APIS as a trip report fall 2018).

These discoveries illustrate that both native unionid and invasive zebra mussels were more widely distributed in APIS than previously thought. Although zebra mussel densities are currently low in the park their true extent and population trajectories are unknown. Dredge sampling, colonization substrates, and remotely operated submerged vehicles have shown a propensity for false negative results at current zebra mussel densities in APIS (A. Tribetz, personal communication, April 2018). To date, SCUBA searches by both transect and catch per unit effort (CPUE) methods have been the most effective at finding both invasive and native mussels at APIS. SCUBA searches are known to be reliable, but at low mussel densities repeat visits may be required to best describe densities at early-stage invasions (Ferguson et al. 2019). Taken together, this previous work raises questions about the pathways of zebra mussel establishment at APIS, the full extent of zebra mussel presence in the park, and the efficacy of SCUBA search and removal efforts over time in delaying or even preventing establishment. Other key concerns are determining the reasons for a drastic decline of

native mussels in Raspberry Bay, the extent of interaction between invasive and native mussels, and determining the full range of habitats used by native mussels.

To address these issues, we undertook the following project objectives:

- Determine the suitability of shoals distributed around park boundaries to serve as sentinel "collectors" of zebra mussels brought to APIS by veliger drift.
- Repeat searches and removal of zebra mussels on key structures to determine removal efficacy and recolonization potential.
- Survey zebra mussels occurring in native mussel beds to describe their interaction with native species.
- Assess the apparent decline of native mussel diversity in Raspberry Bay between 1999 and 2017 with a more detailed survey including Miskominikaaniing-ziibi (Raspberry River) with permission from Red Cliff Band of Lake Superior Chippewa Environmental Department.
- Survey Outer Island lagoon to determine if native mussels still live in the lagoon since being opened directly to Lake Superior by a 2014 storm.

Methods

We conducted timed (visual) SCUBA diver searches for dreissenids and unionids at APIS following procedures in Lafrancois et al. (2019). GPS coordinates of survey sites were taken at the dive boat anchor point or mooring. At each location, all living or dead mussels were collected from the lake bed surface and down to 10 cm below the surface in soft sediment. During the timed searches, each diver covered a roughly 2-meter-wide area, 1 m to each side, while searching for mussels within 2 m of their dive buddy. At docks, one diver checked a 3-meter-wide area around the dock, especially under the "boat shadow", while two or more other divers examined the structure itself, including all reachable surfaces, cribbing, and pass-throughs (Figure 1). After collection, mussels were temporarily held in buckets of water, except during species identification and counting, and for pictures, before being returned to the collection site. Results from timed searches were standardized as catch per unit effort (number of mussels per diver per hour for each species present). The lead diver timed the searches directly underwater, so search times do not necessarily match dive times recorded by observers at the water surface. We searched for shell middens when near shore.

Figure 1. NPS diver Brenda Moraska Lafrancois surveys Rocky Island dock, Apostle Islands National Lakeshore, 2019. Two divers worked the dock (high and low), while one diver swung out to cover the substrate 0 to 3 m from the dock where zebra mussels are often found in the "boat shadow". Photo © T. Lafrancois.

Specimens were identified, measured, and photographed (Figures 2 and 3). Native species were carefully returned to the collection site and dreissenids were frozen for later (destructive) analysis. Each zebra mussel was measured to the nearest millimeter along three axes (length, width, and height) and stored frozen for future condition analysis. The presence of dreissenid byssal threads was noted where they occurred. Following Minnesota Department of Natural Resources mussel survey protocol, we sorted live mussels into two age groups (0–5 years or >5 y) based on external shell ring counts, and we measured the smallest and largest individual of each age class. Unionid nomenclature follows Williams et al. (2017). Some data from the 2017 surveys (Lafrancois et al. 2019) were included in this study for comparison, while this study includes observations from dives in 2018 and two longer field seasons in 2019 and 2020.

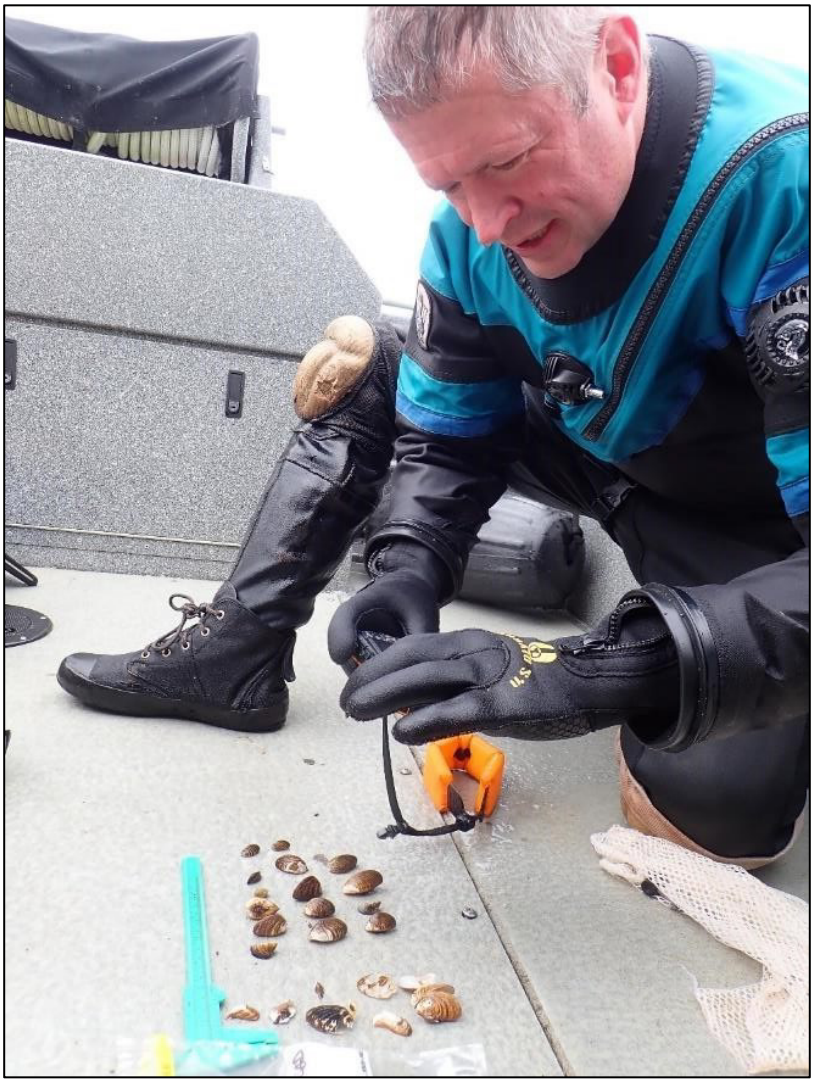

Figure 2. Mark Hove measures, photographs, and records field data after finding zebra mussels on Eagle Island shoal, Apostle Islands National Lakeshore, 2020. Zebra mussels were frozen and stored for future condition analysis. Photo © T. Lafrancois.

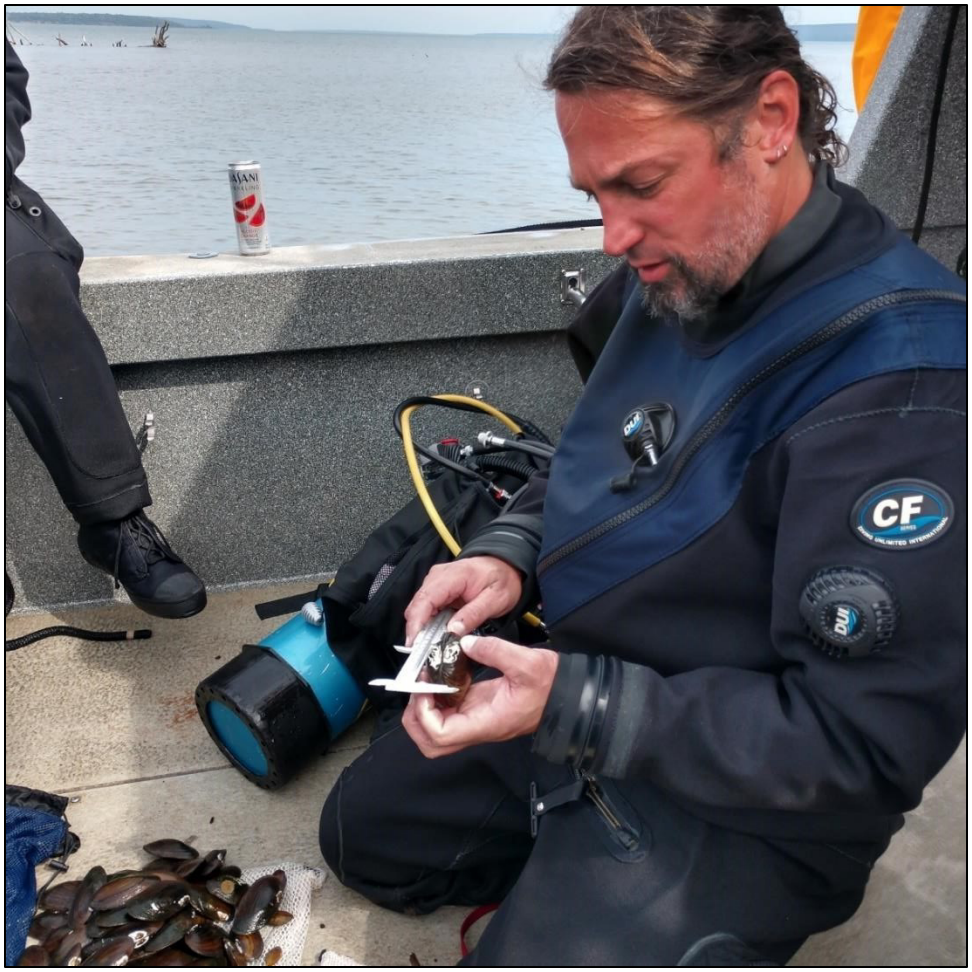

Figure 3. Toben Lafrancois measures a native unionid mussel collected from Miskominikaaniing-ziibi (Raspberry River) feeding into Raspberry Bay, 2019. Native mussels were counted, measured, and respectfully returned to the environment they came from. Photo © M. Hove.

Results

Zebra Mussel Distribution in APIS and Shoal Survey

Zebra mussels were observed at several new and previously identified locations in the park at generally low densities. Zebra mussels were collected at the Rocky Island dock, South Twin Island dock, *Sevona* wreck, Sand Island shoal north of *Sevona* wreck, and southeast of the Quarry Bay dock in 2019, and from the Quarry Bay mooring areas, Eagle Island shoal, *Sevona* wreck, and Rocky Island dock in 2020 (Figure 4). Results were standardized into catch per unit effort as number of mussels per diver per hour (n/diver/hr).

The highest zebra mussel catch rates occurred in the western shoals and the *Sevona* wreck. When these results are combined with the 2017 survey (Lafrancois et al. 2019), zebra mussels continue to be concentrated on the western shoal sites and a central area near Stockton Island on moorings and docks (Figure 5). Zebra mussels were absent at sites surveyed on the east side of the park (Long Island, Gull Island shoal) and less abundant in central mooring areas (Quarry and Presque Isle Bays of Stockton Island). One specimen was collected on Oak Island shoal in 2018, but none were found there in 2019 after similar dive search time. In this survey we did not re-visit the Michigan or Raspberry Island docks, where no zebra mussels were found previously. There was a west to east CPUE gradient across shoals surveyed in 2019 and 2020 (Figure 6). CPUEs were higher around boat docks and wrecks than in the larger, more open shoals and mooring areas of Stockton Island in the park's center (Figure 6 and Table 1). No quagga mussels were observed during this study.

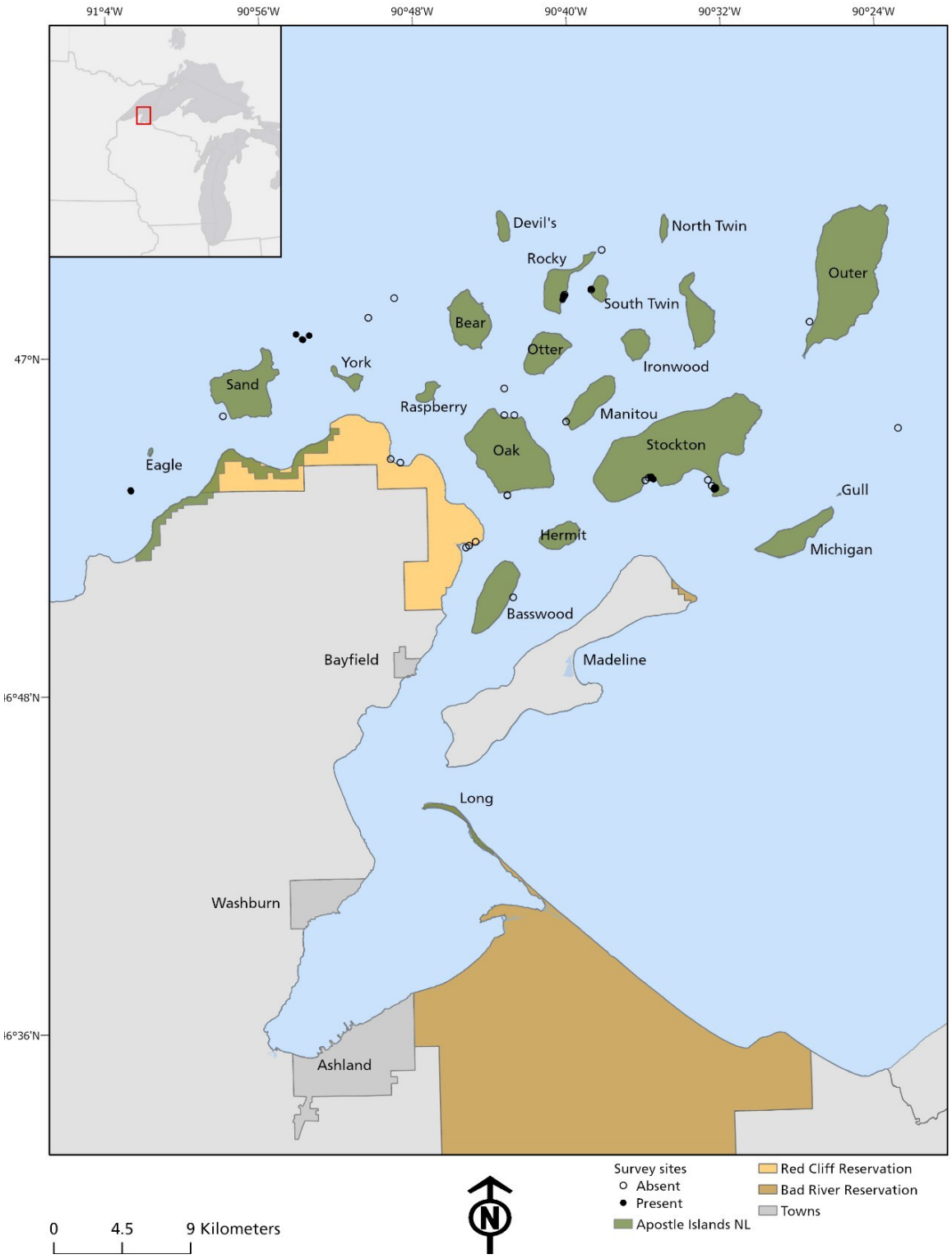

Figure 4. Zebra mussel observation locations in Apostle Islands National Lakeshore during timed SCUBA dives, 2018–2020. Open circles represent searches with no zebra mussels, filled circles represent sites where they were present and removed.

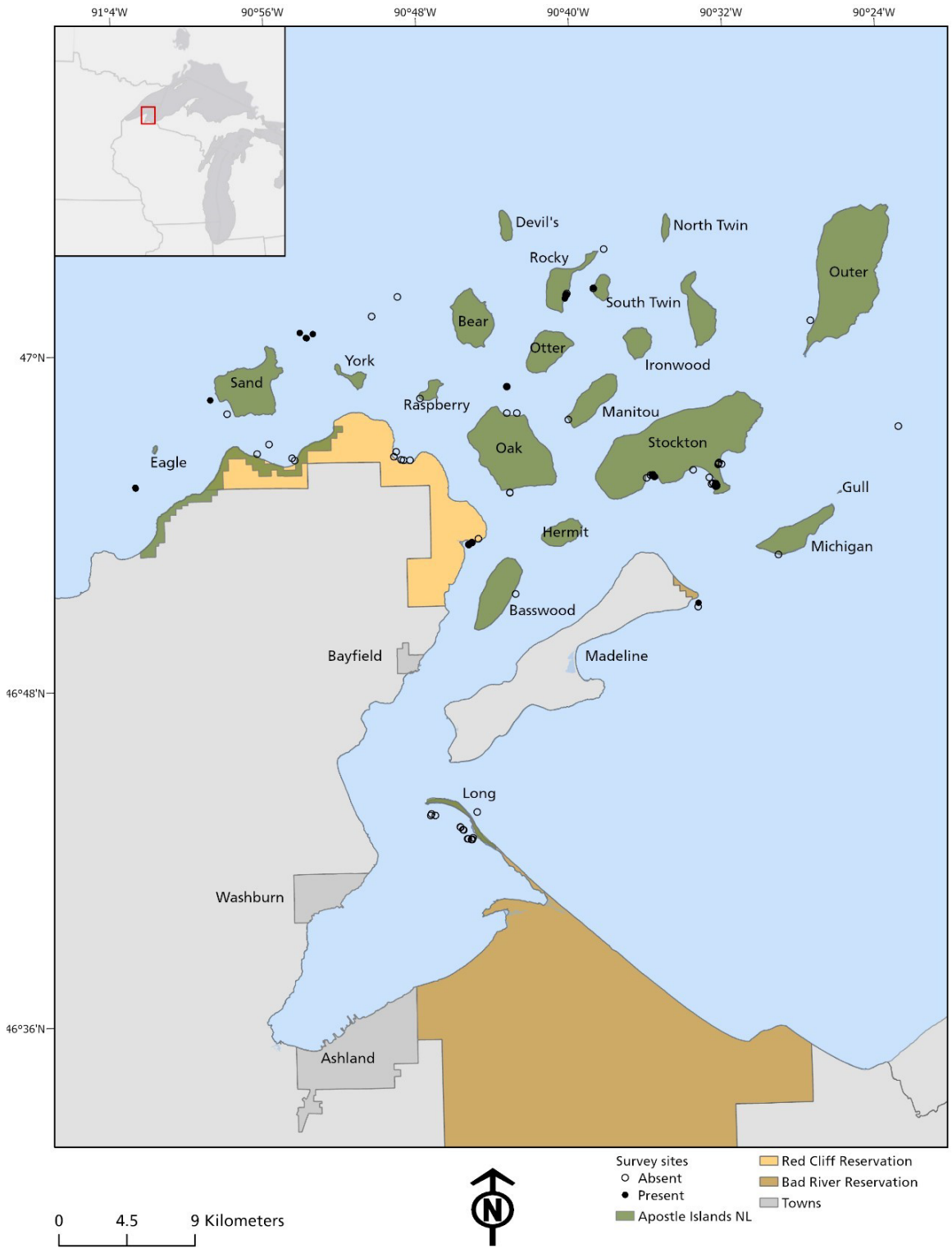

Figure 5. Locations where zebra mussels were observed in Apostle Islands National Lakeshore, combining the 2017 survey (Lafrancois et al. 2019) and the 2018–2020 survey. Open circles represent searches finding no zebra mussels, filled circles represent sites where they were present, removed, and counted.

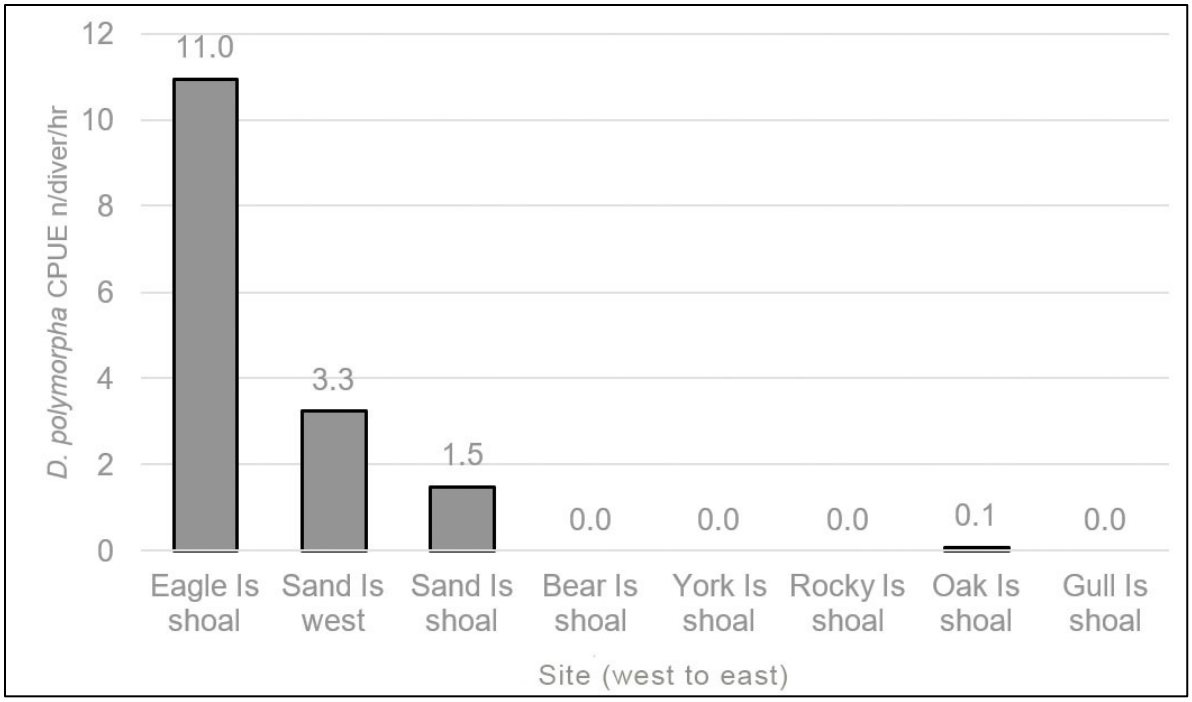

Figure 6. Zebra mussel catch rates (CPUE) at Apostle Islands National Lakeshore, 2019–2020, expressed as number of mussels per diver per hour. Zebra mussels were found on Oak Island shoal in 2019 but not in 2020, so the value shown is the mean CPUE over both years. All other sites represent single visits. Sand Island shoal does not include the Sevona wreck, which was treated later as a distinct site.

We recorded the length, width, and height of all zebra mussels, and samples were frozen for condition analysis. A range of sizes was found (Figure 7). COVID closures prevented completion of the condition analysis, which depended on a closed laboratory and Bayfield High School students, who were on a pandemic lockdown away from school. Condition analysis is planned for the next phase of the project. Field study location and mussel collection records are described in Appendices A and B, respectively. Comprehensive field results and photographic records are presented in Appendix C.

Figure 7. Zebra mussels (*Dreissena polymorpha*) collected on Eagle Island shoal, Apostle Islands National Lakeshore, October 2020. Photo © T. Lafrancois.

Zebra Mussel Removal Efficacy

Zebra mussels occur in APIS at low densities, making quantitative assessment of removal efforts very difficult via traditional means (quadrat surveys, fixed line transects). Removal efficacy was evaluated by focusing on known structures or easily identifiable areas and comparing CPUE rates over time.

Zebra mussel collection rates decreased at all sites but one over time (Table 1). After removal from the dock at South Twin Island in 2019, zebra mussels were not observed on that dock the following year. On Stockton Island, the NPS docks showed that dreissenid removal halved catch rate after one visit, and the second visit reduced the catch rate on the dock to zero in 2020. The visitor docks on Stockton Island were also searched and no invasive mussels were found in all years (but they were present in mooring areas of the nearby bays). Likewise, removal from the *Ottawa* wreck led to two consecutive years of no zebra mussels being found during our searches (Figure 8).

Table 1. *Dreissena polymorpha* catch rates (number per diver per hour) on NPS structures showing repeated search and removal efforts. Dives on the *Sevona* wreck covered different areas of the wreck over sampling years and do not represent comprehensive removal efforts. Asterisks (*) represent sampling efforts over time on the same portion of the *Sevona* (midship port side) and are the only case where densities were higher on subsequent visits. Data for 2017 from Lafrancois et al. (2019).

Site	Year	*D. polymorpha* (n/diver/hr)
Ottawa wreck	2017	3.0
	2019	0.0
	2020	0.0
Rocky Island dock	2019	14.1
	2020	4.4
South Twin Island dock	2019	5.0
	2020	0.0
Sevona wreck	2017	19.0
	2017	23.0*
	2019	42.0*
	2020	16.0
	2020	21.9
Stockton Island NPS dock	2017	4.0
	2019	2.8
	2020	0.0

Detailed records of zebra mussel collection and removal from the *Sevona* wreck were kept due to high mussel density and the size of the wreck, which required careful tracking of zebra mussel locations and removal in order to assess removal efficacy. This wreck has been a popular visitor site making it sensitive to boating visits and thus human vectors of invasive mussels, but it is also in the pathway of veliger drift as confirmed by shoal visits (above). Results presented here (Table 2) combine the present survey with previous results from NPS divers in 2017 (Lafrancois et al. 2019). Zebra mussel removal efforts took place on different parts of the wreck with the midship port side the only portion re-visited (Figure 9). Zebra mussel CPUE midship was higher in 2019 than in 2017, the only site with increased dreissenid CPUE over time. Midship CPUE had generally higher collection rates than at the stern or bow. Preliminary assessment of zebra mussel size distribution shows that at least four individuals were smaller than previous specimens by more than 1 standard deviation, suggesting possible zebra mussel recruitment or immigration (Figure 10). We plan to continue analysis of collected zebra mussels when students become available after COVID-19 safety measures are lifted.

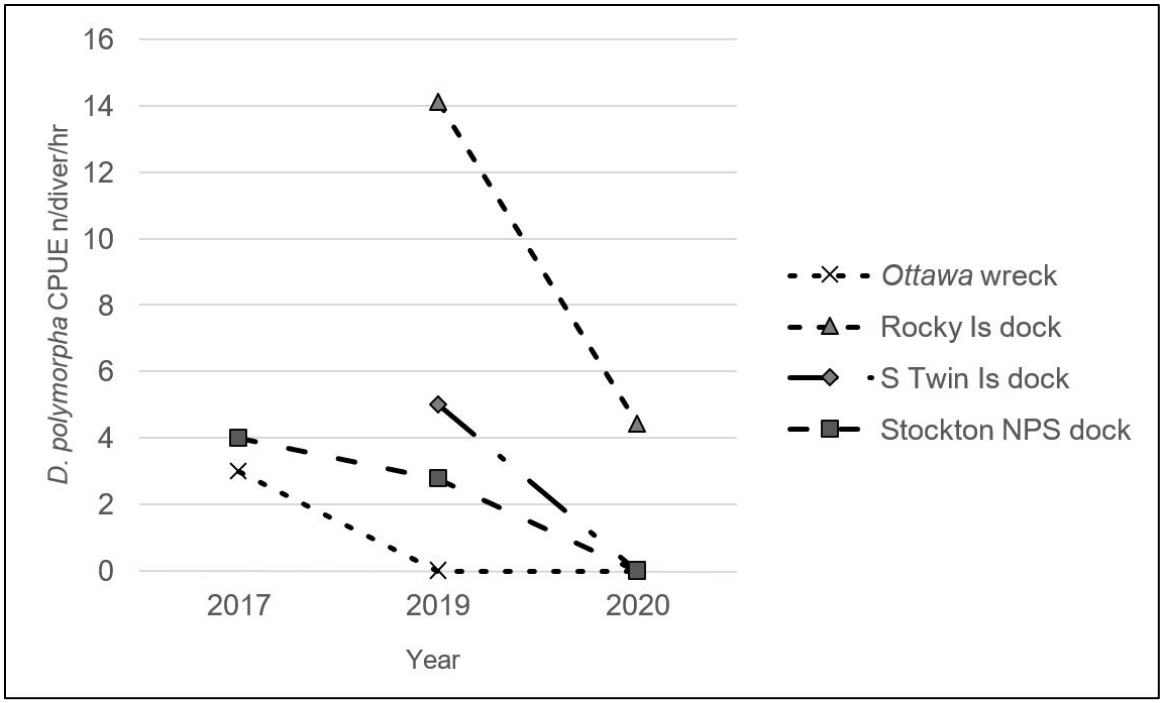

Figure 8. Changes in zebra mussel catch rates (n/diver/hr) over time from sites where they were removed. The *Sevona* wreck is treated separately, as search and removal dives were conducted across different sections of the ship. For each dock structure and the *Ottawa* wreck, all the surfaces divers could reach on the structures were surveyed. Rocky and South Twin docks were not sampled in 2017.

Table 2. *Dreissena polymorpha* CPUE rates (number of mussels/diver/hour) from the *Sevona* wreck near Sand Island across year and location on ship. The original detection in 2015 was midship port side. All zebra mussels encountered were removed and frozen for future condition analysis. Data for 2017 from Lafrancois et al. (2019).

Year	CPUE (n/diver/hr)	Wreck Section
2017	19.0	midship starboard
2017	23.0	midship port
2019	42.0	midship port
2020	16.0	stern
2020	21.9	bow

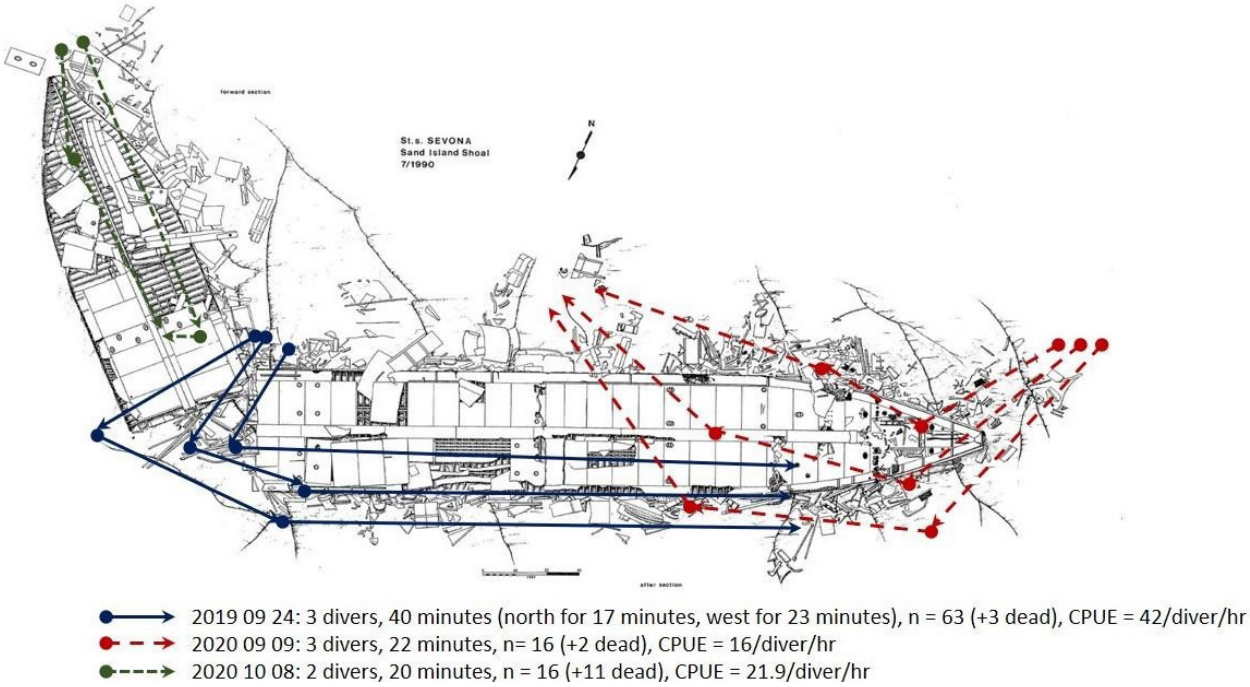

Figure 9. Zebra mussel survey and removal routes on the Sevona wreck in 2019 and 2020. Original detection in 2015 was near midship port side, and removal efforts in 2017 were concentrated on midship port side roughly along the 24 September dive of 2019. Sevona wreck base map courtesy of Wisconsin Historical Society, Maritime Preservation and Archaeology Program.

Figure 10. Zebra mussel (*D. polymorpha*) specimens collected from two dives on the *Sevona* wreck near Apostle Islands National Lakeshore, 2020. Individuals circled in yellow are more than a standard deviation smaller than individuals collected in previous years (Lafrancois et al. 2019). Photos © T. Lafrancois.

Native and Zebra Mussel Interactions and New Native Mussel Beds Found

We observed native mussels at several new locations in or adjacent to APIS, and we re-visited sites where both zebra mussels and native unionid mussels were found in 2017 (Lafrancois et al. 2019).

The 2019–2020 survey added 43 site visits, and unionids were observed at six of these locations (Table 3). Put together with the 2017 survey, these discoveries show a wide distribution of native unionid mussels in APIS (Figure 11). Giant Floater (*Pyganodon grandis*) were collected regularly around Stockton Island and the dock at South Twin Island. The only locations where other native unionid species were observed were at Oak Island, Miskominikaaniing-ziibi (Raspberry River), and Raspberry Bay. The greatest unionid diversity and CPUE was observed at the mouth of the Miskominikaaniing-ziibi, surveyed with permission of the Red Cliff Band of Lake Superior Chippewa. Some sites at Stockton Island had relatively dense beds of Giant Floater (e.g., Quarry Bay).

Table 3. Native mussel survey results from 2019–2020 with mean CPUE (number per diver per hour) across multiple dives (with standard deviation if more than two dives).

Location (dives/subsites)	Year	Mean CPUE	No. Species	Standard Deviation
Miskominikaaniing-ziibi (Raspberry River) (1/1)	2019	72	5	–
Stockton Island (11/5)	2019–2020	41	1	35
Oak Island (3/3)	2019	19	1	8
Red Cliff Bay (1/1)	2019	15	2	–
Raspberry Bay (1/1)	2019	7	2	–
South Twin Island (2/1)	2019–2020	5	1	3

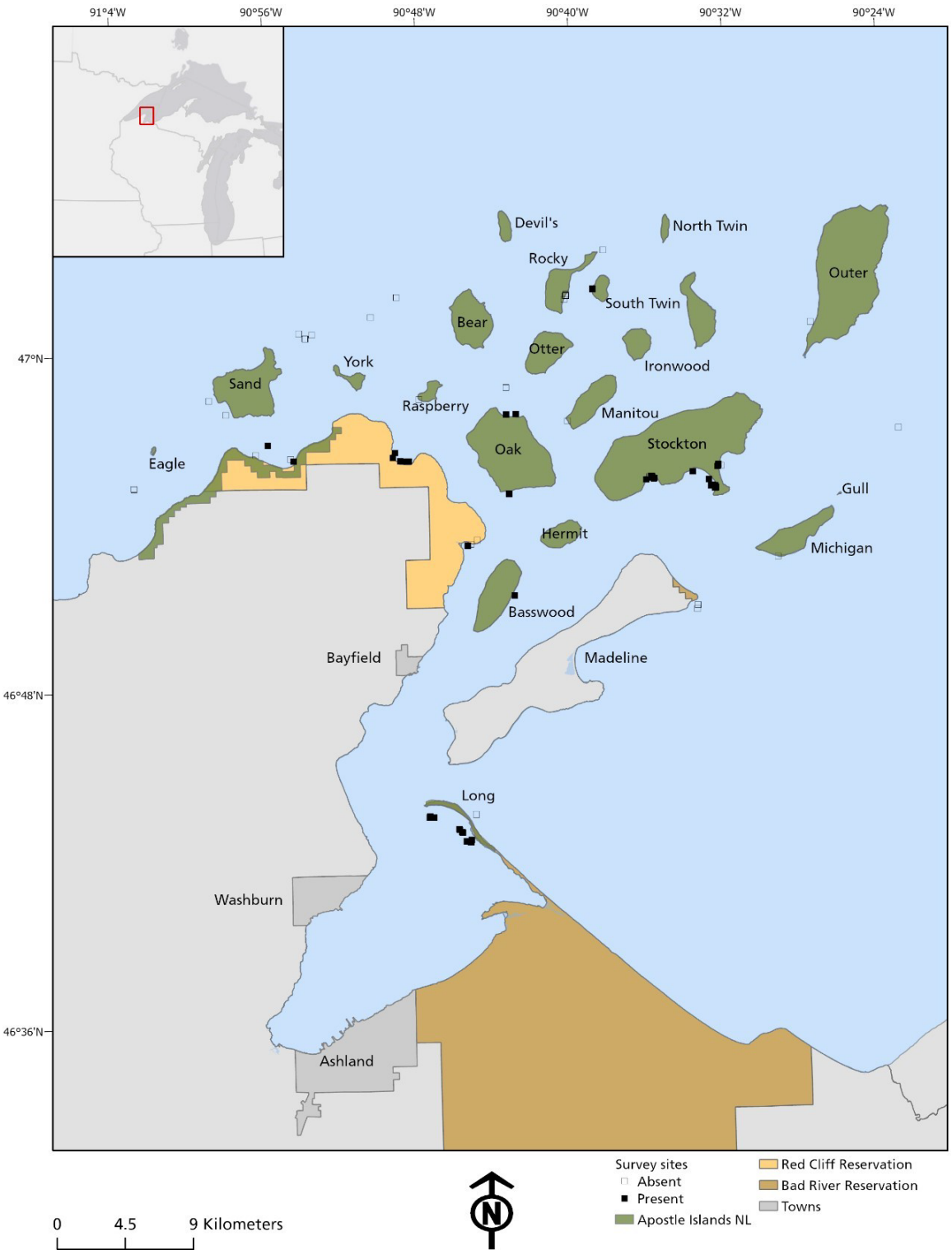

Figure 11. Locations where native mussels were observed in 2017 (Lafrancois et al. 2019) and during this study (2018–2020). All sites with native mussels in 2017 also had native mussels in 2018-2020. In this survey, Quarry and Presque Isle bays of Stockton Island were re-surveyed, as well as Miskominikaaniing-ziibi (Raspberry River). New beds were discovered near Basswood and Oak Islands in 2019 and 2020.

Co-occurrence of zebra mussels with native mussels varied among sites. Zebra mussels did not co-occur with native mussels in the new beds found near Basswood and Oak Islands. However, zebra mussels did co-occur with native mussels at the South Twin Island dock and the Quarry Bay mooring area of Stockton Island (Figures 12 and 13). In both cases of co-occurrence, zebra mussels were found attached to native mussels (Figure 12). A comprehensive description of unionid data is provided in the project field notes in Appendix C.

Figure 12. Toben Lafrancois holds a native unionid mussel (*Pyganodon grandis*) with an invasive zebra mussel (*D. polymorpha*) attached to it. They were found adjacent to the South Twin Island docks, Apostle Islands National Lakeshore, 2019. NPS photo/B. Moraska Lafrancois.

Figure 13. Invasive zebra mussels (*D. polymorpha*, at center top and bottom) adjacent to the South Twin Island dock, Apostle Islands National Lakeshore 2019. NPS photo/B. Moraska Lafrancois.

Outreach

We shared project results with APIS resource management and the public to the best extent possible under 2020 COVID safety restrictions. Year-end trip reports were submitted to APIS staff in fall 2019 and 2020. The 2020 pandemic limited public presentations and eliminated in-person outreach work with local high school students. Student work on zebra mussel condition analysis at Bayfield High School (Bayfield, WI) and college student capstone laboratory work at Northland College (Ashland, Wisconsin) were cancelled due to COVID closures of those campuses and closure of the research laboratory. Outreach and community involvement were shifted to 2021 and 2022. High school students dove two sites and are doing a condition analysis poster presentation at a national competition. A college intern will be doing a capstone project with this data in 2022. APIS Interpretive Rangers used the information and photographs in their communications with the public starting in 2021. Samples were measured and frozen so condition analysis can be continued in the future. Bayfield High School and Zaaga'igan Ma'iinganag (Lakewolves), a Bayfield High School

Alternative Education program organized by T. Lafrancois and R. Erickson, plan to participate in sample analysis and other parts of this project when pandemic safety conditions are met.

During this project, we shifted efforts from direct participation to primarily sharing videos and photographs online. In September of 2019, the Zaaga'igan Ma'iinganag performed a snorkel survey of portions of the Little Sand Bay dock structures to teach hands-on invasive species sampling techniques as part of their underwater photography arts and sciences curriculum. Videos and photographs of zebra mussel removal were shared with Bayfield High School Alternate Education and Biology classes in Fall 2020. Fifth grade classes from Washburn Elementary School (Washburn, Wisconsin) were provided videos and pictures to supplement their readings on zebra mussels in Fall of 2020. Finally, zebra mussel dive operations, removal videos, and photos were shared with residents of Northwest Passage to connect in-class science activities to their experiences photographing the Apostle Islands in their "Under the Surface" program in 2019 and 2020. Videos of zebra mussel removal from the *Sevona* were shared with Wisconsin Sea Grant for a web-based story map for grade school and high school kids for Aquatic Invasive Species Week, 22–26 February 2021 (P. Smith, Arbor Vitae-Woodruff Elementary School and Wisconsin Sea Grant, University of Wisconsin-Madison).

Discussion

Zebra Mussel Distribution in APIS and Shoal Survey

Understanding zebra mussel invasion pathways and vectors is critical if they are to be controlled. At APIS, densities are low enough that there may be time to act to prevent large scale establishment and avoid ecological and economic damages. Unlike native unionid mussels, zebra mussels do not have a host fish but rather send their juvenile veligers into water currents to disperse. Consequently, two primary means of population expansion into APIS are human transport (e.g., on boats, in bilge water, or in live-well tanks) or veliger drift on currents from infested areas (e.g., Twin Ports of Duluth, Minnesota, and Superior, Wisconsin, or nearby populations). In the past, we found zebra mussels on wrecks and well-known mooring areas, but also spread very thinly around areas of Sand Island, Kronn's Reef (Madeline Island), and some of the bays like Red Cliff Bay (Lafrancois et al. 2019). This work could not differentiate between transport mechanisms and there were not sufficient resources to dive all areas of the park to determine the full extent of zebra mussel presence.

In such large waters, it is very difficult to survey most of the bottom. Using cameras and other remote sensing to detect zebra mussels at low densities was found to be unreliable to date (A. Trebitz, personal communication, April 2018). SCUBA searches with trained divers and malacologists have been shown to be the most effective way to find zebra mussels at their current densities. The problem with SCUBA searches is that the effort required to sample an area can be effective but represents only a miniscule fraction of the bottom area of the park waters. This study was conducted with the specific goal of determining whether the shallow shoals around park borders act as sentinel sites for monitoring patterns of zebra mussel spread. Our observations support using shallow shoals along the park periphery as sentinel sites and would provide a set of stable locations for repeated SCUBA assessments of zebra mussel invasion dynamics.

Research scientists from the U.S. Environmental Protection Agency (EPA) studied zebra mussel prevalence at APIS in 2017 and speculated that veligers may have been drifting to APIS from the Twin Ports area (Trebitz et al. 2019). This study used random and targeted sampling to collect zooplankton, benthos, video, environmental DNA, and water quality data to better describe zebra mussel distribution and in turn found more veligers around the western islands and associated with shallower water. The distribution of shoals around APIS create a natural set of monitoring stations, and recently collected data corroborate that veliger drift is likely a source of zebra mussels in the park. If the Duluth-Superior harbor has been a source of veligers, then it would be expected that the initial invasion would first colonize the western shoals and that zebra mussel densities would decrease towards the eastern shoals. To test this, we conducted SCUBA searches from west to east at Eagle Island shoal, Sand Island shoal (north of the *Sevona* wreck), York Island shoal, Bear Island shoal, Oak Island shoal, and Gull Island shoal.

Our observation of zebra mussels on shoals confirms that they can act as sentinel systems. It was known that the *Sevona* wreck supported the densest population of zebra mussels found in the park to date; however, wrecks are also boat mooring sites for recreational divers, so while the *Sevona* remains the most important monitoring site, it alone cannot reveal all vectors of an invasion. The

presence of zebra mussels in relatively large numbers on Eagle Island shoal confirms that zebra mussels are found outside of common mooring sites (Figure 14). Furthermore, the decrease in density from west to east (with no invasive mussels found on the eastern-most shoal) corroborates the hypothesis that zebra mussels are immigrating to APIS from the west and possibly moving along the north side of the park via currents.

Figure 14. A zebra mussel (D. polymorpha) shown on-site at Eagle Island shoal, Apostle Islands National Lakeshore, 2020. The large cobble and boulders provide sheltered attachment points for the invasive mussels. Photo © T. Lafrancois.

These results support the long-term monitoring of these shoals in addition to key shipwrecks. The *Sevona*, *Ottawa*, *Noquebay*, and *Lucerne* are the most useful shipwrecks and most easily visited. While divers cannot scour the entire lakebed, these points provide easily identifiable sites. Because they jut up from the deeper areas, they may also act as aggregate locations for veligers, but we cannot confirm that at this time. Shoals are also ecologically valuable spawn sites for fishes, making zebra mussel removal a priority for them as well as mooring sites, docks, and wrecks. Continued survey work at these sites will allow managers to determine if zebra mussels are likely to attain high densities that could damage infrastructure, park equipment, or native mussel assemblages while also acting as an early warning of the possible immigration of quagga mussels into APIS.

The west-to-east distribution of zebra mussels across APIS shoals supports evidence of veliger drift, but their distribution across central island locations and shoals is difficult to interpret. Zebra mussels were found at very low densities on Oak Island Shoal and Kronn's Reef, and at moderate densities relative to APIS at mooring sites of Stockton Island (Quarry and Presque Isle Bays). The populations

of dreissenids in Stockton Island bays seem persistent, while other central sites show high variability. These locations have received high visitor use in the park, and it is not clear that veliger drift from the west would impact Stockton Island (however, no zebra mussels have yet been found in Julian Bay or on the *Noquebay* wreck). Incidental specimens found in Red Cliff Bay in past surveys (Lafrancois et al. 2019) is highly suggestive of drop-offs from boats, livewells, or bilge. Anonymous local boat owners have approached one of the authors about high densities of zebra mussels on their boat moored in Bayfield, indicating that this vector cannot be ruled out (T. Lafrancois, personal observation).

In this survey, zebra mussels were found on the Rocky Island and Twin Island docks but not on nearby shores or the bedrock substrates off the northeast point of Rocky Island, suggesting but not proving that human transport rather than drift is happening at these central dock sites. Our work, taken together with complementary studies, suggests that both human vectors and veliger drift are mechanisms co-responsible for zebra mussel distribution in APIS. While the pathway(s) of dispersal is unclear, park managers can address the human vector pathways as a preventative measure as we seek ways to prevent a high-density infestation.

Zebra Mussel Removal Efficacy

We observed a decrease in or elimination of zebra mussel abundance at nearly all locations where they were removed (see Table 1 and Figure 8). Zebra mussels were collected at a rate of 3/hr on the *Ottawa* shipwreck during 2017 (Lafrancois et al. 2019), and none were found in 2019 or 2020. Zebra mussels were collected at a rate of 4/hr at the Presque Isle Bay dock (Stockton Island) during 2017, but none were observed during 2020. The effect of zebra mussel removal appears to have been significant for at least 3 years at the Presque Isle Bay dock and *Ottawa* shipwreck. Removal on Rocky Island docks reduced CPUE by an order of magnitude, and we expect continued visits to reduce numbers to zero at other dock sites. It is an open question, however, whether there is going to be any recruitment at these sites by either veliger drift or boat introductions. Continued monitoring of structures is highly recommended to answer these questions.

The *Sevona* wreck was the first place biologists observed zebra mussels *in situ* at APIS in 2015 (J. Glase and T. Lafrancois, personal observation). This is a large and structurally complex wreck. Because it was flattened for navigational purposes by the Coast Guard, there are several areas where divers cannot reach beneath steel plates but where water (and veligers) can flow freely. We believe the best way to monitor this wreck is to divide searches into four sections: bow, midship port, midship starboard, and stern. This allows 2–3 SCUBA divers to search while maintaining safe buddy distance. Midship areas include the debris adjacent to the ship. We have tracked our efforts to date (see Figure 9). Removal efforts will require more visits to evaluate removal effectiveness. We felt it was important to cover the entire wreck for initial zebra mussel removal, but due to the size of the wreck, we have not re-visited all sections. The one section we did re-visit showed an increase in CPUE between 2017 and 2019 (see Table 2). The dive crew was the same both years and consisted of highly trained biologists, so it is difficult to imagine the increase is due to observational error.

Zebra mussel size distribution is beginning to vary at the *Sevona* wreck (Photo 1). In 2017 we found that all zebra mussels on the *Sevona* were nearly the same size, suggesting that this could indicate a

single colonization event with no local recruitment (Lafrancois et al. 2019). Samples from this 2019–2020 survey have been measured and are frozen for future condition analysis, but a wider range of sizes were found, indicating the possibility of recruitment (whether local or veliger drift is unclear). At least four individuals were a standard deviation smaller in size than specimens found in 2017 (see Figure 10). COVID-19 restrictions prevented completion of sample analysis (see below) and efforts were put into increased sampling instead. Our plans to study the size and condition of frozen zebra mussels should better describe the *Sevona* wreck population.

Photo 1. An invasive zebra mussel (*D. polymorpha*) attached to the *Sevona* wreck, Apostle Islands National Lakeshore, 2020. Photo © T. Lafrancois.

Native and Zebra Mussel Interactions and New Native Mussel Beds Found

The authors discovered new native unionid mussel beds in the central Apostle Islands during NPS diver training in 2018. Revisiting these sites during this survey documented these previously

unknown mussel beds near Basswood and Oak Islands (see Figure 11). Depth and substrate were very similar to other mussel bed sites like Quarry Bay at about 4 to 10 meters depth with sandy bottom and scattered macrophytes (Appendix C). In the context of Lake Superior, these are rare and biologically significant habitats where unionids were not known but could be expected to be found.

Recent changes in Outer Island lagoon prompted a check on the native mussels living there. Giant Floater were observed in the lagoon in 2001 during an otter study at APIS (Doolittle 2003; T. Doolittle, personal communication, March 2021). During a 2014 storm, the sandspit separating the lagoon from Lake Superior was blown open, exchanging large amounts of water and sand between lake and lagoon. The Outer Island lagoon remained open through the period of this study. Since APIS island lagoons can hold interesting mussel assemblages, e.g., Stockton Island lagoon contains a relatively unique population of Lake Floater (*Pyganodon lacustris*), and to assess how the lagoon responded to the storm, we revisited this site in 2019. The lagoon habitat appeared promising for unionids, but after 3.4 person-hours of diving, no unionids or zebra mussels were observed. We noticed a steady slow flow of water across the lagoon during our 2019 survey, but this may not preclude the lagoon freezing solid in winter. It is unclear if unionids will colonize or recolonize this habitat and what factors are involved (i.e., distance to other populations, use by host fish, environmental factors).

The encroachment of zebra mussels into APIS is a serious concern, as widespread declines of unionids have been observed in lower Great Lakes (e.g., Schloesser and Nalepa 1994). Zebra mussels have been observed co-occurring and attached to native mussels at APIS since 2017 (Lafrancois et al. 2019). The threat of zebra mussels competing with native mussels varies among locations but is of greatest concern in highly used mooring areas (Quarry Bay and South Twin docks). At no location where they co-occur did we observe zebra mussels at densities where they were smothering native mussels. Thankfully, we did not observe zebra mussels at the most unionid-rich location in the Miskominikaaniing-ziibi (Raspberry River). We did not observe a major impact at current densities but are concerned about future increases in zebra mussel populations that could be driven by currents or humans combined with more favorable conditions for their establishment in a warming lake (Lafrancois et al. 2018).

To this end, while shoals and wrecks should have priority as the most useful zebra mussel monitoring sites, we also recommend continued assessments of native mussel populations, ideally comparing mooring sites like Quarry Bay with less visited mussel bed areas. Quarry Bay, Long Island (Chequamegon Bay), Oak Island, and Basswood Island mussel beds are good candidates for native mussel assemblage monitoring. Ideally, partnerships with the Wisconsin DNR and Ojibwe tribal resource management would be formed to assess the amazing and diverse mussel populations of streams feeding the waters of APIS so that these sentinel species can be understood and used locally to understand the greater coastal ecology we depend on.

Summary and Recommendations

- Zebra mussel collection rates at shoals were highest on western Eagle Island shoal and decreased to zero moving eastward to Gull Island shoal. This spatial distribution supports the idea that veligers have drifted into APIS from the west (e.g., Twin Ports of Duluth and Superior) (Trebitz et al. 2019).
- Monitoring shoals would likely reveal if quagga mussel veligers were to drift into the park.
- West-to-east veliger drift does not preclude local reproduction or anthropogenic delivery. Patterns of zebra mussel distribution in the central and north-central Apostle Island docks and mooring sites may not be related to drift and appear closely associated with anthropogenic delivery.
- Zebra mussels colonized shipwrecks in the same spatial patterns as shoals, that is, in a west-to-east gradient. Zebra mussels were found consistently on the *Sevona* wreck from 2017 to 2020. They were encountered only once on the *Ottawa* in 2017, and were not found on the *Lucerne* to the east. In addition to shoals, then, wrecks make ideal sentinel sites for detection, removal, and evaluation of removal efficacy, and the two features appear to behave similarly as veliger receptors.
- At the low densities found to date, zebra mussel removal by trained SCUBA divers appears to be a consistently effective control measure on docks, reducing or eliminating presence from all docks surveyed.
- Repeat searches for zebra mussels in Quarry Bay mooring area near Stockton Island showed variable collection rates over space and time, but zebra mussels were encountered each survey year. Currently, zebra mussels are consistently found on native mussels here but not in numbers that are smothering.
- The apparent decline of native mussel diversity in Raspberry Bay between 1990 and 2017 (Lafrancois et al. 2019) is likely a sampling artifact. In 2019, with permission of the Red Cliff Band of Lake Superior Chippewa, we conducted a survey up into Miskominikaaniing-ziibi (Raspberry River) and found a highly diverse and abundant mussel assemblage. Doolittle (1991) reported Raspberry Bay held an unusually diverse mussel assemblage in the bay proper, while during both our surveys of Raspberry Bay we only observed two mussel species. Recent communication with Tom Doolittle revealed that he surveyed into the mouth of the Miskominikaaniing-ziibi and reported it as Raspberry Bay (T. Doolittle, personal communication, March 2021). In light of this, it is likely the apparent decline in mussel diversity in Raspberry Bay was due to differences in sample sites between those reported in Doolittle (1991) and this study.

Recommendations

- We recommend regular (annual or biannual) SCUBA assessment of shoals and wrecks as sentinel systems to observe dreissenid population dynamics. Future surveys should be patterned to avoid contamination. Eagle Island shoal, York Island shoal, Bear Island shoal,

and Gull Island shoal would be good candidate sentinel sites. Sand Island and Rocky Island shoals, both of which are fairly expansive and challenging to sample, could be sampled via two or three GPS points to serve as "stations". Wrecks that would serve as best long-term monitoring sites are the *Sevona*, *Ottawa*, *Noquebay*, and *Lucerne*. All dock structures on islands should be regularly monitored. We suggest diving the *Fedora* to assess possible colonization there. None were observed incidentally on a Zaaga'igan Ma'iinganag visit by snorkelers in 2019.

- On the *Sevona* wreck in particular, we recommend careful tracking of ship sections searched as described above. In addition, we recommend searching for zebra mussels on the rocky substrate near the *Sevona* (Photo 2).
- For shoals we recommend a more statistically robust survey pattern, such as randomly selecting locations from shallow shoals for quantitative line transect sampling. Densities are still low enough that CPUE may be the only option at some sites. Eagle Island shoal is likely to be a good candidate for line transects, however.
- Zebra mussels may be entering the park from nearby locations, such as nearby public docks. These locations could be surveyed for zebra mussels and if they are found these locations could be considered for future management or cooperative invasive species control efforts.
- Quarry Bay at Stockton Island supports a large, low density native mussel bed where monitoring should continue. While Doolittle (1991) recommended unionid surveys every 5 years, it was nearly 27 years until the next survey occurred. We concur that native mussel surveys every 5 years here and at other beds would be extremely helpful for understanding this sentinel species assemblage. This would also contribute to increased probability of invasive species detection.
- We recommend working with the Red Cliff Band of Lake Superior Chippewa to monitor the mussel assemblages in Miskominikaaniing-ziibi and Raspberry Bay to better understand mussel assemblage and habitat dynamics of the river and the bay. Extreme care should be taken to avoid bringing zebra mussel-infested equipment into Miskominikaaniing-ziibi.
- To begin assessing natural native mussel recolonization rates within the park, we recommend surveying Outer Island lagoon every 5 years to determine whether dreissenid or native mussels return to the lagoon subsequent to it being opened to the lake.

Photo 2. Mark Hove searches the stern of the *Sevona*, Apostle Islands National Lakeshore, 2020. Photo © T. Lafrancois.

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Appendix A. Field Site Locations.

Table A1. Field site locations.

Year	Site description	Nearest Land	Survey Date (yyyymmdd)	Unique ID	UTM E 15T	UTM N 15T	Lat° N	Lon° W	Lat dd	Lon dd
2018	Oak Island south	Oak	20180926	OA_so_20180926	672889	5198002	46 54.782	90 43.773	46.91303	−90.72955
	Oak Island shoal	Oak	20180926	OA_sh_20180926	672695	5204971	46 58.545	90 43.767	46.97575	−90.72945
	Basswood Island	Basswood	20180926	BA_ea_20180926	673276	5191218	46 51.116	90 43.623	46.85193	−90.72705
2019	Bear Island shoal	Bear	20190718	BR_sh_20190718	665449	5210903	47 1.856	90 49.349	47.03093	−90.82248
	Oak Island shoal	Oak	20190718	OA_sh_20190718	672688	5204958	46 58.538	90 43.773	46.97563	−90.72955
	Sand Island shoal	Sand	20190718	SA_sh_20190718	659008	5208508	47 0.659	90 54.482	47.01098	−90.90803
	York Island shoal	York	20190718	YO_sh_20190718	663750	5209592	47 1.174	90 50.718	47.01957	−90.8453
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693093	5209042	47 0.403	90 27.587	47.00672	−90.45978
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693170	5208965	47 0.360	90 27.528	47.006	−90.4588
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693088	5208887	47 0.319	90 27.595	47.00532	−90.45992
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	692945	5208478	47 0.101	90 27.718	47.00168	−90.46197
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693001	5208495	47 0.109	90 27.674	47.00182	−90.46123
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693209	5209098	47 0.431	90 27.494	47.00718	−90.45823
	Outer Island Lagoon	Outer	20190917	OU_lg_20190917	693134	5209147	47 0.459	90 27.552	47.00765	−90.45920
	Oak Island Camp	Oak	20190918	OA_ca_20190918	673348	5203209	46 57.584	90 43.293	46.95973	−90.72155
	Oak Island North Bay	Oak	20190918	OA_nb_20190918	672704	5203212	46 57.596	90 43.800	46.95993	−90.73
	Raspberry Bay	Mainland	20190918	RB_ba_20190918	665862	5200068	46 56.004	90 49.261	46.9334	−90.82102
	Miskominikaaniing-ziibi	Mainland	20190918	RB_mz_20190918	665233	5200308	46 56.143	90 49.751	46.93572	−90.82918
	Rocky Island docks	Rocky	20190919	RO_dk_20190919	676630	5211062	47 1.769	90 40.523	47.02948	−90.67538
	Rocky Island shoal	Rocky	20190919	RO_sh_20190919	679086	5214065	47 3.349	90 38.514	47.05582	−90.6419
	South Twin docks	South Twin	20190919	ST_dk_20190919	678395	5211490	47 1.971	90 39.120	47.03285	−90.652
	Manitou docks	Manitou	20190920	MT_dk_20190920	676748	5202768	46 57.292	90 40.624	46.95487	−90.67707
	Oak Island south	Oak	20190920	OA_so_20190920	672889	5198002	46 54.782	90 43.773	46.91303	−90.72955
	Quarry Bay - 1	Stockton	20190924	QB_b1_20190924	682489	5198987	46 55.159	90 36.192	46.91932	−90.6032
	Quarry Bay - 2	Stockton	20190924	QB_b2_20190924	681952	5198894	46 55.118	90 36.617	46.91863	−90.61028
	Quarry Bay docks	Stockton	20190924	QB_dk_20190924	682193	5199095	46 55.222	90 36.422	46.92037	−90.60703
	Sevona wreck	Sand	20190924	SV_wr_20190924	659410	5208173	47 0.472	90 54.172	47.00787	−90.90287
	Ottawa wreck	Mainland	20190925	OT_wr_20190925	670383	5194612	46 52.992	90 45.822	46.8832	−90.7637
	Presque Isle marina	Stockton	20190925	PI_ma_20190925	686550	5198372	46 54.760	90 33.010	46.91266	−90.55016

Table A1 (continued). Field site locations.

Year	Site description	Nearest Land	Survey Date (yyyymmdd)	Unique ID	UTM E 15T	UTM N 15T	Lat° N	Lon° W	Lat dd	Lon dd
2019 (cont.)	Presque Isle NPS dock	Stockton	20190925	PI_np_20190925	686504	5198355	46 54.751	90 33.046	46.91252	−90.55077
	Presque Isle visitor dock	Stockton	20190925	PI_vd_20190925	686543	5198418	46 54.784	90 33.014	46.91307	−90.55023
	Red Cliff Bay	Mainland	20190925	RC_ba_20190926	670170	5194488	46 52.928	90 45.993	46.88213	−90.76655
	Sand Island West	Sand	20191004	SA_we_20191004	654197	5203123	46 57.821	90 58.387	46.96369	−90.97312
2020	Presque Isle NPS dock	Stockton	20200902	PI_np_20200902	686515	5198352	46 54.75	90 33.037	46.9125	−90.55062
	Presque Isle visitor dock	Stockton	20200902	PI_vd_20200902	686556	5198412	46 54.781	90 33.004	46.91302	−90.55007
	Eagle Island shoal	Sand	20200909	EA_sh1_20200909	648159	5198199	46 55.247	91 3.243	46.92078	−91.05405
	Sevona wreck	Sand	20200909	SV_wr_20200909	659453	5208163	47 0.466	90 54.138	47.00777	−90.9023
	Gull shoal	Michigan	20200910	GU_sh_20200910	698588	5202347	46 56.694	90 23.43	46.9449	−90.3905
	Ottawa wreck	Mainland	20200910	OT_wr_20200910	670383	5194612	46 52.992	90 45.822	46.8832	−90.7637
	Rocky Island dock	Rocky	20200910	RO_dk_20200910	676630	5211062	47 1.769	90 40.523	47.02948	−90.67538
	Rocky Island near dock	Rocky	20200910	RO_nd_20200910	676633	5211045	47 1.759	90 40.521	47.02932	−90.67535
	Rocky Island north of dock	Rocky	20200910	RO_no_20200910	665256	5210801	47 1.804	90 49.503	47.03007	−90.82505
	Rocky Island south of dock	Rocky	20200910	RO_so_20200910	676600	5211023	47 1.748	90 40.548	47.02913	−90.6758
	South Twin dock	South Twin	20200910	ST_dk_20200910	678395	5211490	47 1.971	90 39.12	47.03285	−90.652
	Presque Isle mooring east	Stockton	20200917	PI_m1_20200917	686345	5198550	46 54.859	90 33.167	46.91432	−90.55278
	Presque Isle mooring central	Stockton	20200917	PI_m2_20200917	686092	5198920	46 55.063	90 33.357	46.91772	−90.55595
	Quarry Bay 3	Stockton	20200917	QB_b3_20200917	682284	5199134	46 55.242	90 36.350	46.9207	−90.60583
	Quarry Bay 4	Stockton	20200917	QB_b4_20200917	682354	5199105	46 55.225	90 36.295	46.92042	−90.60492
	Eagle Island shoal	Sand	20201008	EA_sh2_20201008	648144	5198245	46 55.272	91 3.254	46.9212	−91.05423
	Sevona wreck	Sand	20201008	SV_wr_20201008	659453	5208163	47 0.466	90 54.138	47.00777	−90.9023

Appendix B. Dreissenids and Unionids Observed.

Table B1. Dreissenids and unionids observed.

Year	Site description	Nearest Land	Time (diver hrs)	Species					
				Dreissena polymorpha	***Pyganodon grandis***	***Elliptio complanata***	***Lampsilis siliquoidea***	***Lasmigona complanata***	***Anodontoides ferussacianus***
2019	Bear Island shoal	Bear	1.00	0	0	0	0	0	0
	Oak Island shoal	Oak	1.00	0	0	0	0	0	0
	Sand Island shoal nw of wreck	Sand	0.67	1	0	0	0	0	0
	York Island shoal	York	1.00	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.67	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.67	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.50	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.17	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.50	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.58	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.42	0	0	0	0	0	0
	Outer Island Lagoon	Outer	0.42	0	0	0	0	0	0
	Oak Island Camp	Oak	0.60	0	2	0	0	0	0
	Oak Island North Bay	Oak	1.00	0	16	0	0	0	0
	Raspberry Bay	Mainland	1.00	0	5	2	0	0	0
	Miskominikaaniing-ziibi	Mainland	1.20	0	2	75	4	4	1
	Rocky Island docks	Rocky	1.70	24	0	0	0	0	0
	Rocky Island shoal	Rocky	1.00	0	0	0	0	0	0
	South Twin docks	South Twin	0.60	3	4	0	0	0	0
	Manitou docks	Manitou	0.80	0	0	0	0	0	0
	Oak Island south	Oak	0.33	0	19	0	0	0	0

Table B1 (continued). Dreissenids and unionids observed.

Year	Site description	Nearest Land	Time (diver hrs)	Species					
				Dreissena polymorpha	***Pyganodon grandis***	***Elliptio complanata***	***Lampsilis siliquoidea***	***Lasmigona complanata***	***Anodontoides ferussacianus***
2019 (cont.)	Quarry Bay - 1	Stockton	0.75	2	88	0	0	0	0
	Quarry Bay - 2	Stockton	0.75	0	58	0	0	0	0
	Quarry Bay docks	Stockton	0.67	0	0	0	0	0	0
	Sevona wreck	Sand	1.50	63	0	0	0	0	0
	Ottawa wreck	Mainland	0.8	0	0	0	0	0	0
	Presque Isle marina	Stockton	0.37	0	9	0	0	0	0
	Presque Isle NPS dock	Stockton	1.08	3	15	0	0	0	0
	Presque Isle visitor dock	Stockton	0.67	0	3	0	0	0	0
	Red Cliff Bay	Mainland	1.50	0	21	1	0	0	0
	Sand Island West	Sand	0.50	0	0	0	0	0	0
2020	Presque Isle NPS dock	Stockton	0.60	0	6	0	0	0	0
	Presque Isle visitor dock	Stockton	0.53	0	8	0	0	0	0
	Eagle Island shoal	Sand	1.50	15	0	0	0	0	0
	Sevona wreck	Sand	1.00	16	0	0	0	0	0
	Gull shoal	Michigan	1.70	0	0	0	0	0	0
	Ottawa wreck	Mainland	0.60	0	0	0	0	0	0
	Gull Island shoal dock	Gull	1.50	5	0	0	0	0	0
	Rocky Island dock	Rocky	1.13	5	0	0	0	0	0
	Rocky Island near dock	Rocky	0.33	1	0	0	0	0	0
	Rocky Island north of dock	Rocky	0.17	0	0	0	0	0	0
	Rocky Island south of dock	Rocky	0.17	0	0	0	0	0	0
	South Twin dock	South Twin	0.50	0	1	0	0	0	0
	Presque Isle mooring east	Stockton	0.67	0	29	0	0	0	0

Table B1 (continued). Dreissenids and unionids observed.

Year	Site description	Nearest Land	Time (diver hrs)	Species					
				Dreissena polymorpha	***Pyganodon grandis***	***Elliptio complanata***	***Lampsilis siliquoidea***	***Lasmigona complanata***	***Anodontoides ferussacianus***
2020 (cont.)	Presque Isle mooring central	Stockton	0.43	0	6	0	0	0	0
	Quarry Bay 3	Stockton	0.60	5	33	0	0	0	0
	Quarry Bay 4	Stockton	0.33	0	21	0	0	0	0
	Eagle Island shoal	Sand	0.67	8	0	0	0	0	0
	Sevona wreck	Sand	0.73	16	0	0	0	0	0

Appendix C. Mussel Survey Data.

The following records are data summaries from dreissenid and unionid surveys conducted in the Apostle Islands National Lakeshore between September and October 2019 and October 2020. Questionable taxonomic identifications that could not be verified were excluded from summary data and analysis. Pictures of field collections are included when available. Vouchers were not collected for this project.

2019

Site Number: 2019001

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.403′ N Longitude 90° 27.587′ W

Substrate: Firm sand and debris

Depth: 1–5 feet

Date: 17 September 2019

Survey time: Mark Hove, Toben Lafrancois, Brenda Moraska Lafrancois = 0.67 hr

Equipment: SCUBA

Notes: No mussels observed; noticeable slow south-to-north lagoon current.

Site Number: 2019002

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.360′ N Longitude 90° 27.528′ W

Substrate: Sand with more silt, large woody debris, some macrophytes

Date: 17 September 2019

Survey time: Mark Hove, Toben Lafrancois, Brenda Moraska Lafrancois = 0.67 hr

Equipment: Snorkel

Notes: No mussels observed; noticeable slight south-to-north lagoon current.

Site Number: 2019003

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.319′ N Longitude 90° 27.595′ W

Substrate: Sand, silt (sometimes deep), more vegetation (3–4 species)

Date: 17 September 2019

Survey time: Mark Hove, Toben Lafrancois, Brenda Moraska Lafrancois × 10 min = 30 min

Equipment: Snorkel

Notes: No mussels observed. Observed rushes, bluegill, yellow perch, and northern pike (small) along the shore.

Site Number: 2019004

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.101′ N Longitude 90° 27.718′ W

Substrate: Wood, sand (60%), silt

Date: 17 September 2019

Survey time: Toben Lafrancois × 10 min = 10 min

Equipment: Snorkel

Notes: No mussels observed; observed bryozoans up the stream.

Site Number: 2019005

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.101′ N Longitude 90° 27.718′ W

Substrate: Areas of sand, areas of silt, areas of vegetation (large), also “sponge forest”

Depth: 1–5 feet

Date: 17 September 2019

Survey time: Mark Hove and Brenda Moraska Lafrancois × 15 min = 30 min

Equipment: Snorkel

Notes: No mussels observed.

Site Number: 2019006

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.109′ N Longitude 90° 27.674′ W

Substrate: Initially areas of dense vegetation, then areas of sand and willows and stumps, then sand, then areas of sorted windblown debris lines

Date: 17 September 2019

Survey time: Brenda Moraska Lafrancois × 35 min = 35 min

Equipment: Snorkel

Notes: No mussels observed.

Site Number: 2019007

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.431′ N Longitude 90° 27.494′ W

Substrate: Sand with areas of complete vegetative cover, some areas of sand and sorted windblown debris lines

Date: 17 September 2019

Survey time: Mark Hove × 25 min = 25 min

Equipment: Snorkel

Notes: No mussels observed.

Site Number: 2019008

Location: Lake Superior, Outer Island, Outer Island Lagoon

Coordinates: Latitude 47° 0.459′ N Longitude 90° 27.552′ W

Substrate: Sand with areas of complete vegetation cover

Date: 17 September 2019

Survey time: Brenda Moraska Lafrancois × 25 min = 25 min

Equipment: Snorkel

Notes: No mussels observed.

Site Number: 2019009

Location: Lake Superior, Oak Island, North Bay (center)

Coordinates: Latitude 46° 57.596′ N Longitude 90° 43.800′ W

Substrate: Sand with occasional logs, rare macrophytes

Depth: 15–22 feet

Date: 18 September 2019

Survey time: Mark Hove, Toben Lafrancois, Dave VanderMeulen × 20 min = 60 min

Equipment: SCUBA

Notes: Sphaeriids fairly common. The number, age, and size of mussels sampled at this site can be seen in Table C1, and sample examples can be seen in Figure C1.

Table C1. Number, age, and size of mussels collected at Site 2019009 (Lake Superior, Oak Island, North Bay [center]), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	6	10	16	52	58	59	92	0

Figure C1. *Pyganodon grandis* collected from Site 2019009 (Lake Superior, Oak Island, North Bay (center), 2019.

Site Number: 2019010

Location: Lake Superior, Oak Island, Camp — south end, North Bay east

Coordinates: Latitude 46° 57.584′ N Longitude 90° 43.293′ W

Substrate: Sand

Depth: 15–22 feet

Date: 18 September 2019

Survey time: Mark Hove, Toben Lafrancois, Dave VanderMeulen x 12 min = 36 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C2.

Table C2. Number, age, and size of mussels collected at Site 2019010 (Lake Superior, Oak Island, Camp — south end, North Bay east), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	1	1	2	46	–	84	–	0

Site Number: 2019011

Location: Lake Superior, Miskominikaaniing-ziibi (Raspberry River) mouth

Coordinates: Latitude 46° 56.143′ N Longitude 90° 49.751′ W

Substrate: Large areas of sand with clumps of vegetation, debris aggregations in many areas

Depth: 2–7 feet

Date: 18 September 2019

Survey time: Mark Hove, Toben Lafrancois, Dave VanderMeulen × 24 min = 72 min

Equipment: SCUBA

Notes: Very few mussels near mouth, many more upstream as river becomes more lotic. The number, age, and size of mussels sampled at this site can be seen in Table C3, and sample examples can be seen in Figure C2.

Table C3. Number, age, and size of mussels collected at Site 2019011 (Lake Superior, Miskominikaaniing-ziibi [Raspberry River] mouth), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Anodontoides ferussacianus	–	1	1	–	–	57	–	–
Elliptio complanata	3	72	75	33	46	60	108	10
Pyganodon grandis	–	2	2	–	–	54	56	0
Lampsilis siliquoidea	–	4	4	–	–	72	93	3
Lasmigona complanata	–	4	4	–	–	80	97	0
Pyganodon grandis	–	2	2	–	–	54	56	0

Figure C2. Native mussels collected at Raspberry River mouth. *Anodontoides ferussacianus* (a), *Lasmigona complanata* (b), *Lampsilis siliquoidea* (c), possible *Lasmigona compressa* (d), *Elliptio complanata* (e).

Site Number: 2019012

Location: Lake Superior, Raspberry Bay

Coordinates: Latitude 46° 56.004′ N Longitude 90° 49.261′ W

Substrate: Sand with rare macrophytes and branches

Depth: 14–20 feet

Date: 18 September 2019

Survey time: Mark Hove, Toben Lafrancois, Dave VanderMeulen × 20 min = 60 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C4, and sample examples can be seen in Figure C3.

Table C4. Number, age, and size of mussels collected at Site 2019012 (Lake Superior, Raspberry Bay), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Elliptio complanata	–	2	2	–	–	61	88	0
Pyganodon grandis	–	5	5	–	–	51	72	0

Figure C3. Native mussels collected from Raspberry Bay.

Site Number: 2019013

Location: Lake Superior, Rocky Island dock

Coordinates: Latitude 47° 1.769′ N Longitude 90° 40.523′ W

Substrate: Mostly sand with patches of cobble and few boulders mostly by dock

Depth: 1–10 feet

Date: 19 September 2019

Survey time: Mark Hove, Toben Lafrancois, Brenda Moraska Lafrancois × 34 min = 102 min

Equipment: SCUBA

Notes: Zebra mussels on dock, mostly at dock base and nearby rocks. The number, age, and size of mussels sampled at this site can be seen in Table C5.

Table C5. Number, age, and size of mussels collected at Site 2019013 (Lake Superior, Rocky Island dock), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	0	24	24	–	–	–	–	0

Site Number: 2019014

Location: Lake Superior, South Twin Island, dock

Coordinates: Latitude 47° 1.971′ N Longitude 90° 39.12′ W

Substrate: Sand and cobble

Depth: 1–7 feet

Date: 19 September 2019

Divers: Mark Hove, Toben Lafrancois

Survey time: Mark Hove, Toben Lafrancois × 8 min = 16 min

Equipment: SCUBA

Notes: Searched dock and substrate at dock base. The number, age, and size of mussels sampled at this site can be seen in Table C6.

Table C6. Number, age, and size of mussels collected at Site 2019014 (Lake Superior, South Twin Island dock), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	3	0	3	–	–	–	–	0
Pyganodon grandis	0	4	4	–	–	53	73	0

Site Number: 2019015

Location: Lake Superior, Rocky Island, rocky shoal north of Rocky Island

Coordinates: Latitude 47° 3.349′ N Longitude 90° 38.514′ W

Substrate: All boulders and cobble

Depth: 14–15 feet

Date: 19 September 2019

Survey time: Mark Hove, Toben Lafrancois, Brenda Moraska Lafrancois × 20 min = 60 min

Equipment: SCUBA

Notes: No mussels observed; many snails, a few Johnny Darters, sculpins, and sphaeriids, possibly a whitefish or dace.

Site Number: 2019016

Location: Lake Superior, *Sevona* wreck

Coordinates: Latitude 47° 0.472′ N Longitude 90° 54.172′ W

Substrate: Shipwreck and nearby bedrock

Depth: 19–21 feet

Date: 24 September 2019

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 30 min = 90 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C7.

Table C7. Number, age, and size of mussels collected at Site 2019016 (Lake Superior, *Sevona* wreck), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	–	–	63	–	–	–	–	3

Site Number: 2019017

Location: Lake Superior, Stockton Island, Quarry Bay-1, approx. 1,000 ft southeast of dock

Coordinates: Latitude 46° 55.159′ N Longitude 90° 36.192′ W

Substrate: Sand with patches of scattered macrophytes, couple of branches

Depth: 17–21 feet

Date: 24 September 2019

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 15 min = 45 min

Equipment: SCUBA

Notes: Jay observed a dead Ninespine Stickleback. The number, age, and size of mussels sampled at this site can be seen in Table C8.

Table C8. Number, age, and size of mussels collected at Site 2019017 (Lake Superior, Stockton Island, Quarry Bay-1), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	–	2	2	–	–	–	–	–
Pyganodon grandis	1	87	88	48	–	42	77	26

Site Number: 2019018

Location: Lake Superior, Stockton Island, Quarry Bay-2, approx. 1,000 ft southwest of dock

Coordinates: Latitude 46° 55.118′ N Longitude 90° 36.617′ W

Substrate: Sand with occasional branches, logs, or macrophytes

Depth: 21–30 feet

Date: 24 September 2019

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 15 min = 45 min

Equipment: SCUBA

Notes: Observed a few live Johnny Darters and 1 dead Troutperch. The number, age, and size of mussels sampled at this site can be seen in Table C9.

Table C9. Number, age, and size of mussels collected at Site 2019018 (Lake Superior, Stockton Island, Quarry Bay-2), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	1	57	58	47	–	50	69	15

Site Number: 2019019

Location: Lake Superior, Stockton Island, Quarry Bay dock

Coordinates: Latitude 46° 55.222′ N Longitude 90° 36.422′ W

Substrate: Dock and nearby sand

Depth: 1–8 feet

Date: 24 September 2019

Survey time: Jay Glase, Toben Lafrancois × 20 min = 40 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019020

Location: Lake Superior, Oak Island, south side of island

Coordinates: Latitude 46° 54.782′ N Longitude 90° 43.773′ W

Substrate: Sand with rare branch or macrophyte

Depth: 18–22 feet

Date: 20 September 2019

Equipment: SCUBA

Survey time: Mark Hove, Toben Lafrancois × 10 min = 20 min

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C10.

Table C10. Number, age, and size of mussels collected at Site 2019020 (Lake Superior, Oak Island, south side), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	–	19	19	–	–	53	80	4

Site Number: 2019021

Location: Lake Superior, Manitou Island, Manitou Fish Camp dock

Coordinates: Latitude 46° 57.292′ N Longitude 90° 40.624′ W

Substrate: Dock and nearby sand and occasional stones, macrophytes at one spot

Depth: 15 feet (maximum)

Date: 20 September 2019

Survey time: Mark Hove, Toben Lafrancois × 24 min = 48 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019022

Location: Lake Superior, Bear Island shoal

Coordinates: Latitude 47° 01.856′ N Longitude 90° 49.349′ W

Substrate: Boulders, cobble

Depth: (Not recorded)

Date: 18 July 2019

Survey time: 3 divers × 20 min = 60 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019023

Location: Lake Superior, Oak Island shoal

Coordinates: Latitude 46° 58.538′ N Longitude 90° 43.773′ W

Substrate: Boulders, cobble

Depth: (Not recorded)

Date: 18 July 2019

Survey time: 3 divers × 20 min = 60 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019024

Location: Lake Superior, Sand Island shoal (northwest of wreck)

Coordinates: Latitude 47° 0.659′ N Longitude 90° 54.482′ W

Substrate: Bedrock, cobble

Depth: (Not recorded)

Date: 18 July 2019

Survey time: 2 divers × 20 min = 40 min

Equipment: SCUBA

Notes: One *Dreissena polymorpha* collected.

Site Number: 2019025

Location: Lake Superior, York Island shoal

Coordinates: Latitude 47° 01.174′ N Longitude 90° 50.718′ W

Substrate: Boulders, cobble

Depth: (Not recorded)

Date: 18 July 2019

Survey time: 3 divers × 20 min = 60 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019026

Location: Lake Superior, *Ottawa* wreck

Coordinates: Latitude 46° 52.992′ N Longitude 90° 45.822′ W

Substrate: Wreck, sand, cobble

Depth: (Not recorded)

Date: 25 September 2019

Survey time: 3 divers × 16 min = 48 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2019027

Location: Lake Superior, Stockton Island, Presque Isle Bay marina

Coordinates: Latitude 46° 54.76′ N Longitude 90° 33.01′ W

Substrate: Sand

Depth: (Not recorded)

Date: 25 September 2019

Survey time: 3 divers × 11 min = 22 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C11.

Table C11. Number, age, and size of mussels collected at Site 2019027 (Lake Superior, Stockton Island, Presque Isle Bay marina), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	2	7	9	–	–	–	–	0

Site Number: 2019028

Location: Lake Superior, Stockton Island, Presque Isle Bay NPS dock

Coordinates: Latitude 46° 54.751′ N Longitude 90° 33.046′ W

Substrate: Sand, boulder, dock

Depth: (Not recorded)

Date: 25 September 2019

Survey time: 1.08 hr

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C12.

Table C12. Number, age, and size of mussels collected at Site 2019028 (Lake Superior, Stockton Island, Presque Isle Bay NPS dock), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	–	–	3	–	–	–	–	0
Pyganodon grandis	2	13	15	–	–	–	–	0

Site Number: 2019029

Location: Lake Superior, Stockton Island, Presque Isle Bay visitor dock

Coordinates: Latitude 46° 54.784′ N Longitude 90° 33.014′ W

Substrate: Sand, boulder, dock

Depth: (Not recorded)

Date: 25 September 2019

Survey time: 2 divers × 20 min = 40 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C13.

Table C13. Number, age, and size of mussels collected at Site 2019029 (Lake Superior, Stockton Island, Presque Isle Bay visitor dock), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	–	3	3	–	–	–	–	0

Site Number: 2019030

Location: Lake Superior, Red Cliff Bay

Coordinates: Latitude 46° 52.928′ N Longitude 90° 45.993′ W

Substrate: Sand, small vegetation, silt

Depth: (Not recorded)

Date: 25 September 2019

Survey time: 6 divers × 15 min = 90 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C14.

Table C14. Number, age, and size of mussels collected at Site 2019030 (Lake Superior, Red Cliff Bay), 2019.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Elliptio complanata	1	–	1	–	–	–	–	0
Pyganodon grandis	–	21	21	–	–	–	–	0

Site Number: 2019031

Location: Lake Superior, Sand Island west

Coordinates: Latitude 46° 57.821′ N Longitude 90° 58.387′ W

Substrate: Bedrock, cobble, some boulders

Depth: (Not recorded)

Date: 10 October 2019

Survey time: 2 divers × 15 min = 30 min

Equipment: SCUBA

Notes: No mussels observed.

2020

Site Number: 2020001

Location: Lake Superior, Stockton Island, Presque Isle, NPS dock (lee side only)

Coordinates: Latitude 46° 54.75′ N Longitude 90° 33.037′ W

Substrate: Mostly sand, also silt, cobble, and boulders

Depth: Maximum 8 feet

Date: 2 September 2020

Survey time: Jay Glase, Toben Lafrancois × 18 min = 36 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C15, and sample examples can be seen in Figure C4.

Table C15. Number, age, and size of mussels collected at Site 2020001 (Lake Superior, Stockton Island, Presque Isle, NPS dock, lee side), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	–	6	6	–	–	72	122	2

Figure C4. *Pyganodon grandis* collected from Stockton Island, Presque Isle, NPS dock (lee side only), 2020.

Site Number: 2020002

Location: Lake Superior, Presque Isle, Stockton Island, visitor dock (lee side only)

Coordinates: Latitude 46° 54.781′ N Longitude 90° 33.004′ W

Substrate: Quite a bit of sand, also silt, cobble, and boulders

Depth: Maximum 8 feet

Date: 2 September 2020

Survey time: Jay Glase, Toben Lafrancois × 16 min = 32 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C16, and sample examples can be seen in Figure C5.

Table C16. Number, age, and size of mussels collected at Site 2020002 (Lake Superior, Stockton Island, Presque Isle, visitor dock, lee side), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	2	6	8	68	77	80	130	1

Figure C5. *Pyganodon grandis* collected from Stockton Island visitor dock, 2020.

Site Number: 2020003

Location: Lake Superior, Eagle Isle shoal

Coordinates: Latitude 46° 55.247′ N, Longitude 91° 03.243′ W

Substrate: Gravel, cobble, boulder

Depth: Maximum 22 feet

Date: 9 September 2020

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 30 min = 90 min

Equipment: SCUBA

Notes: *Dreissena polymorpha*—two very distinct size classes among 15 specimens observed, 7 dead.

Site Number: 2020004

Location: Lake Superior, *Sevona* wreck

Coordinates: Latitude 47° 0.466′ N, Longitude 90° 54.138′ W

Substrate: Wreck

Depth: Maximum 22 feet

Date: 9 September 2020

Equipment: SCUBA

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 20 = 60 min

Notes: *Dreissena polymorpha*—16 specimens, a few small specimens, most were longer than 20 mm; 2 dead specimens. Sample examples from this site can be seen in Figure C6.

Figure C6. Zebra mussels collected from *Sevona* wreck, 2020.

Site Number: 2020005

Location: Lake Superior, Rocky Island, dock

Coordinates: Latitude 47° 1.769′ N, Longitude 90° 40.523′ W

Substrate: Dock and nearby sand and cobble

Depth: Maximum 10 feet

Date: 10 September 2020

Survey time: Mark Hove, Toben Lafrancois × 34 min = 68 min

Equipment: SCUBA

Notes: No native mussels observed. Shell dimensions from this sample site can be seen in Table C17, and sample examples can be seen in Figure C7.

Table C17. *Dreissena polymorpha* shell dimensions (in mm) found at Rocky Island dock, 2020.

Specimen	Length	Width	Height
1	23	14	13
2	31	17	16
3	22	12	13
4	22	11	10
5	25	12	13

Figure C7. Zebra mussels collected from Rocky Island dock, 2020.

Site Number: 2020006

Location: Lake Superior, Rocky Island, near dock

Coordinates: Latitude 47° 1.759′ N, Longitude 90° 40.521′ W

Substrate: Sand, some silt and minor cobble, sea wreck

Depth: Maximum 10 feet

Date: 10 September 2020

Survey time: Jay Glase × 20 min = 20 min

Equipment: SCUBA

Notes: Shell dimensions of one *Dreissena polymorpha* found near Rocky Island dock in 2020 were 23 mm (length), 17 mm (width), 11 mm (height).

Site Number: 2020007

Location: Lake Superior, Rocky Island, rocky shore north of dock

Coordinates: Latitude 47° 1.804′ N, Longitude 90° 49.503′ W

Substrate: Mostly sand, some cobble

Date: 10 September 2020

Survey time: 1 diver × 10 min = 10 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2020008

Location: Lake Superior, Rocky Island, rocky shore south of dock

Coordinates: Latitude 47° 1.748′ N, Longitude 90° 40.548′ W

Substrate: Mostly sand, some cobble

Date: 10 September 2020

Survey time: 1 diver × 10 min = 10 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2020009

Location: Lake Superior, South Twin Island, dock

Coordinates: Latitude 47° 1.971′ N, Longitude 90° 39.12′ W

Substrate: Dock and nearby sand

Depth: Maximum 10 feet

Date: 10 September 2020

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 10 min = 30 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C18, and sample examples can be seen in Figure C8.

Table C18. Number, age, and size of mussels collected at Site 2020009 (Lake Superior, South Twin Island, dock), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	–	1	1	–	–	63	–	0

Figure C8. *Pyganodon grandis* collected from vegetation around South Twin Island dock.

Site Number: 2020010

Location: Lake Superior, Gull Shoal, off Michigan Island

Coordinates: Latitude 46° 56.694′ N, Longitude 90° 23.43′ W

Depth: Maximum 39 feet

Substrate: Cobble, boulders

Date: 10 September 2020

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 34 = 102 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2020011

Location: Lake Superior, *Ottawa* wreck

Coordinates: Latitude 46° 52.992′ N, Longitude 90° 45.822′ W

Depth: Maximum 39 feet

Substrate: Wreck

Date: 10 September 2020

Survey time: Jay Glase, Mark Hove, Toben Lafrancois × 12 min = 36 min

Equipment: SCUBA

Notes: No mussels observed.

Site Number: 2020012

Location: Lake Superior, Stockton Island, Quarry Bay 3, directly off dock

Coordinates: Latitude 46° 55.242′ N, Longitude 90° 36.350′ W

Substrate: Sand and silt, some sparse vegetation

Depth: 18–22 feet

Date: 17 September 2020

Divers: Jay Glase, Toben Lafrancois

Survey time: Jay Glase, Toben Lafrancois × 18 min = 36 min

Equipment: SCUBA

Notes: *D. polymorpha* found on rocks, stolons/roots of plants; filtering and active. The number, age, size and dimensions of mussels sampled at this site can be seen in Table C19 and Table C20. Sample examples can be seen in Figure C9.

Table C19. Number, age, and size of mussels collected at Site 2020012 (Lake Superior, Stockton Island, Quarry Bay 3, directly off dock), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Dreissena polymorpha	–	–	5	–	–	–	–	1
Pyganodon grandis	–	33	33	–	–	30	69	8

Table C20. *Dreissena polymorpha* shell dimensions (in mm) found at Site 2020012 (Lake Superior, Stockton Island, Quarry Bay 3, directly off dock), 2020.

Specimen	Length	Width	Height
1	28	13	17
2	22	13	13
3	22	16	9
4	27	17	12
5	30	18	10

Figure C9. Native mussels and zebra mussels collected at Site 2020012 (Lake Superior, Stockton Island, Quarry Bay 3, directly off dock) (*left*). *Dreissena polymorpha* are in the lower right corner of the pan. *Right:* Close up of *Dreissena polymorpha*.

Site Number: 2020013

Location: Lake Superior, Stockton Island, Quarry Bay 4, out from river mouth

Coordinates: Latitude 46° 55.225′ N, Longitude 90° 36.295′ W

Substrate: Sand and silt, some sparse vegetation

Date: 17 September 2020

Survey time: Jay Glase, Toben Lafrancois × 10 min = 20 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C21, and sample examples can be seen in Figure C10.

Table C21. Number, age, and size of mussels collected at Site 2020013 (Lake Superior, Stockton Island, Quarry Bay 4, out from river mouth), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	2	19	21	37	42	49	69	7

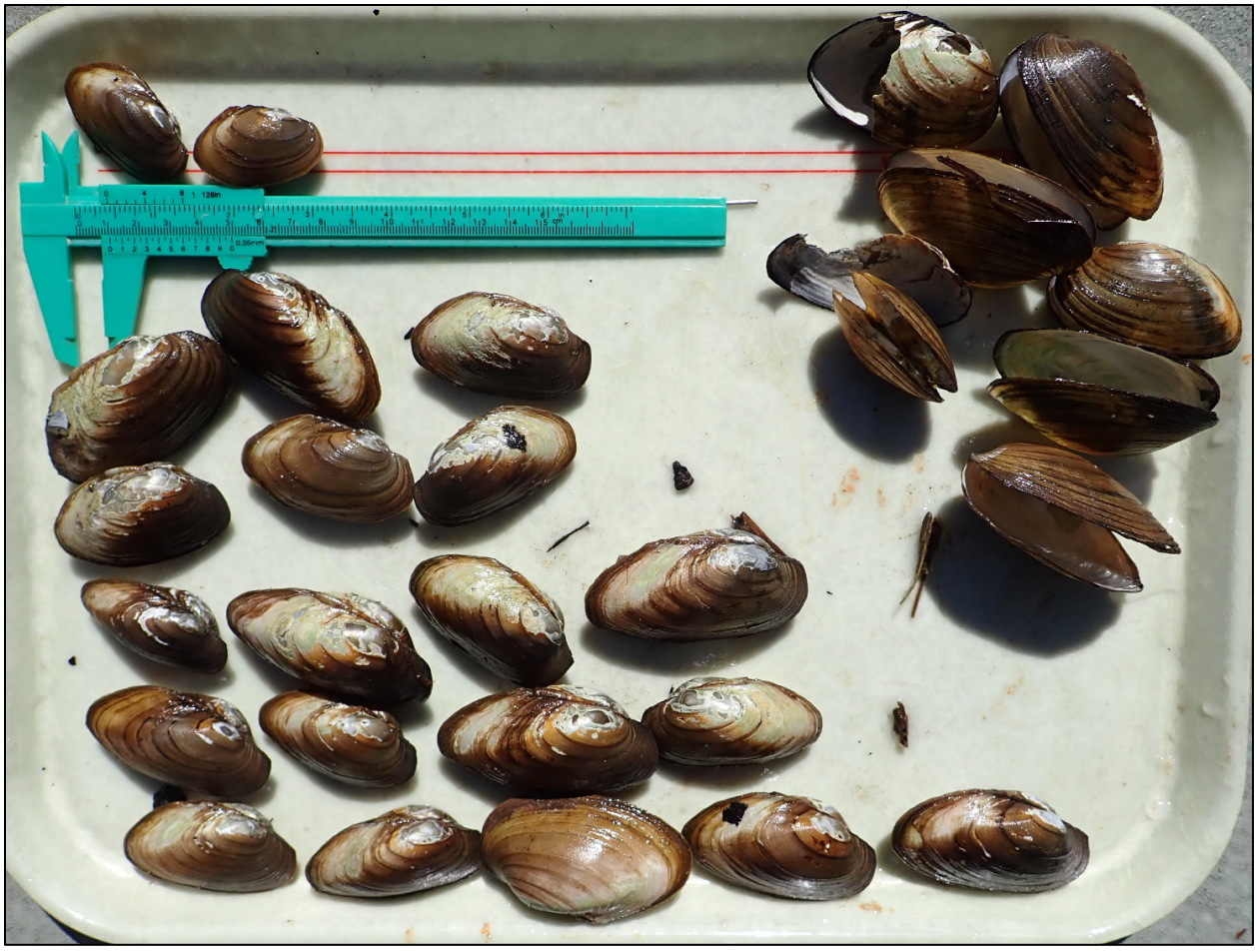

Figure C10. *Pyganodon grandis* collected from Stockton Island, Quarry Bay, out from river mouth, 2020.

Site Number: 2020014

Location: Lake Superior, Stockton Island, Presque Isle mooring area (east)

Coordinates: Latitude 46° 54.859′ N, Longitude 90° 33.167′ W

Substrate: Sand and silt

Depth: Maximum 22 feet

Date: 17 September 2020

Survey time: Jay Glase, Toben Lafrancois × 20 min = 40 min

Equipment: SCUBA

Notes: At least one *P. grandis* was slightly compressed, perhaps due to hybridization or young age. The number, age, and size of mussels sampled at this site can be seen in Table C22, and sample examples can be seen in Figure C11.

Table C22. Number, age, and size of mussels collected at Site 2020014 (Lake Superior, Stockton Island, Presque Isle mooring area (east)), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	6	23	29	42	55	41	71	2

Figure C11. *Pyganodon grandis* collected from Stockton Island, Presque Isle mooring area (east), 2020.

Site Number: 2020015

Location: Lake Superior, Stockton Island, Presque Isle mooring area (central)

Coordinates: Latitude 46° 55.063′ N, Longitude 90° 33.357′ W

Substrate: Sand and silt

Date: 17 September 2020

Survey time: Jay Glase, Toben Lafrancois × 13 min = 26 min

Equipment: SCUBA

Notes: No additional notes recorded. The number, age, and size of mussels sampled at this site can be seen in Table C23, and sample examples can be seen in Figure C12.

Table C23. Number, age, and size of mussels collected at Site 2020015 (Lake Superior, Stockton Island, Presque Isle mooring area (central)), 2020.

Live Species	No.		Total No.	0–5 yr		>5 yr		No. Dead
	0–5 yrs	*>5 yrs*		*Min L*	*Max L*	*Min L*	*Max L*	
Pyganodon grandis	–	6	6	–	–	50	70	0

Figure C12. *Pyganodon grandis* collected from Stockton Island, Presque Isle mooring area (central), 2020.

Site Number: 2020016

Location: Lake Superior, Eagle Isle Shoal

Coordinates: Latitude 46° 55.272′ N, Longitude 91° 03.254′ W

Substrate: Cobble, boulder, some gravel

Date: 8 October 2020

Survey time: Jay Glase, Toben Lafrancois × 20 min = 40 min

Equipment: SCUBA

Notes: Three *Dreissena polymorpha* dead, not described or preserved. The dimensions of mussels sampled at this site can be seen in Table C24, and sample examples can be seen in Figure C13.

Table C24. Shell dimensions (in mm) for *Dreissena polymorpha* collected at site number 2020016 (Lake Superior, Eagle Isle Shoal), 2020.

Specimen	Length	Width	Height
1	*	*	*
2	30	23	20
3	33	17	16
4	30	18	18
5	11	6	7
6	27	17	14
7	20	9	12
8	23	13	13

* Killed in-situ, unrecoverable

Figure C13. Zebra mussels collected from Eagle Isle Shoal, 2020.

Site Number: 2020017

Location: Lake Superior, bow of *Sevona* wreck

Coordinates: Latitude 47° 0.466′ N, Longitude 90° 54.138′ W

Substrate: Wreck

Depth: Maximum 22 feet

Date: 8 October 2020

Survey time: Jay Glase, Toben Lafrancois × 22 min = 44 min

Equipment: SCUBA

Notes: Eleven *Dreissena polymorpha* dead, not described. The dimensions of mussels sampled at this site can be seen in Table C25, and sample examples can be seen in Figure C14.

Table C25. Shell dimensions (in mm) for *Dreissena polymorpha* collected at site number 2020017 (Lake Superior, bow of *Sevona* wreck), 2020.

Specimen	Length	Width	Height
1	33	21	14
2	22	12	12
3	34	20	15
4	39	18	14
5	27	15	14
6	29	15	12
7	29	13	15
8	31	16	16
9	30	18	15
10	32	18	17
11	27	15	14
12	32	17	17
13	30	17	15
14	33	18	14
15	27	17	15
16	30	17	16

Figure C14. Zebra mussels collected from site number 2020017 (Lake Superior, bow of *Sevona* wreck), 2020.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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