



Mussel Survey and Population Assessment, 2017

Apostle Islands National Lakeshore

Natural Resource Report NPS/APIS/NRR—2019/1867



ON THE COVER

Invasive dreissenid mussels attached to a native unionid mussel, *Pyganodon grandis*, in Quarry Bay, Stockton Island. 2 August 2017.

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Toben Lafrancois¹, Mark Hove², and Michael McCartney²

¹Northland College
1411 Ellis Avenue
Ashland, Wisconsin 54806

²Minnesota Aquatic Invasive Species Center
University of Minnesota
2003 Upper Buford Circle
St. Paul, Minnesota 55108

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Abstract

Native pearly mussels (Bivalvia: Unionidae) are benthic filter feeders with a unique life cycle including a non-harmful parasitic stage on fish. Their sensitivity to environmental changes and associations with their host fish make them an ideal sentinel species in aquatic ecosystems. Unionids also function as pelagic food web integrators making them cornerstones of food web, contaminant bioaccumulation, and other related studies. Mussels have historical economic and cultural importance to coastal communities in the Great Lakes region. A 1991 SCUBA-based survey of the Apostle Islands National Lakeshore found several beds of mussels and no invasive zebra or quagga mussels (Bivalvia: Dreissenidae). Since that time, both zebra and quagga mussels have been detected in the Apostle Islands. This survey reprises the 1991 survey with the addition of a few sites where native and non-native mussels have been incidentally encountered by NPS divers. Zebra mussels (*Dreissena polymorpha*) were collected near Sand Island, Stockton Island, and in Red Cliff Bay and genetically identified. No quagga mussels (*Dreissena bugensis*) were found at study sites. Native mussels were found at all sites where they were previously reported as well as in Quarry and Presque Isle Bays of Stockton Island, where mussels were not found in 1991. Principal components plots reveal three distinct community types that explain between 31% and 48% of the variation in community composition depending on whether zebra mussels are included. The native mussel bed near Long Island is thriving, increasing in density between 1991 and 2017 with observed signs of recruitment. Mussel populations in Red Cliff and Raspberry Bays have declined in density. The lagoon on Stockton Island and the Sand Bay area show no major changes. Three species previously reported in the area were not found in 2017 and are potentially extirpated pending confirmation by further study.

Acknowledgments

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Introduction

The Apostle Islands National Lakeshore (APIS) protects Lake Superior coastline and islands near Bayfield and Red Cliff, Wisconsin (USA), including 21 islands and a 12-mile stretch of mainland. Lake Superior has the largest surface area of all freshwater systems in the world, but much of the lakebed is uninhabited by freshwater pearly mussels (Bivalvia: Unionidae). Reasons for the relative paucity of mussels in the lake as a whole include a combination of cold overlaying water, oligotrophy, soft water, depth, and low calcium ion concentration for shell building (Nduku and Harrison 1976, Heming et al., 1988, McMahon and Bogan 2001, Haag 2012). Coastal waters of the lake are warmer and can be shallow with mineral inputs from streams or currents. These conditions support mussels, although little survey work has been conducted on Lake Superior bivalves in general, with fewer studies of mussel population density and community composition than is desirable given their importance for understanding ecosystem processes.

The Unionidae are filter feeding bivalve mollusks that have several important roles in the ecosystem including clarifying water, capturing nutrients suspended in the water, and making nutrients available to aquatic invertebrates—an important food for many fishes (Haag 2012). Ecosystem services and cultural importance of mussels are reviewed in Vaughn (2018). In addition, mussels are a keystone organism for biomonitoring contaminants and quantitative food web studies because they integrate the pelagic food web baseline (e.g., Vuaorio et al. 2007, Fritts et al. 2017). As sentinel species, mussels are sensitive to a wide variety of environmental impacts, and presence of unionids is an indicator of both high water quality and host species (fish) population health. Global extinction rates of unionid mussels is a matter of great concern due to their roles as sentinel species and their critical ecological function (Strayer et al. 2004). Together, the threatened status and ecological functions of these organisms in Lake Superior make the unionid populations of APIS an important feature of this large, globally significant system. The Apostle Islands area of Lake Superior has also been designated a Wisconsin State outstanding and exceptional resource (NR-102 of Water Quality Standards for Wisconsin Surface Waters), underscoring the role of mussels as sentinel species for monitoring programs central to continued resource protections. Furthermore, this region is essential to the Red Cliff and Bad River Bands of Lake Superior Chippewa who value mussels for their biomonitoring and cultural importance (Red Cliff Environmental Department and Great Lakes Indian Fish and Wildlife Commission, personal communication).

The few non-incidental surveys of the Unionidae in Lake Superior have found at least eight mussel species. During the early to mid-1900s live specimens of three species, *Elliptio complanata*, *Lampsilis siliquoidea*, and *Lasmigona complanata*, were reported (Walker 1913, Baker 1928, Matteson 1948), and three additional species were collected as empty shells near Duluth, Minnesota, namely *Lampsilis cardium* (= *L. ventricosa*), *Ligumia recta* (= *L. latissima*), and *Pyganodon grandis* (formerly *Anodonta*) (Dawley 1947). Later in the last century, *Pyganodon lacustris* (= *Anodonta marginata*) was also reported from the Lake Superior (Stern 1979 described in Doolittle 1991). A qualitative 1979 survey of three mainland sites and 12 islands by Stern (1979) described in Doolittle (1991) identified two live unionid species, *P. lacustris* in Lake Superior and *Anodontoides ferussacianus* in the Sand River. Two mussel species—*Anodontoides ferussacianus* and *Lampsilis*

siliquoidea—were collected at the mouths of rivers along the south shore of Lake Superior (Mathiak 1979) while more recently *Elliptio complanata*, *Lampsilis cardium*, *Lasmigona complanata*, and *Ligumia recta* have been reported from Lake Superior (Graf 1997, Graf and Underhill 1999, Sietman 2003).

There have been three published mussel surveys specific to the APIS waters. Hiltunen (1969) is currently out of print. Stern (1979) found *Pyganodon grandis* near Madeline Island, *Pyganodon lacustris* (= *Anodonta cataracta* in Stern) at Stockton Island and Little Sand Bay, and *Anodontoidea ferussacianus* near the Sand River inlet. Voucher samples were collected and curated at University of Wisconsin-Stevens Point, but we were unable to confirm their current status. Most recently, the National Park Service staff at APIS conducted a survey around several islands and shoreline locations (Figure 1) (Doolittle 1991). At the time of Doolittle's survey, invasive zebra mussels had been recently introduced from Eurasia and were spreading through the Great Lakes (French 1990). Consequently, Doolittle used SCUBA based searches to look for both unionids and dreissenids. In addition, local experts were interviewed about the presence of shells.

Several mussel beds surveyed and described in Doolittle (1991) contained by far the most dense mussel beds reported up until that survey, but on the other hand mussels were not found at some sites where they were previously recorded. Specifically, in Quarry Bay of Stockton Island, incidental *Pyganodon* sp. were reported by Dawely (1947), but not found in the 1991 survey. Doolittle found a dense and diverse mussel bed on the Chequamegon Bay side of Long Island, as well as less dense mussel beds in Raspberry Bay, Red Cliff Bay, Sand Bay, and Outer Island. Of particular note was the absence of invasive dreissenids at this time in the Apostle Islands.

Doolittle recommended that mussel resources around the Apostle Islands be monitored at least every five years to determine the impact of invasive bivalves, environmental changes or commercial mussel harvesting. The purpose of the present study was to revisit locations described by Doolittle twenty-six years later and compare our results to these historical data.

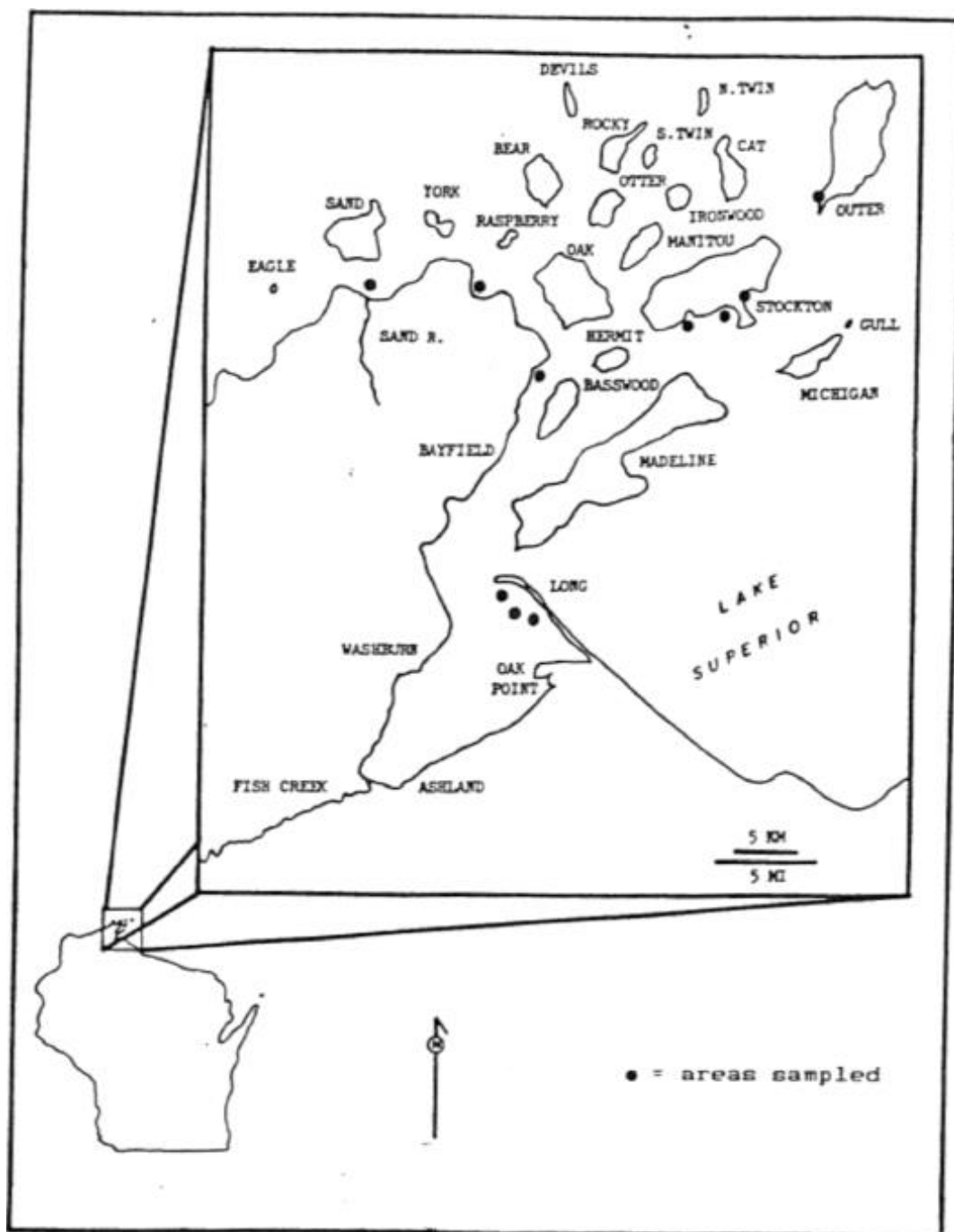


Figure 1. Sampling locations from a previous mussel survey at Apostle Islands National Lakeshore (Wisconsin, USA). Map from Doolittle (1991).

Methods

Dive locations for both unionid and dreissenid surveys are shown in Figure 2. Both mussel groups were surveyed at most sites. Exceptions include dreissenid-specific checks west of Sand Island, east of Sand Island at the *Sevona* wreck, and Kron's Reef off Madeline Island, where invasive mussels were previously found but there were no reports of unionids at that location by trained divers. Survey protocols from the most recent work at APIS (Doolittle 1991) were followed as closely as possible in the 2017 survey, including survey locations, techniques, and effort (Table 1). Coordinates (UTM 15 T) of all dive locations of the 2017 survey are listed below (see Table 2 in the Results section) and mapped (Figure 2) showing the anchor point of the dive boat for either timed or transect searches.

Table 1. Survey sites and sampling methods described in Doolittle (1991) compared to the 2017 survey reported here. Diver hours are the total hours of SCUBA timed searches, and transects indicate the number of 60 m² transects. Some sites surveyed in 1991 did not have associated search times reported (indicated as 'NR'), and a few sites were not surveyed (indicated with 'X'). Some sites included both timed and transect searches.

Site	1991 survey		2017 survey	
	<i>diver hours</i>	<i>60 m² transects</i>	<i>diver hours</i>	<i>60 m² transects</i>
Stockton Island, Quarry Bay	NR	NR	2.40	
Stockton Island, Presque Isle Bay	NR	NR	2.20	
Stockton Island, lagoon	2.00	2	0.67	2
Stockton Island, Julian Bay	X	X	1.25	
Long Island, Chequamegon Bay		18		18
Red Cliff Bay	3.33		1.67	
Raspberry Bay	3.00	2	2.33	
Sand Bay	4.00		3.01	
Outer Island	NR	NR	X	X

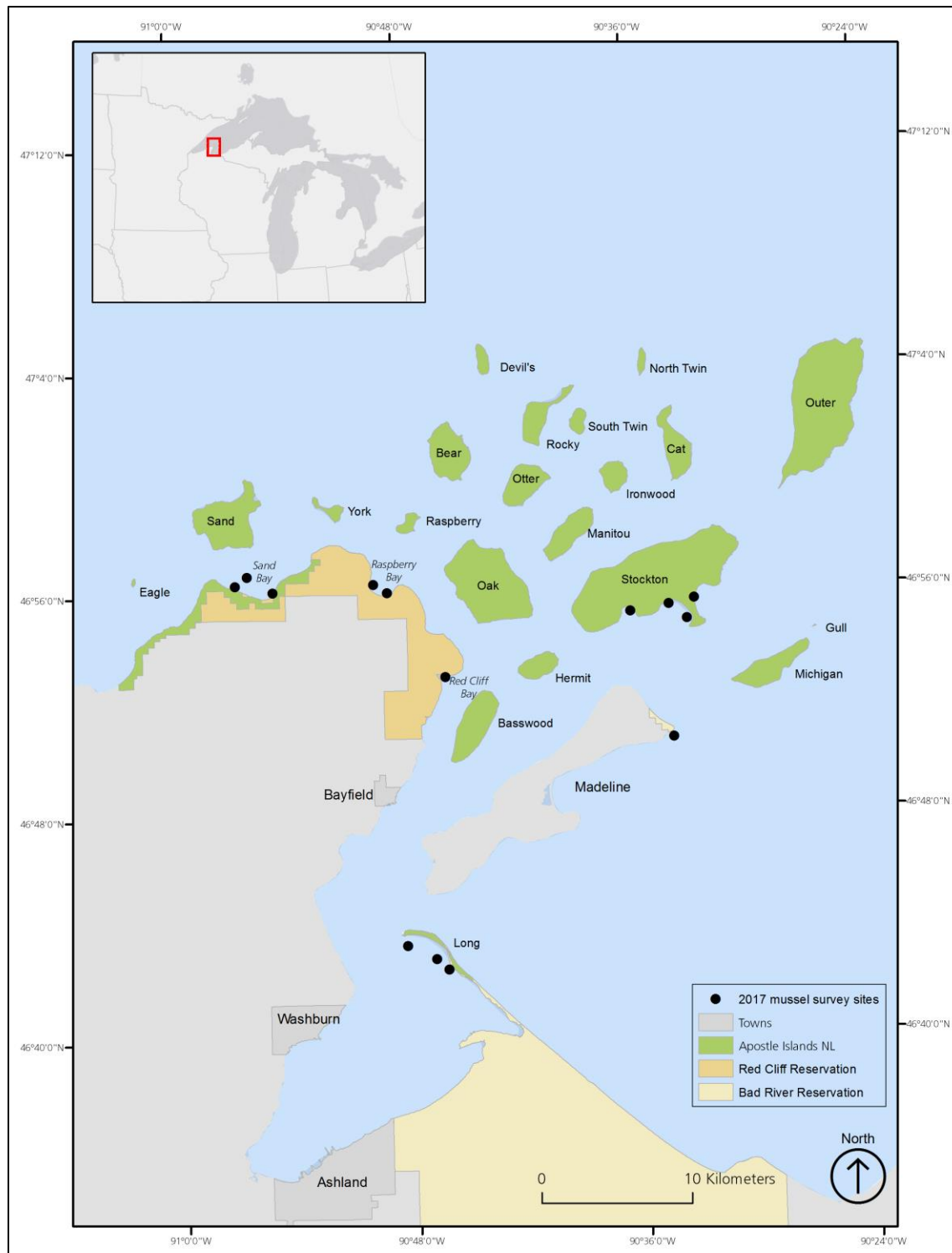


Figure 2. Areas surveyed by divers for unionid mussels at Apostle Islands National Lakeshore, 2017. Timed survey sites were randomly selected starting at each indicated point, with transect sites (Long Island and Stockton Island lagoon) consisting of randomly thrown anchored flags and 15 x 4 m transects heading southwest from the random location.

The 1991 survey employed two sampling methods: quantitative 60 m² belt-line transect methods were used in dense mussel beds, while timed searches were conducted at lower density sites (Doolittle 1987). Transects were sampled by one SCUBA diver reaching 1 m to both sides of a 30-m transect line to cover 60 m². All living and dead shells were collected from the surface and down to 10 cm below the surface of softer sediment.

For the 2017 survey we followed this method with a slight modification: Two divers each searched in a 2-meter-wide transect each, side by side down a 15-meter-long transect line run perpendicular to the shoreline, starting from a randomly thrown, weighted dive flag. This process resulted in the same 60 m² search area, but allowed dive buddies to be in constant contact. This method was set up in a stratified random manner, with UTM coordinates indicating boat anchor points chosen *a priori* to cover sites of the 1991 survey or sites where mussels had been recently observed by the authors. From these points, weighted flags were thrown randomly to indicate starting points of each transect. In 2017 water clarity was good enough that compass bearings could be taken underwater and pre-set lines were not needed (unlike some sites in 1991). Timed (visual) searches were used when there was no distinct mussel bed and densities were low (as in Strayer 2003). In 2017, transects were used in the Stockton Island lagoon and the mussel bed in Chequamegon Bay near Long Island. All other sites were characterized by low unionid densities upon initial diver observation and timed searches were employed with results collected as catch per unit effort (standardized as numbers per diver per hour for each species present).

During dives for both timed and transect searches all unionid and dreissenid mussels (live or dead) were collected, identified, measured, and photographed. Native mussels were returned and dreissenids were frozen for genetic identification and population source analysis. The presence of dreissenid byssal threads was noted where they occurred. Mussels were carefully studied to identify species and voucher specimens were kept of each species and questionable specimens. Voucher shells were deposited with the National Park Service at APIS. As noted in Doolittle (1991), we probed and described the substrate and recorded bivalve length with calipers. Additionally, we determined if mussels were gravid at some locations when warranted. Per MN DNR mussel survey protocol we divided mussels into two age groups (0–5 yr or >5 yr) based on external shell ring counts. Unionid nomenclature follows Williams et al. (2017).

All sites described in Doolittle (1991) were revisited with the exception of Outer Island due to prohibitive weather. The lagoon on Outer Island should be included in future surveys, as the lagoon is currently fully exposed to the lake due to the blow-out from a storm in September 2014. Based on our own observations diving throughout APIS for other projects, we included additional locations around Stockton Island and nearshore areas of Sand Bay for formal surveys. In preparation for the 2017 survey we set aside a similar amount of time to conduct the survey described in Doolittle (1991), although some sites from the earlier survey included records of the amount of effort applied other sites did not include records of search time, requiring us to estimate diver effort in order to standardize results between the two studies. Hazardous weather conditions prevented diving for several days in August of 2017, reducing the effort at some sites and producing some mismatched effort on a few timed searches (Table 1). We do not think this impacted our ability to compare results

because we had the advantage of pre-identified search areas using our own previous observations and maps provided in Doolittle (1991). Consequently, search time was much reduced as each dive started where mussels were found previously. Finally, we performed timed searches in Raspberry Bay proper rather than transects as reported in Doolittle due to low mussel density we observed in 2017. We did not survey the mouth of Raspberry River, which is outside of APIS jurisdiction.

Results

Freshwater mussels were observed at most sites during the 2017 survey. Catch per unit effort (CPUE) in units of live mussels per diver per hour are summarized from each search event (Table 2), with mean CPUE per site shown in Figure 3. Complete field data and photographs of field collections are catalogued in Appendix 1. Voucher shells are archived at APIS under the curation of the National Park Interior Collections Management System (ICMS).

Community composition of the major sites based on CPUE is shown as percent contribution per species in Figure 4. Three primary community groups stand out in this basic plot. Stockton Island lagoon was characterized by a single species (*Pyganodon lacustris*), while Red Cliff Bay and Chequamegon Bay (Long Island) show a mix of species dominated by *Elliptio complanata*. Sand Bay, Raspberry Bay, and Stockton Island (Quarry and Presque Isle Bays) were all dominated by *Pyganodon grandis*.

The strength of association of the community groups intuitively seen in Figure 4 are confirmed by a principal components ordination (PCO) based on a Bray-Curtis similarity matrix of square root transformed CPUE values per species per site (Figure 5). The first axis of the PCO explains 48% of the variation between communities and is most strongly associated with dreissenid presence. The second axis explains only 19.9% of variation in community similarity, and is driven by the dominance of *P. grandis*, which is present at many sites but much more dominant at Stockton Island sites and the mainland bays, excluding Red Cliff Bay. The other end of this weaker axis is the single species *P. lacustris* that uniquely characterizes the Stockton Island lagoon. The ordination shows Sand Bay and Red Cliff Bay outside of the groups that appear similar based on percent composition alone (Figure 4). We think this result could be an artifact zebra mussel (*Dreissena polymorpha*) presence skewing the similarity matrix of the native mussel community in our particular study design. Removing zebra mussels from the unionid community analysis may be problematic because their presence in conjunction with native mussels in Quarry Bay, Presque Isle Bay, and Red Cliff Bay is potentially biologically significant (Krebbs et al. 2015). While dreissenids can affect unionid mussels—and we did observe some direct association (dreissenids attached to shells of living native mussels)—site selection for this study was not designed to determine such impacts. Assuming that the distribution of native mussel communities is currently independent of dreissenid distributions, removing them from the ordination reflects a more direct pattern of unionid communities. Should dreissenid populations increase or spread, this would likely not be a safe assumption in future studies.

Table 2. Catch per unit effort (numbers per diver per hour) by sample location for unionid and dreissenid mussels found in Apostle Islands National Lakeshore between 4 August and 20 October 2017. Species are represented by the first letter of their genus and the first three letters of the species. Sites where transects were sampled (indicated by a '#' in the Site name) were converted to CPUE using dive logs for bottom time.

Site	Site Description	UTM Coordinates (15T)		CPUE (number/diver/hr), by species*					
		North	East	Pgra	Plac	Afer	Ecom	Lsil	Dpol
KR1	Kron's Reef	5190623.0	685374.5	–	–	–	–	–	4.00
KR2	Kron's Reef	5190364.4	685342.9	–	–	–	–	–	
LOt01	Long Is., Chequamegon Bay	5176625.5	667707.6	–	–	–	2.73	–	–
LOt02	Long Is., Chequamegon Bay	5176625.5	667707.6	–	–	–	11.25	3.75	–
LOt03	Long Is., Chequamegon Bay	5176531.7	667666.9	1.88	–	–	135.00	22.50	–
LOt04	Long Is., Chequamegon Bay	5175776.6	669624.3	12.86	–	–	147.86	27.86	–
LOt05	Long Is., Chequamegon Bay	5176534.5	667968.9	9.23	–	–	147.69	36.92	–
LOt06	Long Is., Chequamegon Bay	5176534.5	667968.9	3.00	–	–	9.00	6.00	–
LOt07	Long Is., Chequamegon Bay	5175776.6	669624.3		–	–	129.00	6.00	–
LOt08	Long Is., Chequamegon Bay	5175733.0	669654.9	10.00	–	–	173.33	3.33	–
LOt09	Long Is., Chequamegon Bay	5175066.1	670452.7	9.00	–	–	144.00	3.00	–
LOt10	Long Is., Chequamegon Bay	5175066.1	670452.7	10.71	–	–	160.71	2.14	–
LOt11	Long Is., Chequamegon Bay	5175579.8	669808.4	6.00	–	–	96.00	3.00	–
LOt12	Long Is., Chequamegon Bay	5175551.4	669852.5	8.00	–	–	120.00	10.00	–
LOt13	Long Is., Chequamegon Bay	5174926.0	670412.0	6.92	–	–	120.00	4.62	–
LOt14	Long Is., Chequamegon Bay	5174926.0	670412.0	6.43	–	–	165.00		–
LOt15	Long Is., Chequamegon Bay	5174939.3	670360.7	6.00	–	–	168.00	9.00	–
LOt16	Long Is., Chequamegon Bay	5174946.4	670415.3	14.12	–	–	121.76	5.29	–
LOt17	Long Is., Chequamegon Bay	5174979.6	670147.9	5.00	–	–	92.50	7.50	–
LOt18	Long Is., Chequamegon Bay	5174975.0	670113.6	4.00	–	–	76.00	4.00	–
LU1	Lucerne wreck	5176756.5	670749.0	–	–	–	–	–	–
MI1	Michigan Is. docks	5193838.1	690647.7	–	–	–	–	–	–
NB1	Noquebay wreck	5199831.6	686883.5	–	–	–	–	–	–
OW1	Ottawa wreck	5194612.7	670383.5	–	–	–	–	–	3.00

* Pgra = *Pyganodon grandis*, Plac = *Pyganodon lacustris*, Afer = *Anodontoidea ferussacianus*, Ecom = *Elliptio complanata*, Dpol = *Dreissena polymorpha* (invasive).

Table 2 (continued). Catch per unit effort (numbers per diver per hour) by sample location for unionid and dreissenid mussels found in Apostle Islands National Lakeshore between 4 August and 20 October 2017. Species are represented by the first letter of their genus and the first three letters of the species. Sites where transects were taken (indicated by a 't#' in the Site name) were converted to CPUE using dive logs for bottom time.

Site	Site Description	UTM Coordinates (15T)		CPUE (number/diver/hr), by species*					
		North	East	Pgra	Plac	Afer	Ecom	Lsil	Dpol
PI1	Presque Isle Bay, Stockton Is.	5198496.0	686226.0	23.64	—	0.91	—	—	—
PI2	Presque Isle Bay, Stockton Is.	5199431.0	685018.0	44.55	—	0.91	—	—	—
PI3	Presque Isle Bay, Stockton Is.	5198385.9	686488.0	3.00	—	—	—	—	—
PI4	Presque Isle Bay, Stockton Is.	5198363.9	686503.8	84.00	—	—	—	—	4.00
PI5	Presque Isle Bay, Stockton Is.	5198453.5	686495.9	21.82	—	—	—	—	—
PI6	Presque Isle Bay, Stockton Is.	5198518.3	686501.3	60.00	—	—	—	—	—
QB1	Quarry Bay, Stockton Is.	5198944.0	682455.0	38.33	—	—	—	—	0.83
QB2	Quarry Bay, Stockton Is.	5199024.0	682364.0	58.33	—	—	—	—	11.67
RB1	Raspberry Bay	5200097.2	665719.8	24.00	—	—	4.00	—	—
RB2	Raspberry Bay	5200075.8	666281.6	3.00	—	3.00	3.00	—	—
RB3	Raspberry Bay	5200634.3	665372.3	78.00	2.00	—	—	—	—
RC1	Red Cliff Bay	5194516.1	670189.1	—	—	—	12.00	—	3.00
RC2	Red Cliff Bay	5194516.1	670189.1	1.00	—	—	8.00	—	10.00
RI1	Raspberry Is. dock	5204161.5	666941.2	—	—	—	—	—	—
SB1	Sand Bay	5201106.3	656981.9	3.00	—	—	—	—	—
SB2	Sand Bay	5200468.2	656183.8	—	—	—	—	—	—
SB3	Sand Bay	5200061.5	658677.5	1.50	—	—	—	—	—
SB4	Sand Bay	5200208.3	658485.7	—	—	—	—	—	—
SL1	Stockton Is. lagoon	5199868.4	686693.9	—	20.00	—	—	—	—
SL2t01	Stockton Is. lagoon	5199782.9	686657.4	—	15.00	—	—	—	—
SL2t02	Stockton Is. lagoon	5199782.9	686657.4	—	24.00	—	—	—	—
SL3	Stockton Is. lagoon	5199919.0	686705.2	—	24.00	—	—	—	—
SV1	Sevona wreck	5208171.1	659420.4	—	—	—	—	—	19.00
SV2	Sevona wreck	5208171.1	659420.4	—	—	—	—	—	23.00
SW1	Sand Is. west	5204048.2	653074.7	—	—	—	—	—	8.00
SW2	Sand Is. west	5204048.2	653074.7	—	—	—	—	—	1.76

* Pgra = *Pyganodon grandis*, Plac = *Pyganodon lacustris*, Afer = *Anodontoidea ferussacianus*, Ecom = *Elliptio complanata*, Dpol = *Dreissena polymorpha* (invasive).

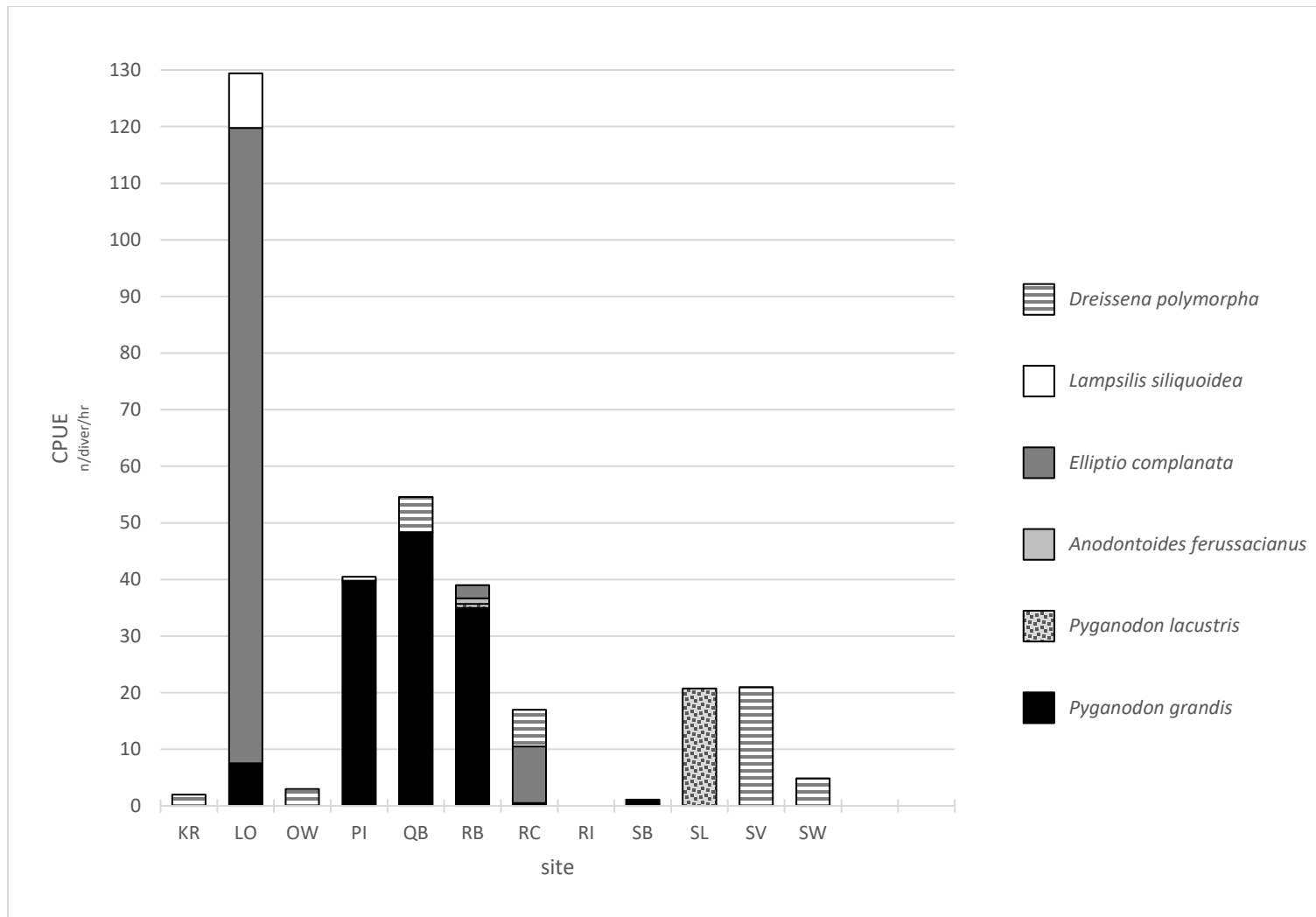


Figure 3. Mean catch per unit effort (CPUE) in numbers of unionids and *Dreissena polymorpha* per diver per hour, Apostle Islands National Lakeshore, 2017. KR = Kron's Reef (Madeline Is.), LO = Long Is., OW = *Ottawa* wreck (Red Cliff Bay), PI = Presque Isle Bay (Stockton Is.), QB = Quarry Bay (Stockton Is.), RB = Raspberry Bay, RC = Red Cliff Bay, RI = Raspberry Island dock, SB = Sand Bay, SL = Stockton Is. lagoon, SV = *Sevona* wreck, SW = lake west of Sand Island. Not shown are Julian Bay and the *Noquebay* wreck (Stockton Island), as neither unionids nor dreissenids were collected.

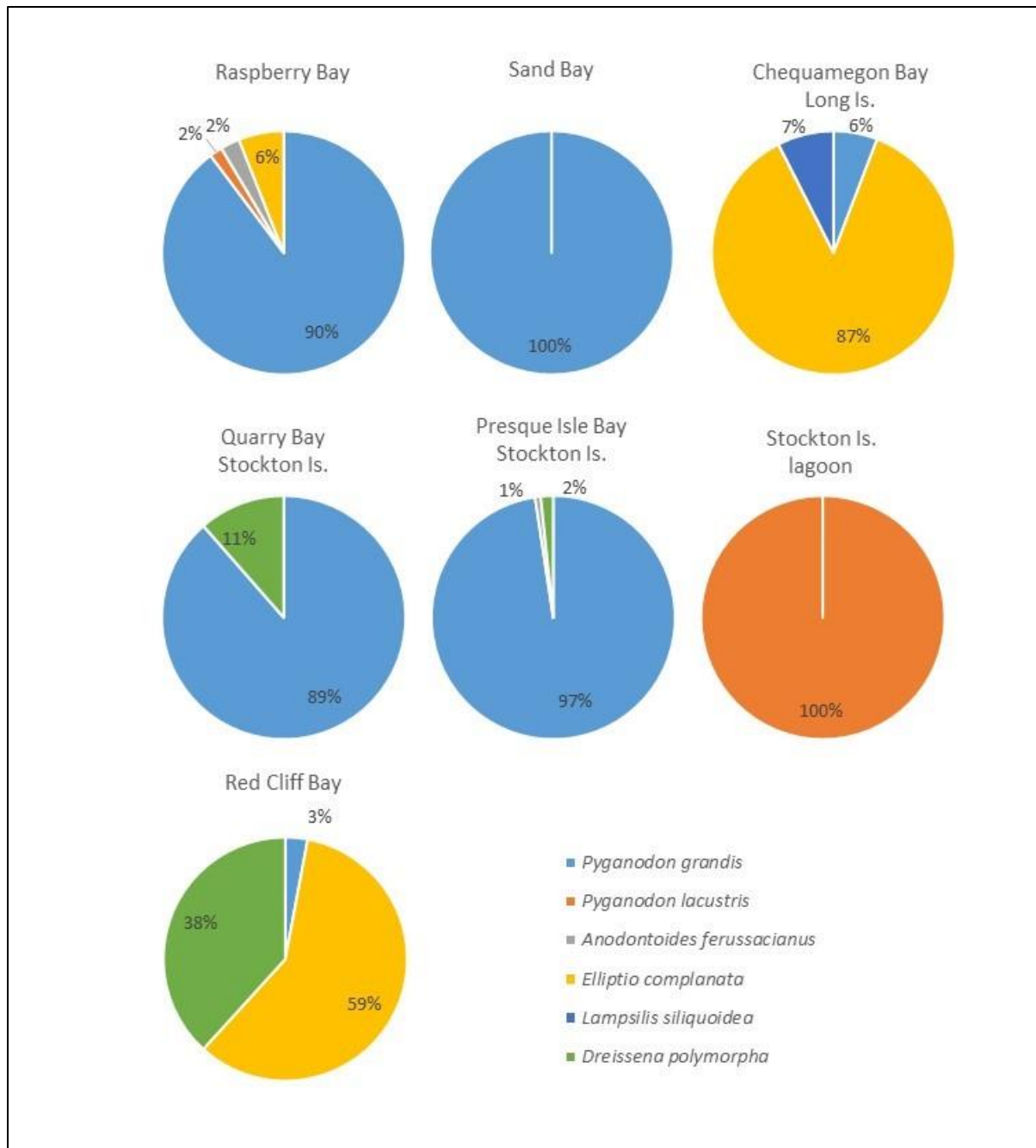


Figure 4. Mussel species composition by site (as percent of catch per unit effort), Apostle Islands National Lakeshore 2017.

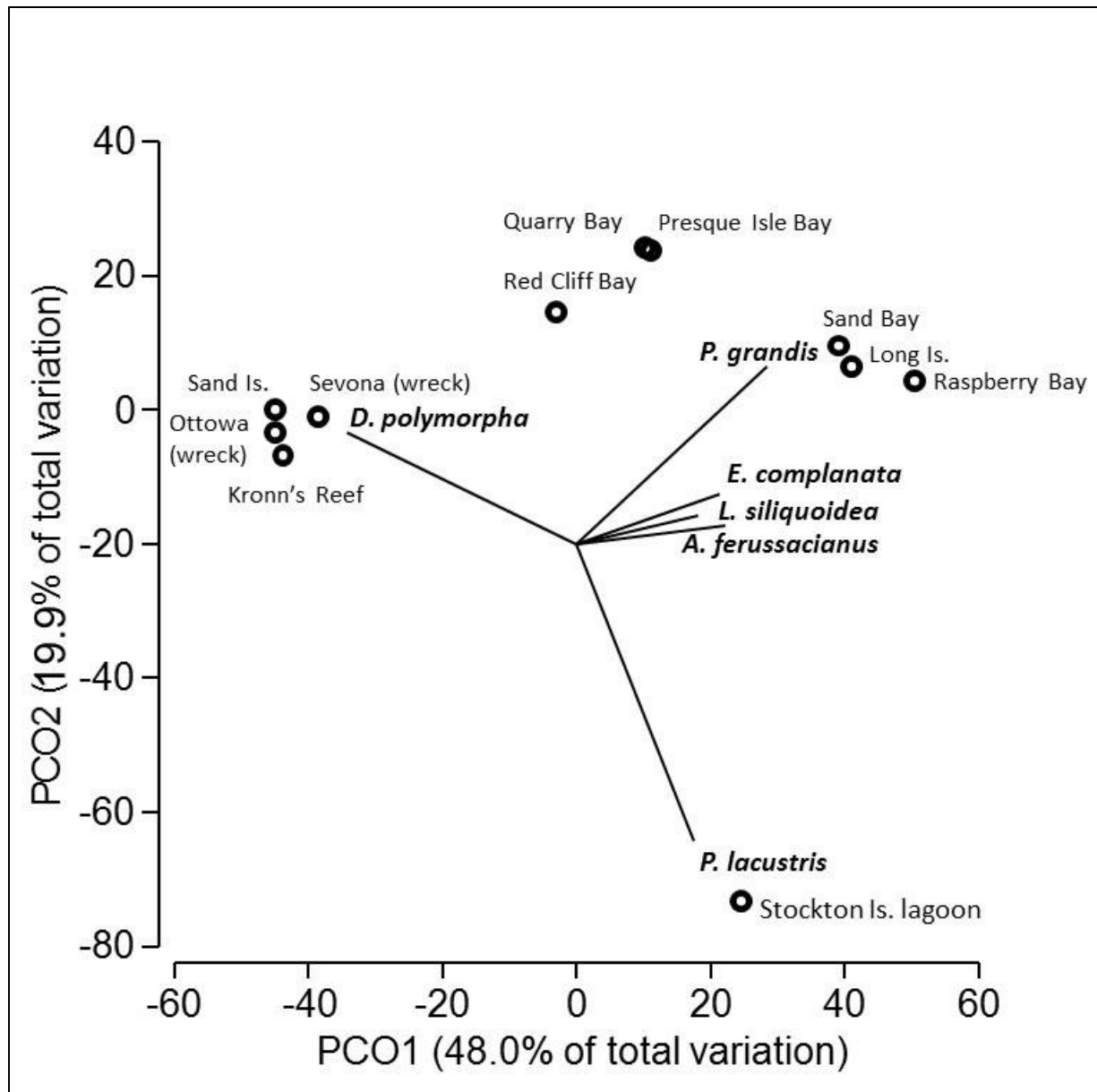


Figure 5. Principal components analysis of mussel community composition based on Bray-Curtis similarity between sites using square root transformed catch per unit effort values (numbers per diver per hour). Species vectors associated with variation in the model are shown by lines (with longer vectors indicating stronger relationship to the variation explained by an axis). This analysis includes both unionid and dreissenid mussels.

The PCO without the dreissenids (Figure 6) draws out differences in the native mussel communities across the Apostle Islands under the assumption of independence from dreissenid distributions. Relative to the first ordination (Figure 5), the axes are reversed, with the *P. grandis* versus *P. lacustris* axis associated with 40% of the variation in community composition and a *Pyganodon* spp. versus *E. complanata* and *L. siliquoidea* axis explaining 31.6% of community variation. This

ordination of community similarity more closely reflects the unionid community composition as corroborated by raw percent composition, both weighted by density (CPUE) in Figure 4.

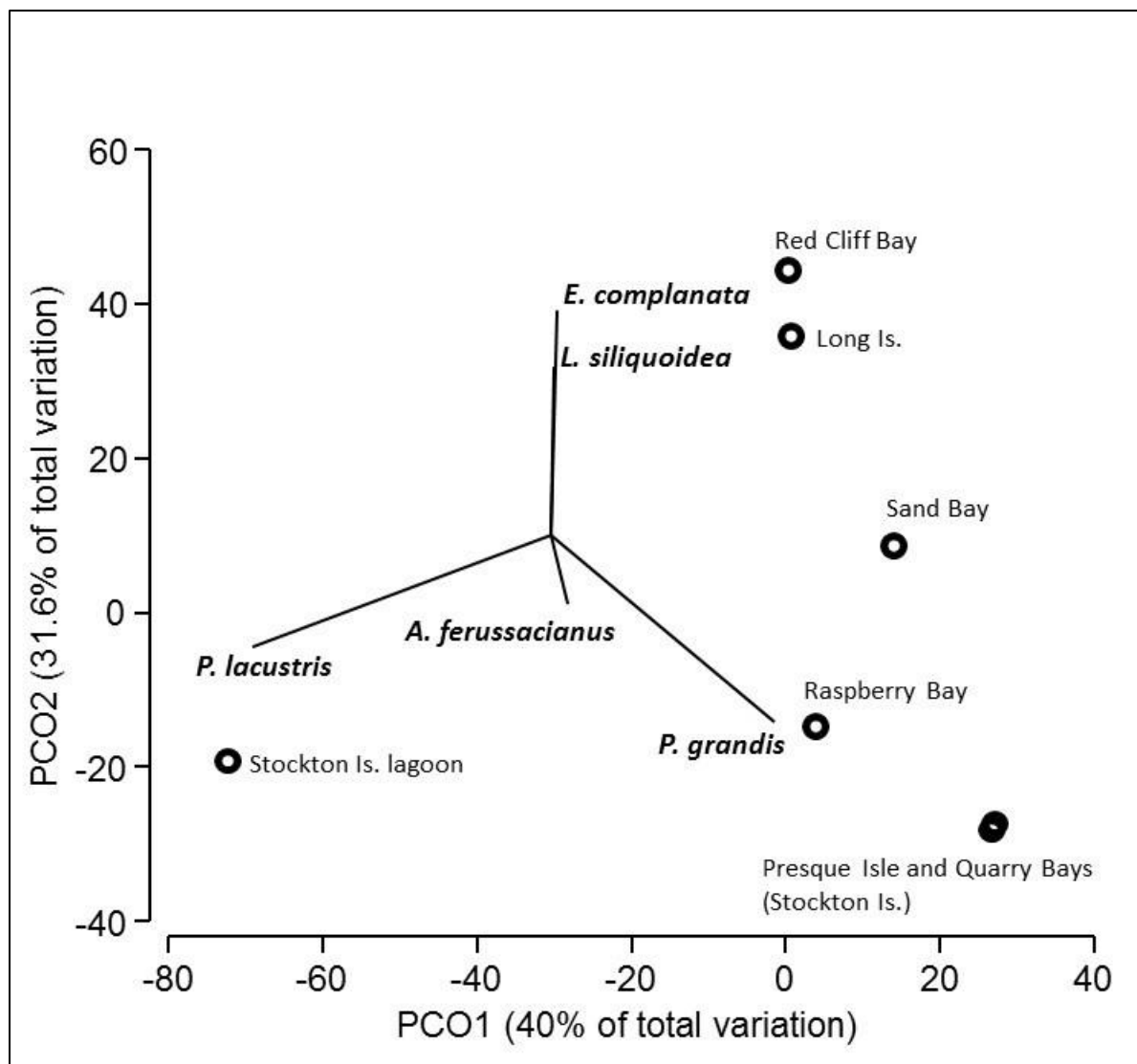


Figure 6. Principal components analysis of mussel community composition based on Bray-Curtis similarity between sites using square root transformed catch per unit effort results (number per diver per hour). Species vectors associated with variation in the model are shown by lines (with longer vectors indicating stronger relationship to the variation explained by an axis). This analysis includes unionid mussels only.

Mussel beds of sufficient density for transect surveys were only found near Long Island and Stockton Island lagoon (Tables 3 and 4, Figure 7). Most of the unionid mussels across all sites were found at depths of 6–7 meters in a mix of silt and sandy bottom. Complete site characteristics and comprehensive field data collected are presented in Appendix 1. The Long Island mussel bed was by far the most dense and diverse of all mussel beds in the survey. Long Island mussel species included *Elliptio complanata*, *Lampsilis siliquioidea*, and *Pyganodon grandis*. A wide variety of ages of *E.*

complanata and *P. grandis* were observed, indicating recruitment was occurring at that location. A few gravid individuals of both species were also observed at that site (Appendix 1), confirming active recruitment. *Elliptio complanata* was dominant at all transects except 16, where *P. grandis* was similarly abundant (Table 3, Figure 7). No evidence of *Dreissena* spp. were observed at Long Island on either the Chequamegon Bay side or on or near the *Lucerne* wreckage lakeside.

Table 3. Pearly mussel density (numbers per m²) from 60 m² transects on the Chequamegon Bay side of Long Island and the Stockton Island lagoon, Apostle Islands National Lakeshore, between 4 and 11 August of 2017. Mussels are represented by the first letter of their genus and the first three letters of the species.

Site	Site Description	UTM Coordinates (15T)		Number of Individuals/sq. meter*				
		North	East	<i>Pgra</i>	<i>Plac</i>	<i>Afer</i>	<i>Ecom</i>	<i>Lsil</i>
LOt01	Long Is., Chequamegon Bay	5176625.5	667707.6	–	–	–	0.0333	–
LOt02	Long Is., Chequamegon Bay	5176625.5	667707.6	–	–	–	0.1000	0.0333
LOt03	Long Is., Chequamegon Bay	5176531.7	667666.9	0.0167	–	–	1.2000	0.2000
LOt04	Long Is., Chequamegon Bay	5175776.6	669624.3	0.1000	–	–	1.1500	0.2167
LOt05	Long Is., Chequamegon Bay	5176534.5	667968.9	0.0667	–	–	1.0667	0.2667
LOt06	Long Is., Chequamegon Bay	5176534.5	667968.9	0.0167	–	–	0.0500	0.0333
LOt07	Long Is., Chequamegon Bay	5175776.6	669624.3		–	–	0.7167	0.0333
LOt08	Long Is., Chequamegon Bay	5175733.0	669654.9	0.0500	–	–	0.8667	0.0167
LOt09	Long Is., Chequamegon Bay	5175066.1	670452.7	0.0500	–	–	0.8000	0.0167
LOt10	Long Is., Chequamegon Bay	5175066.1	670452.7	0.0833	–	–	1.2500	0.0167
LOt11	Long Is., Chequamegon Bay	5175579.8	669808.4	0.0333	–	–	0.5333	0.0167
LOt12	Long Is., Chequamegon Bay	5175551.4	669852.5	0.0667	–	–	1.0000	0.0833
LOt13	Long Is., Chequamegon Bay	5174926.0	670412.0	0.0500	–	–	0.8667	0.0333
LOt14	Long Is., Chequamegon Bay	5174926.0	670412.0	0.0500	–	–	1.2833	
LOt15	Long Is., Chequamegon Bay	5174939.3	670360.7	0.0333	–	–	0.9333	0.0500
LOt16	Long Is., Chequamegon Bay	5174946.4	670415.3	1.1333	–	–	1.1500	0.0500
LOt17	Long Is., Chequamegon Bay	5174979.6	670147.9	0.0333	–	–	0.6167	0.0500
LOt18	Long Is., Chequamegon Bay	5174975.0	670113.6	0.0333	–	–	0.6333	0.0333
SL2t01	Stockton Is. lagoon	5199782.9	686657.4	–	0.0333	–	–	–
SL2t02	Stockton Is. lagoon	5199782.9	686657.4	–	0.0667	–	–	–

Table 4. Summary statistics of density data for the Long Island mussel bed based on 18 transects of 60 m² each, Apostle Islands National Lakeshore. Mean number per square meter are shown with standard deviation of the sample (SD) and standard deviation with an outlier transect 16 removed (SD*) that was unique in extremely high *P. grandis* density.

Summary Parameter	No. Individuals/m ² (by species)		
	<i>P. grandis</i>	<i>E. complanata</i>	<i>L. siliquoidea</i>
Mean	0.1211	0.7917	0.0719
SD	0.2810	0.4027	0.0802
SD*	0.0240	0.4048	0.0828

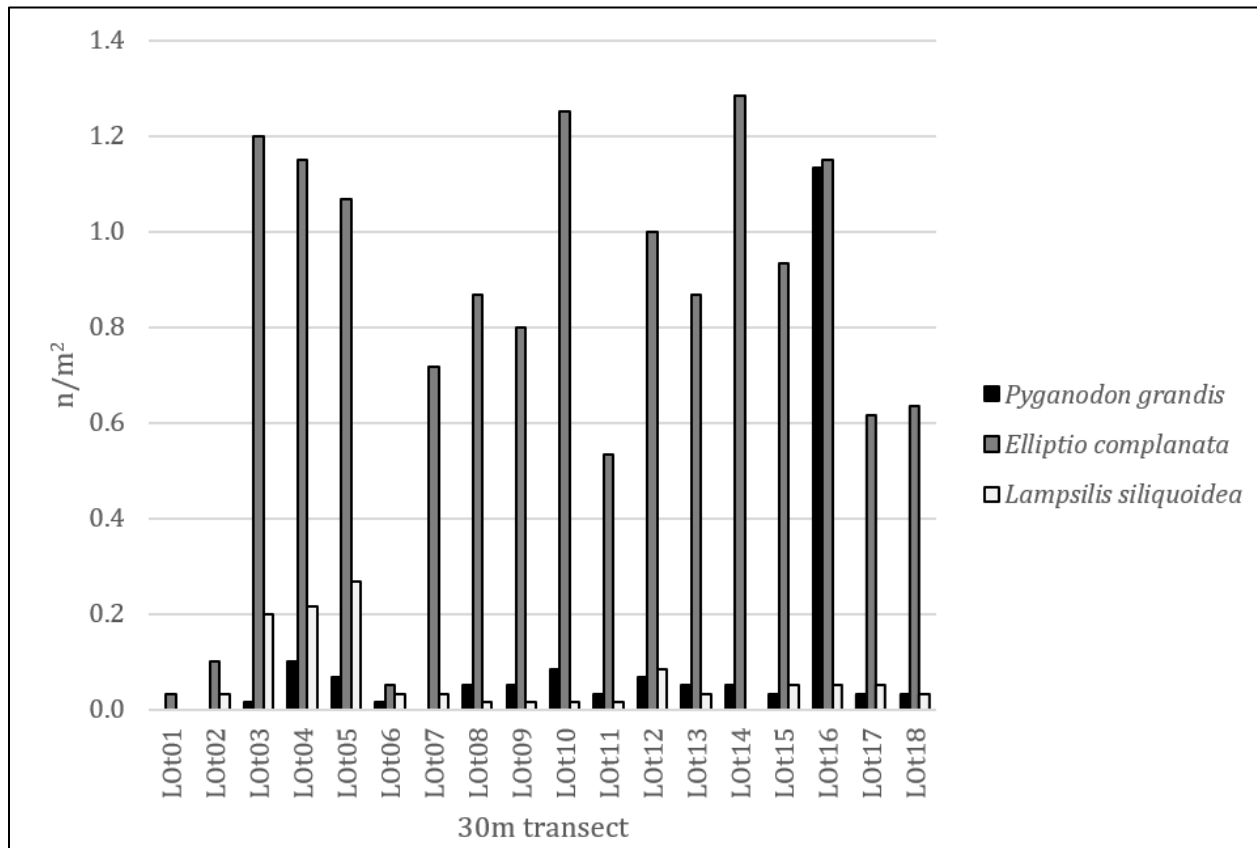


Figure 7. Unionid density and species composition of Long Island mussel bed from each 60 m² transect, Chequamegon Bay, August 2017.

Data from the 1991 study did not include sufficient detail for us to perform statistical tests, but we compared our results and included standard deviation where possible (Tables 5 and 6). Using standard deviation without standard error estimates limits the inferences to the communities as

collected and not the greater populations, but we feel the similarity and standard use of the collection methods warrants cautious inferences about changes in mussel populations between 1991 and 2017.

The most diverse and abundant mussel bed found in both studies was at Long Island, and 2017 results indicate a distinct increase in density by at least one standard deviation. The fact that we found exactly the same density of the single species *P. lacustris* in Stockton Island lagoon indicates that the methods used are producing similar results (although having a third point would make that inference more comfortable). CPUE results were calculated using the density results against diver specific bottom time in order to standardize the units over all sites and include those where densities were too low for transects (Table 6), while for future reference we present our transect results at each transect start point (Table 3 and Figure 7). CPUE comparisons between the surveys show that among the three regions labelled by Doolittle one (the Sand Cut) stands out as higher, suggesting patchiness that could mask variation and raises the question of whether differences between years are artifacts of differences in spatial distribution. However, comparing the 1991 study sites to ours, we covered a similar range of Long Island, ranging from what Doolittle labeled Long Island North, Middle, and sand cut (Doolittle, personal communication, 2018). There was some spatial variation as seen in transects LI t01, LI t02, and Lit06 as well as a singular community composition change at LI t16 (Figure 7). Those sites do not correspond to Doolittle's Long Island North, Middle, and Sand Cut differences. The distributions we found indicate that the density differences between studies are a true change over time and not space.

Mussels at other sites were not as abundant as those in the Long Island community (Table 6). We found more mussels in Sand Bay and Stockton lagoon than Doolittle (1991). We found fewer mussels at Raspberry and Red Cliff Bays, with the latter being of more concern due to the greater difference between surveys (33.3 CPUE in 1991 versus 11.0 in 2017). We did not survey the mouth of the stream at Red Cliff Bay.

Table 5. Comparison of total unionid mussel density between this study and Doolittle (1991). Coordinates of the three sections in 1991 were not available, so we combined the 2017 into one mean and compared it with Doolittle's three reported sections of the mussel bed. Doolittle reports total density as numbers per 60 m², which we convert to n/m². Standard deviation was not available from 1991 but was calculated for the 2017 survey and estimated from Doolittle by taking the mean and standard deviation of the three sections reported from the mussel bed in 1991.

Site	Doolittle (1991)		Present survey (2017)	
	Density (n/60 m ²)	n/m ²	Mean n/m ²	SD
Long Is. N	4.20	0.07	—	—
Long Is. M	11.00	0.18	—	—
Long Is. sand cut	13.90	0.23	—	—
(Long Is. combined)	—	0.16 +/- 0.08	0.96	0.57
Stockton lagoon	3.00	0.05	0.05	0.02

Table 6. Comparison of catch per unit effort (CPUE, as number per diver per hour) of unionid mussels between this study and Doolittle (1991). Coordinates of the three sections in 1991 were not available so we combined the 18 transects taken in 2017 into one mean value. Values for Long Island and Stockton Island lagoon were re-calculated based on diver bottom times to convert to CPUE. Results from 2017 are means of all the dives at each site. This table does not include sites where mussels were found in 2017 but not 1991.

Site	Doolittle (1991)	Present survey (2017)
	CPUE	Mean CPUE
Long Is. N	76.00	129.44
Long Is. M	53.00	–
Long Is. sand cut	108.00	–
Stockton lagoon	11.50	20.75
Raspberry Bay	53.70	43.50
Red Cliff Bay	33.30	11.00
Sand Bay	0.40	2.25

Common species richness and evenness measures are shown in Table 7. The most species-rich site was Raspberry Bay, the only site outside of the Stockton lagoon where *Pyganodon lacustris* was observed. *Pyganodon grandis* was observed at all sites where mussels were collected except at Stockton lagoon. *Elliptio complanata* was also fairly widespread and was the most abundant mussel species encountered. *Anodontoidea ferussacianus* occurred fairly broadly but was the least frequently observed mussel species, and consequently sites with relatively higher richness did not have much higher diversity in terms of calculated indices. Species richness and evenness measures are most useful in cross study or long term comparisons. Calculations based on 1991 survey results were not possible as original data were not available at the time of this publication.

Table 7. Diversity of unionid mussels sampled in Apostle Islands National Lakeshore in August and September of 2017. Dreissenids were not included in the diversity calculations. S is the number of species, d is Margaleff's diversity index, J' = Pielou evenness, $H'(\log e)$ is Shannon diversity, and $1-\lambda'$ is the Simpson diversity index. Values for evenness could not be calculated for sites where one species was collected. Calculations were based on mean CPUE in numbers per diver per hour units.

Site	S	d	J'	H'(loge)	1- λ'
Quarry Bay	1	0	–	0	0
Presque Isle Bay	1	0	–	0	0
Long Island	3	0.4113	0.4400	0.4834	0.2413
Stockton Island lagoon	1	0	–	0	0
Raspberry Bay	4	0.7952	0.5076	0.7037	0.3473
Sand Bay	1	0	–	0	0
Red Cliff Bay	2	0.4170	0.4395	0.3046	0.1818

Dreissenid presence (closed circles) and absence (open circles) at survey sites is shown in Figure 8 with CPUE results summarized in Figure 10. All specimens found were zebra mussels (*D. polymorpha*), confirmed with genetic testing (companion study to this report, forthcoming from M. McCartney). Zebra mussels were found near Sand Island (both on the *Sevona* wreck northeast of the island and west of the island), Red Cliff Bay, and Stockton Island (Quarry Bay, Presque Isle Bay, and the docks, but not in Julian Bay) (Figure 9). Diver effort for sites with and without zebra mussel encounters are compared in Figure 10 for Presque Isle and Quarry Bay to show the relationship between effort and encounters for individual dives. Presque Isle dives 1–3 were in open bay areas, while dives 4–6 were on dock structures. A thorough search of dock structures at a pace equivalent to the open water searches was relatively quick, thus the apparent skew in effort. Both Quarry Bay dives were in open bay areas. Areas with sparse zebra mussels were detected in the timed dives at about 1 diver-hour effort. We include non-detection times to clarify what a ‘negative’ result truly indicates relative to diving effort, because a non-detection is not necessarily equivalent to absence.

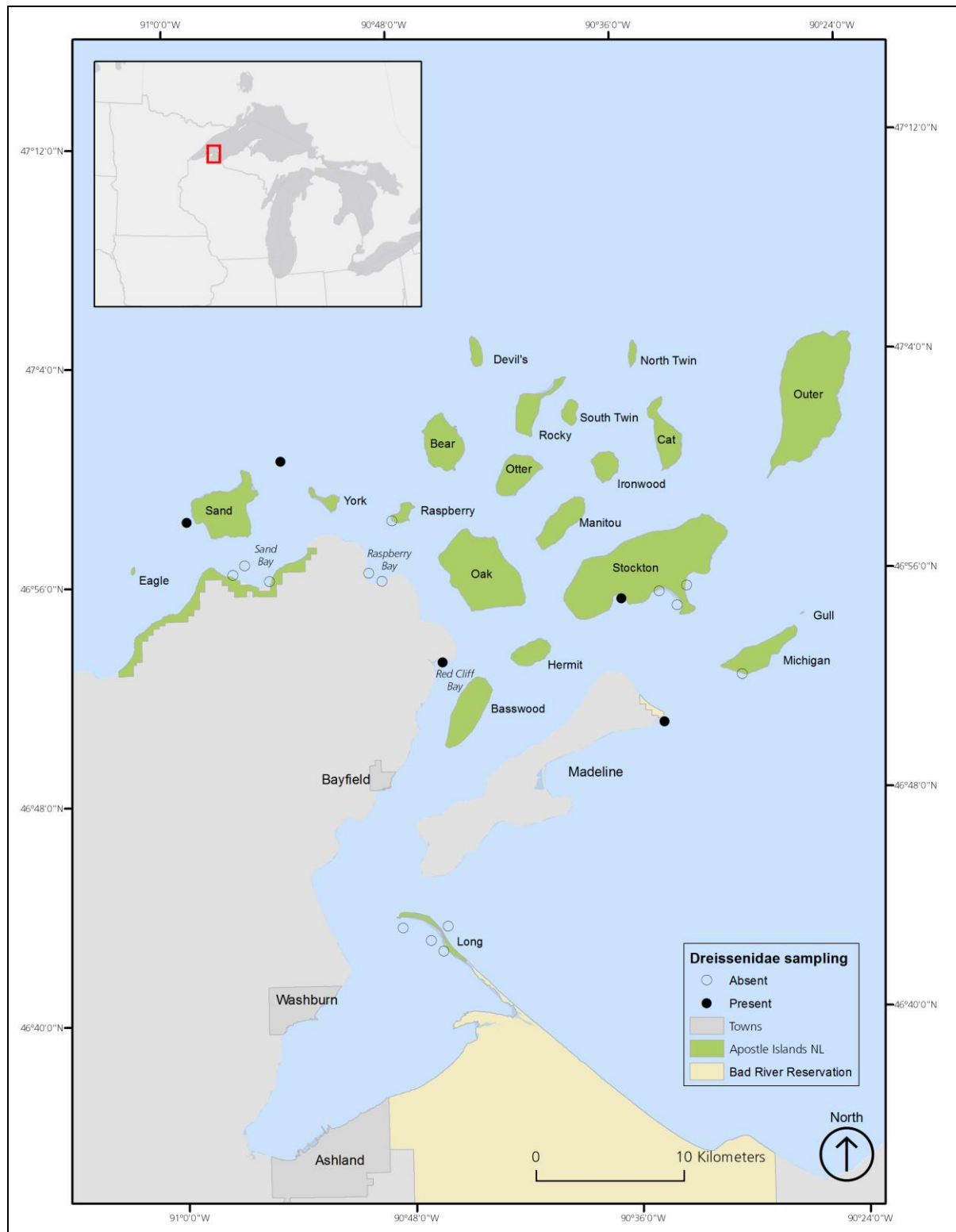


Figure 8. Dreissenid survey dive areas, Apostle Islands National Lakeshore, 2017. Site locations indicate anchor points for boat operations and whether dreissenid mussels were present (*closed circle*) or absent (*open circle*).

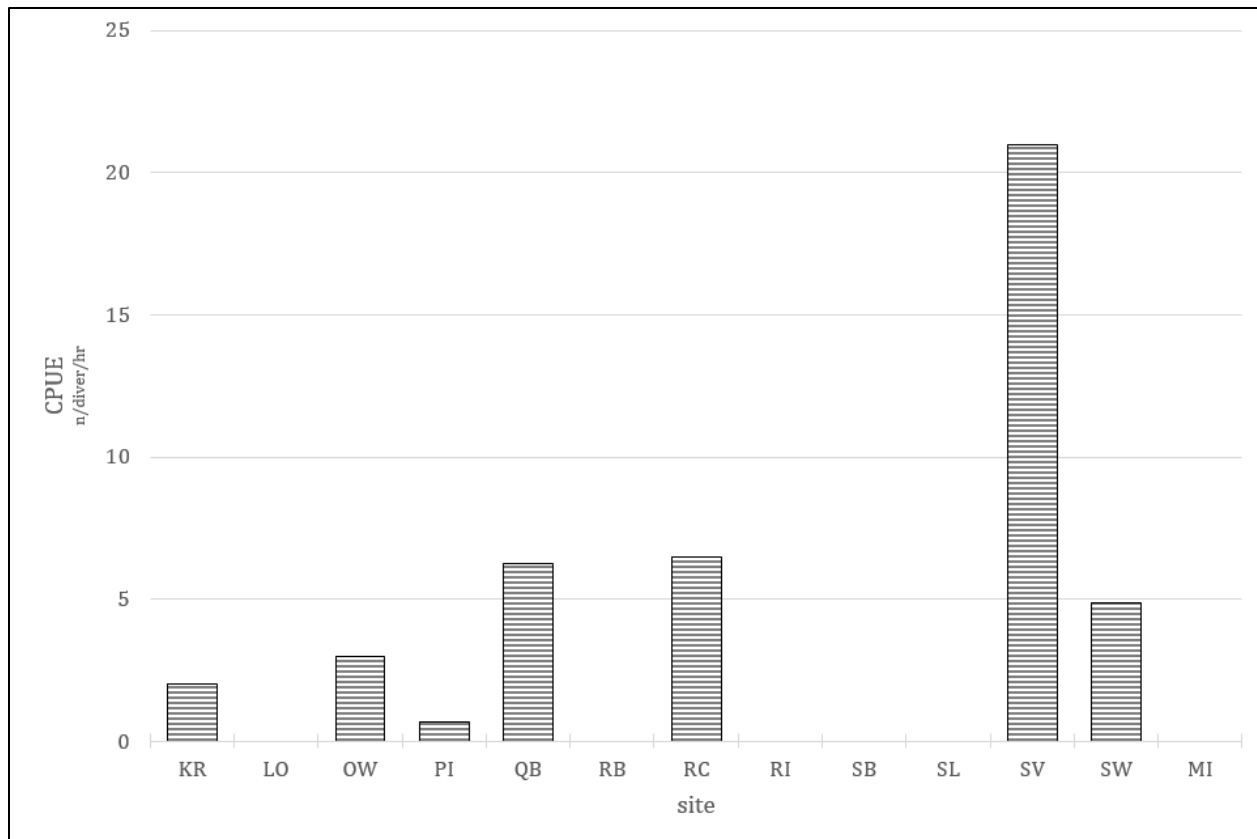


Figure 9. Mean zebra mussel (*D. polymorpha*) catch per unit effort (CPUE) per site searched by divers, Apostle Islands National Lakeshore, August to October 2017. KR = Kron's Reef, LO = Long Island (Chequamegon Bay), OW = *Ottowa* wreck (Red Cliff Bay), PI = Presque Isle Bay (Stockton Island), RB = Raspberry Bay, RC = Red Cliff Bay, RI = Raspberry Island dock, SB = Sand Bay, SL = Stockton lagoon (Stockton Island), SV = *Sevona* wreck, SW = Sand Island (lake to west), MI = Michigan Island dock.

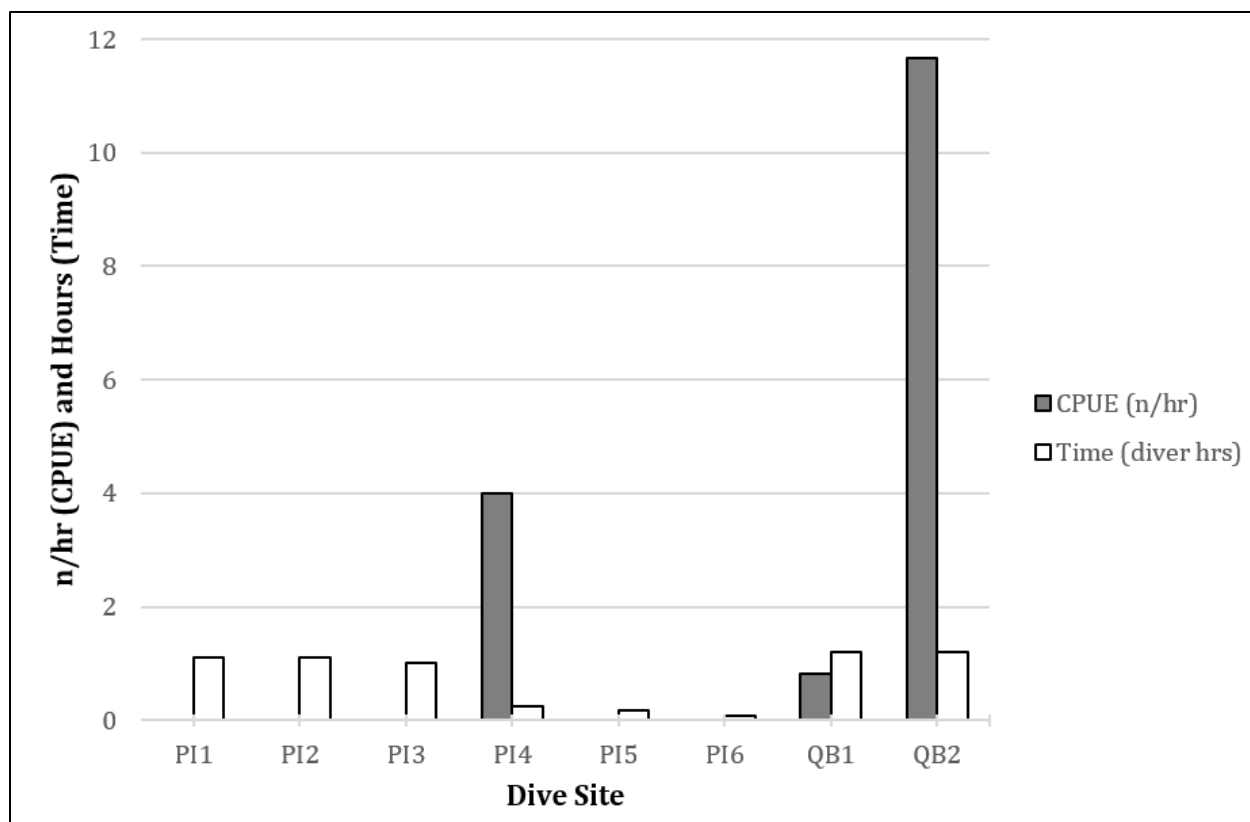


Figure 10. *Dreissena polymorpha* catch per unit effort (CPUE, number collected per diver per hour) divided by individual dives showing CPUE against diver search time, Apostle Islands National Lakeshore, 2017. Open bars = diver hours with no dreissenids collected. PI = Presque Isle dives, QB = Quarry Bay dives. Presque Isle dives 1–3 were in the open bay, 4–6 were on dock structures at the public and National Park Service docks. Both Quarry Bay dives were in the open bay at two points about 0.5 km apart.

Mean and standard deviation values for zebra mussel shell sizes over two years of collections from the *Sevona* wreck and Sand Island are shown in Figure 11. Dreissenids collected in 2017 at other sites were immediately taken for genetic analysis and shells were not measured. Results from the *Sevona* suggest a single age-class that did not grow between 2016 and 2017, with no evidence of recruitment.

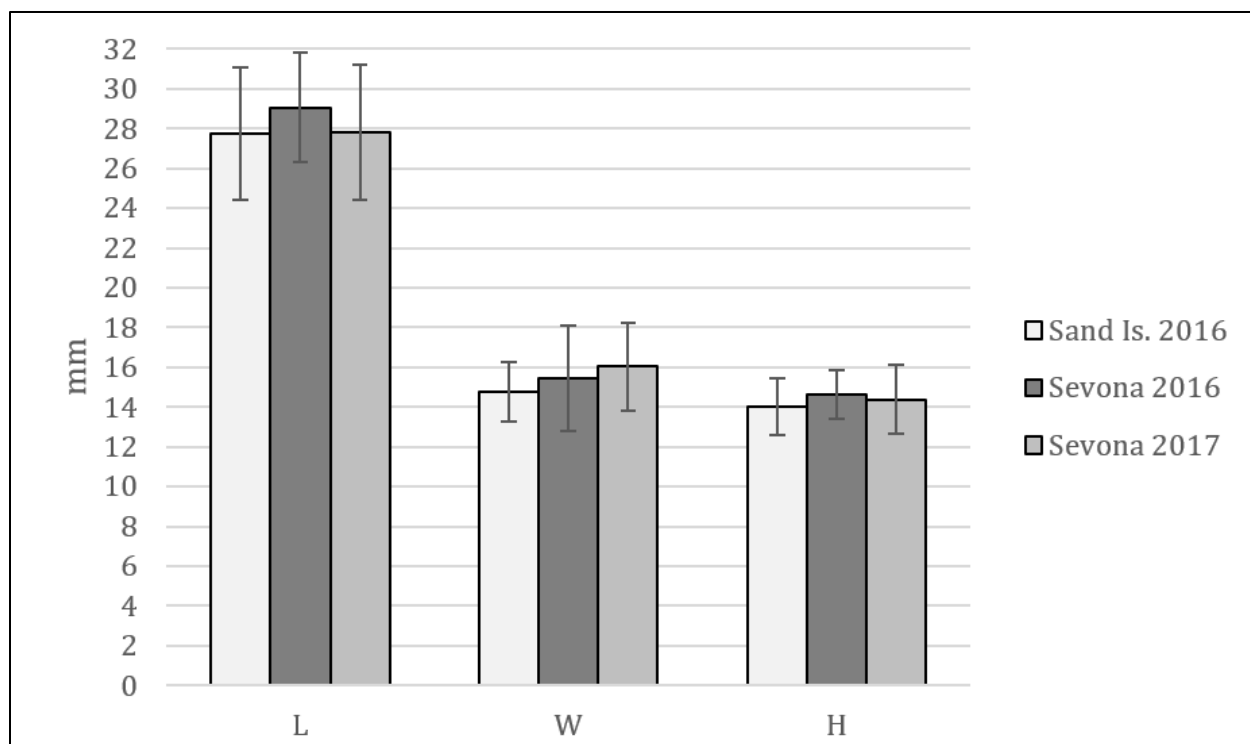


Figure 11. Shell dimensions of *Dreissena polymorpha* removed from Sand Island (west) and the *Sevona* wreck in 2016 and 2017. Mean shell length, width, and height are shown with standard deviation ($n = 4$, 19, and 23 for Sand Island, *Sevona* 2016, and *Sevona* 2017, respectively).

Discussion

The Apostle Islands supports a surprisingly diverse and abundant native mussel community with three distinct community types. Our findings from Lake Superior conform to results from other Great Lakes in that as unionid populations decline globally, there are more refugia than previously thought in Great Lakes coastal areas (Zanatta et al. 2015). During the 2017 survey we observed six common mussel species known from Lake Superior, including all species observed during the 1991 survey except for *Lasmigona complanata* (Doolittle 1991). The historical population of *P. grandis* at Quarry Bay, Stockton Island reported by Stern (1979) and documented in this study, was not observed in 1991, which we speculate was due to obscuring sediment and vegetation from a beaver dam break (Doolittle 1991). *Ligumia recta* and *Lampsilis cardium* were reported from Lake Superior in Dawley (1947), but were not reported from the 1991 survey other than one *L. recta* shell collected near Long Island (Doolittle 1991); nor did we find them during our work. There are a few examples of *L. cardium* from the Duluth estuary in the Bell Museum of Natural History (University of Minnesota, St. Paul MN) from 1945 and 2001 (MN DNR, D. Kelner) but no others were found in the watershed. It is unclear what the natural distribution of this species was and is. Future work on this question would benefit mussel conservation in the region. The absence of *L. recta* is of special concern because it has been a common species in the St Louis R. system and Twin Ports area, e.g. in the St. Louis R. they are often in stream from the lake up to any rapids which apparently prevent upstream advance (B. Sietman, MN DNR, personal communication). Long-term monitoring in the region should be conducted to determine if they have been extirpated from the Apostle Islands and/or Tribal lands, particularly river mouths like the Raspberry R. inlet. The issue is of concern at Red Cliff because the Tribal lands are subject to impacts outside of their control upstream in the watershed, which could be an explanation for mussel population changes near the stream mouths in Red Cliff and Raspberry Bays.

Unfortunately, the quantitative work by Doolittle did not report relative abundance per species at all sites so that natural variation in populations over time could be addressed directly. We can, however, compare densities as reported in terms of total mussels of all species as both transect densities and CPUE from Stockton Island lagoon and Chequamegon Bay at Long Island. We found exactly the same average density of *P. lacustris* across transects in Stockton Island lagoon compared to previous counts (referred to as “Tombolo lagoon” in Doolittle [1991]). However, we found nearly twice as many mussels in the lagoon in our timed searches compared to the 1991 report. This result makes it appear that large differences in diver search effectiveness may cause CPUE values to differ compared to transect based densities, which do not appear subject to this same error. In this case, search pattern is the most likely explanation of the differences between the CPUE and transect methods. We had the advantage of prior knowledge of the locations within the lagoon where Doolittle found mussel beds and ran both transects and CPUE dives at those locations only. In general, we do not think CPUE is unreliable for future comparisons if prior targeting is taken into account. Using GPS coordinates helps this process so that future surveys can account for the effect of searching for mussel beds versus measuring densities. Consequently, we recommend distinguishing between CPUE associated with initial search dives and CPUE dives at identified mussel bed sites where density is too low for transects. To ensure that comparisons over time and place are robust, it

is essential to report not only summary statistics, but also the original data collected on each dive (Appendix 1).

Dense mussel beds are more easily measured with quantitative density techniques using the transect methods. Transects ensure that comparing results between surveys is not impacted by search time spent finding the mussel bed, differences in diver search patterns, or other factors. The comparisons between 1991 and our survey cannot be statistically tested without the original data, inaccessible at this time (Doolittle, personal communication). Using standard deviation without standard error estimates limits the inferences to the communities as collected and not the greater populations, but we feel the similarity and standard use of the collection methods warrants cautious inferences about changes in mussel populations between 1991 and 2017 (see Tables 5 and 6). The most diverse and abundant mussel bed found in both studies was at Long Island, and in 2017 we see a distinct increase in density, with 2017 numbers higher by at least one standard deviation of the sample. The geographical and methodological agreement between the studies indicate the density differences over time are biologically real. We also observed evidence of recruitment, with presence of young recruits, 0–5-year category, as well as some gravid adults (see Appendix 1). We conclude that the population at Long Island grew between 1991 and 2017 and is actively recruiting.

On the other hand, we find it alarming that even given prior knowledge of sites to survey, our timed searches of Red Cliff Bay and Raspberry Bay indicate a decline in mussel density. The decline in Red Cliff Bay is the most precipitous and shows a declining population trend between 1991 and 2017 (see Table 6). The decline is more modest in Raspberry Bay, but determining normal population variance will require long term monitoring before it can be known for certain whether this smaller drop is ecologically significant. It would be helpful to address this issue in collaboration with Red Cliff Environmental Department because the inlet on Tribal lands may contain more mussel species and contribute to the richness of the community in the bay, while here we sampled only the bay itself.

Dreissenids were also found in Red Cliff Bay, including specimens attached to native mussels; however, it seems unlikely that they are a direct cause of the decline in native pearly mussels at this time given relatively low dreissenid density. While we observed up to three dreissenids on some native mussel shells, these levels are two orders of magnitude lower than numbers observed to cause direct mortality (Ricciardi et al. 1995). Dreissenid impacts on unionid mortality and recruitment rates have been studied in other Great Lakes systems (Haag et al. 1993, Schloesser et al. 1994, Lucy et al. 2014, Krebs et al. 2015) and it should be noted that impacts need not be associated only with direct attachment on unionids (Strayer et al. 1996). Comparing Red Cliff and Raspberry Bays, we found native mussel population decline in Red Cliff Bay where zebra mussels are present and not Raspberry Bay where they are absent. Zebra mussel densities are low in Red Cliff Bay, however, and our results do not definitively address whether population decline of native mussels is related directly to invasive species or other factors (Ricciardi et al. 1995). We observed very few hard substrate attachment points other than native mussels, docks, and shipwrecks. Zebra mussel invasions can initiate on soft substrates (Berkman et al. 2000) and outside of docks and the Sevona most attachment points observed were sand, pebbles, and to other zebra mussels. Invasion dynamics and the

relationship between zebra mussel density and native unionids in the Apostle Islands requires more detailed study.

In contrast to previous work, we found evenly and widely distributed populations of mussels in Quarry Bay and Presque Isle Bay (Stockton Island), including both native unionids and invasive dreissenids. The native mussels were not found in distinct beds but more or less evenly distributed across the bays at what appeared to be a consistent range of 3 to 6 meters depth. It is possible that unionids were not found in these areas in the 1991 survey due to recent storms that blew a lot of sediment and vegetation into the bay (APIS staff, personal communication; Doolittle, personal communication). While mussels were reported here before 1991, it is unclear what the densities were. Long-term monitoring and a detailed age structure and recruitment study would help determine what the population trends are here and whether the area is recovering from past impacts, host fish recovery, or other processes. At this time it appears that native mussel populations of the Apostle Islands are for the most part more robust than seen in previous surveys, but we also see the appearance and likely establishment of invasive dreissenids. No mussels, native or invasive, were found in Julian Bay, which is likely a much higher energy environment. On the other hand, it is a large area to cover and we searched only nearshore from the *Noquebay* south to the tombolo. We suspect there are other mussel beds around other islands.

This study was designed to assess current mussel populations and we did not have the resources to study all the environmental factors that could determine mussel species distributions or density. However, we did note some common features that allow us to make observations about common conditions the mussels seem to favor in the Apostle Islands region. The densest beds were found at Long Island and Stockton lagoon, both low energy environments with relatively rich nutrient inputs from wetlands or estuaries that feed directly into the two areas. The sediment was also noticeably siltier and softer, with patches of macrophytes (particularly in the lagoon). Other sites with unionids present were softer sand/silt mixes with at least some macrophyte growth in relatively protected embayments. Across all sites, we noticed an ideal depth of 4 to 7 meters, with a “sweet spot” of about 6 meters. We think these observations could be used to predict more areas likely to support mussels in the Apostle Islands in conjunction with highly valuable NPS efforts to create benthic maps of APIS.

The most biologically significant difference between previous surveys and ours is the presence of *Dreissena polymorpha*. All specimens encountered were removed and lethally sampled for genetic identification (McCartney et al., forthcoming). Densities were highest on the *Sevona* wreck, where zebra mussels were discovered by NPS Dive Team members in September 2015. We expected small numbers near Sand Island, but we were alarmed to find zebra mussels attached to the docks at Stockton Island, attached to native mussels near Stockton Island and in Red Cliff Bay, and living freely in the sediment in Red Cliff Bay, apparently able to survive in the sediment somewhat like a quagga mussel might.

Forthcoming work by Michael McCartney will help determine genetic relationships between zebra mussels collected at APIS and source populations. A focus for that genetic work will be to determine whether mussels originate from other locations in Lake Superior (e.g., Duluth/Superior Harbor),

other Great Lakes, or inland waters. Great Lakes sourcing is important because possible vectors (e.g., recreational boaters using Bayfield Peninsula marinas) might also transport the quagga mussel, a highly damaging species in the lower Great Lakes that has been recorded in APIS (we did not find any in this survey). The forthcoming aspect of this project will allow prevention measures to target specific routes of introduction.

It was thought that cold temperatures and low calcium ion concentrations would prevent establishment of dreissenids in Lake Superior (Grigorovich, et al. 2003). The presence of mussels themselves confirm that there is sufficient calcium for survival, while growth and reproduction are a more difficult question. The presence of large dreissenids on the *Sevona* and west of Sand Island strongly suggests that there is indeed sufficient calcium and temperature; the question is how much of each and how strongly recruitment and establishment will be supported. Recent calcium ion results from this region are cause for concern (Lafrancois et al. 2018). Veliger production in zebra mussels is thought to require about 5 $\mu\text{g/L}$ of Ca^{2+} , but perhaps even less, which appears to be exceeded in this area, particularly in streams like Sand Creek. Whether temperature or pH may be limiting growth or reproduction is another matter (Cohen and Weinstein 2001, Veldhuizen et al. 2011). We observed that most of the shells of older unionids and most dreissenids showed severe decay, indicating Ca^{2+} deficiency, harsh mechanical disturbances, or both. Because mussels seem fine in the obviously tannic lagoon on Stockton Island, we think it is most likely mechanical disturbance that is agitating mussel shells and not mineral depletion, but this matter requires further study. The fact that dreissenids we found were all of a similar size (and by inference, age) indicates discrete colonization events and little to no recruitment into these this populations from nearby or distant sites between 2016 and 2017. However, the size and wide distribution of zebra mussels is cause for concern.

Conclusions

Summary

- Native unionid mussels are surprisingly abundant and diverse across the Apostle Islands.
- Three distinct communities of native unionid mussels were found at sites surveyed in 2017.
 - The Stockton Island lagoon had a unique single-species bed of *P. lacustris*.
 - Red Cliff Bay and Long Island mussel beds were characterized by *E. complanata* and *L. siliquoidea* with a mix of other species.
 - Sand Bay, Raspberry Bay, and Stockton Island (Presque Isle and Quarry Bay) were dominated by *P. grandis* with small numbers of other species.
- Three species historically reported as present (*L. complanata*, *L. recta*, and *L. cardium*) were not found in this survey.
- Far fewer mussels were found in Red Cliff Bay and Raspberry Bay than previously reported.
- Invasive zebra mussels (*D. polymorpha*) were found in low densities across the Apostle Islands, with the noted exception of the mussel bed near Long Island.
- Compared to their absence in a previous survey (Doolittle 1991), native unionid mussel beds were found in Quarry and Presque Isle Bays of Stockton Island and in Sand Bay. Native mussel densities were higher in 2017 than 1990 at Long Island and Stockton Island with age and size ranges indicating recruitment and generally healthy populations.
- Our results indicate conditions in the Apostle Islands conducive to mussels are more widespread than previously thought. There are likely other populations of both unionid mussels and dreissenids throughout APIS.

Recommendations

- Regular surveys of unionid mussel populations using both CPUE and transect methods are recommended, particularly in light of climate related changes, landscape impacts, and invasive species. Our work reinforces Doolittle's conclusion that native mussels ought to be surveyed at least every 5 years, if not more regularly.
 - It is unclear to what extent native populations naturally fluctuate and how they may respond to water quality, landscape changes (sedimentation), changes to host fish ecology, and invasive species. More regular monitoring will help identify these factors against the background of natural variation.
 - Red Cliff and Raspberry Bays are cause for concern due to declining mussel populations and should be monitored more regularly in the future.

- Attention to river or stream mouths could help determine if watershed impacts are related to declines in mussel populations, identify hotspots of unionid diversity, and find easy access to mussel beds for development of monitoring programs with participation of local schools and coastal communities.
- Continuous monitoring of all sites for invasive dreissenids is critical. **At current densities, immediate and sustained manual removal SCUBA dives have highest potential for substantial benefits and detection.**
 - SCUBA diver searches have, to date, been the best method of detecting, collecting, and removing dreissenids. Physical removal from wrecks and docks is a feasible prevention model at current densities.
 - Removing dreissenids from the lake bottom at Red Cliff, Presque Isle, and Quarry Bays would be diver-intensive because they are large areas with low zebra mussel density. However, annual timed searches including removal of zebra mussels in these areas would provide a consistent measure of the zebra mussel population while removing as many as feasible in hopes of driving down densities faster than recruitment via veliger drift.
- Interpretive staff could help ensure that boats mooring at NPS sites are clean and share information with visitors about what they can do to help prevent the further spread of zebra mussels.

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Appendix A. Mussel Survey Data.

Field summary data for the unionid and dreissenid SCUBA survey, Apostle Islands National Lakeshore, Wisconsin, August to October 2017. Data summary statistics are compiled in Tables 2–4, above. Questionable taxonomic identifications that could not be verified were excluded from summary data and analysis. Pictures of field collections are shown with the data when available, and shells of each species collected have been archived at Apostle Islands National Lakeshore.

Site No.: 2017005

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 43.328, Longitude 90 48.323

Location Notes: Transect 1

Substrate: Compact sand, surficial flocculent

Site Code: LO t1*

Drainage: St. Lawrence

Date: 4 August 2017

Table A1. Mussel species collected.

Live Species	No. (0–5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	2	2	–	–	58	81	–	–	–	60	0.03	Transect

Notes: 0 of 1 *E. complanata* gravid.

* Site name includes transect number (LO = Long Island, tn = nth transect)

Site No.: 2017006

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 43.214, Longitude 90 48.250

Location Notes: Transect 2

Substrate: Fairly coarse sand, surficial flocculent

Site Code: LO t2

Drainage: St. Lawrence

Date: 4 August 2017

Table A2. Mussel species collected.

Live species	No. (0–5)	No. (>5)	Total No.	0–5 yr		>5 yr		No. dead	Search time (hr)	CPUE msl/hr	Area (m ²)	Mussel density	Survey method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	6	6	–	–	49	71	4	–	–	60	0.10	Transect
<i>L. siliquoidea</i>	–	2	2	–	–	70	76	2	–	–	60	0.03	Transect
<i>P. grandis</i>	–	–		–	–	–	–	2	–	–	60	0.00	Transect
unionid total=	–	–	8	–	–	–	–	–	–	–	60	0.13	–

Notes:



Mussels collected from site LO t2.

Site No.: 2017007

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 43.278, Longitude 90 48.357

Location Notes: Transect 3

Substrate: Fairly coarse sand, surficial flocculent

Site Code: LO t3

Drainage: St. Lawrence

Date: 4 August 2017

Table A3. Mussel species collected.

Live species	No. (0–5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. dead	Search time (hr)	CPUE msl/hr	Area (m ²)	Mussel density	Survey method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	4	68	72	28	33	39	74	2	–	–	60	1.20	Transect
<i>L. siliquoidea</i>	–	12	12	–	–	47	78	3	–	–	60	0.20	Transect
<i>P. grandis</i>	1	7	8	62	–	62	92	2	–	–	60	0.13	Transect
unionid total=	–	–	92	–	–	–	–	–	–	–	60	1.53	–

Notes: 0 of 2 *L. siliquoidea* gravid.



Mussels collected from site LO t3.

Site No.: 2017008

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.841, Longitude 90 46.838

Location Notes: Transect 4

Substrate: Coarse and fine sand, surficial flocculent

Site Code: LO t4

Drainage: St. Lawrence

Date: 4 August 2017

Table A4. Mussel species collected.

Live species	No. (0–5)	No. (>5)	Total No.	0–5 yr		>5 yr		No. dead	Search time (hr)	CPUE msl/hr	Area (m ²)	Mussel density	Survey method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	2	67	69	31	40	42	74	–	–	–	60	1.15	Transect
<i>L. siliquoidea</i>	–	13	13	–	–	50	72	–	–	–	60	0.22	Transect
<i>P. grandis</i>	3	3	6	39	54	64	78	–	–	–	60	0.10	Transect
unionid total=	–	–	88	–	–	–	–	–	–	–	60	1.47	–

Notes: 1 of 1 *L. siliquoidea* gravid, 0 of 2 *P. grandis* gravid, 1 of 5 *E. complanata* gravid.



Mussels collected from site LO t4.

Site No.: 2017009

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 43.275, Longitude 90 48.120

Location Notes: Transect 5

Substrate: Sand and silt, surficial flocculent, more clay & silt than Transect 4; sparse macrophytes

Site Code: LO t5

Drainage: St. Lawrence

Date: 4 August 2017

Table A5. Mussel species collected.

Live species	No. (0–5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. dead	Search time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel density	Survey method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	64	64	–	–	50	78	2	–	–	60	1.07	Transect
<i>L. siliquoidea</i>	2	14	16	19	53	54	75	1	–	–	60	0.27	Transect
<i>P. grandis</i>	1	3	4	58	–	73	81	–	–	–	60	0.07	Transect
unionid total=	–	–	84	–	–	–	–	–	–	–	60	1.40	–

Notes: 0 of 1 *L. siliquoidea* gravid



Mussels collected from site LO t5.

Site No.: 2017010

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 43.297, Longitude 90 48.066

Location Notes: Transect 6

Substrate: Sand more coarse than Transect 5, little vegetation

Site Code: LO t6

Drainage: St. Lawrence

Date: 4 August 2017

Table A6. Mussel species collected.

Live species	No. (0–5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	3	3	–	–	51	75	1	–	–	60	0.05	Transect
<i>L. siliquoidea</i>	–	2	2	–	–	70	72	–	–	–	60	0.03	Transect
<i>P. grandis</i>	–	1	1	–	–	66	–	1	–	–	60	0.02	Transect
unionid total=	–	–	6	–	–	–	–	–	–	–	60	0.1	–

Notes:



Mussels collected from site LO t6.

Site No.: 2017011

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.841, Longitude 90 46.838

Location Notes: Transect 7

Substrate: Fine sand, silt, clay, few plants

Site Code: LO t7

Drainage: St. Lawrence

Date: 4 August 2017

Table A7. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0–5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	43	43	–	–	44	71	1	–	–	60	0.72	Transect
<i>L. siliquoidea</i>	–	2	2	–	–	76	80	1	–	–	60	0.03	Transect
unionid total=	–	–	45	–	–	–	–	–	–	–	60	0.75	–

Notes: 1 of 1 *L. siliquoidea* gravid, 0 of 10 *E. complanata* gravid

Site No.: 2017012

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.817, Longitude 90 46.815

Location Notes: Transect 8

Substrate: Fine sand, silt, clay, very few plants

Site Code: LO t8

Drainage: St. Lawrence

Date: 4 August 2017

Table A8. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	52	52	–	–	46	77	2	–	–	60	0.87	Transect
<i>L. siliquioidea</i>	–	1	1	–	–	71	–	1	–	–	60	0.02	Transect
<i>P. grandis</i>	2	1	3	62	72	67	–	1	–	–	60	0.05	Transect
unionid total=	–	–	56	–	–	–	–	–	–	–	60	0.93	–

Notes: 1 of 1 *L. siliquioidea* gravid, 0 of 3 *P. grandis* gravid, 0 of 14 *E. complanata* gravid; no evidence of *Dreissena* spp. observed at Long Island

Site No.: 2017013

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.445, Longitude 90 46.204

Location Notes: Transect 9

Substrate: Sand, surficial flocculent, scattered plants

Site Code: LO t9

Drainage: St. Lawrence

Date: 9 August 2017

Table A9. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	2	46	48	26	33	47	89	7	–	–	60	0.8	Transect
<i>L. siliquoidea</i>	–	3	3	–	–	61	67	–	–	–	60	0.05	Transect
<i>P. grandis</i>	–	1	1	–	–	94	–	1	–	–	60	0.02	Transect
unionid total=	–	–	52	–	–	–	–	–	–	–	60	0.87	–

Notes:

Site No.: 2017014

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.445, Longitude 90 46.204

Location Notes: Transect 10

Substrate: Sand, surficial flocculent, scattered plants

Site Code: LO t10

Drainage: St. Lawrence

Date: 9 August 2017

Table A10. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	1	73	74	28	–	32	73	5	–	–	60	1.23	Transect
<i>L. siliquoidea</i>	1	–	1	27	–	–	–	1	–	–	60	0.02	Transect
<i>P. grandis</i>	–	5	5	–	–	60	84	1	–	–	60	0.08	Transect
unionid total=	–	–	80	–	–	–	–	–	–	–	60	1.33	–

Notes:

Mussels collected from site LO t10.

Site No.: 2017015

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.732, Longitude 90 46.698

Location Notes: Transect 11

Substrate: Sand, surficial flocculent

Site Code: LO t11

Drainage: St. Lawrence

Date: 9 August 2017

Table A11. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	32	32	–	–	31	76	–	–	–	60	0.53	Transect
<i>L. siliquoidea</i>	–	1	1	–	–	48	–	–	–	–	60	0.02	Transect
<i>P. grandis</i>	–	2	2	–	–	40	62	–	–	–	60	0.03	Transect
unionid total=	–	–	35	–	–	–	–	–	–	–	60	0.58	–

Notes:

[illegible]

Site No.: 2017016

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.716, Longitude 90 46.664

Location Notes: Transect 12

Substrate: Sand, surficial flocculent, scattered plants

Site Code: LO t12

Drainage: St. Lawrence

Date: 9 August 2017

Table A12. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	2	58	60	26	35	42	79	8	–	–	60	1	Transect
<i>L. siliquoidea</i>	–	5	5		–	57	73	3	–	–	60	0.08	Transect
<i>P. grandis</i>	1	3	4	23	–	59	76	1	–	–	60	0.07	Transect
unionid total=	–	–	69	–	–	–	–	–	–	–	60	1.15	–

Notes:



Mussels collected from site LO t12.

Site No.: 2017017

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.370, Longitude 90 46.239

Location Notes: Transect 13

Substrate: Sand

Site Code: LO t13

Drainage: St. Lawrence

Date: 9 August 2017

Table A13. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	1	51	52	26	–	45	84	–	–	–	60	0.87	Transect
<i>L. siliquoidea</i>	1	1	2	30	–	56	–	–	–	–	60	0.03	Transect
<i>P. grandis</i>	–	3	3	–	–	71	92	–	–	–	60	0.05	Transect
unionid total=	–	–	57	–	–	–	–	–	–	–	60	0.95	–

Notes:



Mussels collected from site LO t13.

Site No.: 2017018

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.370, Longitude 90 46.239

Location Notes: Transect 14

Substrate: Sand

Site Code: LO t14

Drainage: St. Lawrence

Date: 9 August 2017

Table A14. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	2	75	77	34	36	38	87	5	–	–	60	1.28	Transect
<i>P. grandis</i>	–	3	3	–	–	80	86	–	–	–	60	0.05	Transect
unionid total=	–	–	80	–	–	–	–	–	–	–	60	1.33	–

Notes:



Mussels collected from site LO t14.

Site No.: 2017019

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.378, Longitude 90 46.279

Location Notes: Transect 15

Substrate: Sand

Site Code: LO t15

Drainage: St. Lawrence

Date: 9 August 2017

Table A15. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	5	51	56	23	38	41	79	3	–	–	60	0.93	Transect
<i>L. siliquioidea</i>	2	1	3	27	28	50		3	–	–	60	0.05	Transect
<i>P. grandis</i>	–	2	2	–	–	69	69	3	–	–	60	0.03	Transect
unionid total=	–	–	61	–	–	–	–	–	–	–	60	1.02	–

Notes:



Mussels collected from site LO t15.

Site No.: 2017020

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.381, Longitude 90 46.236

Location Notes: Transect 16

Substrate: Sand

Site Code: LO t16

Drainage: St. Lawrence

Date: 9 August 2017

Table A16. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	1	68	69	24	–	36	80	5	–	–	60	1.15	Transect
<i>L. siliquoidea</i>	–	3	3	–	–	36	84	1	–	–	60	0.05	Transect
<i>P. grandis</i>	–	8	8	–	–	60	87	2	–	–	60	0.13	Transect
unionid total=	–	–	80	–	–	–	–	–	–	–	60	1.33	–

Notes:



Mussels collected from site LO t16.

Site No.: 2017021

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.403, Longitude 90 46.445

Location Notes: Transect 17

Substrate: Silt with some sand

Site Code: LO t17

Drainage: St. Lawrence

Date: 9 August 2017

Table A17. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	5	32	37	16	24	44	79	–	–	–	60	0.62	Transect
<i>L. siliquioidea</i>	1	2	3	34	–	53	73	–	–	–	60	0.05	Transect
<i>P. grandis</i>	–	2	2	–	–	60	73	–	–	–	60	0.03	Transect
unionid total=	–	–	42	–	–	–	–	–	–	–	60	0.7	–

Notes:



Mussels collected from site LO t17.

Site No.: 2017022

Location: Lake Superior, Long Island

County: Ashland, WI

Coordinates: Latitude 46 42.401, Longitude 90 46.472

Location Notes: Transect 18

Substrate: Silt with some fine sand

Site Code: LO t18

Drainage: St. Lawrence

Date: 9 August 2017

Table A18. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	2	36	38	24	33	34	72	2	–	–	60	0.63	Transect
<i>L. siliquoidea</i>	1	1	2	33	–	69	–	1	–	–	60	0.03	Transect
<i>P. grandis</i>	–	2	2	–	–	68	70	–	–	–	60	0.03	Transect
unionid total=	–	–	42	–	–	–	–	–	–	–	60	0.7	–

Notes:



Mussels collected from site LO t18.

Site No.: 2017027

Location: Lake Superior, Stockton Island, Noquebay

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Coarse sand

Site Code: NB1

Drainage: St. Lawrence

Date: 11 August 2017

Table A19. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				<i>Min L</i>	<i>Max L</i>	<i>Min L</i>	<i>Max L</i>						
(none)	–	–	0	–	–	–	–	–	1.25	0	–	–	Timed

Notes:

Site No.: 2017003

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: UTM 15T 5198496N, 686226E

Location Notes:

Substrate: Sand

Site Code: PI1

Drainage: St. Lawrence

Date: 2 August 2017

Table A20. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	–	27	27	–	–	59	71	2	1.1	25	–	–	Timed
<i>A. ferussacianus</i>	–	1	–	–	–	X	X	–	1.1	0.9	–	–	Timed

Notes: 0 of ≈ 5 *P. grandis* gravid; 5–20 mites/mussel common; all mussels fairly eroded, can only see beak sculpture in $\approx 1/3$ animals. The *A. ferussacianus* was not measured in error.



Mussels collected from site PI 1.

Site No.: 2017004

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: UTM 15T 5199431N, 685018E

Location Notes:

Substrate: Sand finer

Site Code: PI2

Drainage: St. Lawrence

Date: 2 August 2017

Table A21. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>A. ferussacianus</i>	–	1	1	–	–	72	–	–	1.1	1	–	–	Timed
<i>P. grandis</i>	–	49	49	–	–	56	76	11	1.1	45	–	–	Timed
unionid total=	–	–	50	–	–	–	–	–	1.1	45	–	–	–

Notes: 0 of ≈ 5 *P. grandis* gravid; stopped finding mussels <15'.



Mussels collected from site PI 2.

Site No.: 2017037

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: Latitude 46 50.917, Longitude 90 32.803

Location Notes:

Substrate:

Site Code: PI3

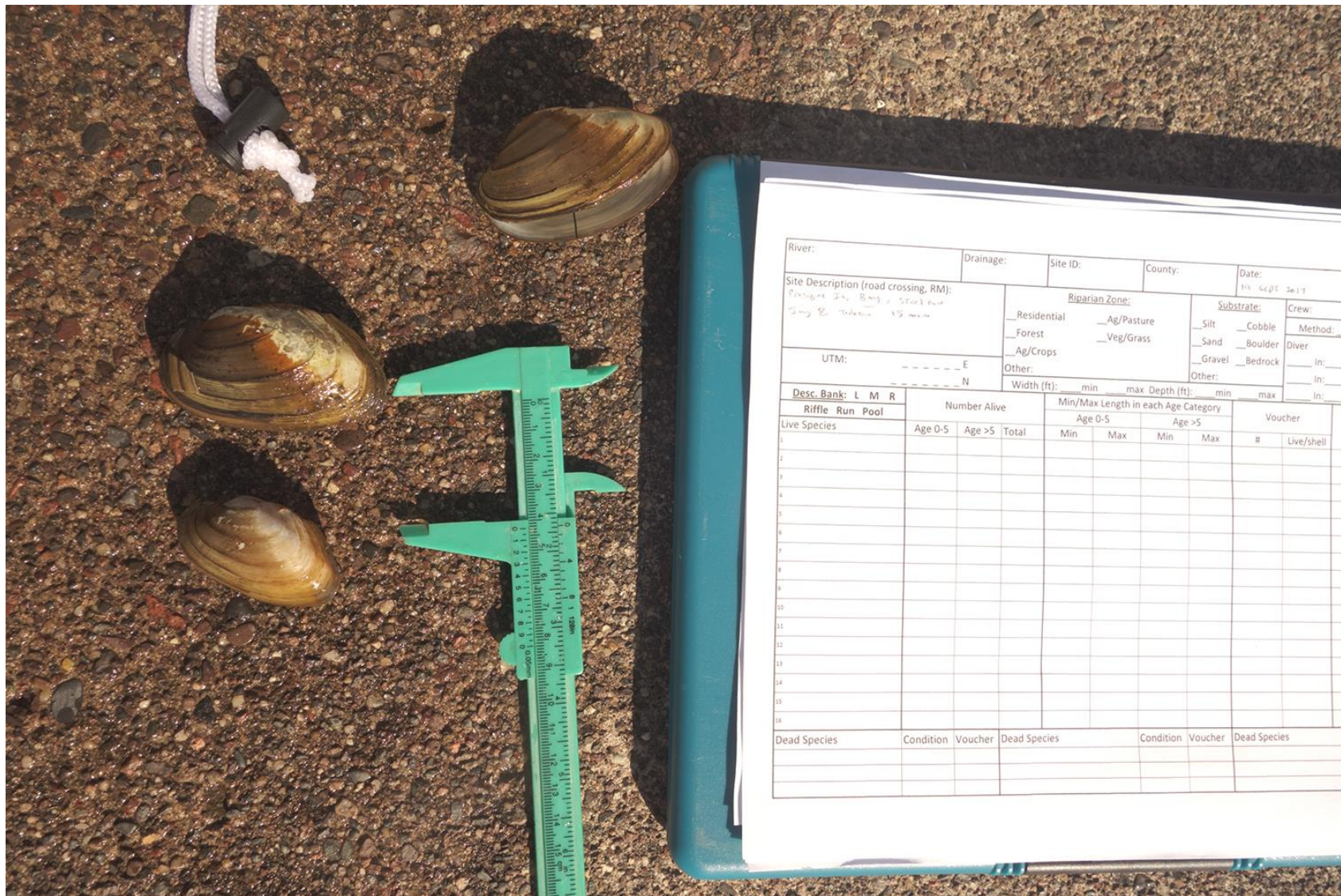
Drainage: St. Lawrence

Date: 19 September 2017

Table A22. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	–	3	3	–	–	54	68	1	0.5	6	–	–	Timed

Notes:



Mussels collected from site PI 3.

Site No.: 2017038

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Sand & silt

Site Code: PI4

Drainage: St. Lawrence

Date: 19 September 2017

Table A23. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	–	14	21	35	54	50	88	–	0.25	84	–	–	Timed
<i>Dreissena</i>	–	–	1	–	–	–	–	–	0.25	4	–	–	Timed

Notes:



Mussels collected from site PI 4.

Site No.: 2017039

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Sand & silt

Site Code: PI5

Drainage: St. Lawrence

Date: 19 September 2017

Table A24. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	1	3	4	61	–	64	72	–	0.18	22	–	–	Timed

Notes: Picture includes two oyster shells from marine species dropped by park visitors.



Mussels collected from site PI 5.

Site No.: 2017040

Location: Lake Superior, Stockton Island, Presque Is. Bay

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Sand & silt

Site Code: PI6

Drainage: St. Lawrence

Date: 19 September 2017

Table A25. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	–	5	5	–	–	73	84	–	0.08	60	–	–	Timed

Notes:



Mussels collected from site PI 6.

Site No.: 2017001

Location: Lake Superior, Stockton Island, Quarry Bay

County: Ashland, WI

Coordinates: UTM 15T 5198944N, 682455E

Location Notes:

Substrate: Compact sand, surficial flocculent

Site Code: QB1

Drainage: St. Lawrence

Date: 2 August 2017

Table A26. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>A. ferussacianus</i>	1	–	1	49	–	–	–	–	1.2	1	–	–	Timed
<i>P. grandis</i>		46	46	–	–	50	73	5	1.2	38	–	–	Timed
unionid total=	–	–	47	–	–	–	–	–	–	39	–	–	–
<i>D. polymorpha</i>	–	1	1	–	–	–	–	–	1.2	1	–	–	Timed

Notes: 0 of 5 *Pygandon grandis* gravid; 15 ft visibility; most mussels between 15 and 20 ft.



Mussels collected from site QB 1.

Site No.: 2017002

Location: Lake Superior, Stockton Island, Quarry Bay

County: Ashland, WI

Coordinates: UTM 15T 5199024N, 682364E

Location Notes: Near creek mouth

Substrate: Sand, surficial flocculent

Site Code: QB2

Drainage: St. Lawrence

Date: 2 August 2017

Table A27. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	1	69	70	42	–	43	77	20	1.2	58	–	–	Timed
<i>D. polymorpha</i>	–	14	14	–	–	–	–	–	1.2	12	–	–	Timed

Notes: 0 of 5 *Pygandon grandis* gravid; 15–20 ft visibility; most mussels between 18 and 20 ft.



Mussels collected from site QB 2.

Site No.: 2017028

Location: Lake Superior, Wisconsin shore, Raspberry Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.022, Longitude 90 49.372

Location Notes:

Substrate: Mostly sand, a little silt, few plants

Site Code: RB1

Drainage: St. Lawrence

Date: 11 August 2017

Table A28. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	2	2	–	–	–	–	–	0.5	4	–	–	Timed
<i>P. grandis</i>	1	11	12	54	–	59	85	–	0.5	24	–	–	Timed
unionid total=	–	–	14	–	–	–	–	–	0.5	28	–	–	–

Notes: 0 of 12 *P. grandis* gravid, 0 of 2 *E. complanata* gravid; fair number Sphaeriids.



Mussels collected from site RB 1.

Site No.: 2017029

Location: Lake Superior, Wisconsin shore, Raspberry Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.002, Longitude 90 48.930

Location Notes:

Substrate: Sand

Site Code: RB2

Drainage: St. Lawrence

Date: 11 August 2017

Table A29. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>A. ferussacianus</i>	–	1	1	–	–	51	–	–	0.33	3	–	–	Timed
<i>E. complanata</i>	–	1	1	–	–	68	–	–	0.33	3	–	–	Timed
<i>P. grandis</i>	–	1	1	–	–	50	–	–	0.33	3	–	–	Timed
unionid total=	–	–	3	–	–	–	–	–	0.33	9	–	–	–

Notes:



Mussels collected from site RB 2.

Site No.: 2017030

Location: Lake Superior, Wisconsin shore, Raspberry Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.317, Longitude 90 49.634

Location Notes:

Substrate: Sand

Site Code: RB3

Drainage: St. Lawrence

Date: 11 August 2017

Table A30. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	1	38	39	54	–	57	84	7	0.5	78	–	–	Timed
<i>P. lacustris</i>	–	1	1	–	–	91	–	–	0.5	2	–	–	Timed
unionid total=	–	–	40	–	–	–	–	–	0.5	80	–	–	–

Notes:



Mussels collected from site RB 3.

Site No.: 2017035

Location: Lake Superior, Wisconsin shore, Red Cliff Bay

County: Bayfield, WI

Coordinates: Latitude 46 52.943, Longitude 90 45.977

Location Notes:

Substrate: Sand & silt, small plants

Site Code: RC1

Drainage: St. Lawrence

Date: 18 September 2017

Table A31. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	8	8	–	–	47	73	5	0.33	24	–	–	Timed
<i>Dreissena</i>	–	–	2	–	–	–	–	–	0.67	3	–	–	Timed

Notes:



Mussels collected from site RC 1.

Site No.: 2017036

Location: Lake Superior, Wisconsin shore, Red Cliff Bay

County: Bayfield, WI

Coordinates: Latitude 46 52.943, Longitude 90 45.977

Location Notes:

Substrate: Sand & silt, small plants

Site Code: RC2

Drainage: St. Lawrence

Date: 18 September 2017

Table A32. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>E. complanata</i>	–	8	8	–	–	54	66	4	1	8	–	–	Timed
<i>L. siliquoidea</i>	–	–	0	–	–	–	–	1	1	0	–	–	Timed
<i>P. grandis</i>	1	–	1	40	–	–	–	–	1	1	–	–	Timed
<i>Dreissena</i>	–	–	10	–	–	–	–	2	1	10	–	–	Timed
unionid total=	–	–	9	–	–	–	–	–	1	9	–	–	–

Notes:



Mussels collected from site RC 2.

Site No.: 2017031

Location: Lake Superior, Wisconsin shore, Sand Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.694, Longitude 90 56.234

Location Notes:

Substrate: Sand

Site Code: SB1

Drainage: St. Lawrence

Date: 13 September 2017

Table A33. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	–	2	2	–	–	64	92	–	0.67	3	–	–	Timed

Notes: In the field picture, SB1 is on the left, SB3is on the right.



Mussels collected from site SB 1.

Site No.: 2017032

Location: Lake Superior, Wisconsin shore, Sand Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.361, Longitude 90 56.876

Location Notes:

Substrate: Mostly boulder, some gravel & sand

Site Code: SB2

Drainage: St. Lawrence

Date: 13 September 2017

Table A34. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				<i>Min L</i>	<i>Max L</i>	<i>Min L</i>	<i>Max L</i>						
(none)	–	–	0	–	–	–	–	1	0.67	0	–	–	Timed

Notes:

Site No.: 2017033

Location: Lake Superior, Wisconsin shore, Sand Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.106, Longitude 90 54.920

Location Notes:

Substrate: Soft sand, occasional Potamogeton, looks good like Long Island

Site Code: SB3

Drainage: St. Lawrence

Date: 13 September 2017

Table A35. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. grandis</i>	1	–	1	58	–	–	–	–	0.67	2	–	–	Timed

Notes:

Site No.: 2017034

Location: Lake Superior, Wisconsin shore, Sand Bay

County: Bayfield, WI

Coordinates: Latitude 46 56.188, Longitude 90 55.068

Location Notes:

Substrate: Sand

Site Code: SB4

Drainage: St. Lawrence

Date: 13 September 2017

Table A36. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				<i>Min L</i>	<i>Max L</i>	<i>Min L</i>	<i>Max L</i>						
(none)	–	–	0	–	–	–	–	–	0.33	0	–	–	Timed

Notes:

Site No.: 2017023

Location: Lake Superior, Stockton Island, Tombolo Lagoon

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Silt and sand

Site Code: SL1

Drainage: St. Lawrence

Date: 11 August 2017

Table A37. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
P. lacustris	2	8	10	83	91	79	104	3	0.5	20	–	–	Timed

Notes: Mussels found within $\approx 1 \text{ m}^2$; This lagoon is usually called Stockton Lagoon but appears in some reports as Tombolo Lagoon, although it is located north of the geological Tombolo feature.



Mussels collected from site SL 1.

Site No.: 2017024

Location: Lake Superior, Stockton Island, Tombolo Lagoon

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Silt and sand

Site Code: SL2 t1

Drainage: St. Lawrence

Date: 11 August 2017

Table A38. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. lacustris</i>	–	2	2	–	–	94	104	–	–	–	60	0.03	Transect

Notes: In weed bed, mucky substrate; Taxonomic identifications were confirmed in the lab via shell morphology by M. Hove and B. Sietman (Minnesota DNR).



Mussels collected from site SL 2, t1.

Site No.: 2017025

Location: Lake Superior, Stockton Island, Tombolo Lagoon

County: Ashland, WI

Coordinates: Latitude 46 55.482, Longitude 90 32.864 (location is at beach where measured)

Location Notes:

Substrate: Sand

Site Code: SL2 t2

Drainage: St. Lawrence

Date: 11 August 2017

Table A39. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. lacustris</i>	–	4	4	–	–	92	106	–	–	–	60	0.07	Transect

Notes: 1 of 13 *P. lacustris* gravid



Mussels collected from site SL 2, t2.

Site No.: 2017026

Location: Lake Superior, Stockton Island, Tombolo Lagoon

County: Ashland, WI

Coordinates: Latitude Longitude

Location Notes:

Substrate: Some areas of sand near L. Superior, otherwise silt and flocculent Site Code: SL3

Drainage: St. Lawrence

Date: 11 August 2017

Table A40. Mussel species collected.

Live species	No. (0-5)	No. (>5)	Total No.	0-5 yr		>5 yr		No. Dead	Search Time (hr)	CPUE (msl/hr)	Area (m ²)	Mussel Density	Survey Method
				Min L	Max L	Min L	Max L						
<i>P. lacustris</i>	–	4	4	–	–	102	124	–	0.17	24	–	–	Timed

Notes:



Mussels collected from site SL 3.

Table A41. Other field sites, Dreissenid searches only.

Site	Nearest Land	Date	Site No.	Site ID	UTM N 15T	UTM E 15T	Species	n	Method	Time (diver hrs)	CPUE (n/hr)
Kron's Reef	Madeline Is.	19-Sep-17	2017041	KR1	5190623	685374.5	<i>D. polymorpha</i>	1	timed	0.25	4
Kron's Reef	Madeline Is.	19-Oct-17	2017042	KR2	5190364	685342.9	<i>D. polymorpha</i>	0	timed	0.5	0
Lucerne wreck	Odanah, WI	19-Oct-17	2017043	LU1	5176757	670749	<i>D. polymorpha</i>	0	timed	0.67	0
Ottawa wreck	Red Cliff, WI	18-Sep-17	2017044	OW1	5194613	670383.5	<i>D. polymorpha</i>	1	timed	0.33	3
Sand Island (West)	Red Cliff, WI	25-Oct-16	2017045	SW1	5204048	653074.7	<i>D. polymorpha</i>	4	timed	0.5	8
Sand Island (West)	Red Cliff, WI	11-Jul-17	2017046	SW2	5204048	653074.7	<i>D. polymorpha</i>	1	timed	0.57	1.76
Sevona	Sand Is.	15-May-17	2017047	SV1	5208171	659420.4	<i>D. polymorpha</i>	19	timed	1	19
Sevona	Sand Is.	20-Oct-17	2017048	SV2	5208171	659420.4	<i>D. polymorpha</i>	23	timed	1	23
Michigan Is. dock	Michigan Is.	19-Oct-17	2017049	MI1	5193838	690647.7	<i>D. polymorpha</i>	0	timed	1	0
Raspberry Is. dock	Raspberry Is.	18-Oct-17	2017050	RI1	5204162	666941.2	<i>D. polymorpha</i>	0	timed	0.45	0

Appendix B. Photos.



National Park Service divers Allison Holdhusen and David VanderMeulen prepare to conduct a timed mussel search in Quarry Bay, Stockton Island, Apostle Islands National Lakeshore. PHOTO © T. LAFRANÇOIS.



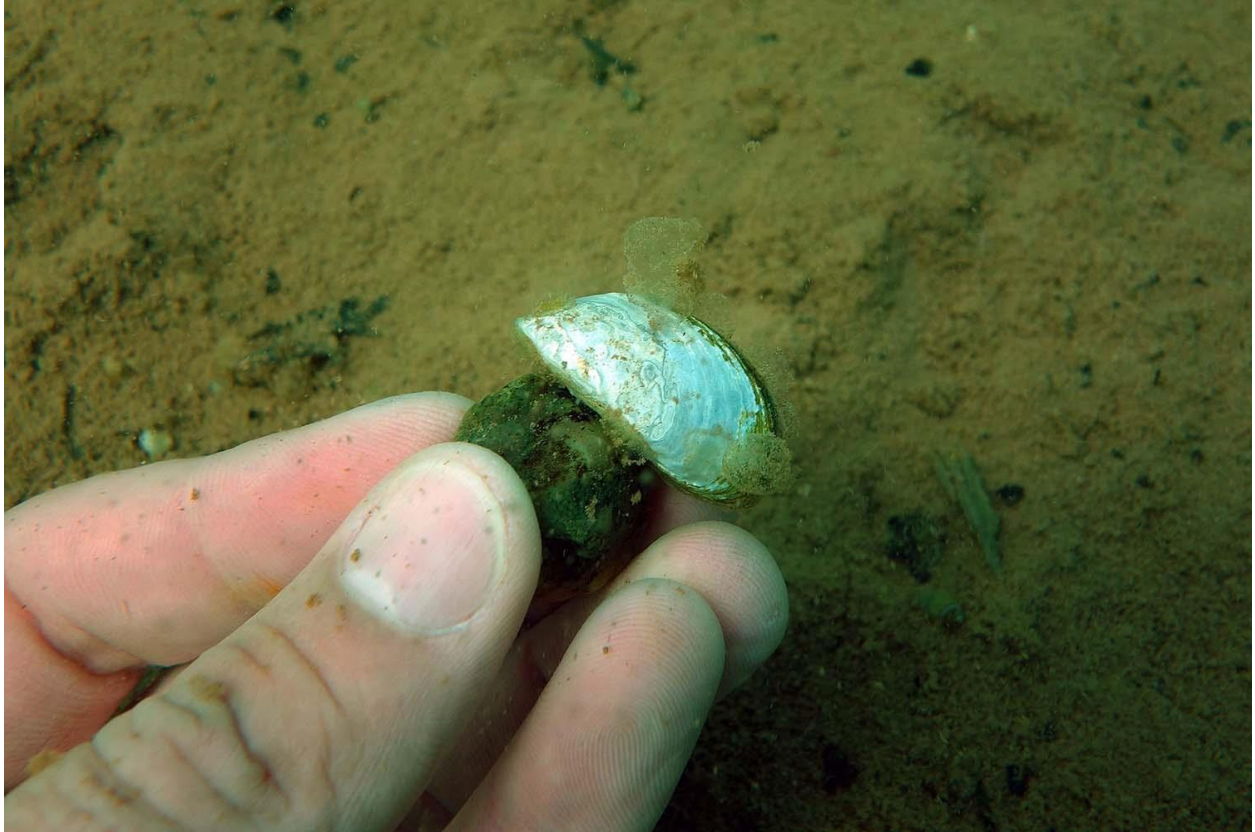
A *Pyganodon grandis* exhibits incurrent and excurrent apertures in Quarry Bay, Stockton Island, Apostle Islands National Lakeshore. Sediment composition shown here—a mix of silt and sand—was the most common substrate found to support mussels in the Apostle Islands. PHOTO © T. LAFRANÇOIS.



A *Pyganodon grandis* actively filters water from Red Cliff Bay (near Apostle Islands National Lakeshore). The substrate shown here was atypical of areas where mussels were found during this survey because the cobble was inside the *Ottawa* wreckage. NPS PHOTO/B. MORASKA LAFRANÇOIS.



National Park Service diver Jay Glase inspects the wreck of the *Noquebay* for zebra mussel presence near Stockton Island, Apostle Islands National Lakeshore. No invasive mussels have been found on the *Noquebay* to date. PHOTO © T. LAFRANÇOIS.



A zebra mussel (*Dreissena polymorpha*) adhered to a small stone in Quarry Bay, Stockton Island, Apostle Islands National Lakeshore. PHOTO © T. LAFRANÇOIS.



A zebra mussel (*Dreissena polymorpha*) attached to the wreckage of the *Sevona* off Sand Island, Apostle Islands National Lakeshore. The white "bubbly" surface in front of the mussel is a freshwater sponge.

PHOTO © T. LAFRANÇOIS.



T. Lafrancois speaks to a group of students about mussels, invasive species, and research diving. Little Sand Bay, Apostle Islands National Lakeshore, October 2017.

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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National Park Service
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1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525