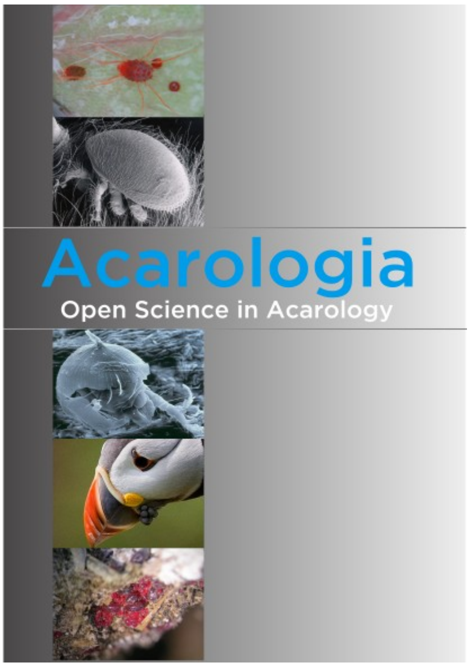

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First data on water mite (Acari, Hydrachnidia) assemblages of Point Rosa Marsh, Harrison Township, Michigan, USA, and their use as environmental bioindicators of aquatic health

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Original research

ABSTRACT

Water mites are aquatic arachnids that have been used in Europe and Central America as bioindicators of ecological health in various freshwater ecosystems (including bogs). Water mites can be found in high densities in the Laurentian Great Lakes and adjacent habitats. Although they are abundant, water mites are generally not used in the assessment of aquatic habitats in the Great Lakes and are usually assigned to the "other" category in macroinvertebrate assessments. This is despite evidence of their utility as aquatic bioindicators. In the present study we consider water mites as bioindicators of the environmental health of Point Rosa marsh, a threatened marsh found on the US side of transboundary Lake St. Clair. The abundance of water mites in Point Rosa Marsh increased from 2017 to 2019 as lake water levels increased. Although increasing water levels in Lake St. Clair can be considered a negative event due to loss of irreplaceable coastal habitat by erosion with potential economic impacts, this present study indicates that water mite populations in Point Rosa Marsh increased during the same period (2017 to 2019). As a result of our study we: update the biodiversity of water mites from Lake St. Clair with new records compared to the last report from the lake over 45 years ago, first report on water mite assemblages at Point Rosa marsh at the Lake St. Clair Metropark on Lake St. Clair and the first demonstration of water mites used as bioindicators in the habitats of the Laurentian Great Lakes.

Keywords Arachnid; macroinvertebrate; Laurentian Great Lakes; high lake level; flooding

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Introduction

Freshwater aquatic invertebrates can be used as bioindicators of ecosystem health depending on their biodiversity, tolerance to pollution, capacity to be identified to an informative taxonomic level and ease of capture. Several macroinvertebrates can be used to document the chemical and physical changes in freshwater ecosystems (Lazorchak *et al.* 2003). However, as freshwater ecosystems face increased environmental stressors, there is a need to include other so far less studied bioindicator groups, like Hydrachnidia (Buss *et al.* 2015; Goldschmidt

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2016). Expanding the diversity of invertebrate taxa used as bioindicators and obtaining more knowledge on the species-specific responses of invertebrates to chemical and physical environmental changes (anoxia, eutrophication, contaminants, sediment loads, and temperature changes) can be greatly beneficial.

Water mites are biodiverse aquatic arachnids and have been defined as a true bioindicator species due to their sensitivity to a variety of changes in environmental conditions (Kowalik and Biesiadka 1981; Goldschmidt 2016). Water mites also have a wide global distribution and inhabit a variety of freshwater habitats, including wetlands, streams, lakes, ponds, brackish bays and rivers in impressive diversities and abundances (Di Sabatino *et al.* 2008; Proctor *et al.* 2015; Smit 2020). The life cycle of water mites is complex including parasitic-phoretic larvae (discussed below) and predatory deutonymphs and adults which enable them to be interwoven in complex associations with several other members of freshwater assemblages. In the littoral zone of eutrophic lakes they can reach impressive numbers of up to 2000 specimens and 75 species (25 genera) per m^2 (Proctor *et al.* 2015). The vast distribution and diversity of water mites in freshwater systems and their ease of capture make them a very suitable bioindicator for aquatic habitats. Water mites also have phoretic relationships with established bioindicator invertebrate species, including dragonflies and chironomids but water mites are not typically used as a bioindicator species to the same extent as these commonly used taxa (Smith and Oliver 1986; Proctor *et al.* 2015). Dispersal through phoresy and parasitism suggests that water mites may have sensory recognition to select hosts that have similar habitat requirements and the ability to interpret suitable new habitats when deciding to dislodge from a host (Houck and O'Connor 1991; Proctor *et al.* 2015; Goldschmidt and Ramirez Sanchez 2020). This may provide a way to colonize new habitats prior to regional extinction, as well as increase the number of water mite-inhabited freshwater habitats through dispersal. Therefore, the same taxa can be used across a long temporal scale to monitor specific changes and successes of remediated environments. Despite these life history advantages, the use of water mites as bioindicators have been largely ignored in the health assessment of aquatic habitats in North America (Proctor *et al.* 2015), this is despite the practical use of water mites to assess the health integrity of neotropical (Central America) and European streams and endangered peat moss habitats (Wiecek *et al.* 2013; Goldschmidt 2016; Goldschmidt *et al.* 2016).

In the Laurentian Great Lakes water mite abundance and diversity is high and presents a good opportunity to start to include water mites in aquatic habitat health assessment (Vasquez *et al.* 2020a). Water mites have a wide range of pollution tolerance as reported in Klemm *et al.* (1990) where up to 40 water mite species were assessed for pollution tolerance. Water mite assemblages and individual water mite genera and species provide potential for further insight on water quality integrity, where sensitivity levels are found to differ across water mite taxa (Goldschmidt 2016). Water mites might be considered difficult to work with because of limitations in properly identifying them but this has been considered as an incorrect assumption (Goldschmidt 2016). In actuality there are taxonomic keys available for water mite identification including a North American taxonomic key by Smith *et al.* (2010). The lack of water mite use in biomonitoring of aquatic habitats is thought to be for customary or even cultural reasons rather than science-based reasons (Walter and Proctor 2013; Goldschmidt 2016).

Water related crises in the Laurentian Great Lakes have been increasing in recent years with multiple incidents of declining water quality including increasing pollutant levels of emerging contaminants such as PFAS (Remucal 2019), heavy sediment and nutrient loads from stormwater runoff after large storm events (McLellan *et al.* 2007) and more recently unprecedented lake level rises (Theuerkauf and Braun 2021). The Environmental Protection Agency (EPA), has declared Lake St. Clair and the Clinton River watersheds as an area of significant impairment resulting from human disturbances. Point Rosa marsh is one of the largest remaining Great Lakes coastal marsh communities along Lake St. Clair and the St. Clair-Detroit River System and found in a region that is suffering from many negative anthropogenic environmental impacts (Uzarski *et al.* 2019). Point Rosa marsh is approximately 8094 m^2

in size and is hydrologically connected to the lake. Point Rosa Marsh is found along the eastern coast of Lake St. Clair and the adjoining ponds and forested areas are protected, and were the site for water mite biomonitoring studies including nearshore habitats of the lake (see Figure 1). These biomonitoring studies were done due to the historical stressors that have impacted Lake St. Clair including invasive dreissenid mussels and pollution from three connecting channels that are Areas of Concern including the St. Clair River, Clinton River and the Detroit River (Baustian *et al.*, 2014). Besides supporting migratory bird species, it also provides fish nursery habitat for some of the nation's most important sport fishery (Baustian *et al.* 2014). The marshes are within the Clinton River Area of Concern and were protected in the late 1990's by the Detroit Audubon Society because of their importance as bird habitat for Michigan's threatened and endangered species of concern. Habitat degradation has continued in the coastal marshes by hydrological manipulation, increased impervious landscape, sediment accumulation, high flooding events, and invasive species infestation. Recently, environmental remediation efforts have been focused on Point Rosa Marsh, through aquatic and riparian habitat restoration, installation of stormwater control bioswales, and invasive species removal (EPA 2010).

Water mites could be useful as a metric to study and monitor the health status of Point Rosa Marsh and Lake St. Clair after these restoration efforts. Given the lack of knowledge on the use of water mites as bioindicators (and lack of monitoring in Point Rosa Marsh) we tested the use of water mites as bioindicators of Point Rosa Marsh and Lake St. Clair. Increasing water mite diversity and abundance in Point Rosa Marsh was observed during record-breaking rising lake levels during 2017 to 2019. In addition, we found increasing diversity of water mites in Lake St. Clair when compared to historical data. Our work aims to increase the profile of water mites as sentinels of aquatic environmental change in freshwater habitats in North America.

Methods

Lake St. Clair and Point Rosa Marsh study site

Lake St. Clair Metropark (LSCM) is a 1.2 mi^2 park located in the city of Harrison Township, Michigan. It contains Point Rosa Marsh, one of the last marsh habitats on the shore of Lake St. Clair in the US state of Michigan. Lake St. Clair is a shallow basin which connects the upper and lower Laurentian Great Lakes of North America (Baustian *et al.* 2020). Water mites were sampled during the end of Summer and Fall (August to October) during the years 2017-2019 in up to four locations (sites 1-4) within Point Rosa Marsh and abundance and diversity of water mites was investigated (see Figure 1 and 2). Four sites (sites A-D) outside of the Point Rosa Marsh protected area were also sampled, including Lake St. Clair and the North Marsh (see Figure 1). The four sites in Point Rosa Marsh represents varying marsh habitats with 1 and 2 located nearest to Lake St. Clair containing primarily cattails and submergent vegetation. Site 3 is under forest canopy and site 4 has no canopy but is deeper than the rest. Sites outside the marsh include site A found in Lake St. Clair which was a sandy bottom with few emergent vegetation and subjected to strong waves, B was a sample from a bioswale that contained cattails and C and D which were continuously sampled were found in the nearshore habitats of adjoining North Marsh. Site C and D had many submergent vegetation, few large trees near it and sloped to the deep. Whenever possible, water quality parameters were collected at sampling locations with instruments and water quality kits including YSI Professional Plus handheld multiparameter probe, H2OQ Chemical Testing Kits - Hanna Brand and installed YSI exo sondes. Further historical environmental background of these habitats was provided by Joshua Tellier, Aquatic Biologist, Michigan Department of Environment, Great Lakes and Energy (EGLE) and can be viewed at https://mywaterway.epa.gov/community/lake%20st%20clair%20metropark/overview and by Luc Bujold, Projects leader, Marine Environmental Data Section, Oceans Science Branch

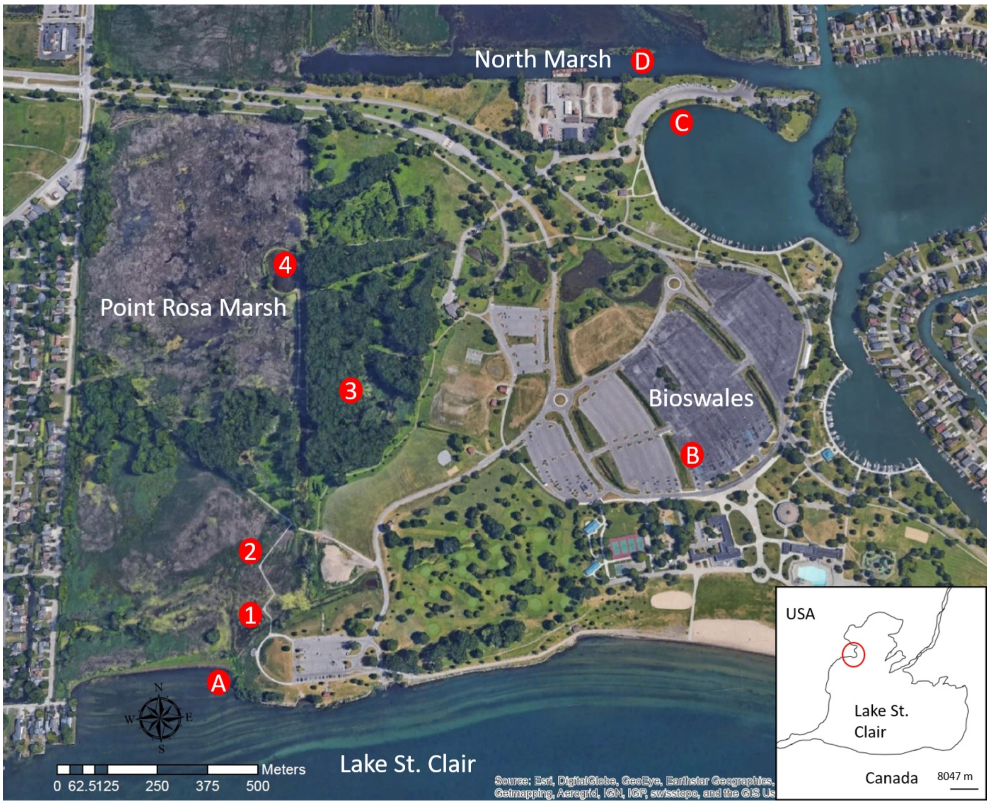

Figure 1 Map of Lake St. Clair Metropark with inset showing placement in the Lake St. Clair basin. Red dots and labelling indicate sampling sites that were studied. Google Earth Image, earth.google.com/web/.

Fisheries and Oceans Canada, Government of Canada which can be retrieved at DFO (2022). Supplemental Table 1 has water chemistry data obtained for historical and current dates.

Water mite sampling for biomonitoring

Water mites were collected during 2017, 2018, and 2019 at the end of summer and fall months (August to October). Total sampling done in Point Rosa marsh and Lake St. Clair for 2017 was 8 sampling events, 2018 was 6 sampling events and 2019 was 7 sampling events. Collection was done as described in Vasquez *et al.* (2020a) using a 250 µm swoop net which was dragged

Figure 2 Point Rosa Marsh along Lake St. Clair, Harrison Township, Michigan, USA. (A) Taken at the entrance of Point Rosa Marsh showing dry area where it connects with Lake St. Clair. (B) Point Rosa Marsh in 2018 with red arrow depicting Lake St. Clair and yellow arrow depicting the marsh. (C) Point Rosa Marsh in 2019 showing flooding during record breaking high lake water levels.

along vegetation at the bottom and across the water column of the habitat and thereafter passed through a 250 µm sieve. The contents collected in the sieve were transferred into 473 ml commercially available plastic containers and processed for identification. At each site 5 plastic containers of samples were obtained with each container containing 10 "swoops" of the net through the vegetation and water column of the habitat. Processing was done using sorting trays to collect water mites with a plastic pipette. Water mites were either set aside for water quality assays or they were blanched for future study as was done in Vasquez *et al.* (2020a). After the mites are sorted alive, blanching is done. Blanching entails submerging water mites for approximately 3-5 seconds in boiling water using a 250 µm sieve and thereafter transferring mites to cold 100% ethanol (isopropyl alcohol could also be used). This enables the mite legs to extend making identification easier and also preserves the tissue for extracting the DNA later.

Morphologic identification

A Nikon SMZ 745T stereomicroscope was used to visualize the dorsal and ventral side of water mites. An Infinity 1 Lumenera digital camera mounted on the microscope was used to take micrographs of water mites. Water mites were identified taxonomically by using published keys from Cook (1974) and Smith *et al.* (2010). As reported in Vasquez *et al.* (2020a), water mites were morphologically assessed to genus and species whenever possible and those that could not be identified (immature or morphologically damaged) were assigned an "unknown" category. Representative water mites were DNA barcoded as described in Vasquez *et al.* (2020a) and resulting sequences have been uploaded to GenBank and are reported under accession Id: MH091920 - MH091926.

Results

Water mite abundance and biodiversity in Point Rosa Marsh and adjoining habitats

In total 14 water mite genera were collected across all habitats sampled (see Figure 3). Water mite total abundance in Point Rosa Marsh in 2017 from all sites was 5 mites (see Table 1 and Figure 4). In the same year water mite total abundance in Lake St. Clair, bioswales and North Marsh was 266 mites (see Table 2 and Figure 5). In 2018, total mite abundance in Point Rosa marsh was 26 mites while 218 was seen in Lake St. Clair and the North Marsh. In 2019 there was a total of 128 mites recovered from Point Rosa marsh while Lake St. Clair and North Marsh had 205. For data from dates that cover 2 sites the sampling was split evenly between the adjoining sites and was reported as one date.

Table 1 Number of specimens and genera of water mites from all sites in Point Rosa Marsh.

Genera[1]	18 Oct. 2017 (1&2)	19 Oct. 2017 (4)	19 Oct. 2017b (3)	7 Aug. 2018 (1&2)	21 Aug. 2018 (1&2)	24 Aug. 2018 (1&2)	23 Aug. 2019 (1&2)	16 Sept. 2019 (1&2)	17 Oct. 2019 (1&2)
Arrenurus	1					7	30	30	12
Piona	1					2			
Limnesia						9	4	11	15
Oxus			1			2	8	4	1
Unionicola							1	1	1
Hydrochoreutes						2	1		
Lebertia								1	
Hygrobates					1			1	
Neumania								3	
Hydrachna									1
Koenikea		1	1						

[1]Undetermined mites numbered 6.

Historical water mite assemblages of Lake St. Clair compared to present day

We compared the assemblage of water mites collected from Lake St. Clair to previous historical studies of assemblages of water mites from Lake St. Clair. In Table 3 we compared the results from Reighard (1894), Modlin and Gannon (1973) and Hudson *et al.* (1986) to our present-day

Table 2 Number of specimens and genera of water mites from all sites surrounding Point Rosa Marsh including Lake St. Clair.

Genera[1]	18 Oct. 2017 (B)	20 Oct. 2017 (A)	20 Oct. 2017b (B)	27 Oct. 2017 (D&C)	7 Aug. 2018 (A)	21 Aug. 2018 (A)	31 Aug. 2018 (D&C)	16 Sept. 2019 (A)	23 Sept. 2019 (A)	17 Oct. 2019 (A)	24 Oct. 2019 (D&C)
Lebertia			36	2				8	9	70	
Hygrobates			166	1	3	5		4	26	28	
Limnesia		1		1			7	2	1		
Mideopsis								1		1	
Forelia									1		
Neumania						4			2		
Oxus	1		2						4		
Albia							1		1		
Hydrochoreutes			1								
Piona						1				1	
Arrenurus				37			193				42
Koenikea							1				
Unionicola											1

[1]Undetermined mites numbered 24.

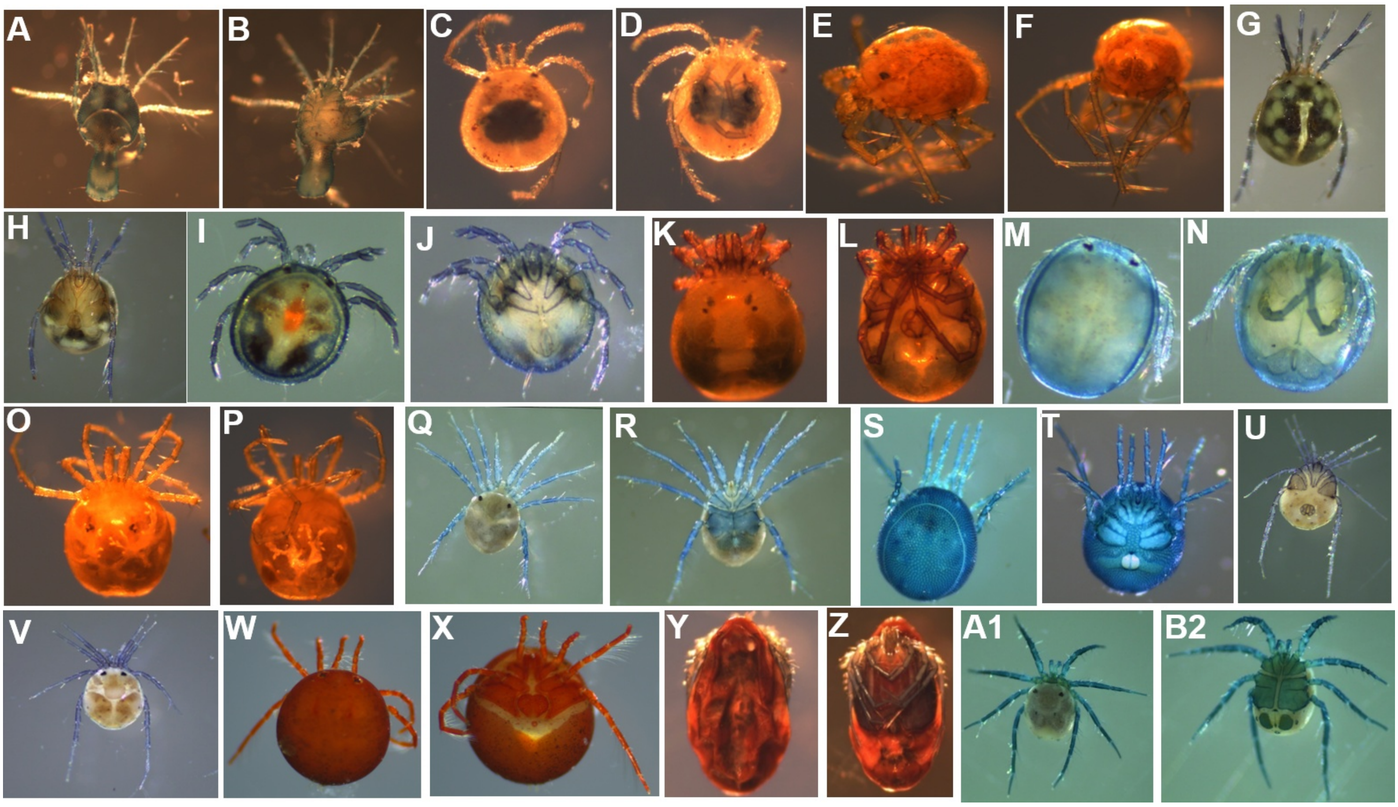

Figure 3 Micrographs of water mites from St. Clair Metropark. Images depict both dorsal and ventral side with the dorsal aspect presented first except where otherwise noted. (A-B) *Arrenurus* (male), (C-D) *Koenikea*, (E-F) *Unionicola*, (G-H) *Lebertia*, (I-J) *Mideopsis*, (K-L) *Limnesia*, (M-N) *Albia*, (O-P) *Hygrobates*, (Q-R) *Piona*, (S-T) *Arrenurus* (female), (U-V) *Hygrobates* (ventral aspect first), (W-X) *Hydrachna*, (Y-Z) *Oxus*, and (A1-B2) *Neumania*.

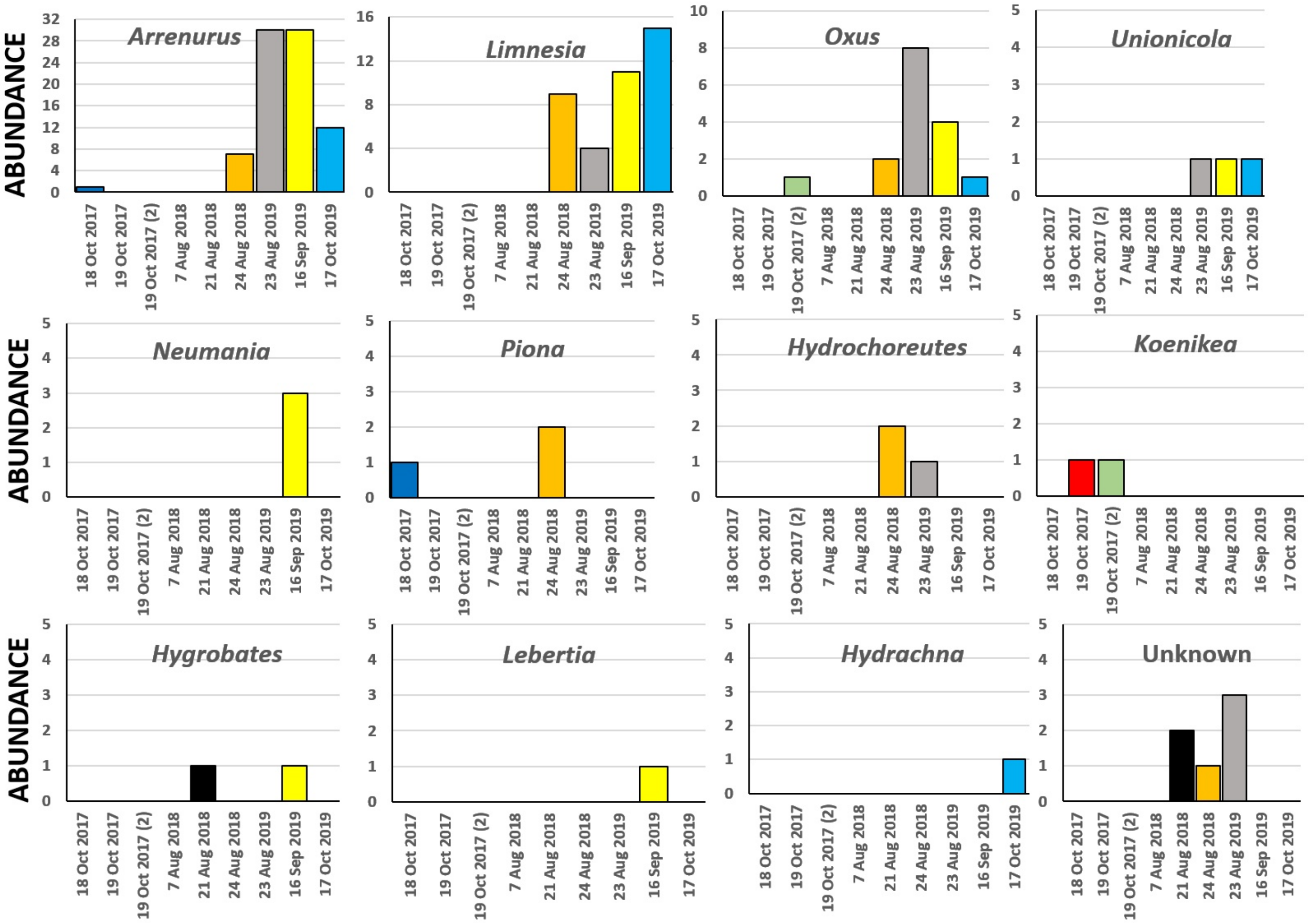

Figure 4 Frequency of water mite genera collected in Point Rosa Marsh. Comparable samples were collected on nine collection dates during 2017, 2018 and 2019. Graphs are arranged (left to right, and then by row) in the order of the overall frequency of each genus. Each bar graph shows the number of taxa collected on the six collection dates with bars color-coded to assist in comparing graphs on various dates. Dark blue (1&2) [Oct. 18 2017], red (4) [Oct. 19 2017], light green (3) [Oct. 18 2017 (2)], no data (1&2) [Aug. 7 2018], black (1&2) [Aug. 21 2018], orange (1&2) [Aug. 24 2018], grey (1&2) [Aug. 23 2019], yellow (1&2) [Sept. 16 2019] and light blue (1&2) [Oct. 17 2019].

work. While Modlin and Gannon (1973) only reported species of *Limnesia* in Lake St Clair, Hudson *et al.* (1986) only reported the instance of a single "Acari" in the same area in 1986. However, Reighard (1894) collected up to 1,369 specimens of water mites in 1893 in Lake St. Clair. This comprised 18 genera and 36 species with possibly others (Reighard 1894). In Table 4 we have shown the taxa reported in 1893, 1973, 1986 and our present work. Our present work from 2017 to 2019 had a gradual increase in genera seen at both sites.

Discussion

We investigated the potential use of water mites as bioindicators of environmental health of an imperiled marsh adjacent to Lake St. Clair and of the nearshore habitats of Lake St. Clair. This study contributes (1) water mite abundance and diversity assessed for the first time in Point Rosa Marsh, (2) updated water mite abundance and diversity found in Lake St. Clair, (3) and evidence of increased water mite abundance in Point Rosa Marsh which suggests ongoing changes in the habitat that may allow water mite populations to thrive.

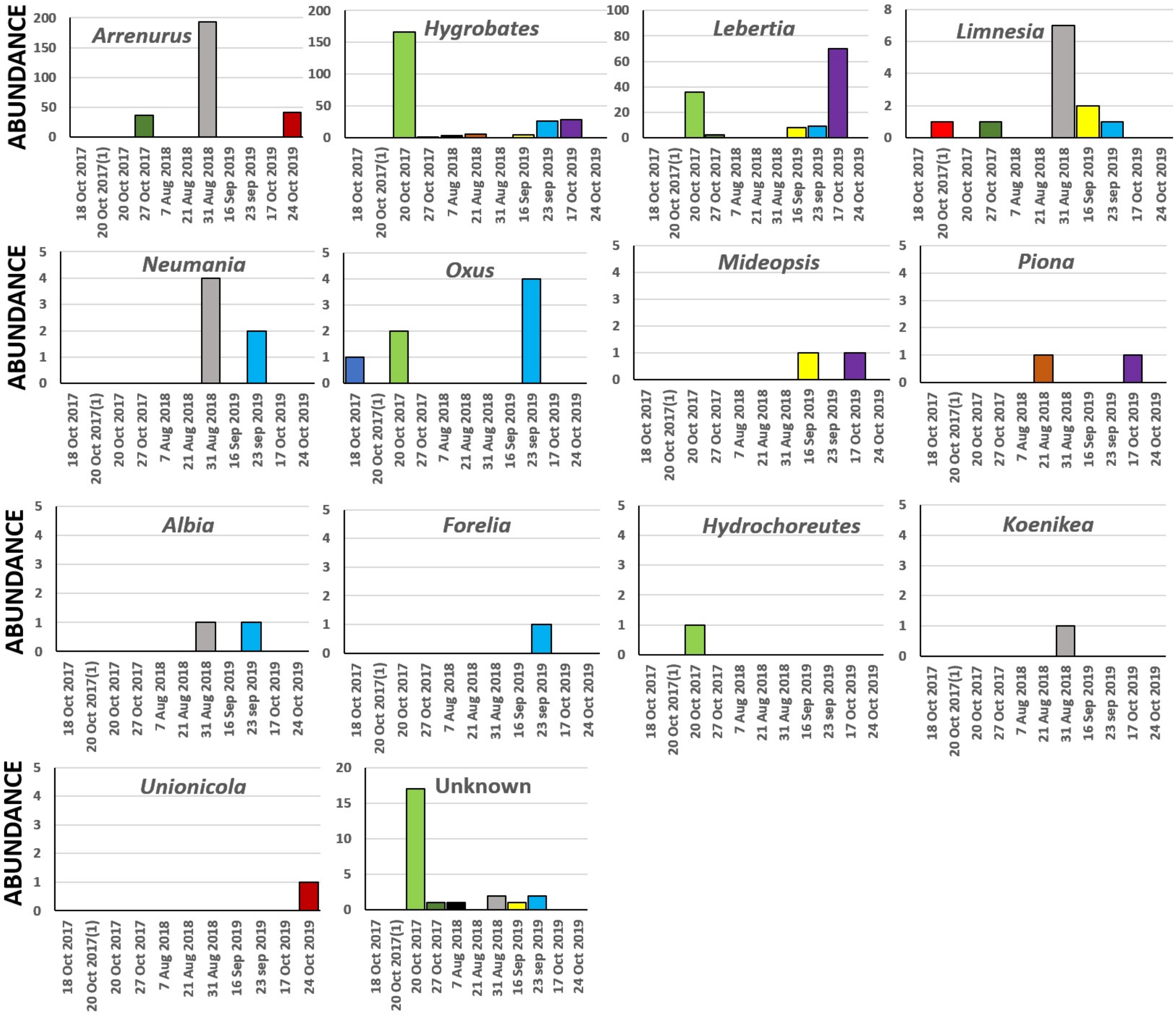

Figure 5 Frequency of water mite genera collected from habitats surrounding Point Rosa Marsh including Lake St. Clair. Comparable samples were collected on ten collection dates during 2017, 2018 and 2019. Graphs are arranged (left to right, and then by row) in the order of the overall frequency of each genus. Each bar graph shows the number of taxa collected on the six collection dates with bars color-coded to assist in comparing graphs on various dates. Dark blue (B) [Oct. 18 2017], red (A) [Oct. 20 2017 (1)], light green (B) [Oct. 20 2017], dark green (D&C) [Oct. 27 2017], black (A) [Aug. 7 2018], orange (A) [Aug. 21 2018], grey (D&C) [Aug. 31 2018], yellow (A) [Sept. 16 2019], light blue (A) [Sept. 23 2019], purple (A) [Oct. 17 2019] and red (D&C) [Oct. 24 2019].

Recently, the use of water mites as bioindicators has been investigated in Europe and Central America (Miccoli *et al.* 2013; Wiecek *et al.* 2013; Goldschmidt *et al.* 2016). There has been a long history of water mite research that has shown that they are important indicators of aquatic environmental health with an exhaustive review on the topic by Goldschmidt (2016). However, to our knowledge, use of water mites as bioindicators is lacking, and research in this area is deficient and there is no scientific justification for this except that it might be cultural (Proctor *et al.* 2015; Goldschmidt 2016). We have conducted research with water mites in the Laurentian Great Lakes ecosystem and have shown their high biodiversity, diet diversity and valuable ecosystem services contribution as mosquito larvae predators (Vasquez *et al.* 2017; Vasquez *et al.* 2020a; Vasquez *et al.* 2020b; Vasquez *et al.* 2021b; Vasquez *et al.* 2022). Now we show their use as bioindicators in the Laurentian Great Lakes ecosystems.

Previous use of water mites as bioindicators was done by studying their assemblages. Kowalik and Biesiadka (1981) studied water mite assemblages in a polluted river and characterized mites that were found in polluted and cleaner sections of the river. Amongst the many taxa encountered, *Hygrobates* and *Lebertia* were found in polluted sections of the river. This is consistent with our studies in the highly disturbed Lake St. Clair where the mites with greatest abundance were *Lebertia* and *Hygrobates*. Our own work in the Detroit River (Blue Heron Lagoon) showed that *Arrenurus*, *Neumania* and *Lebertia* were amongst the most abundant taxa (Vasquez *et al.* 2020a). On a scale of 0-5, where 5 is most tolerant to organic wastes, *Hygrobates* is considered highly tolerant to organic wastes (category 4) (Klemm *et al.* 1990). This indicates that *Hygrobates*, one of the most abundant mites in Lake St. Clair, suggests a habitat that might have organic wastes limiting diversity and abundance of other more sensitive water mites.

The work by Modlin and Gannon (1973), done over 45 years ago in Lake St. Clair, was the only recent work where they reported one genus: *Limnesia*. In a 1986 study encompassing the St. Clair River-Lake St. Clair-Detroit River corridor, Hudson *et al.* (1986) only found 1 "Acari" in a study of macroinvertebrates. Our current study, from the nearshore region of Lake St. Clair, found up to 14 genera (see Table 3). A study from over 100 years ago by Reighard (1894), found 18 genera in Lake St. Clair which could mean that the lake was previously rich in mite fauna but later became less suitable for mites and is now rebounding. The results of our work could mean improving habitat. In addition to *Limnesia*, we found *Lebertia*, *Hygrobates*, *Mideopsis*, *Forelia, Neumania*, *Oxus*, *Albia*, *Hydrochoreutes* and *Piona* in Lake St. Clair. During the mid-20th century, Lake St. Clair had been negatively impacted by surrounding channels that are currently listed as Areas of Concern and these include the St. Clair River, the Clinton River and the Detroit River (Baustian *et al.* 2014). The unchecked pollution that occurred within the Laurentian Great Lakes triggered the establishment of several regulatory boards and major policies in the border nations of Canada and USA (Hartig *et al.* 2020). These include the Canada Water Act of 1970 and US National Environmental Policy Act of 1970 (Hartig *et al.* 2020). Our work found several more genera than the work of Modlin and Gannon (1973) which was only a few years after active restoration of the lakes, therefore, the increase of water mites in our study could be a result of positive environmental interventions that are improving the water quality of the lake. Reighard (1894) found up to 18 genera in Lake St. Clair in 1893 but this was before major industrialization took over that contributed to poor water quality in the earlier part of the twentieth century.

The changes of water mite diversity could also be the result of benthic changes that Lake St. Clair has undergone due to the invasion of *Dreissenid* mussels back in the late 80s and early 90s (Baustian *et al.* 2020). Recent studies on the phytoplankton of the Detroit River, which receives most of its water from Lake St Clair, has shown that historical phytoplankton assemblages has shifted when present day data was compared to pre-1980s data which suggests changes in the trophic structure of the lake that would affect predatory invertebrates like water mites (Vasquez *et al.* 2021a). Hudson *et al.* (1986), who sampled shortly after Modlin and Gannon (1973), found only one "Acari" in Lake St. Clair. It is also possible that the sieve size Modlin and Gannon (1973) used (565 µm) and Hudson *et al.* (1986) used (650 um) are larger than the 250 µm sieve size that was used in this study which may have impacted their collections of water mites. Reighard (1894) used a toothed dredge and screened with a Birge net which might have been a better way to collect water mites. However, water mites have traditionally been ignored in macroinvertebrate studies which has prompted us to work on these important aquatic arachnids.

In Point Rosa marsh, water mite abundance and diversity increased from only 5 specimens (representing 3 genera) collected in 2017, 26 specimens (7 genera) in 2018 and 128 specimens (10 genera) in 2019. The increase in diversity and abundance of mites in Point Rosa marsh could be an indication of improving marsh habitat for water mites. This was supported by water chemistry data obtained for Point Rosa Marsh and Lake St. Clair (see Supplemental Table 1). In particular, dissolved oxygen (DO) was markedly different in the lake compared to the marsh with the marsh having a DO of 1% and lake 111% on a reading during the summer of 2018. In 2019 the DO of the marsh showed potential improvement having a DO of 49% compared to 43% in a reading taken from the lake. Even so the DO was considered poor in 2019 by the Clinton River Watershed Council and an overall Water Quality Index for Point Rosa Marsh was good to fair (pers. comm., Eric Diesing, Chief Watershed Ecologist). Water mites are known to prefer well oxygenated and clean water.

Better oxygenated and cleaner water could have entered Point Rosa Marsh after 2017, since the marsh channel was blocked with debris at the start of our project with low water level and no flow from Lake St. Clair into the marsh (pers observation) (see Figure 2). However, unprecedented high water levels from Lake St. Clair during the 2018, and 2019 seasons resulted in debris being washed away from the entrance of the marsh leading to increased water flow and water level in the marsh (see Figure 2) (Theuerkauf and Braun 2021). The sudden increase in abundance and diversity of water mites in Point Rosa marsh that we observed could be due to improved aquatic habitat due to the high-water levels entering the marsh (Mlive 2020). While the park is surrounded by residential housing, where precipitation events result in stormwater entering the marsh, the major hydrological feature that controls the water level in the marsh is the water level of Lake St. Clair. The water level directly impacts the water level in Point Rosa marsh because the marsh is found along the edge of the lake and directly connected to it. Although winter and summer are the major seasons that influence lake level, with small rises in water levels due to the snowmelt, rain and reduced evaporation, the water level of Lake St. Clair for our study years was during unprecedented high lake levels (Theuerkauf and Braun, 2021).

Herbicide spraying for *Phragmites* has also been routinely done in the marsh during the 2017-2019 seasons which could be detrimental to water mite survival (Metroparks 2015). *Hydrachna* with biocides showed high toxicity with chlorinated hydrocarbons and less with organophosphate but it is unclear what type of herbicide was used in Point Rosa Marsh (Nair 1981). It is possible that the herbicide was not flushed out of the marsh during 2017 when the channel was blocked with debris. However, the rising water level flow from Lake St. Clair in the years 2018 and 2019 could have flushed out the herbicide.

The high-water levels might have brought in new water mite adults or deutonymphs. The typical water mite life cycle includes an adult phase and a parasitic larval stage (Proctor *et al.* 2015). There are several calyptostatic (inactive) stages called protonymph and tritonymph (Proctor *et al.* 2015). However, water mites are more likely to have arrived as adults and deutonymphs in the rushing in of water or by detaching from flying hosts and landing in nutrient rich water that was brought in from the lake due to high water levels. Hurricanes, which are destructive storms that develop in the tropics, have been shown to have a positive effect on mangrove marsh habitats bringing in nutrients due to the flooding and high surges (Castaneda-Moya *et al.* 2020). This could be a similar case in Lake St Clair nearshore habitats which were made more suitable for water mites due to flooding events. It is possible that Point Rosa marsh depends on a temporal and spatial disturbance such as increased water levels to maintain biodiversity and health of its aquatic habitat. In the Blue Heron Lagoon, found in the Detroit River, an intermediate disturbance, like a flooding event in Point Rosa marsh, resulted in a seasonal shift in the biodiversity of water mites (Vasquez *et al.* 2020a).

As anthropogenic influenced changes to freshwater bodies increase, the use of water mites as bioindicators could prove beneficial. While this work was being conducted, several new taxonomic keys were published including the comprehensive work of Smit (2020) and Goldschmidt and Ramirez Sanchez (2020) which will greatly help future water mite workers in the area of bioindicator studies. New types of pollution are making their way into aquatic habitats and knowledge of water mite sensitivity to these specific pollutants could be used to monitor these environments. Given the importance and increasing degradation of freshwater habitats, water mites represent an important bioindicator organism that can be used to identify specific abiotic and biotic causes of environmental degradation.

The results of our use of water mites as bioindicators of aquatic health of Point Rosa marsh and Lake St. Clair nearshore habitats demonstrated an increase in abundance and diversity of water mites. This was not only shown by the gradual increase in abundance and diversity of water mites in Point Rosa marsh but also from our comparison with historical data from Lake St. Clair. It suggests that the habitats might have become better suited for water mites and that unusual high-water levels may have had an impact.

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Supplemental material

Supplemental material is available here https://doi.org/10.24349/2m5p-c5ku.

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