Trends in 100 Years of Macrophyte Data for Green Lake, Wisconsin

Dr. Robert Pillsbury and Anthony Budrick
University of Wisconsin-Oshkosh

September 2022

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This report was prepared for and edited by the Green Lake Association and sponsored by Mary Jane Bumby.

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Dedication: Mary Jane Bumby—A Life in Service and Science

In 1971, Mary Jane Bumby began her first survey of the Aquatic Plants of Green Lake as part of her Master's thesis (Bumby, 1972). Her intent was to just compare her work with Rickett's (1924) plant study.

But somewhere along the line, the health of Green Lake became a passion for her. Every 10 year afterwards, (1971-2001) she organized a massive effort to repeat the plant surveys.

In 2014, the Green Lake Association contacted me to see if I could help Mary Jane with future surveys. At that point I was involved with teaching Ecology during the summers at the University of Michigan's Biological Station and so I could not assist directly with the surveys, but I did have a master's student (Ben Murphy) who needed a project.

Mary Jane invited Ben and me to her home on Green Lake to discuss continuing the long-term plant survey project. Mary Jane was not only very generous with her time but was also very knowledgeable about many aspects of Green Lake. She often took us out in her boat to show us various sampling sites, and graciously shared all her data (stored on floppy discs) from past surveys. She also showed me the copious amounts of other data on Green Lake that she had amassed over the years. Most notable was her meticulous work she had done with the phytoplankton and zooplankton communities she had collected monthly with her own plankton net and analyzed using her own microscope. It was very clear to me that she cared deeply about the health of the lake.

In 2021, one hundred years after the first plant survey, we were once again contacted by the Green Lake Association. This time Mary Jane offered to financially support the work to make sure it was completed during this auspicious year. Another of my grad students, Anthony Budrick, agreed to coordinate the field work.

Modern science often seems like a race to get funding, find something new, publish the results as quickly as possible, and then seek more funding for the next project. Careers are often measured in the number of publications someone has authored (publish or perish syndrome). Therefore, it is increasingly rare to find studies that span more than 5 years (Kuebbing et al., 2018 and Turner et al., 2003). Detailed data sets for lakes that span more than 20 years are exceedingly rare and those over 100 years are nearly unheard of.

This emphasis on shorter studies can often lead to erroneous conclusions. This is because many ecological processes simply take time for researchers to see important trends rather than short-term noise inherent in many systems. Longer-term studies, especially in the wake of processes such as climate change or pollution on larger systems, are becoming much more important.

It is only by the dedication and foresight brought to bear by people like Mary Jane that any such studies exist at all. I would personally like to thank Mary Jane Bumby for her efforts on monitoring Green Lake. As such, we dedicate this publication to her.

Acknowledgements

Long-term studies depend on a lot of people and this study relied on many volunteers. As much as possible we wanted to acknowledge the numerous folks involved over this one-hundred-year project. Of course, we want to specifically acknowledge Mary Jane Bumby who, without her constant leadership and vision, this project would not have been possible.

As extensive the following list is, it is regrettable that not all volunteers that have assisted over the years are included or, if included, is their full name known. Also, whenever possible we have listed the people that helped with more specialized tasks such as Scuba divers, Boat drivers (and likely boat owners) and depth finders.

Initial Study: 1921

All assistance listed here come from Rickett (1924):

Collections:
Dr Juday
L.E. Noland

For assistance with taxonomy:
Dr. E.A. Baird
Dr. R.H. Denniston
Dr. G.M. Smith
Dr. G.E. Nichols

From 1971-2001

Mary Jane Bumby organized these efforts during this time and was especially good at listing volunteers and the roles they played:

Year	Zone	Volunteers	SCUBA	Boats	Depth finder
1971	1	Mary Jane Bumby			
1971	1	Margaret Summerfield		Mary Jane Bumby	
1971	1	Everett Fee			
1971	2	Mary Jane Bumby			
1971	2	Margaret Summerfield			
1971	2	Everett Fee			
1971	3	Mary Jane Bumby	E. Curtis Rodgers	E.B. Boston	Larry Miller
1971	3	Margaret Summerfield		Art Carter	
1971	3	Everett Fee		David Carter	
1971	3	Nancy Vieth		Nancy Carter	
1971	3	Nancy Vieth		Jane Carter	
1971	3	Nancy Vieth		E. O'Conner	
1981	1	Mary Jane Bumby		Mary Jane Bumby	
1981	1	Steve Carpenter			
1981	1	Lois Carver			
1981	1	Christopher Cody			
1981	1	Philip Cody			
1981	1	Elizabeth Harrington			
1981	1	Bill Harrington			

Year	Zone	Volunteers	SCUBA	Boats	Depth finder
1981	1	Tom Harrington			
1981	1	David Retzinger			
1981	1	Scott Rysden			
1981	1	David Swanson			
1981	2	Mary Jane Bumby		Mary Jane Bumby	
1981	2	Steve Carpenter			
1981	2	Lois Carver			
1981	2	Christopher Cody			
1981	2	Philip Cody			
1981	2	Elizabeth Harrington			
1981	2	Bill Harrington			
1981	2	Tom Harrington			
1981	2	David Retzinger			
1981	2	Scott Rysden			
1981	2	David Swanson			
1981	3	Mary Jane Bumby	Diane Meredith	James Meredith	James Meredith
1981	3	M. Summerfield			
1981	3	David Retzinger			
1981	3	Virginia Retzinger			
1991	1	Mary Jane Bumby		Mary Jane Bumby	
1991	1	Heidi Pucker			
1991	1	Loraine Abbott			
1991	1	Virginia Carpenter			
1991	1	Carla Goode			
1991	1	Malcolm Gross			
1991	1	Karin Serra			
1991	2	Mary Jane Bumby		Mary Jane Bumby	
1991	2	Heidi Pucker			
1991	2	Loraine Abbott			
1991	2	Virginia Carpenter			
1991	2	Carla Goode			
1991	2	Malcolm Gross			
1991	2	Karin Serra			
1991	3	Mary Jane Bumby	Christopher J. Rauch	Harold Runkelmann	Harold Runkelmann
1991	3	Heidi Pucker			
2001	1	Mary Jane Bumby		Mary Jane Bumby	
2001	1	Scott Seltzner			
2001	1	Chad Ziesmer			
2001	2	Mary Jane Bumby		Mary Jane Bumby	
2001	2	Scott Seltzner			
2001	2	Chad Ziesmer			

Year	Zone	Volunteers	SCUBA	Boats	Depth finder
2001	3	Mary Jane Bumby	Christopher J. Rauch	Harold Runkelmann	Harold Runkelmann
2001	3	Scott Seltzner			
2001	3	Chad Ziesmer			

2014

At this point, Benjamin Murphy and I took over this effort. Since Mr. Murphy has left my lab and I have lost contact with him. Therefore, I have no information on the various folks who assisted this year.

Mary Jane Bumby-Boat driver
Stephanie Prellwitz, Green Lake Association

2021

In this sampling year, my graduate student Anthony Budrick agreed to conduct the survey.

Boat drivers:
Kent DeLucenay
Ron Aplin
Tess Maier

Divers:
Shawn Richeson
Don Betler
Kory Anderson

Jennifer Fjelsted, Green Lake Association

Introduction

Background of Study

H.W. Rickett completed a survey of the macrophytes of Green Lake in 1921 for the Geological and Natural History Survey (Rickett, 1924). His survey included information on the distribution of aquatic plants and their depth in the lake.

Fifty years later, in 1971, Mary Jane Bumby followed up with another survey of the Green Lake macrophyte community (Bumby 1977). She modeled her study after Rickett's work, but also collected data on the abundance of filamentous algae in the lake. In general, she observed an overall decrease in total macrophyte biomass compared to 1921. The deepest area observed, Zone 3 (3-10m), experienced the largest decrease in total biomass, followed by Zone 2 (1-3m) and then Zone 1 (0.5-1m). Mary Jane continued conducting comparative surveys of Green Lake macrophytes in 1981, 1991, 2001, and 2011. These last four surveys of Bumby's collections formed a large, previously unpublished data set that she graciously allowed us to access and analyze to contribute to the historical record of this lake.

In 2014, our lab at the University of Wisconsin-Oshkosh was asked to help with repeating a similar study to continue the data set. My graduate student. Benjamin Murphy, and I met with Bumby several times to establish a sampling protocol before conducting this survey. After that, Ben led that year's survey efforts.

In 2021—100 years after Rickett's initial study—the Green Lake Association contracted our lab to conduct another survey once again. This time, the survey was headed up by another one of my graduate students (Anthony Budrick).

The purpose of all of these studies was to follow up the work of Rickett and Bumby to further document changes in Green Lake's littoral zone macrophyte community. With most research studies only spanning at most five years or less, **it should be stressed how rare long-term studies like this are**.

We hope that this research will continue to be tracked at least once a decade and that these records can give insight for the best suited lake management practices in the future.

Uniqueness of the Lake

Green Lake resides in Green Lake County, Wisconsin (Figure 1). It has a surface area of 7,920 acres and, with a maximum depth of 236 feet, is Wisconsin's deepest natural inland lake. Formed by glaciers, the lake was considered oligotrophic—having low amount of nutrients—for much of its history (Johnson, 2021).

European settlement began in its watershed around the early-mid 1800s. Over the years, much of the watershed was cleared for agriculture (Garrison 2002). This large lake also became a tourist destination with many hotels and resorts. Today, much of the shoreline has been developed with many large lake homes. The lake is currently considered mesotrophic—having a medium amount of nutrients—due to the anthropogenic nutrient additions.

The lake has eight tributaries (Wuerches Creek, Roy Creek, Spring Creek, Hill Creek, White Creek, Dakin Creek, Silver Creek, and Assembly Creek) that flow into it. It is part of the larger Fox River watershed, with water leaving the lake via a single outlet, the Puchyan River.

Study Goals

Our goals for this study were to:

1. Update the taxonomy for the various surveys on aquatic plants done over the last 100 years.
2. Search for meaningful trends in the community composition over time.
3. Apply these changes to a framework of recent nutrient studies conducted on Green Lake.

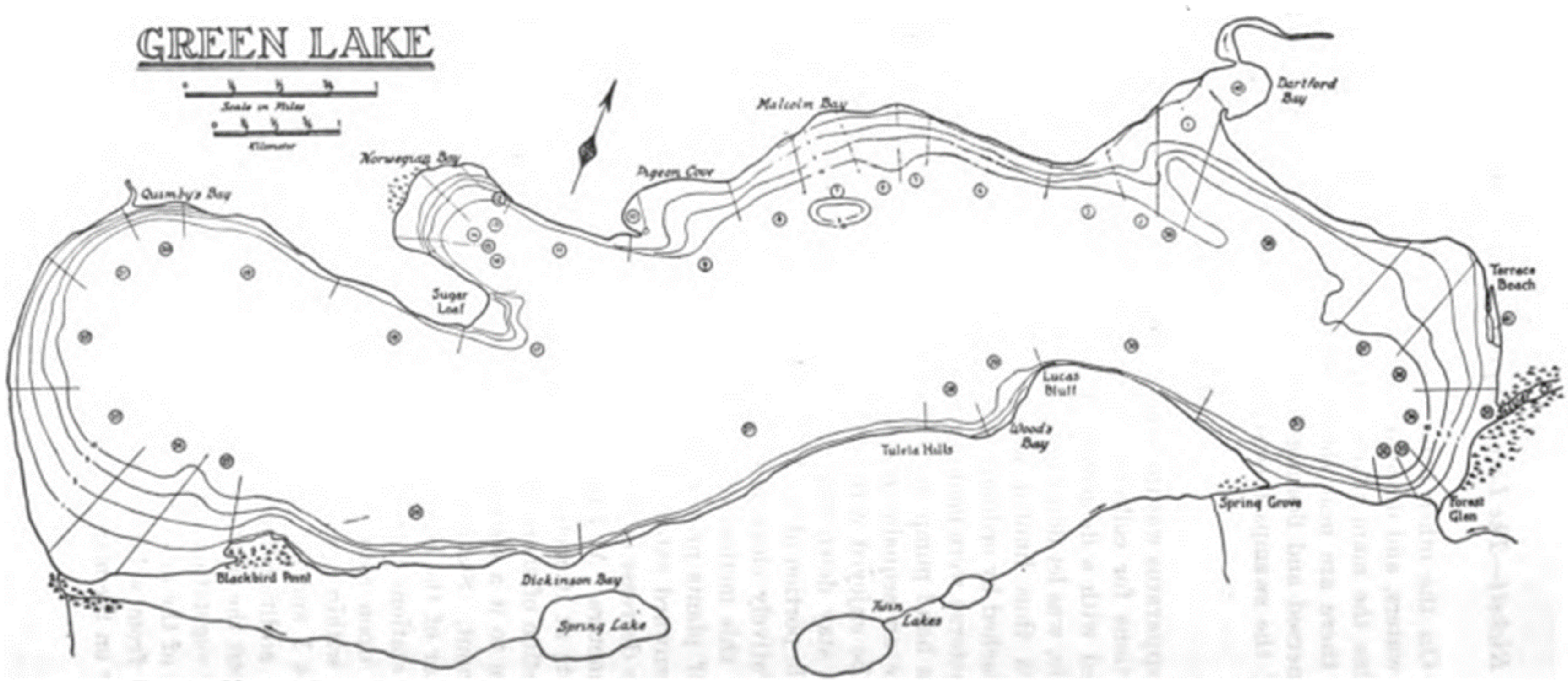

FIG. 4. Map of Green Lake showing 1, 3, 5, and 10 meter contour lines and the 41 stations from which plants were collected.

Figure 1. Map from Rickett (1924) showing the locations of the original 1921 plant survey, including the original figure numbering.

Methods

In the spring of 2021, we were approached by the Green Lake Association to conduct a survey of the aquatic plants of Green Lake in a way that would be directly comparable to previous studies—including past surveys conducted by my lab in 2014, by Mary Jane Bumby (1971, 1981, 1991, and 2001), and by the original survey (1921) by Rickett.

Typically, thirty sites across the perimeter of Green Lake were sampled during mid-late summer. The sites were placed into three zones defined by depth (Zone 1 = 0.5-1m depth, Zone 2 = 1-3m depth, and Zone 3 = 3-10m depth) with generally ten sites per zone. For each site, three to four quadrants (0.5m x 0.5m) were randomly placed within the appropriate depth for the location's zone and all plant matter was collected, sorted, identified, and weighed (wet weight).

General Approach

We attempted the daunting task of trying to make sense of aquatic plant data taken over a span of 100 years. During this time, there has been many changes in plant taxonomy, as well as several different teams of researchers doing the survey.

In addition, we also have to take into account the natural variation inherent in the system. Therefore, we have decided to examine the data broadly in hopes of avoiding some of the random noise generated within different sites.

Therefore, we are only presenting data averaged across sites of similar depths from the whole lake.

Sample Locations

In 1921, Rickett (1924) sampled plants from 41 locations or "stations" (Figure 1) which circumvent the lake (including three marshy bay sites). At each station, three zones were sampled.

1. **Zone 1** ranged in depth from 0.5 to 1.0m. Within each station for Zone 1 samples were taken at three different "anchorages." To sample the macrophytes at their peak seasonal biomass, all Zone 1 stations were sampled first in the season, since these plants tended to flower earlier (Rickett [1924] considered this important to finding plants at peak biomass) compared to deeper zones.

2. **Zone 2** (1-3m depth) was also sampled at three random "anchorages" from each station. All Zone 2 locations were sampled before Zone 3 sites since it was thought that peak plant biomass occurred in Zone 2 before Zone 3 (since these sites received a medium amount of light).

3. **Zone 3** (3-10 m depth) was sampled after Zones 1 and 2 were completed. By this time, the sampling crew was facing the end of the season (Rickett [1924], although Rickett gave no sampling dates) and divers needed to be used. Sites at Zone 3 were only sampled once utilizing a site representing the area (Rickett 1924). Rickett (1924) described these divers using a "divine hood" whose air supply came from a "hand pump" on the boat. This allowed the divers to stay down for only "15 to 20 minutes at a time."

In subsequent efforts (1971 onward), Bumby chose a subset of the original 41 locations to sample (Table 1). For each zone, she chose ten locations—picked by examining the five highest plus the five lowest for total plant biomass. This resulted in a situation where, for instance, Zone 1 sites were not always sampled for Zone 2 or 3. This process also likely selected a combination from each zone that would produce a high amount of variability.

Sampling Methods

Rickett Study

Rickett (1924) was vague when describing his sampling methods, stating only that multiple samples were taken for Zones 1 and 2. For Zone 3—since Rickett observed that plant distribution was more homogenous at this depth—only one collection was typically made per station. Not all locations were sampled for Zone 3, which resulted in some locations serving as estimates for adjacent locations as well.

A total of 221 plant collections were made. For each collection, a 0.25 m^2 square quadrant was (presumably) randomly placed on the sediment and all plants were harvested (including roots). Plant material was then sorted by species. Both wet and dry weight were determined, and an average of these collections were reported for each common species found for each zone within each station.

In this 1921 survey, filamentous algae was not collected and its biomass was not therefore not determined. This was due to Rickett not believing filamentous algae to be an important component of plant biomass during this survey. He did compare this "lack of *Cladophora*" (a filamentous green alga typically found in mid-western lakes) in Green Lake worthy of note, since during a previous macrophyte study of Lake Mendota, Wisconsin, that lake was deemed to have significant amounts of it. No dates for any sampling times were provided.

Bumby Study

In 1971-2001, Bumby (1977) attempted to replicate Rickett's methods based on the limited amount of information he supplied.

However, Bumby's methods did differ in the following ways:

1. Bumby did collect and quantify filamentous green algae (identified as *Cladophora* by Bumby).

2. Bumby did attempt to identify, separate, and quantify rarer macrophytes.

3. SCUBA divers were employed for Zone 3 samples.

4. Zone 1 was sampled between July 7-9 (90 transects from 30 locations); Zone 2 was sampled between July 16-30 (90 transects from 30 locations); Zone 3 was sampled between August 7-8 (30 transects from 30 locations).

Pillsbury Study

In 2014-2021, Murphy and Pillsbury attempted to accurately compare the 2014 survey to those previously collected by using the sample sites as Bumby (1977). GPS locators were used to navigate to the center of each predefined sample location. A square frame of sand-filled tubing of polyvinyl chloride (PVC) measuring 50 x 50cm was lowered at random into the water at each location. A metered rope was attached to one corner of the quadrat. This aided the divers in locating the quadrat and allowed us to record the exact depth of each sample collected. Samples collected in Zones 1 and 2 were collected in triplicate and averaged together. Data from Zone 3 samples was the product of a single collection. Two SCUBA divers from the Wisconsin DNR aided in the collections of all Zone 3 samples.

After the quadrat was placed on the lake bottom, a diver used a small three-tined hand rake to collect the plants. The rake was dragged through the substrate, always working from top to bottom and repeating this motion from left to right. This allowed the entire area within the quadrat to be passed over just once with the hand rake. Plants were then placed in small mesh bags and carefully transported back to the surface. All plants collected were placed into sealable plastic bags (Ziplock), labeled with the sample site, and stored in a cooler for examination and identification within 48 hours.

Data Collection

Data collection for Rickett (1924) was surprisingly vague. Bumby (1977) tried to follow Rickett as best she could, but simply had to guess about some of the procedures. We followed Bumby's methods as close as possible.

The one exception to this was that we did not attempt to collect dry weight data. Collected plant material was placed into a shallow, square, white sorting pan filled with water. This thin layer of water aided in pulling apart the entangled plant material.

Identification of each species was performed using *Aquatic Plants of the Midwest* (Skawinski 2011) and Aquatic and Wetland Plants of Northeastern North

America: Volumes 1 and 2 (Crow and Hellquist 2000) as primary references.

After sorting, the samples were wrapped in absorbent paper towels to remove excess water (similar to Bumby [1974]). Individual species of filamentous green algae were not identified, but rather lumped together as in previous studies. Paper towels were removed and the samples were weighed using a Mettler/Toledo Classic Light, top-loading, scale, accurate to 0.1 gram.

Data Analysis

Bumby had taken Ricketts' (1924) data and stored it onto floppy discs along with data she collected from 1971-2001. When we were handed this data in 2001, we transferred this data to a hard drive and updated it to a newer version of Excel. All data collected since has also been collected in this format. During 2001-2002, old and new data was "harmonized" to some degree by making sure things like dates and stations were presented in the same way across all files. Taxonomy (the codes used for species ID) were also standardized. The database manager Access was used to organize the files for analysis. The Statistical package R was used for the actual analysis.

Data Analysis Approach

Since Bumby's approach to selecting quadrants from most zones involved selecting the five quadrants with the highest biomass and five quadrants with the lowest biomass (thereby inflating variability estimates), we decided to work with the average values at each location. This would allow a better comparison between our methods and those of Bumby. Also, since we did not have access to decadal changes in the watershed next to each location, we decided to focus on changes across the whole lake.

Taxonomic Consistency

Another problem common to long-term data sets is taxonomic consistency. Over the years taxonomic ideas change for many reasons:

1. Taxonomic authorities change how they very species. For example, a form or variety may later be considered a separate species (or vice versa).

2. Taxonomic authorities may simply not agree on the correct name or even where to place the plant within a taxonomic framework,

3. Over the years, and as the project leaders have switched, it is possible that some plants were misidentified. This could especially be a problem if the plants collected at sub-optimal times (for instance when the plants are not flowering, or not mature, or starting to decay). This can be especially true for groups of plants notoriously hard to identify (such as those in the *Potamogeton* genus).

In response to point 3, we used two different datasets for our analysis. One assumed that all plant identification was correct for the times collected (we named this dataset *"splitters"*). Plant taxa in this case were simply just updated with the current names. This dataset should be most sensitive to changes in community composition or species diversity over time—but it could introduce errors into the analysis by not taking into account any human induced mistakes in plant identification over the years.

Another dataset (which we named *"lumpers"*) was created by assuming mistakes in plant identification over the last 100 years were likely. This was achieved by lumping all similar taxa (for instance, all of the broad leaved *Potamogeton*) into one taxonomic unit. The dataset created using this philosophy is much more conservative for finding any differences in community composition, but any changes that were identified would likely be real. It is hoped that we can reach some meaningful conclusions by examining both datasets. Table 1 details the differences between the two datasets.

In addition, we also decided to analyze the data by including the filamentous green algae (FGA) or not. Since the original survey did not included FGA as a component, data from 1921 cannot be properly compared with the rest of the surveys if it was included. However, we felt that to ignore the presence of FGA would have been wrong, since in many cases it was an important component of the total biomass and could also indicate some environmental conditions.

Therefore, we ultimately ended up with four datasets to analyze: 1) splitter with algae, 2) splitter without algae, 3) lumpers with algae, and 3) lumpers without algae. When algae were included, the surveys for 1921 were not included in the analysis.

Table 1. Species identifiers used for both the "lumper" and "splitter" groups. The lumper group assumed mistakes in plant identification over the last 100 years were likely; the splitter group assumed that all plant identification was correct for the times collected.

Lumper Group	Splitter Group	Code Name
Ceratophyllum demersum	*Ceratophyllum demersum*	Cerdem
Chara sp.	*Chara* sp.	Charas
Elodea canadensis	*Elodea canadensis*	Elocan
Myriophyllum sibiricum	*Myriophyllum sibiricum*	Myrsib
Myriophyllum spicatum	*Myriophyllum spicatum*	Myrspi
Najas flexilis	*Najas flexilis*	Najfle
	Potamogeton crispus	Potcri
	Potamogeton praelongus	Potpra
Potamogeton natans		potbroad
Potamogeton richardsonii	*Potamogeton richardsonii*	Potric
Potamogeton zosteriformis	*Potamogeton zosteriformis*	Potzos
	Ranunculus aquatilis	Ranaqu
	Ranunculus longirostris	Ranlon
Ranunculus sp.		RanTot
Stuckenia pectinate	*Stuckenia pectinate*	Stupec
Vallisneria americana	*Vallisneria americana*	Valame
Zannichellia palustris	*Zannichellia palustris*	Zanpal
Zosterella dubia	*Zosterella dubia*	Zosdub

Results and Discussion

Plant Biomass Dynamics

One overall interest concerning this study was to try to assess water quality and how it has improved or degraded over the last 100 years. To attempt to do this using total biomass, we need to examine the known relationships between aquatic plants, light, and water clarity.

Of course, all plants need light to survive. So, if all situations were equal, except for light, then *clearer* lake water should result in higher plant biomass.

However, plants can also be limited by nutrient availability (mainly phosphorus and nitrogen). This complicates this otherwise simple relationship between light and plants in a few ways. For example, increased nutrients in the water (as opposed to sediments) will cause an increase in planktonic algae which, in turn, can decrease available light and thus limit plant growth.

Filamentous green algae (FGA) also respond to high light conditions. Since this is a single-celled colonial organism, its populations can rapidly increase (and decrease) when conditions are optimal (or sub-optimal). FGA also obtains its nutrients from the water column rather than the sediment, like most macrophytes. This means that, as nutrients enter the lake from the watershed, algae would likely be able to respond *first* since the nutrients first arrive to the lake via the water column.

Total Plant Biomass

Total plant biomass was analyzed two different ways: 1) including filamentous green algae (FGA), and 2) not including FGA (Table 2).

The average total plant biomass is presented in Table 2 (1971 to 2021). For total biomass with algae, 1971 and 2021 had very similar values for both biomass distribution across depth and the sum of biomass from all depths. Both times had relatively low plant biomass with Zone 2 producing most of the biomass. In contrast, 1991 had double the total plant biomass with the majority of the plant mass coming from Zone 3. When plant biomass without algae is examined (Table 2) from 1921-2021, 1991 and 1921 exhibit the highest biomass with most of the biomass found again in Zone 3. The % of algal biomass (for 1971-2021) was fairly large for most of the decades (1971-2014, range = 9-29 % of total biomass) with the highest percentages found in Zone 1. But in 2021 there was relatively much less algae and the greatest amount of it was found in Zone 2 at 4%.

Changes in the Biovolume of Specific Plants

Table 2 lists the biomass of important plants—found greater than 100g in at least one site and also recorded in more than one time period—along the 3 depth zones.

Figure 2 presents comparable data in graph form, and Figure 3 presents the data by species, zone, and biomass.

Photograph 1. Filamentous green algae on Green Lake. Photo provided by the Green Lake Association and not part of study.

Table 2. Mean total plant biomass of Green Lake found across three different depth zones (Zone 1 = 0.5-1.0m depth, Zone 2 = 1-3m depth, and Zone 3 = 3-10 m depth) ranging from 1921 to 2021.

	Year			**Total biomass with algae**			
Zones	**1921**	**1971**	**1981**	**1991**	**2001**	**2014**	**2021**
1	N/A	689	756	689	347	603	820
2	N/A	1,078	1,400	855	423	556	1,307
3	N/A	688	347	4,245	734	275	664
Total (sum of depth zones)	**N/A**	**2,456**	**2,504**	**5,789**	**1,504**	**1,435**	**2,790**

Zones				**Total biomass without algae**			
1	627	164	373	164	143	187	801
2	1,894	980	1,026	788	356	434	1,188
3	2,258	644	285	4,244	718	275	579
Total (sum of depth zones)	**4,780**	**1,789**	**1,684**	**5,196**	**1,218**	**896**	**2,568**

Zones				**% of algae biomass**			
1	N/A	76.2%	50.7%	76.2%	58.8%	69.0%	2.3%
2	N/A	9.1%	26.7%	7.8%	15.8%	21.9%	9.1%
3	N/A	6.4%	17.9%	0.0%	2.2%	0.0%	12.8%
	N/A	**27.2%**	**32.8%**	**10.2%**	**19.0%**	**37.6%**	**8.0%**

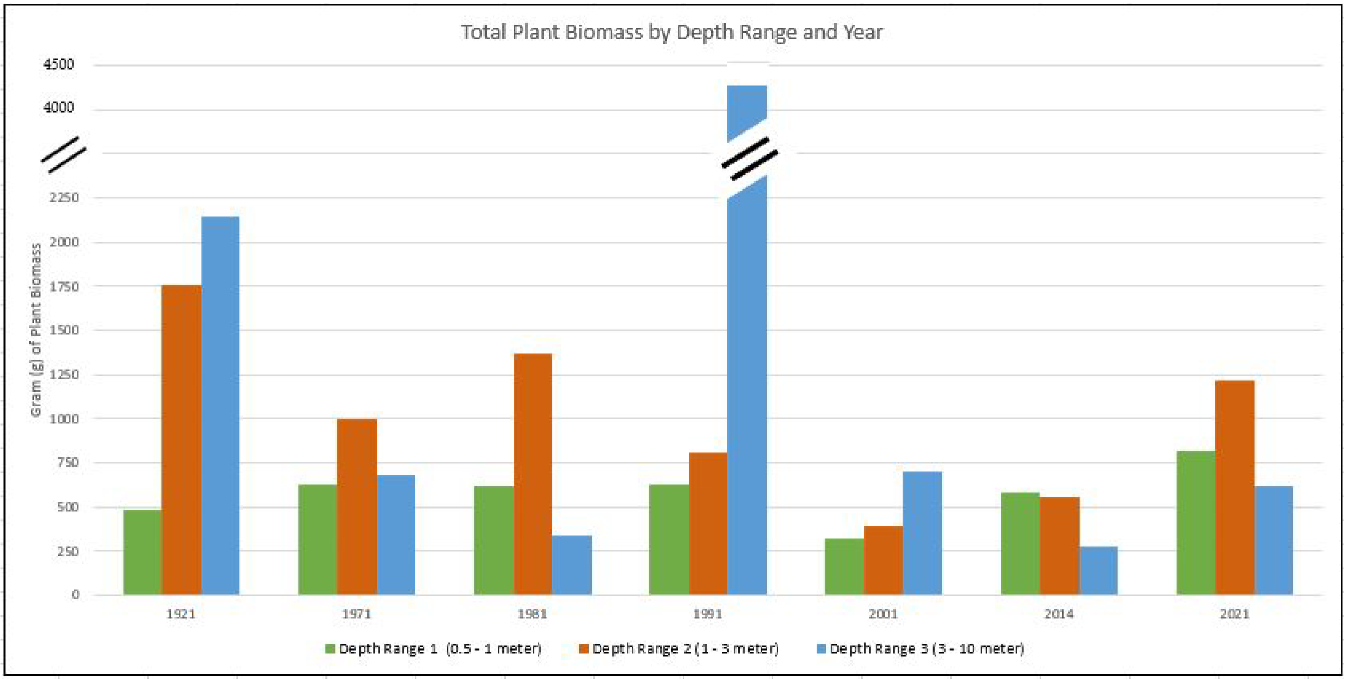

Figure 2. Total plant biomass by year.

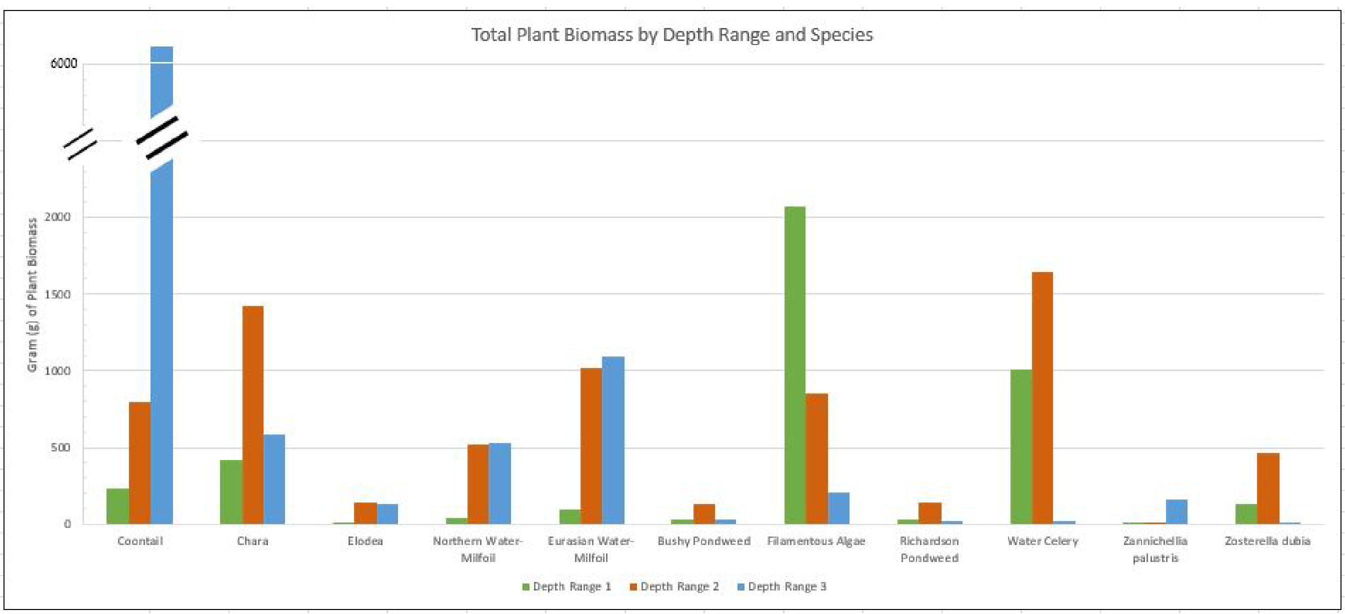

Figure 3. Total plant biomass by species.

Environmental Indicators

There is surprisingly little published about the environmental preferences of specific aquatic plant species in the Midwest region. We found Nichols (1999) to be the best source for this. Nearly all the plants found in Green Lake have a wide range of depths, pH, and conductivity. Since the ranges of these parameters are so wide and greatly overlap with each other, we could not use them reliably as indicators of past environmental trends. However, one potentially useful thing that Nichols (1999) reported for each species was their tolerance of turbidity.

Species that were considered tolerant towards turbid conditions were:

- *Ceratophyllum demersum*
- *Elodea canadensis*
- *Vallisneria americana*
- *Zannichellia palustris*
- *Zosterella dubia*.

Plants (and algae) that were considered not turbidity tolerant were:

- *Myriophyllum sibiricum*
- *Myriophyllum spicatum*
- *Najas flexilis* (Nichols, 1999)
- Filamentous green algae (Pillsbury, personal communication)

The macro alga *Chara* sp. is not, strictly speaking, an aquatic plant, and so Nichols (1999) did not include this taxa. *Potamogeton richardsonii* was considered to have no preference with turbidity (Nichols 1999).

However, we did not see a strong correlation with turbidity preferences and environmental trends noted in the literature. But perhaps this is not surprising since we sampled the lake during times when it was historically most clear (mid-summer and not spring).

Nutrients and Green Lake in Recent Literature

Panuska (1999) considered Green Lake eutrophic during spring sampling, with no significant differences found in phosphorus levels across the lake. Stauffer (1985) also found high levels of phosphorus during spring but concluded that phosphorus concentrations were low (and Secchi transparency was high) in most summers due to sedimentation of this nutrient into the deeper parts of the lake. Stauffer reported that much of the phosphorus remained in the deeper water with only 25% of it being recycled during turnover, thus allowing for high water clarity much of the year.

In fact, based *solely* on water clarity data, Carlson (1977) classified Green Lake as oligotrophic.

Robertson et al. 2022 found Secchi Disc (SD) readings during summers often greater than 6m during the late 60s and early 70s but declining to 3-5m during the late 70s. Green Lake saw a significant increase in SD readings between 1978 and 2020—which may have been aided by the introduction of zebra mussels (Dreissena polymorpha) in 2014.

Garrison (2002) found—by using diatoms as bioindicators and sediment core analysis—that, starting in the 1930s, phosphorus had a tendency to increase, especially in the western end of the lake. This trend continued until it peaked around 1990.

This agrees with Johnson (2021), who studied how phosphorus flowed into the Green Lake watershed for the past several decades. She determined that there was an increase in phosphorus flowing into the watershed system from the 1980s until 2007, due to factors such as agricultural fertilizers, dairy feed supplements, imported manure, wastewater treatment upgrades, and pesticide use. After approximately 2007, there was a net decrease in the input of phosphorus to the watershed system, so that more phosphorus was leaving Green Lake than was going into the system.

This suggests that the macrophytes of Green Lake experienced three different phases since European settlement.

1. **Phase I** would have been pre-settlement to the 1880s. Conditions during this time are predicted to have low nutrients in the water column of Green Lake (due to a largely intact watershed) and low nutrients being deposited in the lake sediments. This

suggests that there was high light availability due to less phytoplankton in the water column and low nutrient availability for aquatic plants due to low deposition rates.

2. **Phase II** (roughly 1880 to 2007) would be characterized by relatively increased nutrient availability in both the water column and sediments due to greater inputs of nutrients from disturbances within the watershed. This meant that there should be more phytoplankton (resulting in less light for aquatic plants) but more nutrients.

3. **Phase III** (2007 till present) started to see a reduction of nutrients into Green Lake due to better agricultural practices and phosphorus abatement plans. This meant that there would be less nutrients available in the water column—and therefore less phytoplankton, resulting in more light. But, since most macrophytes acquire their nutrients from the sediments, nutrient availability for aquatic plants should still be relatively high. This is because it takes much longer for nutrients stored in sediment ("internal loading") to leave the system compared to nutrients in the water column.

The distribution of macrophytes over time and depth supports these three phases.

In the 1921 survey, we found the second highest total for plant biomass (4780g dry weight/m^2)—with Chara sp. providing most of the biomass (especially for Zone 3). The dominance of Chara sp. in deeper water is typical of clear water lakes (Blindow, 1992).

However, this alga's presence was much reduced by 1971 and completely absent in the deeper Zone 3 from 1981- 2014, only showing up in this zone again in 2021 (presumably responding to better light

Photograph 2. Aerial photograph of Green Lake showing some of the agricultural best management practices that play a role in reducing phosphorus loading to Green Lake. Photo provided by the Green Lake Association and taken by Damon Reabe.

conditions at those depths) (Figure 2 and Figure 3).

To a lesser degree, the same basic pattern—of being most abundant in Zone 3 in the earliest and last survey while exhibiting very low numbers in between—can be found with *Elodea canadensis* (Figure 2 and Figure 3). And although the high-light loving, filamentous green algae was not recorded as part of the 1921 survey, the remaining records are also consistent with this trend (Figure 2 and Figure 3). Additional detail can be found in Appendix A.

During Phase II, *Ceratophyllum demersum* and *Myriophyllum spicatum* dominated Zone 3. *C. demersum* peaked in 1991 (3932.5 g/m^2) while *M. spicatum* peaked in 2001 (517.9 g/m^2). *Ceratophyllum demersum* is considered to tolerate turbidity well (Nichols 1999). However, Nichols (1999) also considered *Myriophyllum spicatum* rather intolerant to turbidity, yet had its highest densities along Zone 3 in 2001. *M. spicatum* is an introduced species to the Midwest, which explains why it was not found in the 1921 survey. *M. sibiricum* was common in 1921, but was found in much lower number in subsequent years. This taxa seemed to be to be largely replaced by *M. spicatum* along Zone 3 once it was established, leaving *M. sibiricum* to persist mainly in Zone 2.

For Phase III, (relatively higher light and high sediment nutrients) we see that *Chara* sp., filamentous green algae, and *Elodea canadensis* begin to increase during 2014 and 2021 along Zone 3. We also noted a large increase with *Vallisneria americana* in Zones 1 and 2 in 2021. *Potamogeton richardsonii* and *Zannichellia palustris* also appeared for the first time in the deeper waters of Zone 3 during 2021.

Biplots of Macrophytes

The data was analyzed using Non-Metric Multidimensional Scaling (NMDS) and many different data manipulation techniques—including outlier removal, using actual biomass measurements or relative abundances, including or not including measurements of algal abundances, and using the taxonomically conservative "lumpers" schema compared to the "splitters" schema which took all identification at face value. Appendix A features a series of NMDS biplots.

Photograph 3. Chara sp.

Photograph 4. Elodea canadensis.

Photograph 5. Vallisneria americana

In all cases, we are confident in the biplots presented since a stable solution was always reached with just 2-dimensions and the stress was always under 0.2 (McCune and Grace, 2002).

We are also confident in our interpretation of the data, in spite of some initial concerns mentioned earlier over whether or not to include algae, or whether or not to be taxonomically cautions (lumpers) or to accept species identification "as is" by several different taxonomists over the last century, since the basic patterns seen in the various biplots were very similar.

However, the inclusions of the outlier (143aw) or not did have a large impact on the biplots (Figure 4, Figure 6, Figure 8, and Figure 10). But since we know the reason for the outlier—relative abundance of 1.00 of just one taxa -*Ceratophyllum demersum*— and knowing that its inclusion compressed much of the rest of the information, we will only discuss the biplots where this outlier was not included.

In the biplots, the first axis often seems to correspond with depth and time with deeper (and often older) samples often on one side and being represented by higher amounts of *Ceratophyllum demersum* (Figure 5, Figure 7). While the opposite side of the biplot is characterized by *Vallisneria americana* and *Potamogeton richardsonii* typically found in shallower, more recent samples.

Figure 7 and Figure 9 show that, even if the 1921 samples are included in the analysis, the greatest community shifts are between 1971 and 2021, while the community composition from 1921 are more closely related to those of 2021. These two sampling dates seem to have more *Chara* sp. *Potamogeton zosteriformis*, and *Ranunculus aquatilis* (Figure 9 and Figure 11). This pattern agrees with our interpretation of the three lake phases discussed in a previous section. In Figure 15 (with 1921 removed since filamentous green algae was included) the first axis of the biplot seems to mostly correspond with depth.

When relative abundance data was used instead of total plant biomass, this emphasized the relative importance of a taxa within a community rather than its actual mass. However, the patterns depicted are largely the same with:

1) The shallow areas of 2021 (dominated by *Vallisneria americana*) are most different to the deeper waters of the past over a range of times (1921-2014) being dominated by *Ceratophyllum demersum* (Figure 12 and Figure 14).

2) 1921 and 2021 often appeared more similar in community composition than other samples, especially the shallower sites. The largest differences found between these sites (Zones 1 and 2) over the past 100 years was that 1921 tended to have a greater relative abundance of *Potamogeton zosteriformis* and *Chara sp.* When algae is included in the analysis (Figure 13), this pattern remains but filamentous green algae plays more of an important role in the shallow areas (Zone 1) between 1971 and 2014 (Phase 2) which is what we would have predicted for samples that had turbid conditions (low light) and high nutrients.

Conclusions

Although some common species are reported to be tolerant or non-tolerant to turbidity, we could not find an interpretable pattern using this information. Perhaps this was due to the once-every-10-years mid-summer snap-shot nature of the surveys. For instance, turbidity may be much more pronounced in the spring and its affects may have disappeared by mid-summer.

With this remarkable data set spanning 100 years, we were able to find several trends. These trends were discernible using Non-Metric Multidimensional Scaling and many different data manipulation techniques. Since the same trends kept showing up in these various permutations, this strongly suggests any trends are real and not an artifact of data manipulation.

The community shifted with depth, with *Ceratophyllum demersum* consistently being part of the deepest zone. Larger changes in species composition occurred in the shallower zones, with *Chara* sp. playing an important role in 1921, but being largely replaced by *Vallisneria americana* by 2021.

These and other community changes—especially when viewed in the light of recent reports such as Garrison (2002), Johnson (2021) and Robertson et al. (2022) —suggest three different phases of plant communities.

1. **Phase I** is comprised by samples from 1921 and represents a time before much of the watershed was cleared and increased sediments had time to settle in the lake. *Chara* sp., as previously mentioned, dominated the deeper Zone 3 with *Potamogeton zosteriformis* and *Myriophyllum sibiricum* and *Vallisneria americana* dominating in the shallower waters. With the upper zones (1 and 2) typically having more *Potamogeton zosteriformis*, and *Vallisneria americana*.

2. **Phase II** (represented by samples from 1971-1991) depicts a time when increases in sediment nutrient from anthropogenic sources was greatest. During these years, *Ceratophyllum demersum* remained an important part of Zone 3. We also saw the introduction and importance of *Myriophyllum spicatum*. The shallower areas held more algae, *Potamogeton richardsonii*, *Ranunculus longirostris*, and broad-leaved *Potamogeton*.

3. **Phase III** (2001-2021) we suggest represents a time when fewer nutrients are entering the lake due to nutrient abatement practices. *Vallisneria americana* becomes very dominant in the shallow area of Zone 1 and *Chara* sp. once again becoming an important taxon for Zone 2. While in Zone 3, *Ranunculus aqtatilis*, *Potamogeton zosteriformis*, and *Myriophyllum spicatum* were relatively important.

One bit of evidence that Green Lake has begun to recover is that, in many of the biplots, 2021 had more in common with the plant composition of 1921 compared to other survey years. We find these trends encouraging and suggest continued monitoring to better understand these shifts in the plant communities of Green Lake.

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Appendix A

NMDS biplots

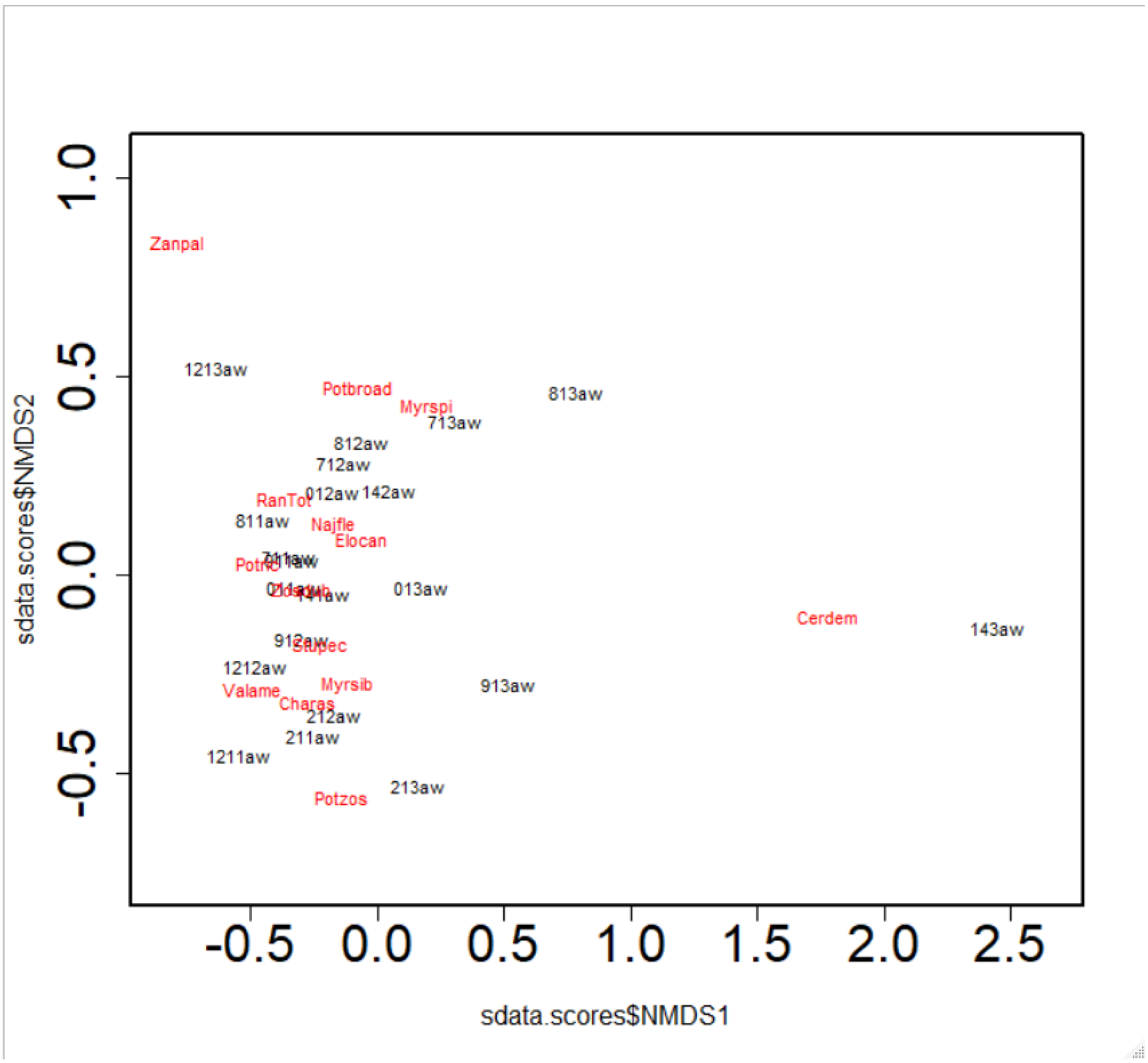


Figure 4. NMDS biplot (using 2 dimensions, stress=0.137) using total plant biomass (not including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

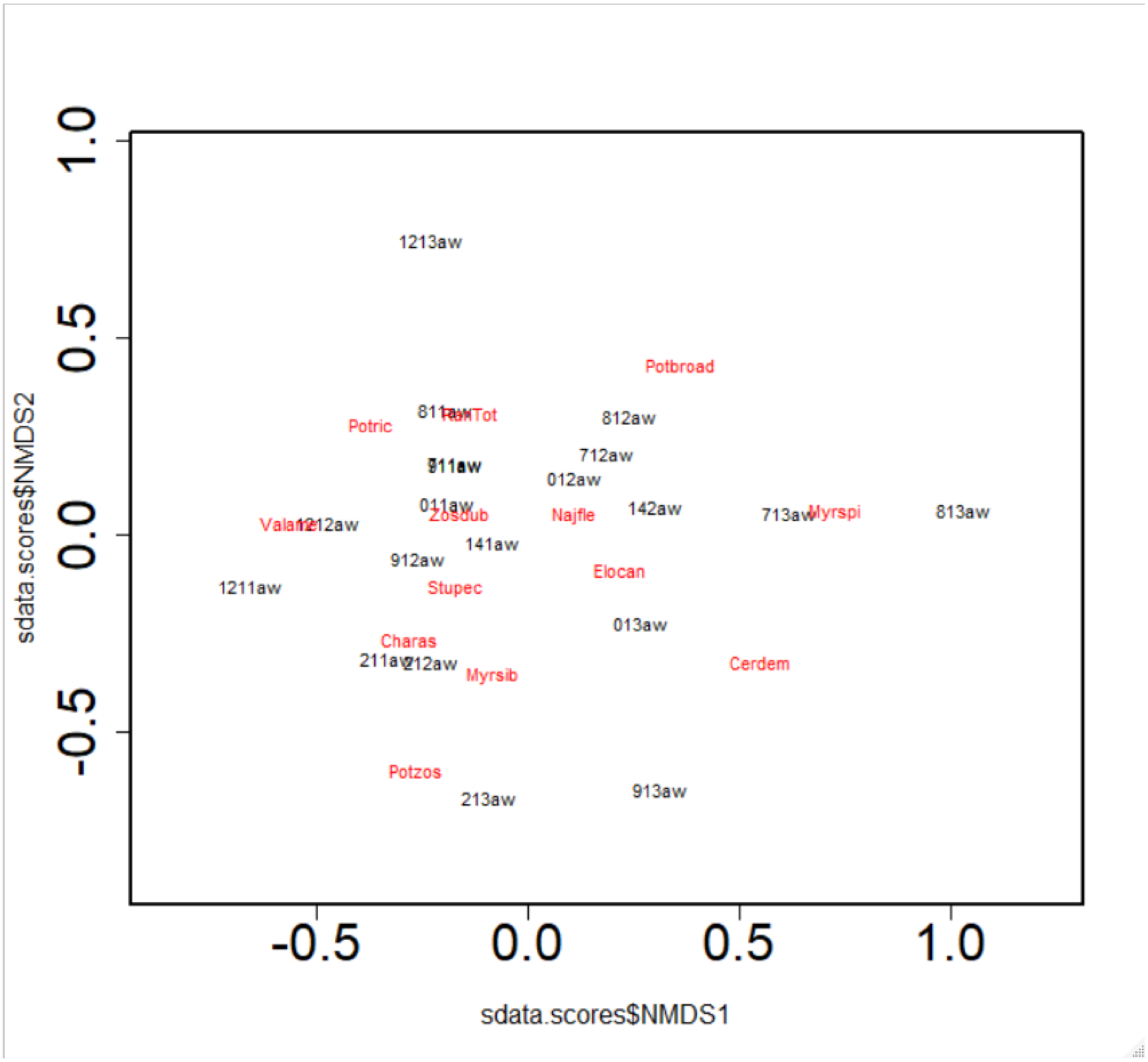


Figure 5. NMDS biplot (using 2 dimensions, stress=0.186) using total plant biomass (not including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1921 to 2021. The outlier from the previous figure was removed. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

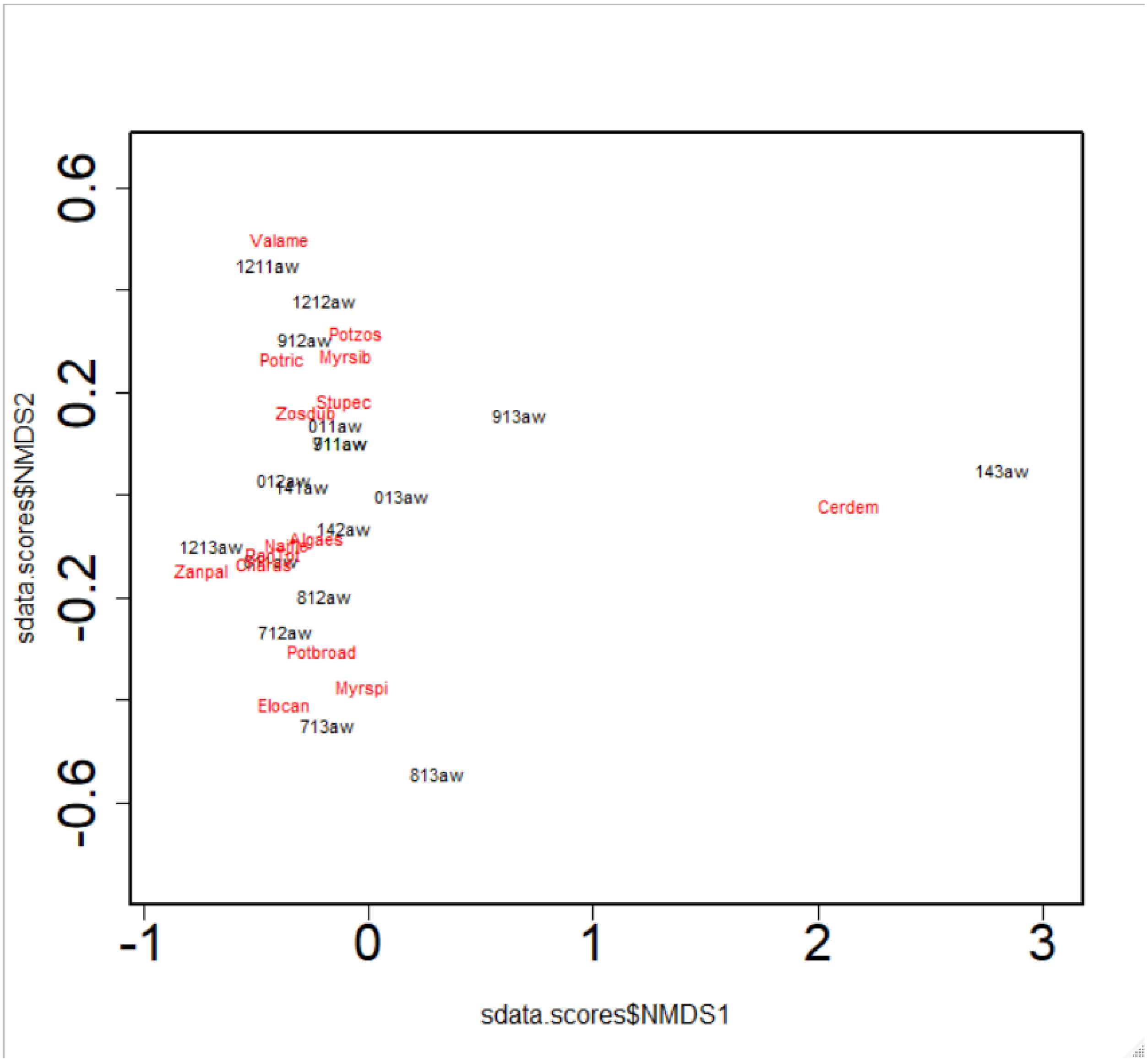


Figure 6. NMDS biplot (using 2 dimensions, stress=0.117) using total plant biomass (including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1971 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

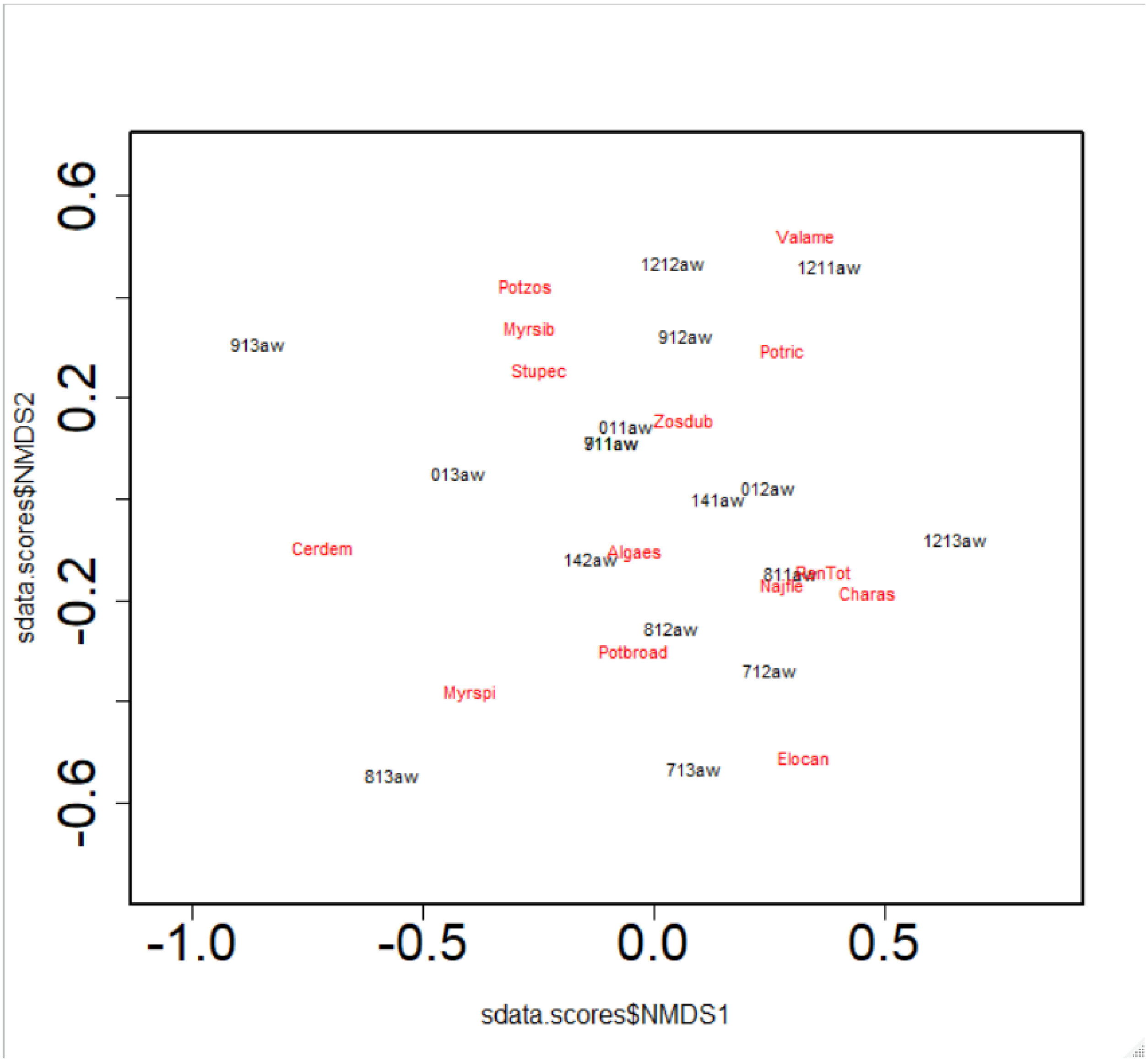


Figure 7. NMDS biplot (using 2 dimensions, stress=0.176) using total plant biomass (including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1971 to 2021. The outlier from the previous figure was removed. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

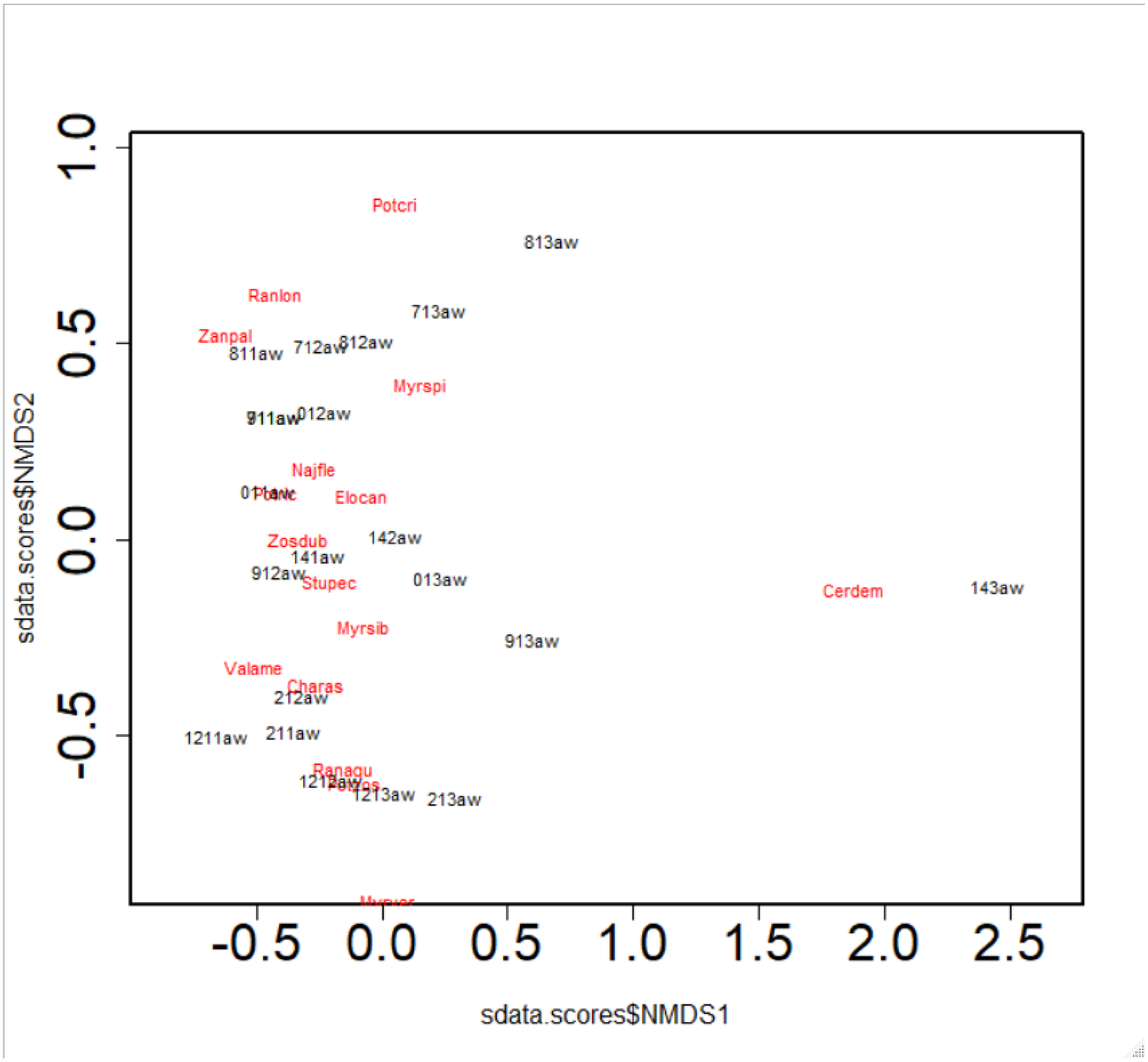


Figure 8. NMDS biplot (using 2 dimensions, stress=0.135) using total plant biomass (not including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

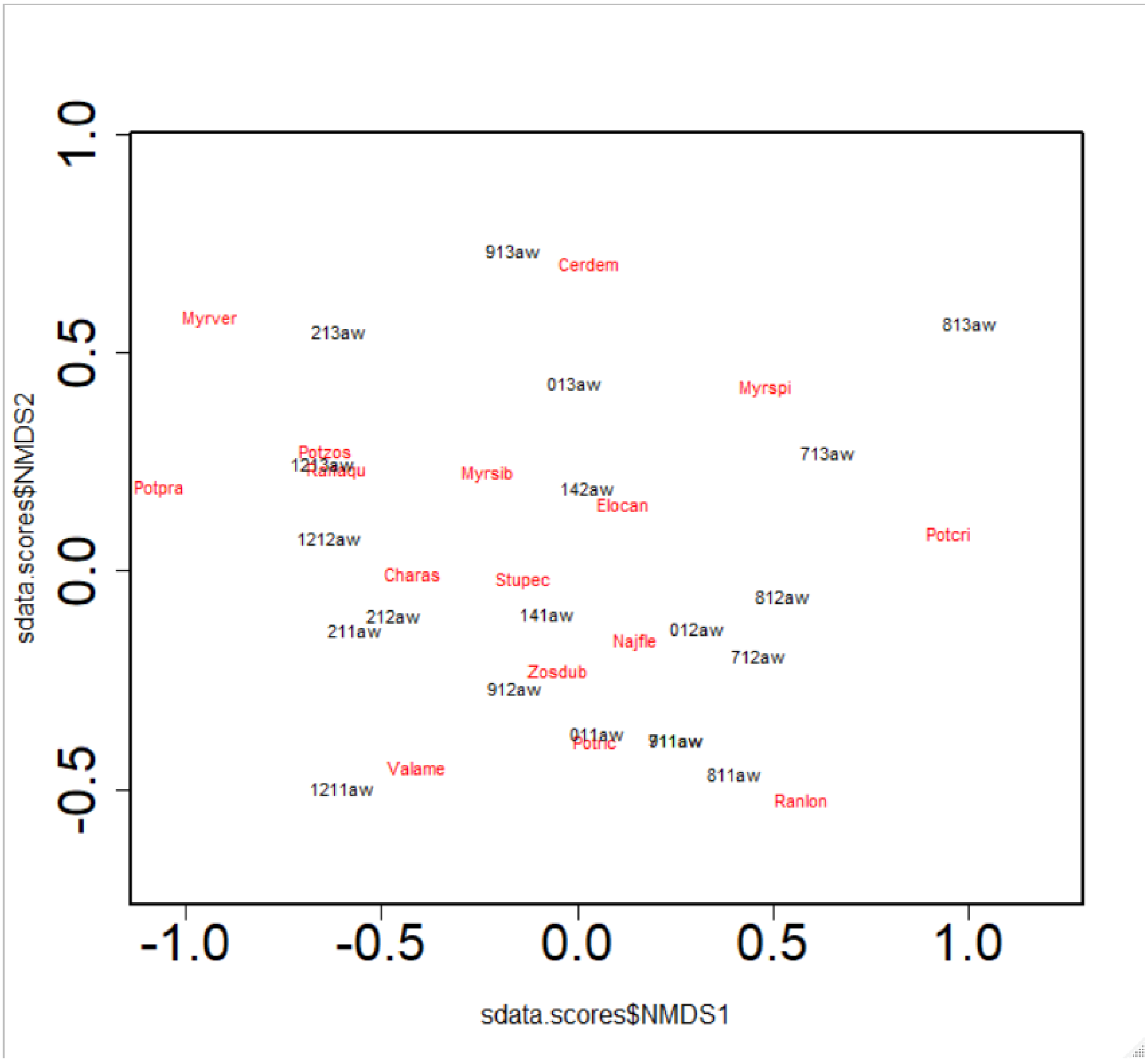


Figure 9. NMDS biplot (using 2 dimensions, stress=0.137) using total plant biomass (not including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1921 to 2021. Any outliers have been removed. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

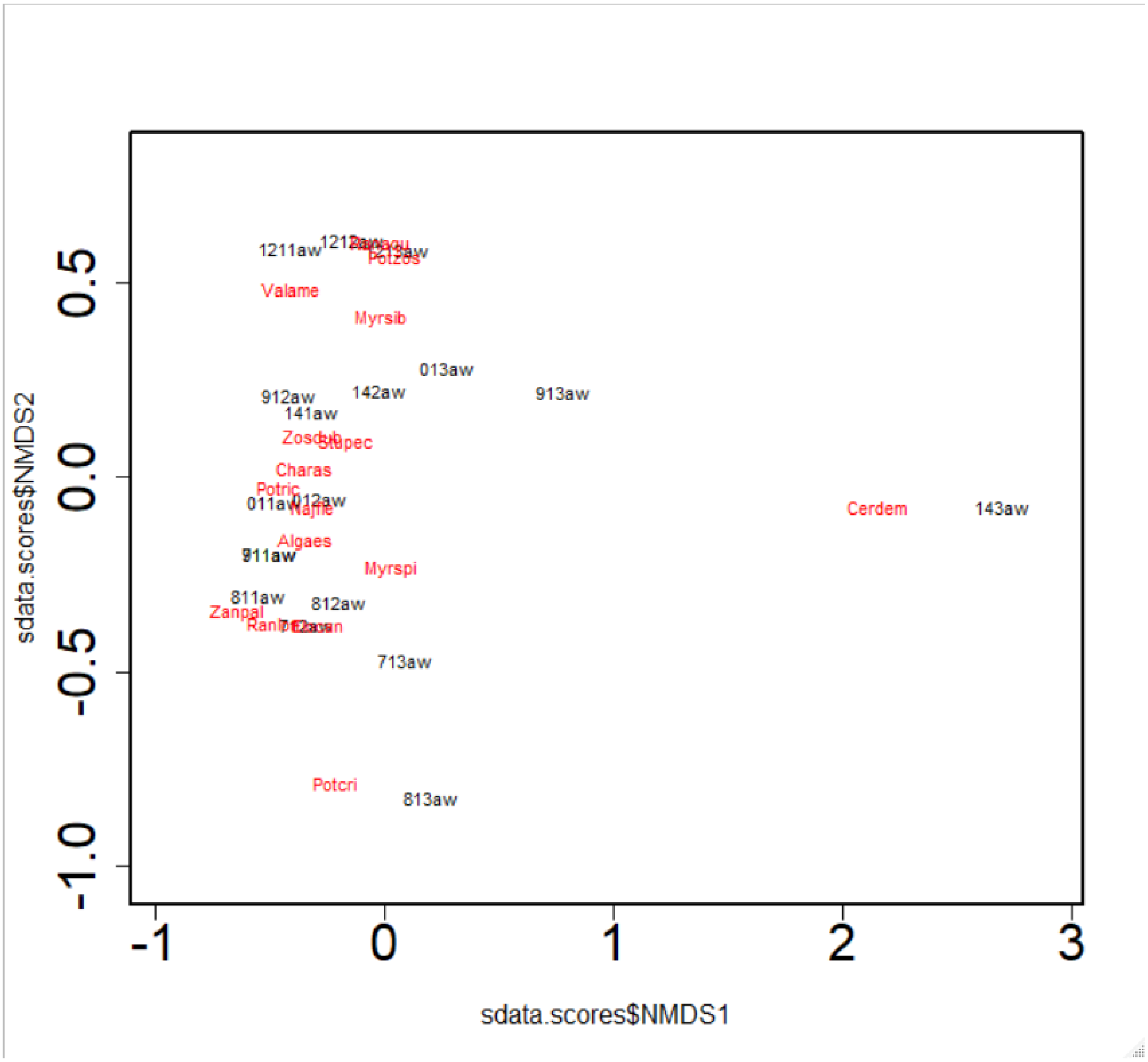


Figure 10. NMDS biplot (using 2 dimensions, stress=0.105) using total plant biomass (including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1971 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

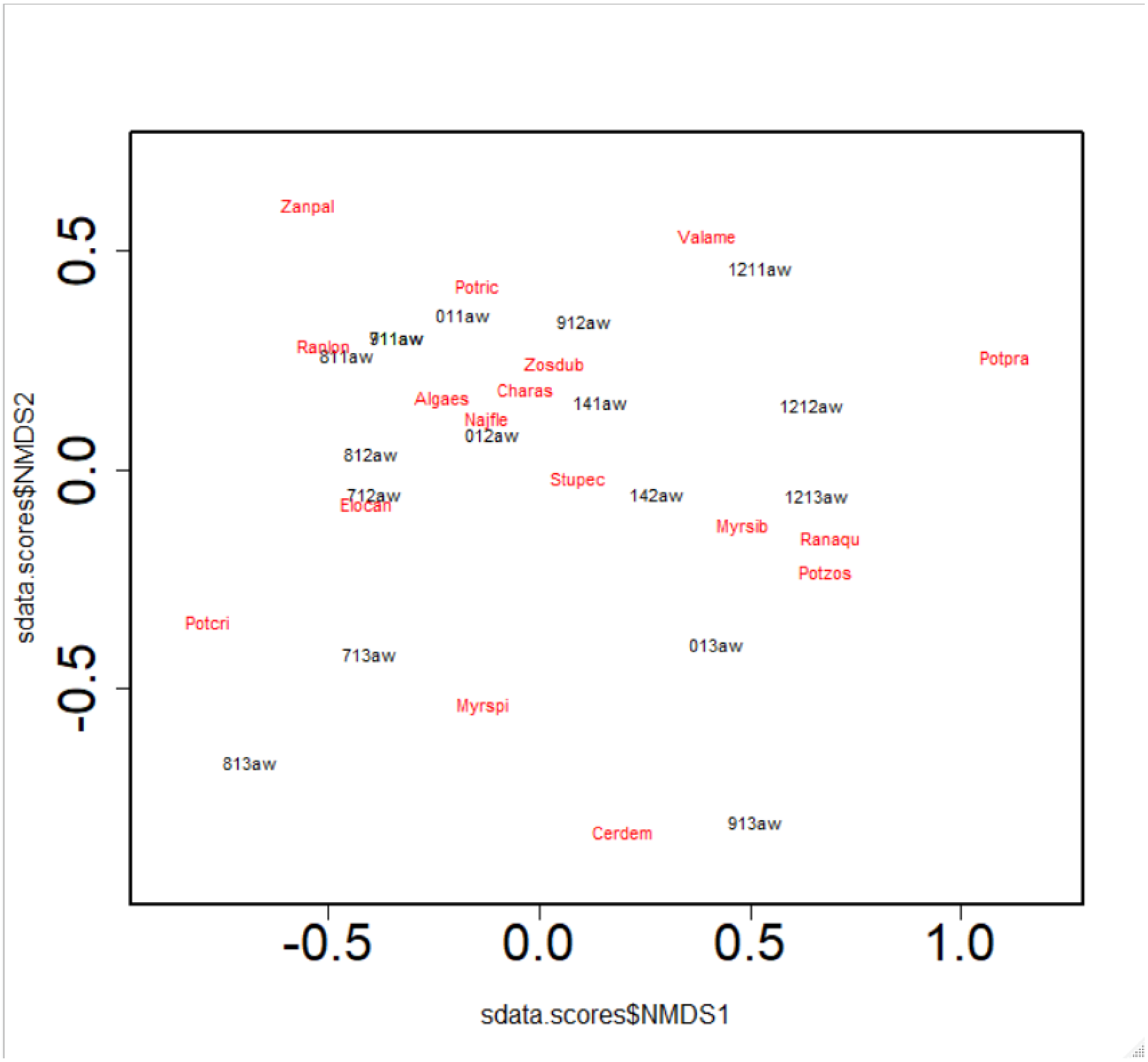


Figure 11. NMDS biplot (using 2 dimensions, stress=0.151) using total plant biomass (including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1971 to 2021. Outliers were removed. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

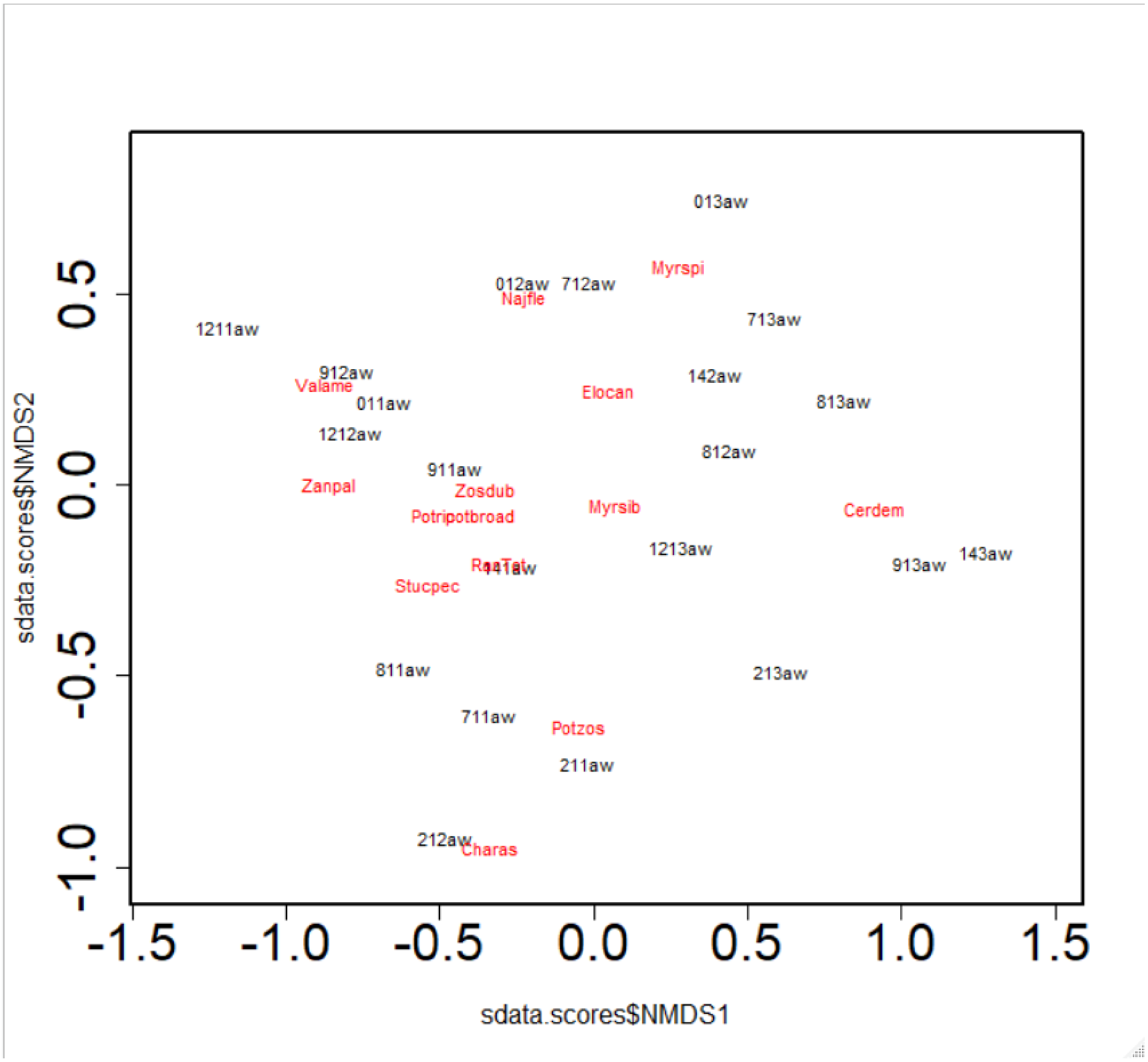


Figure 12. NMDS biplot (using 2 dimensions, stress=0.152) using relative abundance (not including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

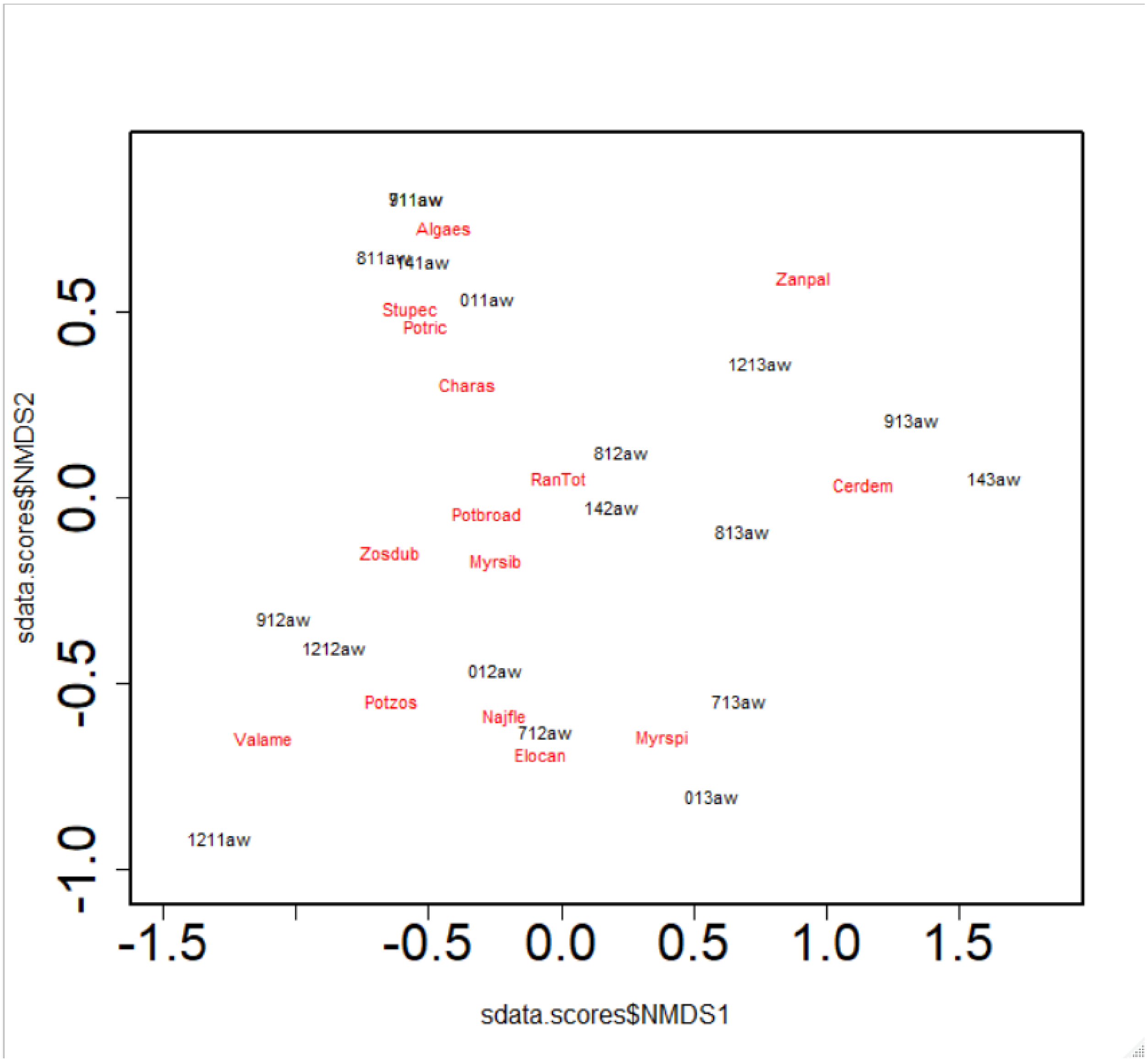


Figure 13. NMDS biplot (using 2 dimensions, stress=0.110) using relative abundance (including filamentous green algae) and ambiguous species lumped together from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, potbroad =Broad leaved Potamogeton, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, RanTot = Ranunculus sp., Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

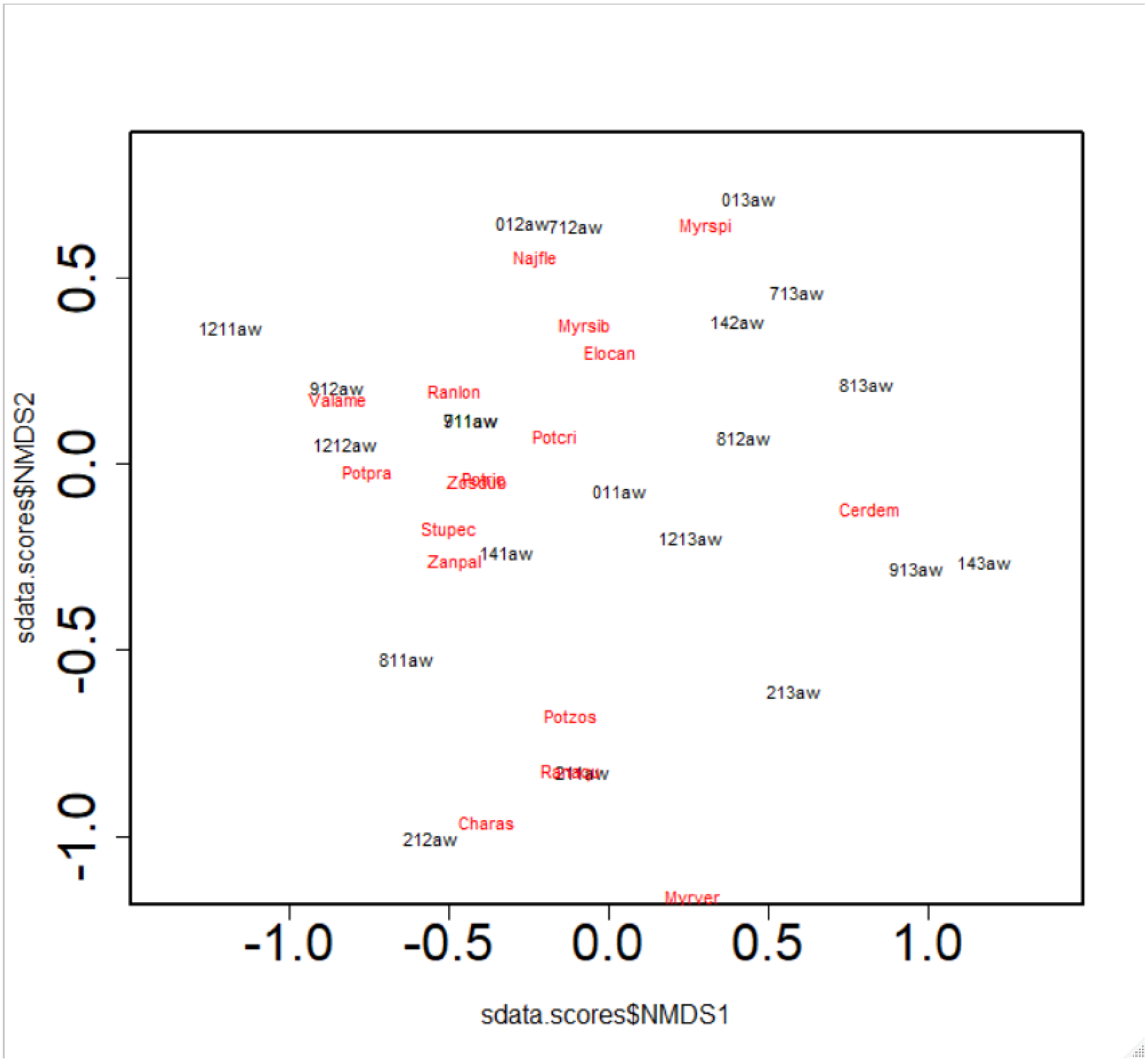


Figure 14. NMDS biplot (using 2 dimensions, stress=0.137) using relative abundance (not including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

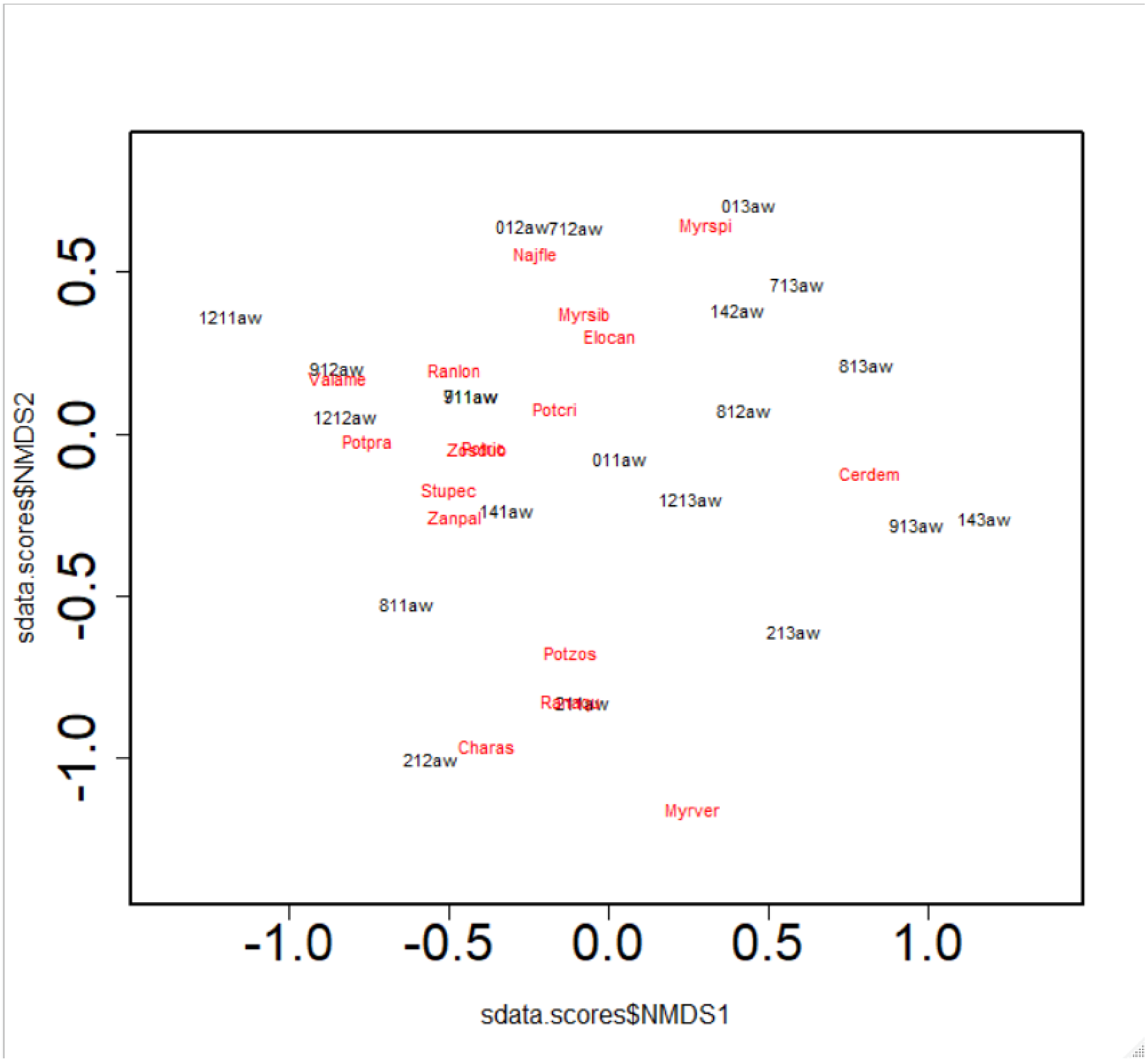
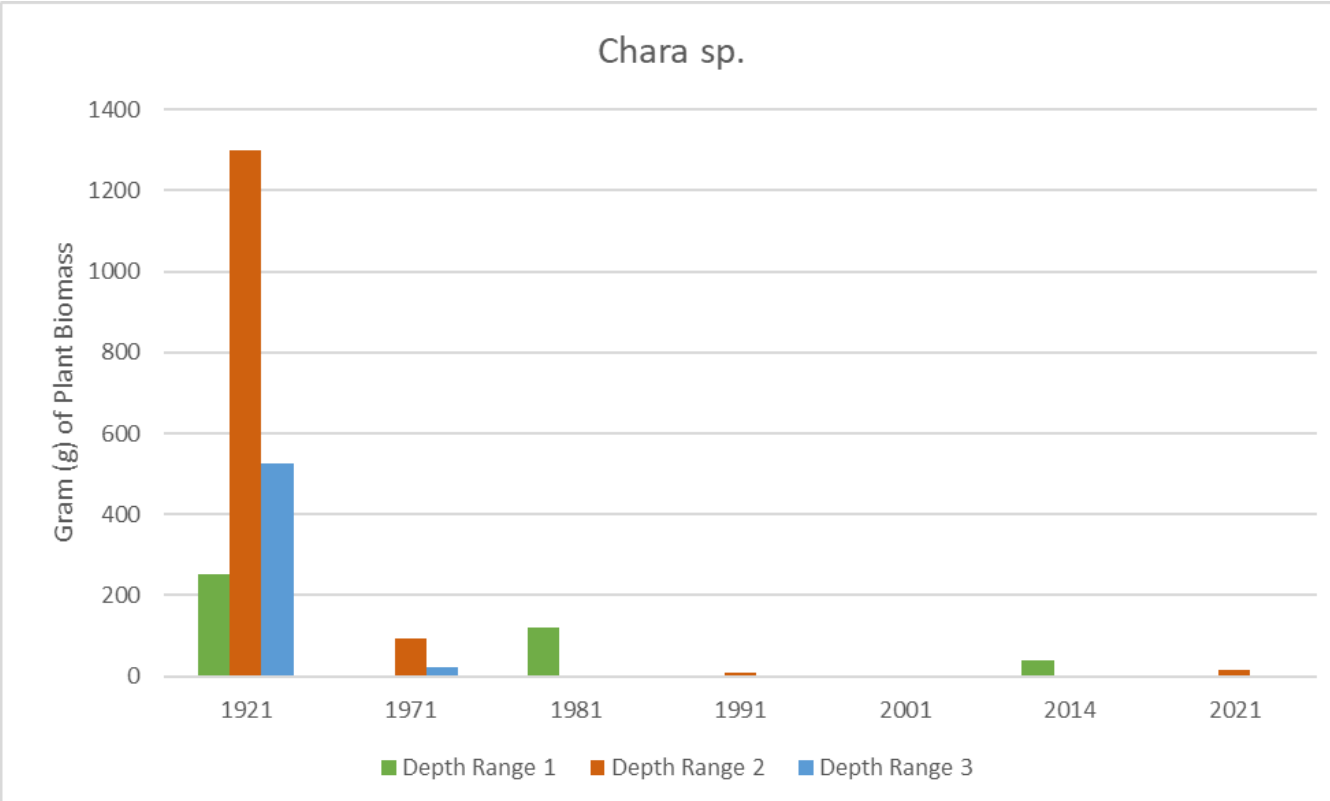
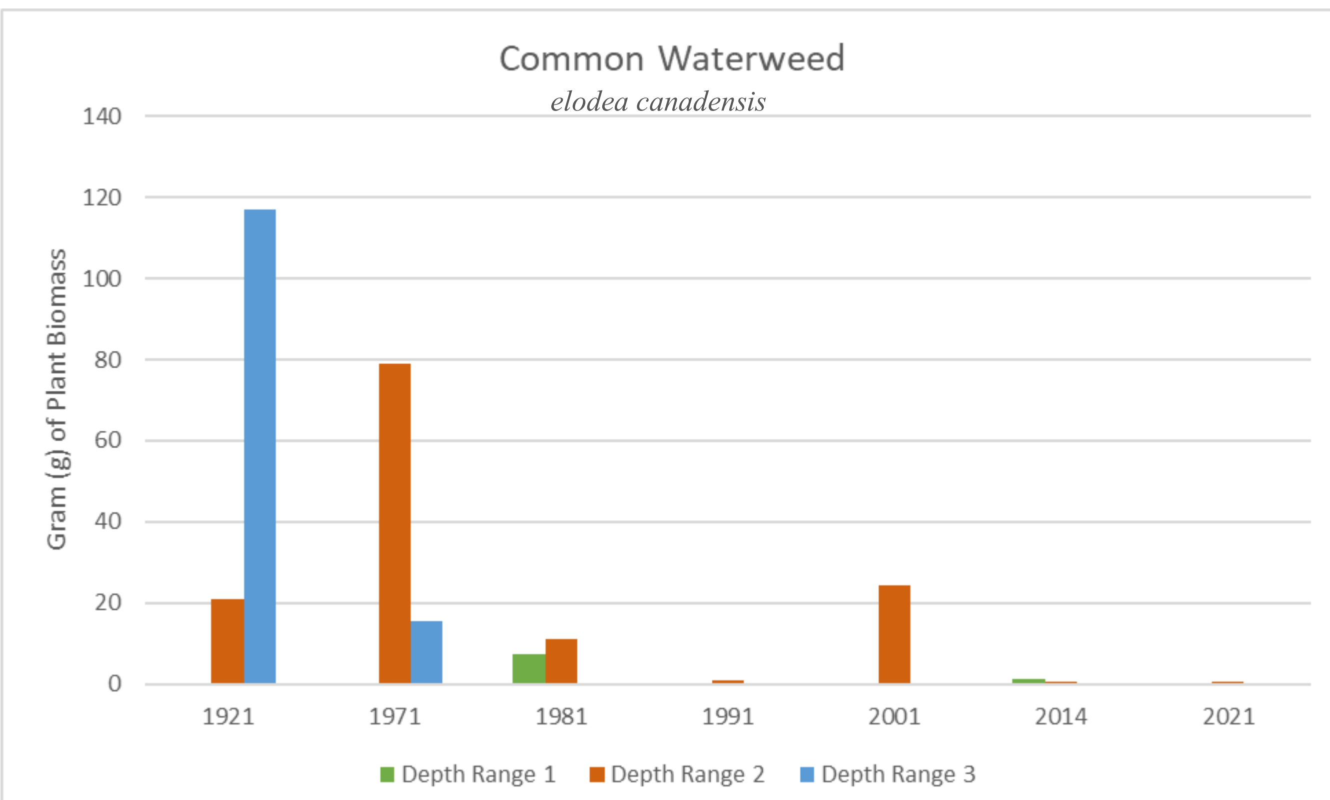


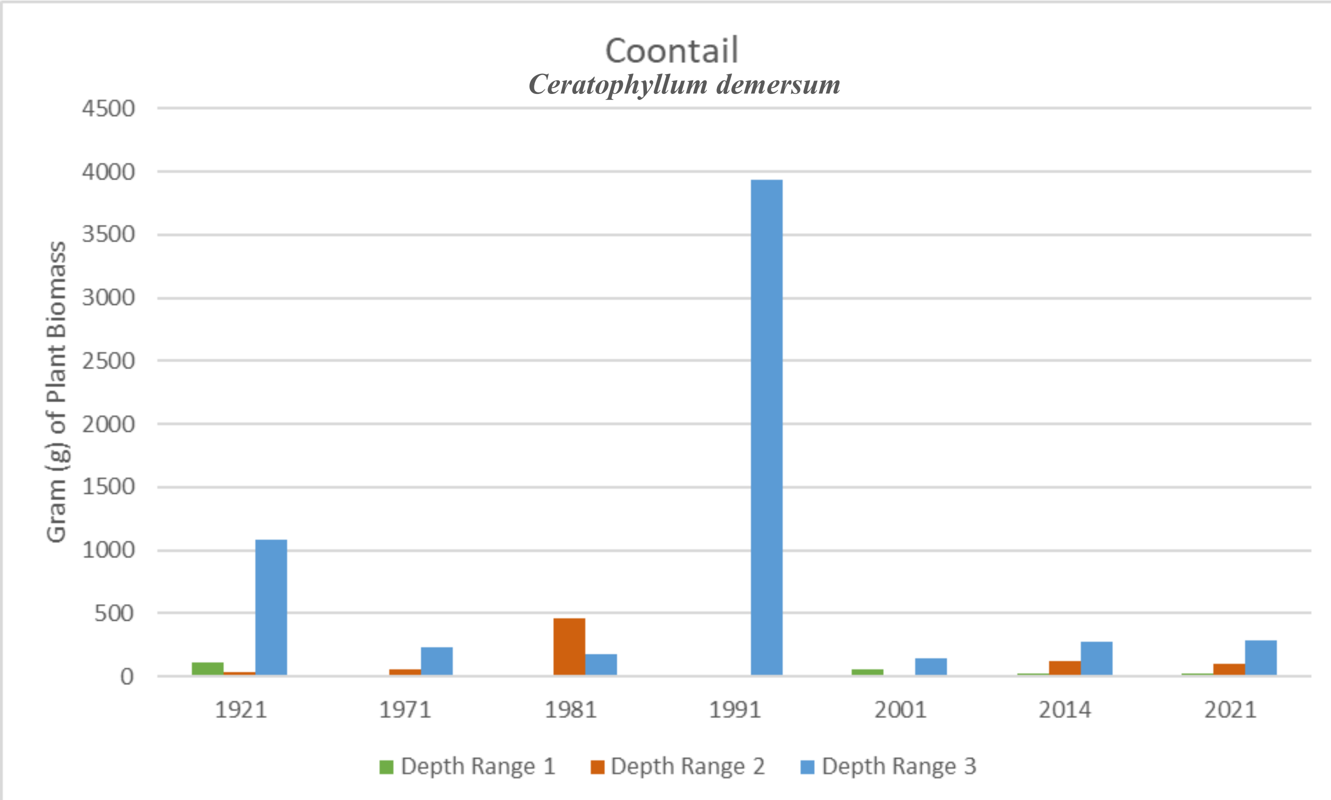
Figure 15. NMDS biplot (using 2 dimensions, stress=0.137) using relative abundance (including filamentous green algae) and using all species identified (splitters) from surveys of Green Lake from 1921 to 2021. The black labels are site scores with the rightmost 3 places representing the depth zones (1= 0.5-1.0m, 2=1-3m, and 3=3-10m depth) and "aw" = average wet weight. The leftmost numbers are the code for the survey year: 21=1921, 71=1971, 81= 1981, 91=1991, 01=2001, 14=2014, and 121=2021. The red labels represent species scores; Cerdem=Ceratophyllum demersum, Charas= Chara sp., Elocan = Elodea canadensis, Myrsib = Myriophyllum sibiricum, Myrspi = Myriophyllum spicatum, Najfle = Najas flexilis, Potcri = Potamogeton crispus, Potpra = Potamogeton praelongus, Potric = Potamogeton richardsonii, Potzos = Potamogeton zosteriformis, Ranaqu = Ranunculus aquatilis, Ranlon = Ranunculus longirostris, Stupec = Stuckenia pectinate, Valame = Vallisneria americana, Zanpal = Zannichellia palustris, and Zosdub =Zosterella dubia.

Appendix B

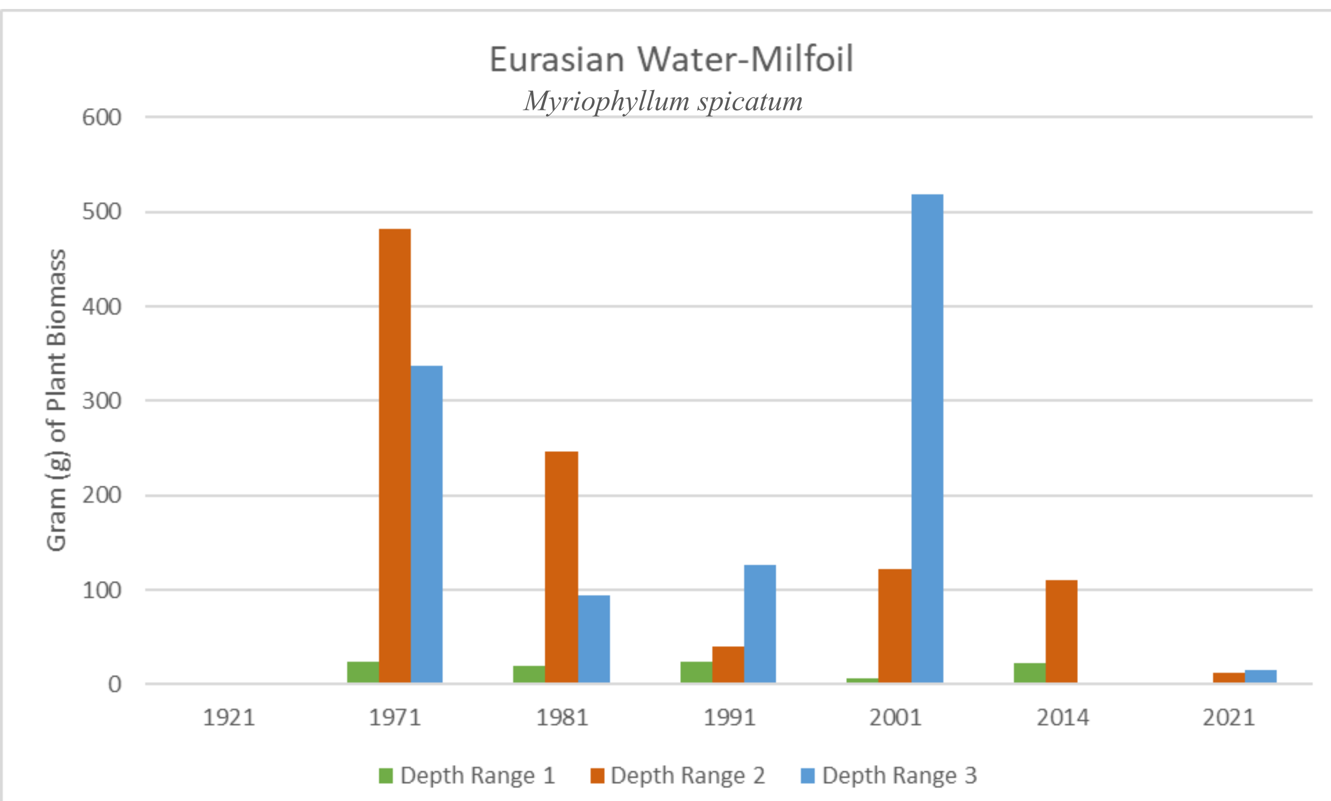
Bar charts by Zone and species


Chara sp.
Gram (g) of Plant Biomass
1400
1200
1000
800
600
400
200
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3

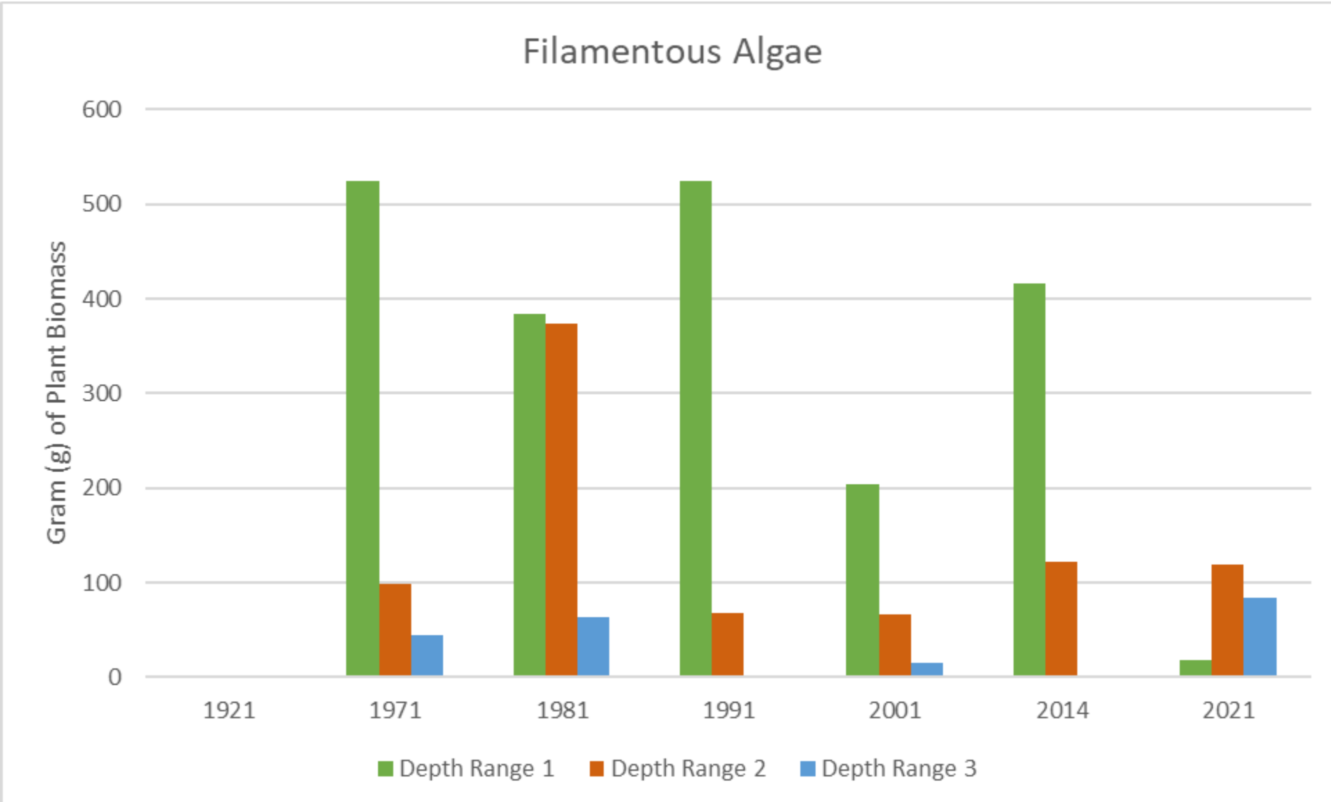

Common Waterweed
elodea canadensis
Gram (g) of Plant Biomass
140
120
100
80
60
40
20
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3

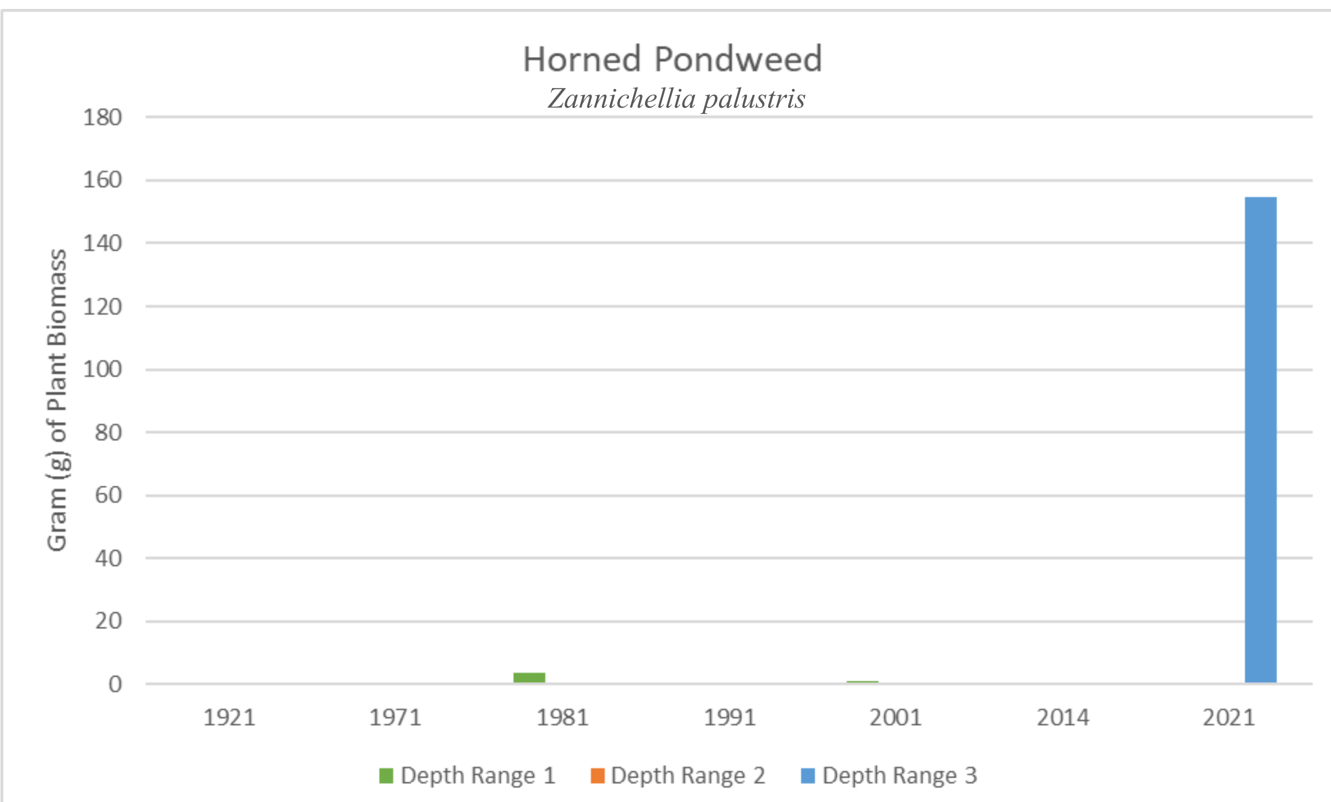


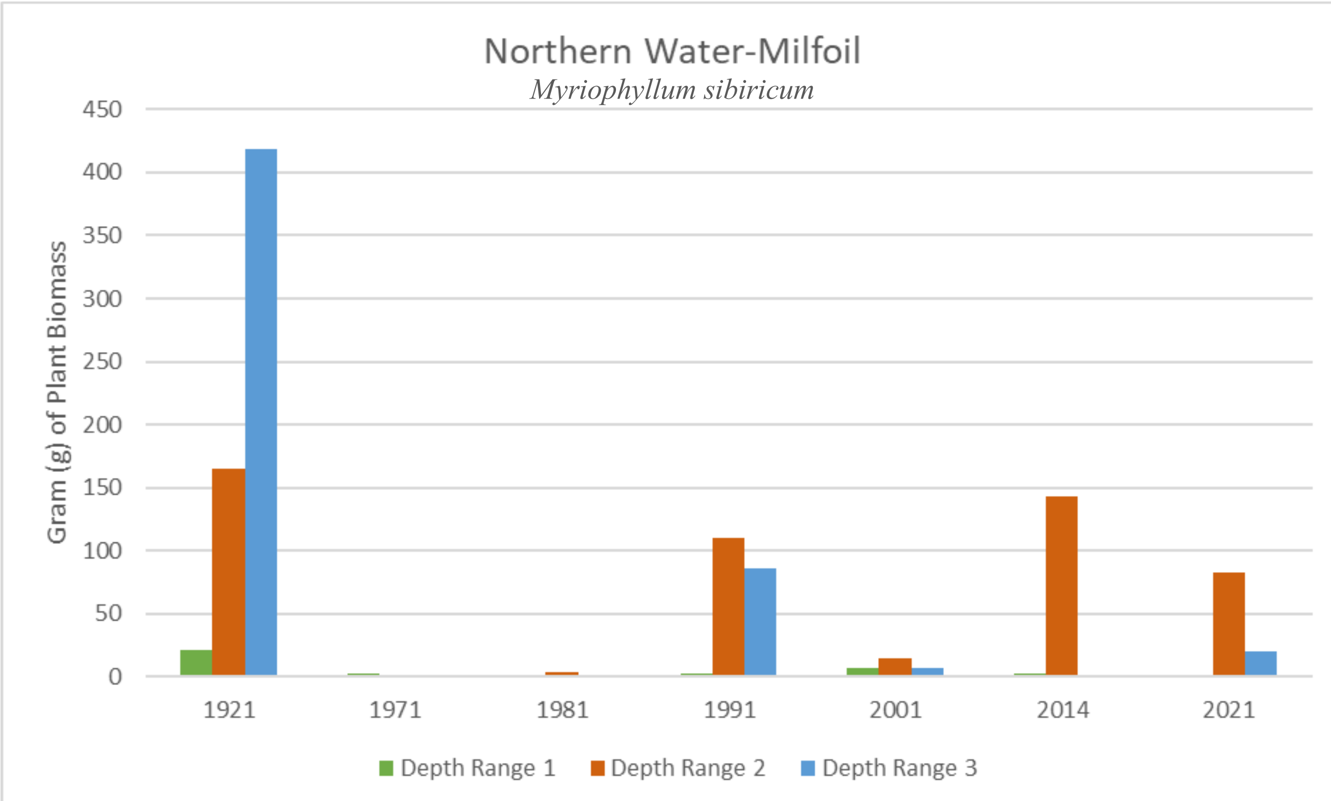
Coontail
Ceratophyllum demersum
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Gram (g) of Plant Biomass
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3

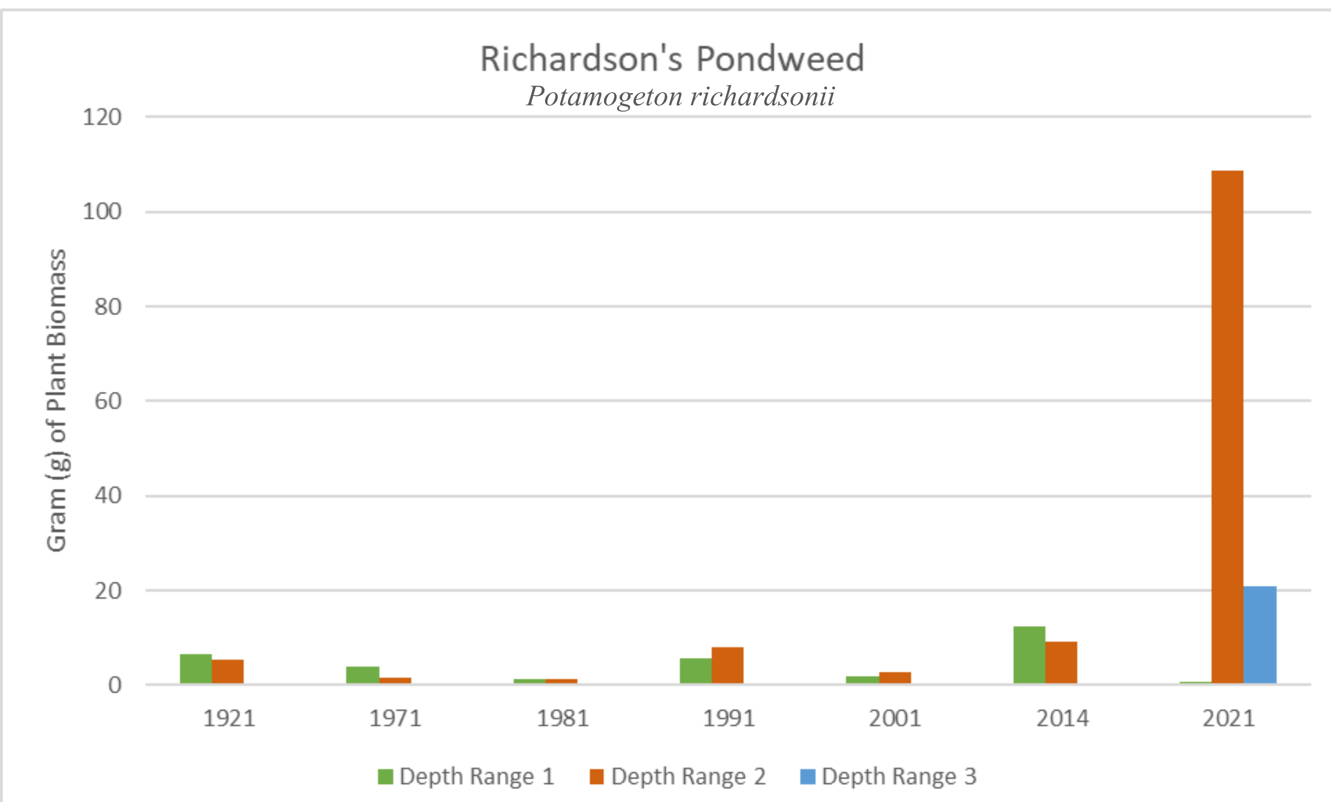


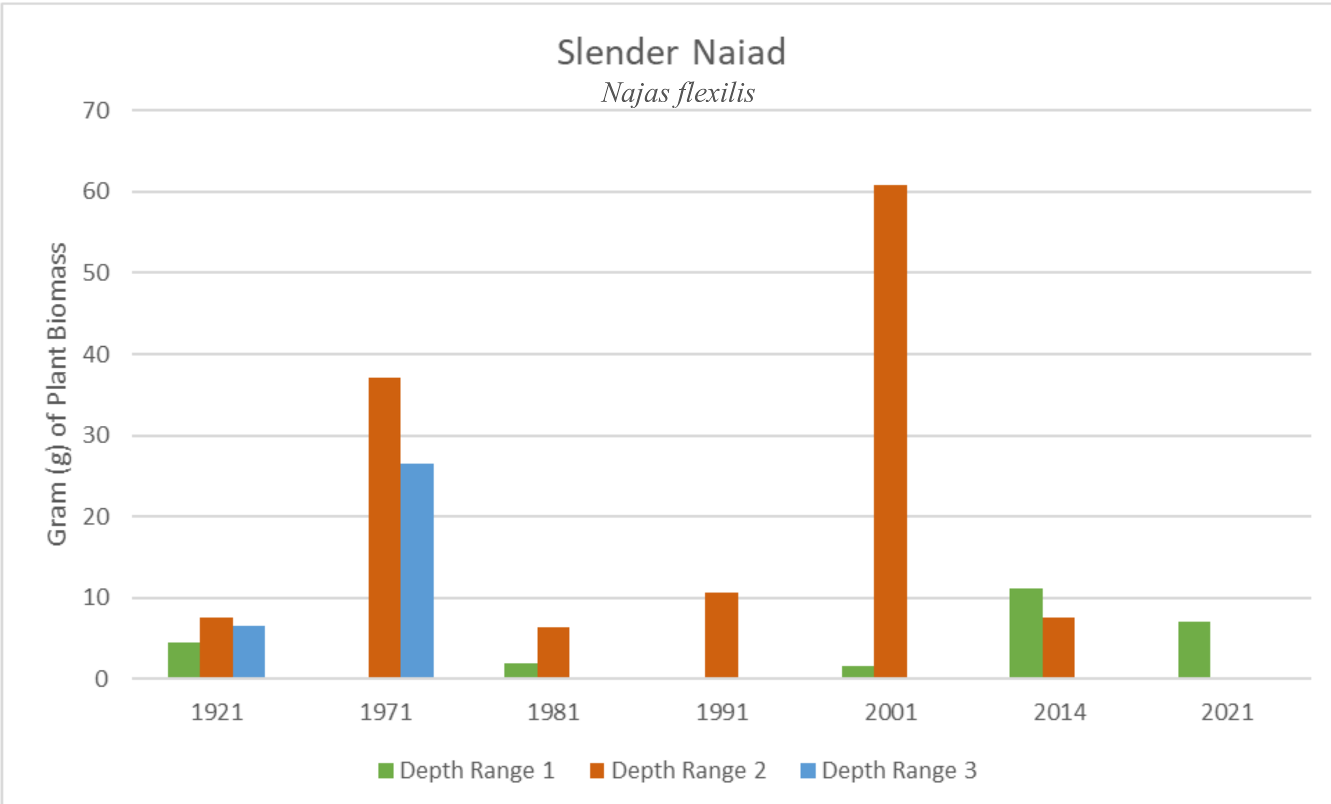
Eurasian Water-Milfoil
Myriophyllum spicatum
600
500
400
300
200
100
0
Gram (g) of Plant Biomass
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3

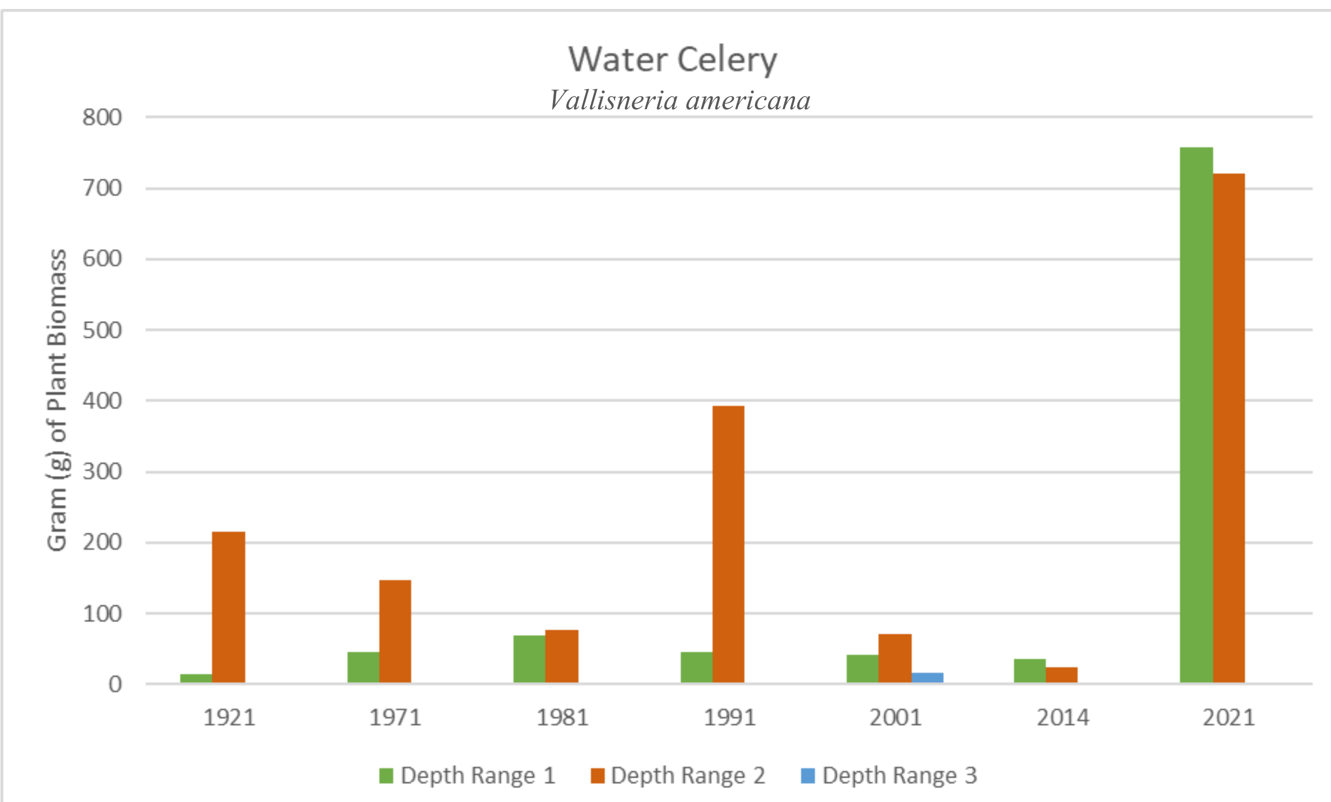

Filamentous Algae
600
500
400
300
200
100
0
Gram (g) of Plant Biomass
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3

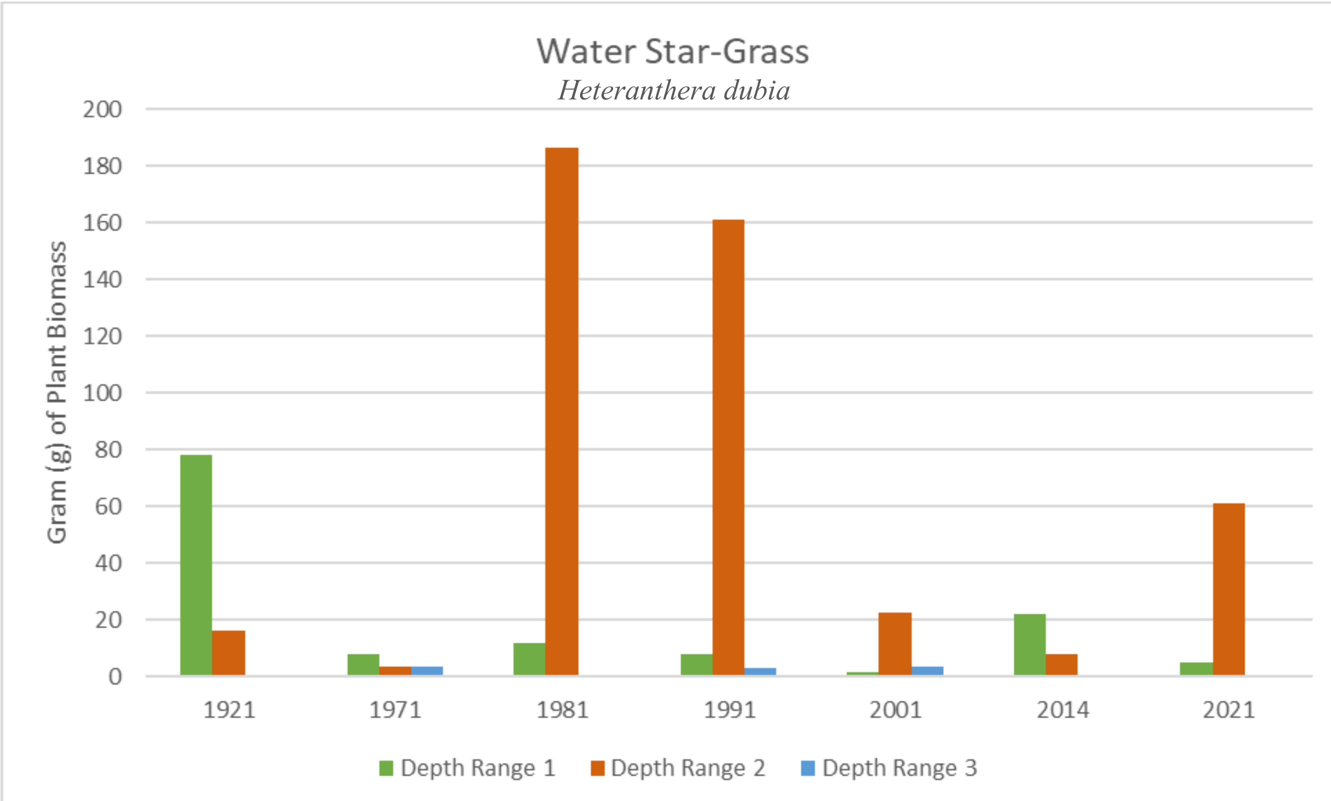

Horned Pondweed
Zannichellia palustris
180
160
140
120
100
80
60
40
20
0
Gram (g) of Plant Biomass
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3


Northern Water-Milfoil
Myriophyllum sibiricum
Gram (g) of Plant Biomass
450
400
350
300
250
200
150
100
50
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3


Richardson's Pondweed
Potamogeton richardsonii
Gram (g) of Plant Biomass
120
100
80
60
40
20
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3


Slender Naiad
Najas flexilis
Gram (g) of Plant Biomass
70
60
50
40
30
20
10
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3


Water Celery
Vallisneria americana
Gram (g) of Plant Biomass
800
700
600
500
400
300
200
100
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3



Water Star-Grass
Heteranthera dubia
Gram (g) of Plant Biomass
200
180
160
140
120
100
80
60
40
20
0
1921
1971
1981
1991
2001
2014
2021
Depth Range 1
Depth Range 2
Depth Range 3