ECOLOGY AND BIOGEOGRAPHY OF FRESHWATER DIATOMS IN PONDS OF MCMURDO DRY VALLEYS AND PARTS OF THE ROSS ISLAND

by

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Abstract

Aneliya Sakaeva (M.S. Environmental Studies)

Ecology and biogeography of freshwater diatoms in ponds of McMurdo Dry Valleys and parts of the Ross Island

Thesis directed by Professor Diane McKnight

The McMurdo Dry Valleys (MDVs) and the exposed coastal areas of the nearby Ross Island in Antarctica represent some of the coldest, driest places in the world. However, during the austral summer warmer temperatures and constant sunlight allow microbial life to flourish nearly anywhere there is water. Diatoms are single-celled algae encapsulated in a silica shell and diatom communities constitute an important component of the microbial mats that grow in the streams, lakes and ponds in these regions. As part of the Long Term Ecological Research station in the McMurdo Dry Valleys diatom communities have been studied extensively in the streams over the last 20 years. Although the diatoms present in pond microbial mats at Cape Royds have been previously studied, modern-day knowledge of the characteristics of diatom communities in ponds and small lakes throughout the region is limited. This work sought to find the relationships between water chemistry and diatom community structure in ponds. Because water flow is not a factor in ponds and small lakes, influences of salinity, nutrients, pH and other factors can be more easily distinguished. This study looked at 24 separate bodies of water in the Taylor Valley, Labyrinth region in Wright Valley, Cape Royds and McMurdo Station area on Ross Island. The results suggest that geography, dispersal and historical environmental conditions play a significant role in structuring diatom communities, in addition to water chemistry. The results also expand the knowledge of habitat preferences for some of the species present in this region.

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INTRODUCTION

In cold, polar deserts aquatic ecosystems are important sources of biodiversity in an otherwise barren landscape. In the absence of higher plants and crustacean zooplankton, microbial life represents much of the diversity in these environments (Vincent and James, 1996). Southern Victoria Land in Antarctica, including McMurdo Dry Valleys (MDV) and parts of the nearby Ross Island, is one of the coldest and driest places on Earth. Average annual temperatures in MDV range from -14.8 to -30.0 C (Doran *et al*., 2002) and precipitation averages 5 cm a^{-1} (Witherow *et al*., 2006). During the austral summer in the mountainous landscape of the MDV ephemeral streams carry meltwater from glaciers to large lakes and throughout the landscape. While the large, perennially ice-covered lakes are some of the best-known aquatic ecosystems in Antarctica, small ponds that freeze over winter and become partially or completely ice-free for several weeks during the summer are one of the most common aquatic ecosystems in the polar regions (Howard-Williams & Hawes, 2007).

Benthic microbial mats in these ponds throughout Southern Victoria Land contain much of the biodiversity of this region. The mats are composed of cyanobacteria and various types of algae, including diatoms. Diatoms (Bacillariophyceae) are single-celled, photosynthetic eukaryotes that are present in nearly all aquatic environments (Mann, 1996). The individual cells are encapsulated in a silica shell called the frustule, with unique shapes and features that make it possible to identify these cells to the species level using light microscopy. This task is much more difficult with many other types of algae and cyanobacteria. Particular species of diatoms have narrow habitat ranges, with sensitivity to salinity, pH, temperature and other chemical and physical variables and these attributes make diatoms important indicators of long-term environmental change (Stoermer and Smol, 1999). Additionally, the silica frustules persist at the bottom of lakes and marine sediments, which allows researchers to reconstruct past environmental conditions.

Diatoms are one of the most abundant freshwater algal groups in the Antarctic and Sub-Antarctic regions (Jones, 1996). Much work has been done describing the diatom diversity and ecology on the Antarctic Peninsula (Kopalova *et al*., 2012; Kopalova *et al*., 2011) and the Sub-Antarctic (Van de Vijver *et al*., 2001; Van de Vijver *et al*., 2010; Van de Vijver *et al*., 2011) and recently the ecology of these diatoms has been investigated (Kopalova *et al*., 2013a, Kopalova *et al*., 2013b, Kopalova *et al*., 2014). These areas have received much attention because of the severe environmental change underway there (Vaughan *et al*., 2003). However, the ecology of freshwater diatoms from the Antarctic Continent has not been studied in as much detail by comparison (although see Sabbe *et al*., 2003, Van de Vijver *et al*., 2012), and much of that has been done has been in the McMurdo Dry Valleys.

The McMurdo Dry Valleys have been extensively studied in the past 20 years as part of the McMurdo Long-Term Ecological Research project (mcmlter.org). The purpose of this and all Long-Term Ecological Research Stations is to conduct ecological research over the span of decades (www.lterner.edu). In particular, diatom species in the ephemeral streams have been described (Esposito *et al*, 2008), sampled continuously (Antarctic Freshwater Diatoms website) and studied in relation to flow conditions (Stanish *et al*., 2011, Stanish *et al*., 2012), and coexisting microbial communities (Stanish *et al*., 2013). Flow was found to be an important factor in structuring diatom communities in the stream algal mats (Stanish *et al*., 2011). However, it is still largely unknown what chemical factors affect habitat preferences of diatom species in this region. A study of ponds and small lakes is an opportunity to establish the relationships between water chemistry and diatom communities, and may be helpful in creating environmental reconstruction from paleo-material (Whittaker *et al*., 2008; Konfirst *et al*., 2011; Spaulding *et al*., 1997).

In the small lakes and ponds diatoms live primarily in benthic cyanobacterial mats and become active during the austral summer (Vincent *et al*., 1993b). During this time the ice cover on the ponds retreats and a moat opens up around the shore. Jones *et al*. (1996) summarizes many studies that have been done on diatom flora in ponds, lakes and streams throughout Antarctica. The Cape Royds ponds and lakes were sampled by the Shackleton's Nimrod Expedition of 1907-1909 and became some of the first descriptions of Antarctic diatoms (West & West, 1911) and our study aimed to re-sample the same water bodies over a hundred years later. Since then, many studies have followed (Kawecka *et al*., 1998; Roberts *et al*., 2001; Sabbe *et al*., 2004 and others), and ponds in the McMurdo Dry Valleys have been studied for water chemistry (Lyons *et al*., 2012), isotopic composition (Hage *et al*., 2007) and the structure of cyanobacterial mats in which diatoms live has been examined (Vincent *et al*., 1993b). However, no known study has looked at diatom flora in the sampled ponds in recent years.

Biogeography is the study of distribution of species in geographical space as well as geological time. The ubiquity hypothesis (Baas-Becking 1934, Finlay 2002) of the distribution of microorganisms postulates that "everything is everywhere" and it is the environmental conditions that select and structure communities. In this case, geographic isolation is nonexistent, and therefore allopatric speciation is absent. However, a growing body of recent studies of various microscopic organisms and habitats (Vanormelingen *et al*., 2008) suggest that microorganisms do display restricted geographical ranges. The historical approach suggests that within basin and regions evolution creates lineages, that is taxa within a basin is more closely related to each other than outside of the basin (Kociolek & Spaulding, 2000). A study by Vyverman *et al*. (2007) looked at global freshwater diatom data and found that at a regional level, historical factors play a more significant role in explaining geographical patterns of distribution than do contemporary environmental conditions. Because of the geographical spread and varying environmental conditions of the study undertaken here one of the major questions that can be answered is whether diatom communities are determined strictly by water chemistry or whether geographical distribution plays a role as well.

The sampled ponds are surrounded by a barren, inhospitable landscape. For diatoms in the McMurdo Dry Valleys, three other freshwater habitats exist – streams that carry glacial meltwater into large lakes, the moats of these large lakes and cryoconite holes on the surface of the glaciers. An exchange of material occurs by wind, when pieces of freeze-dried benthic mats from lakes and ponds are carried throughout the landscape (Parker *et al*., 1982). No streams were seen in the vicinity of the ponds and small lakes sampled at Cape Royds. There are also no large lakes equivalent to those in the Dry Valleys present on Cape Royds, and so diatom habitat is limited to the ponds and small lakes.

In order to obtain a wider range of salinity, pH and other chemical variables, ponds and small lakes from nearby areas outside of the Dry Valleys were also sampled. Cape Royds on the Ross Island is a relatively small area, containing numerous ponds and lakes. The results of this study can contribute to our knowledge of diatom ecology in this particular region of Antarctica. The results can also inform some theories about diatom distribution and dispersal over geographical distances, since the samples were collected over a significant geographical area. While it is beyond the scope of this study, the samples from Cape Royds can help resolve some taxonomic questions about specific species, such as *Luticola murrayi*. These samples can also be used for a study in environmental change over a hundred years, since the original samples from Shackleton's expedition still exist and could be directly compared.

METHODS

Study Sites

The McMurdo Dry Valleys comprise the largest ice-free region in Antarctica, stretching from the Ross Sea to the Polar Plateau. The climate is considered a polar desert. There are several ponds throughout the Taylor Valley that were sampled for this study (Figure 1). Many Glaciers Pond is in Lake Fryxell Basin of Taylor Valley. It receives glacial meltwater from the Commonwealth Glacier to the North and Aiken stream flows directly out of the pond into Lake Fryxell. Picture Pond is a few miles East of Many Glaciers Pond in the Eastern part of the valley and it has no major streams flow into or out of it. Spaulding Pond is located in the South of Lake Fryxell, close to and receiving meltwater from the Howard Glacier. Delta stream flows out of this pond and into Lake Fryxell. At the time of sampling, all of these ponds had well thawed-out moats, several feet wide with orange mats floating close to shore.

Parera Pond is located South of Andrew's Ridge in South Central Taylor Valley. It receives flow from several glaciers but no outflow (Lyons *et al.*, 2012). Nussbaum Riegel Pond is located South of its namesake and has no apparent inflow or outflow. Finally, two of the Marr ponds, 3 and 4 were also sampled, located close to Marr Glacier. Marr Pond 3 has an outflow into Marr Pond 4. At the time of sampling, all four of these ponds were mostly under ice cover, with narrow moats one to two feet wide.

The Labyrinth region of the Wright Valley (Figure 2) is an isolated area close to Wright Upper Glacier and surrounded by mountains on three sides. There are many small ponds in this region, and four of them, located West of the famous Don Juan pond, were sampled for this study. All four ponds had a cover of ice over most of the area, with the moat thawed out just enough to collect samples.

On the Ross Island, two ponds were sampled in close proximity to McMurdo Station (Figure 4). These two ponds are located along the designated Hut Ridge trail that starts at the Discovery Hut and moves uphill along the ridge. Both ponds were ice-free during the time of collection with bright, thick orange mats floating near the shore.

Also on the Ross Island is the historic Cape Royds (Figure 3). The Cape is an exposed, ice-free area surrounded by McMurdo Sound. There is an Adelie penguin rookery located at Cape Royds, close to Pony Lake and CR Pond 1 and 5, which likely contributes a lot of nutrients to these bodies of water. As seen in Figure 3 all the lakes and ponds on the cape are located close to each other and the coast, with Blue Lake, farthest inland, being only half a mile from the ocean. A total of eleven bodies of water was sampled in this area.

Table 1 shows the names of GPS locations of all the sampling sites. Figures 1-4 are maps displaying all the sampling sites in relation to other sites and McMurdo Station. Note that Picture Pond, Nussbaum Riegel Pond, McMurdo Hut Ridge Lower and Upper Ponds are not official names of these water bodies. Ponds collected in the Labyrinth region are also unnamed, and were simply numbered 1-4 as sampled. The six unnamed ponds at Cape Royds were also numbered 1-6 as sampled.

Table 1: Sampling Site Locations

Site Name	Region	Latitude	Longitude
Blue Lake North Lobe	Cape Royds, Ross Island	-77.54400	166.17663
Blue Lake South Lobe	Cape Royds, Ross Island	-77.54592	166.18173
Clear Lake	Cape Royds, Ross Island	-77.54218	166.16143
Coast Lake	Cape Royds, Ross Island	-77.54227	166.15038
Cape Royds Pond 1	Cape Royds, Ross Island	-77.55282	166.16377
Cape Royds Pond 2	Cape Royds, Ross Island	-77.54900	166.17730
Cape Royds Pond 3	Cape Royds, Ross Island	-77.54410	166.17265
Cape Royds Pond 4	Cape Royds, Ross Island	-77.54335	166.16695
Cape Royds Pond 5	Cape Royds, Ross Island	-77.55285	166.15843
Cape Royds Pond 6	Cape Royds, Ross Island	-77.54672	166.17207
Green Lake	Cape Royds, Ross Island	-77.54977	166.15743
Pony Lake	Cape Royds, Ross Island	-77.55285	166.16720
Labyrinth Pond 4	Labyrinth, Wright Valley	-77.56048	161.06362
Labyrinth Pond 1	Labyrinth, Wright Valley	-77.55837	160.94333
Labyrinth Pond 2	Labyrinth, Wright Valley	-77.55762	160.94950
Labyrinth Pond 3	Labyrinth, Wright Valley	-77.55577	160.97662
McMurdo Hut Ridge Lower Pond	McMurdo Hut Ridge, Ross Island	-77.84348	166.64460
McMurdo Hut Ridge Upper Pond	McMurdo Hut Ridge, Ross Island	-77.84122	166.64503
Many Glaciers Pond	Taylor Valley	-77.59823	163.31602
Marr 3	Taylor Valley	-77.70057	162.71142
Marr 4	Taylor Valley	-77.69602	162.71618
Nussbaum Riegel Pond	Taylor Valley	-77.68438	162.81473
Parera Pond	Taylor Valley	-77.65418	162.91317
Picture Pond	Taylor Valley	-77.58828	163.42370
Spaulding Pond	Taylor Valley	-77.65810	163.12335

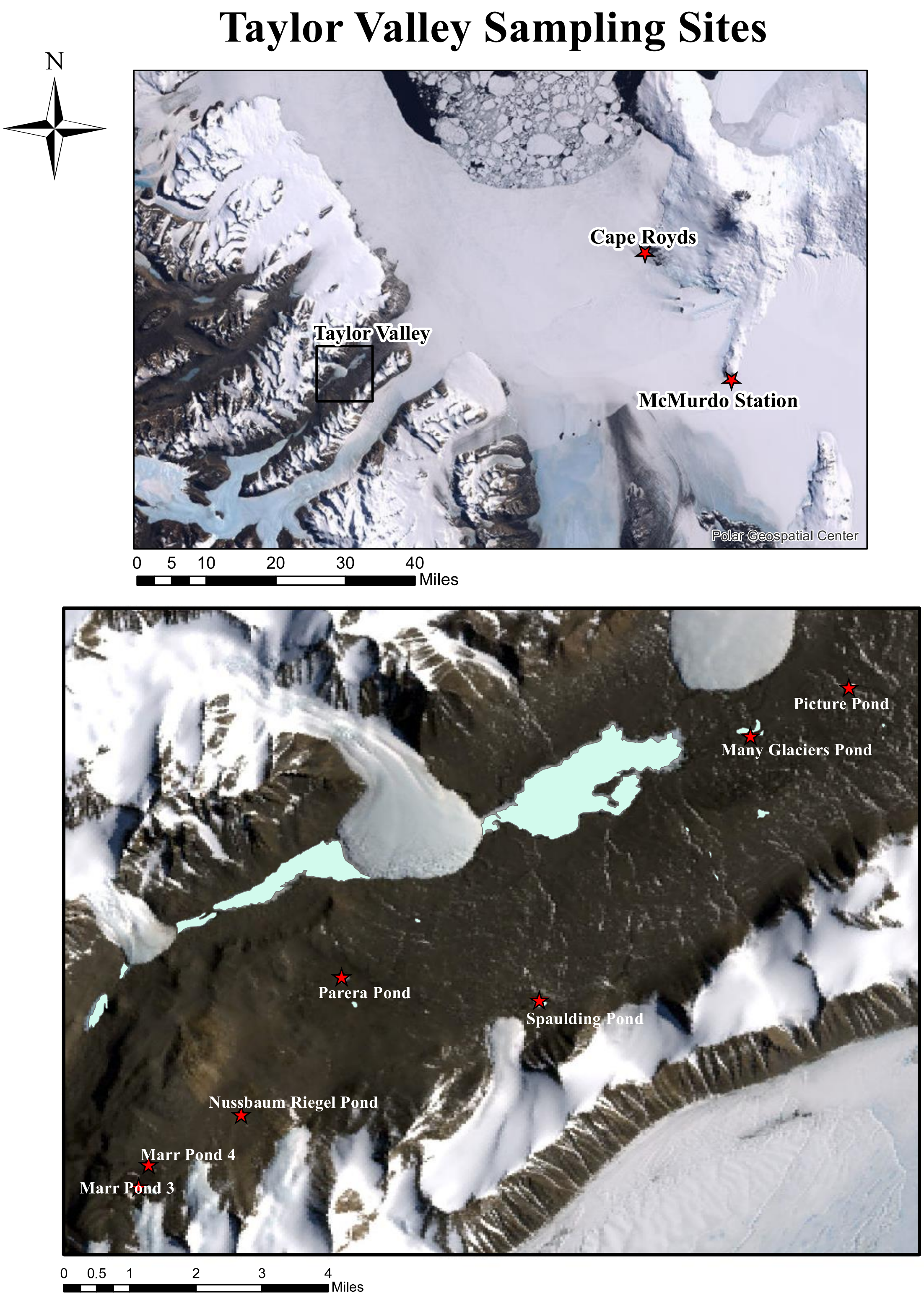


Figure 1: Sampling sites in the Taylor Valley with a larger map showing the valley in relation to other sampling sites

Labyrinth Sampling Sites

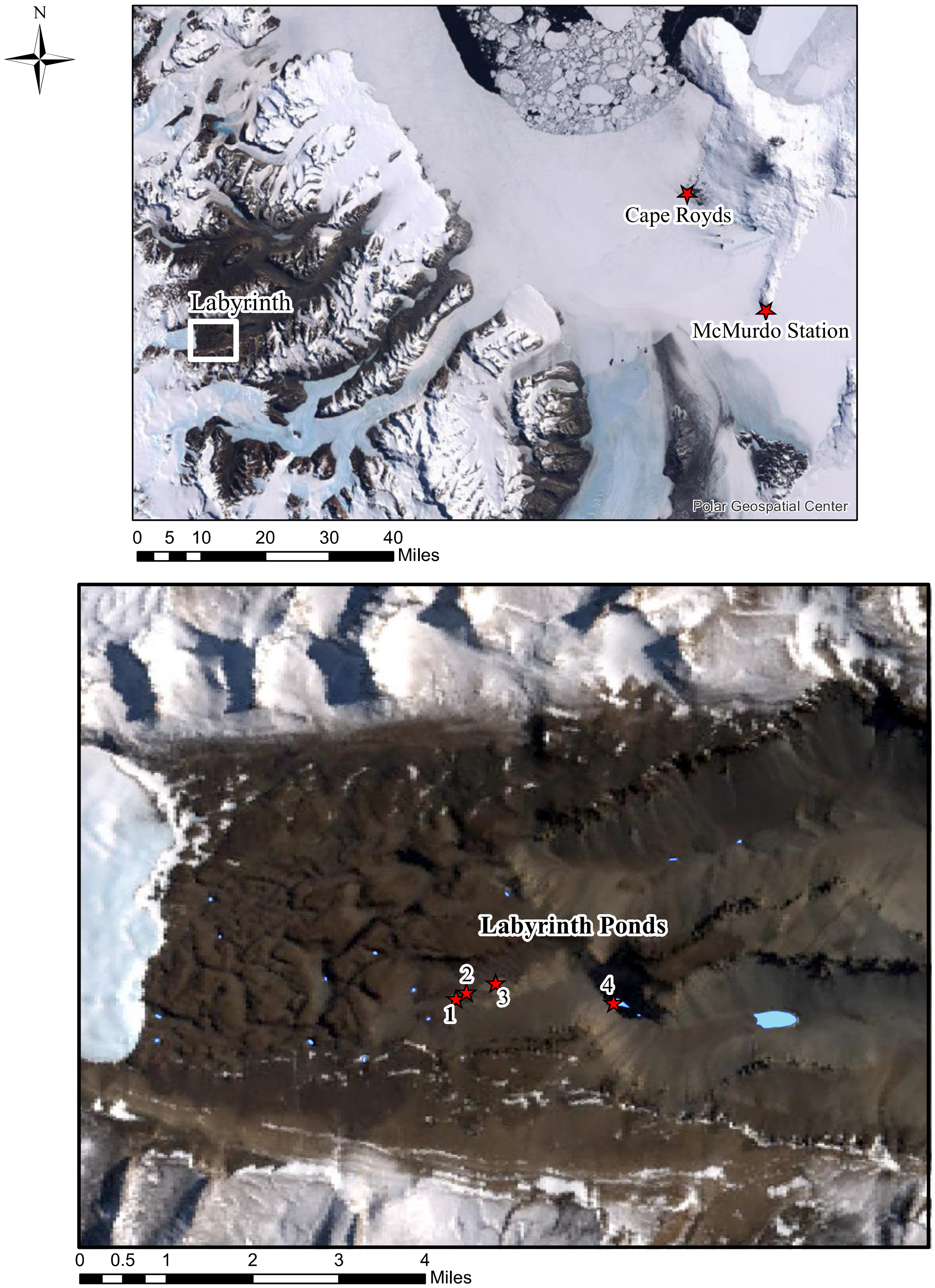


Figure 2: Sampling sites in the Labyrinth region of the Wright Valley and a larger map showing Labyrinth in relation to other sampling sites.

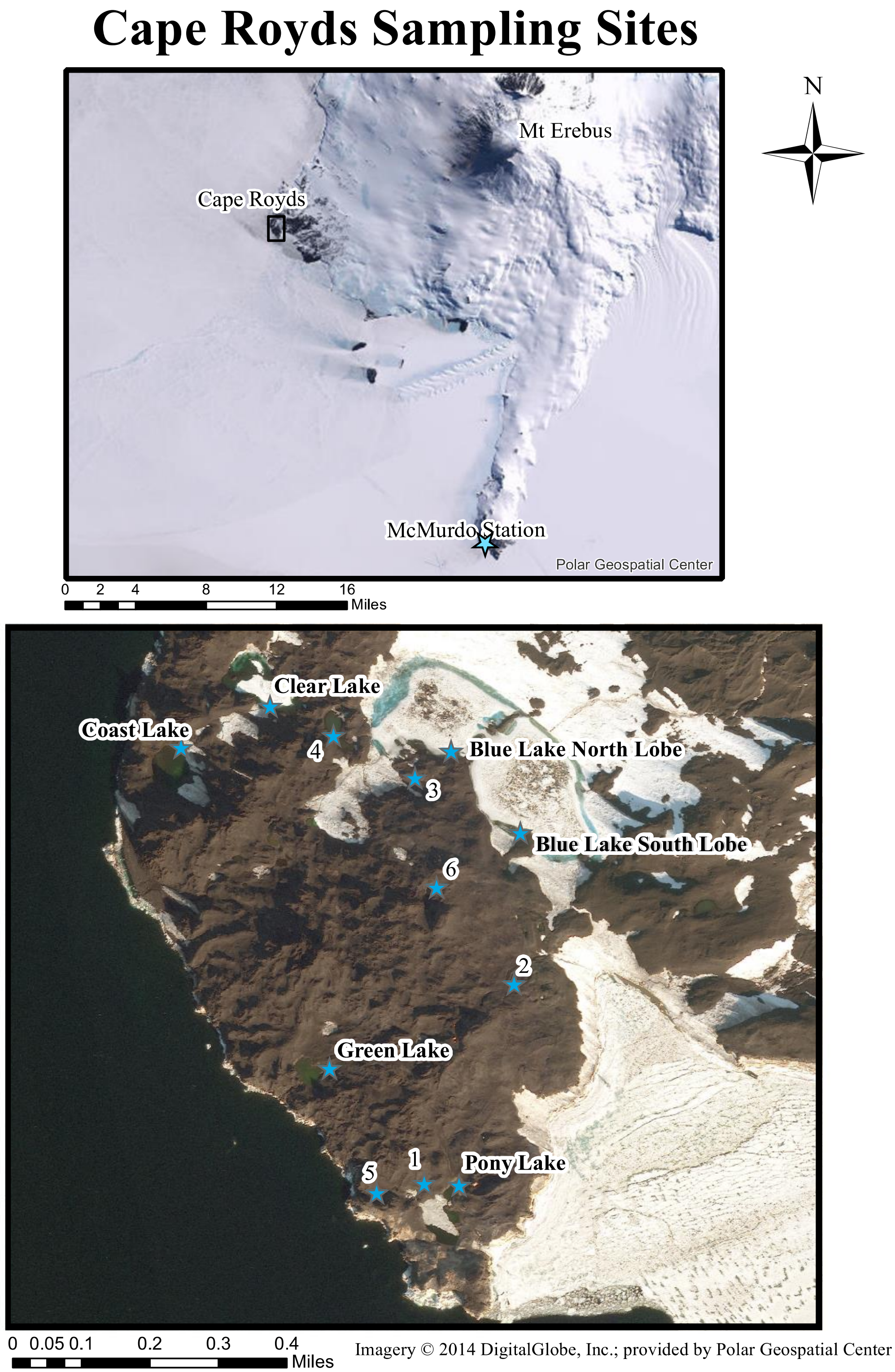


Figure 3: Cape Royds sampling sites and a larger map showing the cape in relation to other sampling sites.

McMurdo Hut Ridge Sampling Sites

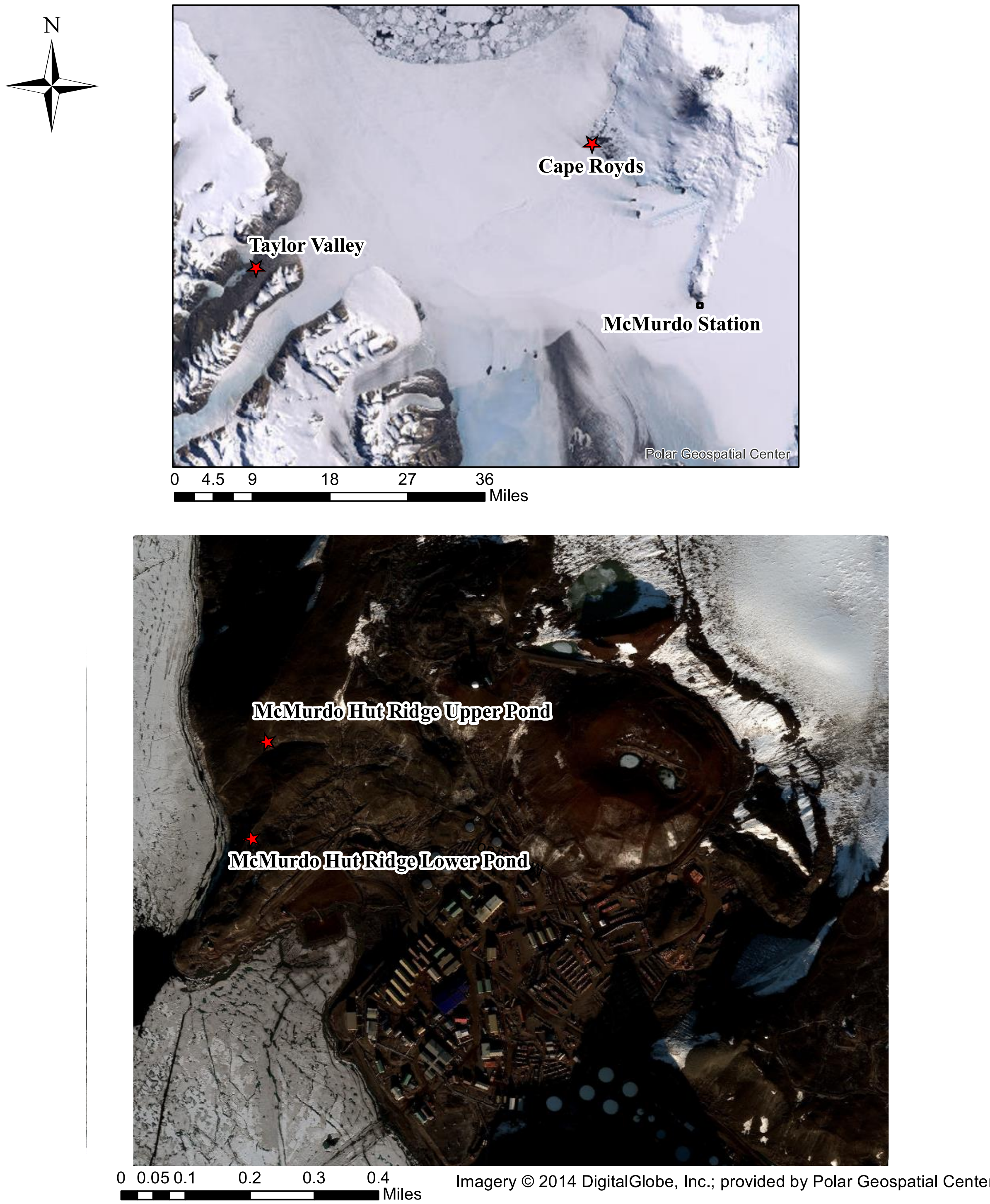


Figure 4: McMurdo Hut Ridge sampling sites and a larger map showing the ridge in relation to other sampling sites.

Field Collections

Algal mat samples were collected from 11 small lakes and ponds at Cape Royds, on Ross Island, 2 ponds near McMurdo Station on Ross Island, 7 ponds in the Taylor Valley and 4 ponds in the Labyrinth region of Wright Valley. Algal mats for this study were collected from mid-December 2013 to early January 2014 from similar habitats across all ponds and small lakes in order to control for any variation. Samples were collected from the ice-free moat of the ponds or small lakes, and from the most dominant mat type present, which in most cases was orange mat. Samples were collected using a brass cork borer (1.7 cm in diameter) and placed in a Whirlpack container with about 15 ml of pond water. For each sample three replicates were collected – one for diatom community analysis, one for ash-free dry mass (AFDM) analysis and one for chlorophyll-a (Chl-a) analysis. In the field laboratory, samples for diatom community analysis were preserved in 10% formalin and later shipped to University of Colorado at room temperature. Samples for AFDM and Chl-a were filtered onto pre-combusted (and pre-weighed in case of AFDM) Whatman GF/C filters, wrapped in foil and frozen for later analysis. All samples were filtered and processed within 24 hours of collection.

Temperature and conductivity was measured at the time of sample collection with YSI model 30 meters, with conductivity measurement corrected for temperature automatically by the instrument. Water samples were collected at the same time as the algal mat samples. Water for dissolved organic carbon (DOC) analysis was collected in 125-ml, pre-combusted amber glass bottles. Raw water was collected in 250-ml Nalgene. All water samples were filtered within 24 hours of collection in a field laboratory and water for DOC analysis was acidified using concentrated HCl and kept at 4 C until analyzed. Samples for nutrient analysis were frozen and later shipped to University of Colorado. Samples for all other aspects of water chemistry were kept at 4 C and either analyzed at the Crary Lab in McMurdo Station or shipped to Byrd Polar Research Center at Ohio State University for further analysis.

Lab Analysis

At the Crary Lab in McMurdo Station, chlorophyll-a samples were extracted in buffered acetone for 24 hours and analyzed using Turner Designs 10-AU field fluorometer (Welschemyer, 1994.). Ash-free dry mass (AFDM) samples were dried at 55 degrees C for 24 hours, weighted, then burned at 450 degrees C for 4 hours, weighted again, and then rewetted and dried again in order to determine mass loss due to hydration of sediments (Steinman, Lamberti, 1996).

Samples for diatom community analysis were digested using H_2O_2 in a hot water bath for several days and rinsed with distilled water at least 6 times to achieve a neutral pH. A subset of the digested material was dried onto glass cover slips and permanently mounted onto glass microscope slides with the mounting medium Z-rax (W.P. Dailey, Philadelphia, U.S.A). Olympus Vanox light microscope at 1250x was used to determine the relative abundances of species, with at least 300 individual valves counted per slide. This method limits the ability to distinguish between dead and live cells, but is necessary in order to make accurate species-level identifications.

In addition to the samples collected during the 2013/2014 season, several samples from the previous season were available with corresponding water chemistry data. The samples were collected a year earlier and at a later time in the season, in late January, comparing to the late December to mid January timeline of collections for the 2013/2014 season. These samples were collected using the same methods, however there is no AFDM and Chl-a data available. While this is limiting, these samples are still useful in determining seasonal and year-to-year variation in diatom communities of interest. Some of the samples collected during the 2013/2014 season also had replicates, so that for example, for a particular pond 3 samples for diatom community, 3 samples for AFDM and 3 samples for Chl-a were collected at the same location. This was done in order to determine if just one sample per location was enough to truly represent a snapshot of the current diatom community there or if there was a lot of variation that would be reflected in the 3 replicates.

Taxonomic identifications were done using updated information and references shown in Table 2 and the Antarctic Freshwater Diatom database (http://huey.colorado.edu/diatoms).

Table 2: Updated Taxonomic Information

Taxon	Authorship and Year	Current Antarctic Freshwater Database name
Halamphora oligotraphenta	(Lange-Bertalot) Levkov 2009	*Amphora oligotraphenta* (Haworth) Lange-Bertalot and Metzeltin 1996
Chamaepinnularia cymatopleura	(West and West) Cavacini 2006	*Chamaepinnularia cymatopleura* (West and West) Cavacini 2006
Humidophila arcuata	(Heiden) Lowe, Kociolek, Johansen, Van de Vijver, Lange-Bertalot & Kopalová 2014	*Diadesmis contenta* (Grunow) Mann 1990
Humidophila australis	(Van de Vijver and Sabbe) Lowe, Kociolek, Johansen, Van de Vijver, Lange-Bertalot & Kopalová 2014	*Diadesmis perpusilla* (Grunow) Mann 1990
Microcostatus naumannii	(Hustedt) Lange–Bertalot 1999	*Fallacia naumannii* (Hustedt) Mann 1990
Nitzschia cf. *commutata*	Grunow 1880	*Hantzschia* sp. #5
Hantzschia hyperaustralis	Van de Vijver and Zidarova 2010	*Hantzschia subrupestris* Lange-Bertalot 1993
Luticola murrayi sensu West	(West and West) Mann 1990	n/a
Luticola murrayi sensu Levkov	(West and West) Levkov 2013	n/a
Luticola vermeulenii	Van de Vijver 2011	*Luticola mutica* (Kützing) Mann 1990
Luticola permuticopsis	Kopalová and Van de Vijver 2011	*Luticola muticopsis fo. capitata* (Carlson) Mann 1990
Navicula cf. *seibigiana*	Lange-Bertalot 1993	*Navicula cincta* (Ehrenberg) Ralfs 1861
Nitzschia westiorum	(West and West) Van de Vijver 2012	*Nitzschia westii* (West and West) Kellogg and Kellogg 1980
Psammothidium papilio	(Kellogg, Stuiver, Kellogg and Denton) Van de Vijver and Kopalová 2012	*Psammothidium chlidanos* (Hohn and Hellerman) Lange-Bertalot 1999
Stauroneis cf. latistauros	Van de Vijver and Lange-Bertalot 2004	*Stauroneis pseudagrestris* Lange-Bertalot and Werum 2004
Craspedostauros laevissimus	(West & West 1911) Sabbe 2003	*Stauronella constricta* (Ehrenberg) Mereschkowsky 1901

Data Analysis

Diatom community richness was calculated by adding the total number of different species present in a particular sample. When performing the relative abundance counts, at times fragments of diatom valves cannot be identified down to the species level. In this case, the fragments are counted towards a genus. For the calculations of community richness, diversity and evenness these genus counts were only considered if no species of that genus were identified in the whole sample and only fragments were seen.

Community diversity was calculated with the Shannon-Weiner index as follows:

$$H' = -\sum_{i=1}^{S} \left(p_i \ln p_i \right)$$

where p_i is the relative abundance of a species i and S is the number of species in a sample. Evenness was calculated as the ratio of H' to H'_{max}, which equals lnS.

In order to see how similar the replicate counts are to each other and see how similar the communities of different bodies of water may be to each other a hierarchical cluster analysis was performed on diatom community data using Bray–Curtis dissimilarity distance matrices. The average linkage method was chosen because it produced a classification tree with the highest cophenetic correlation coefficient.

Nonmetric multidimensional scaling (NMDS) analysis was performed on all of the diatom community samples, as well as several stream community counts. All counts less than 1% of relative abundance were removed. This analysis used the Bray-Curtis dissimilarity matrix of relative abundance data (in form of proportions), using the vegan package in R.

Principal Components Analysis (PCA) was used to examine the variation of environmental variables in the sampled bodies of water. All of the water chemistry variables, plus the Chlorophyll-a and AFDM were used for this analysis. The data was transformed as follows: log10(x+1).

A redundancy analysis (RDA) was performed, which explicitly uses the environmental variables to explain the variation in community species composition. Unlike the PCA, not all environmental variables were chosen for this analysis. Significant variables ($p < 0.05$) were chosen and consisted of: sodium, nitrate, phosphate, ammonium and chlorophyll-a. The environmental variables were transformed the same way as for the PCA analysis and the species abundance data was transformed using the Hellinger transformation (cite). In order to account for geographical differences between the sites, the longitudinal data for each body of water was used. This data was used as the conditional variable and accounted for only 5% of variability. The environmental variables accounted for 50% of variability.

RESULTS

Cape Royds Collections

Ernest Shackleton's Nimrod Expedition of 1907-1909 chose Cape Royds for their winter-over quarters, and the hut still stands there to this day. The expedition collected many samples from the small lakes and ponds on the Cape. These samples became the source for some of the first descriptions of freshwater algae in Antarctica (West & West, 1911). One of the goals of our study was to follow the expedition's steps and take samples from the same lakes and ponds in order to examine any environmental change that occurred over the last hundred years in this area. All the major lakes at Cape Royds were sampled – Blue Lake (North and South Lobe), Clear Lake, Coast Lake, Green Lake and Pony Lake. In addition, six smaller ponds throughout the cape were sampled.

Two maps exist from the members of the Expedition, one is included in James Murray's (1910) report and is shown in Figure 5 and the other comes from Raymond Priestley's (1908) journals from the expedition and shows in in Figure 6. Both maps show the major lakes on the Cape, though with slightly differing shapes. Priestley's map shows more detail, with several ponds throughout the area, labeled simply "Tarn". In addition, this map shows several small islands present in Clear Lake. At the time of collection in 2013, Clear Lake was partially covered by ice, but some of these islands are still visible (see Appendix A). This is important to note since it points to the fact that the water level in this lake has not changed dramatically in the last 100 years since the Nimrod Expedition.

The two maps also vary in the location of the small Round Lake, as named in Priestley's map. According to his map, this Round Lake is the middle of three small water bodies located just off of the North lobe of Blue Lake. Murray's map shows this small lake as being the first, closest to Blue Lake. This discrepancy is important to note, as this Round Lake was sampled for this study and is named Cape Royds Pond 4.

Descriptions of the lakes written by the members of the expedition are astonishingly accurate to what the lakes look like to this day. Murray (1910) commented on the Blue Lake as being the largest of all, and most deserving of the name "lake". It was then and still is "divided into two portions, with a very narrow strait". West and West (1911) publication describes Blue Lake as "never even partially melted… the ice of this lake yielded water of such purity that it could be used in place of distilled water in chemical experiments". At the time of sampling Blue Lake in the 2013/2014 season, the material was found under a thin layer of ice that had to be broken and moved in order to sample, which is consistent with the descriptions from a hundred years prior. The two-lobed structure of the lake is clearly evident from satellite photos. West and

West (1911) also did not find any diatoms in samples from Blue Lake, while the samples from the past season had diatoms in enough abundance to perform relative abundance counts.

Clear Lake was named for the quality of the ice (West & West, 1911). The lake has extensive descriptions of the particular mat type that occurs there – coarsely lobed and undulate, and can be seen through the clear ice growing from the bottom (Murray, 1910). At the time of sampling for this study, the ice on Clear Lake was well melted out, forming a large moat around the shore of the lake. The ice in the middle of the lake was melted so that it formed a shelf about 6 inches under the surface of the water and pink, lobed mat, much like the description in Murray's journal, sat on top of the shelf. Large pieces of mat were floating in melted water and lay close enough to shore to be sampled. While West and West (1911) did not mention presence of diatoms in the lobed, floating mats, they do mention that samples collected from the bottom of the lake contained many species of diatoms.

Coast Lake is described as completely ice-free by January (West & West, 1911), which was the case during sample collection in the 2013/2014 season as well. Here again, West and West found no diatoms in the samples, while this study found them in abundance.

"Almost dried-up lake", as described by West and West (1911), located close to the penguin rookery on the Cape and containing large numbers of *Navicula muticopsis*. One of the ponds sampled in 2013/2014 season, pond 5, is located closest to the rookery and the relative abundance count for this sample has 80% *Luticola muticopsis*, which is a modern, updated name for *N.muticopsis*. If this is in fact the same body of water as was sampled by the Nimrod Expedition then its diatom community shows great stability over time.

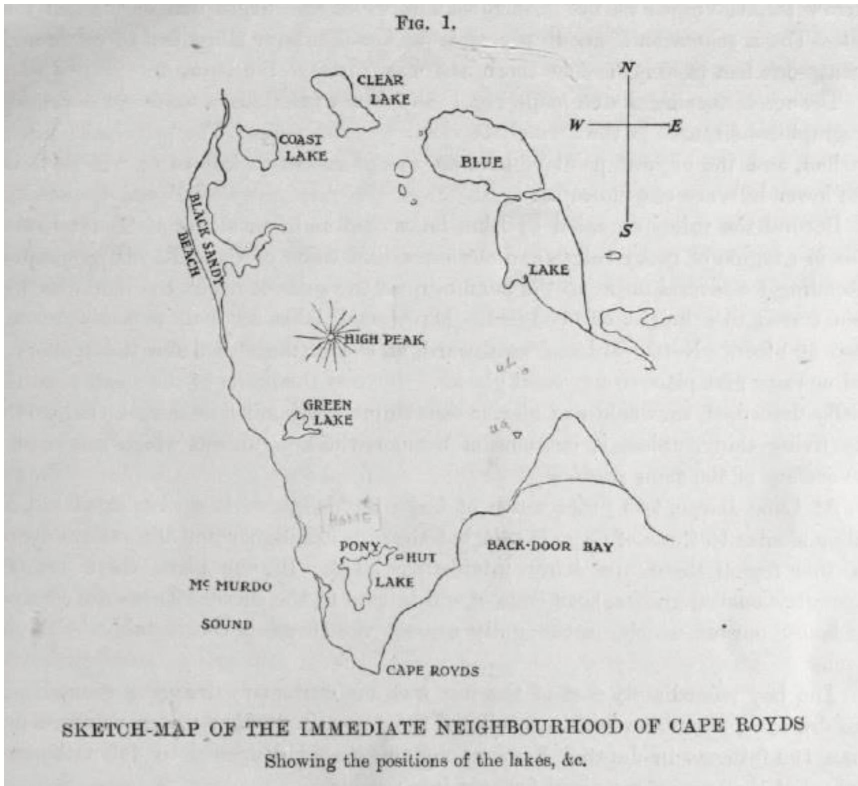


Figure 5: Murray's sketch map of Cape Royds

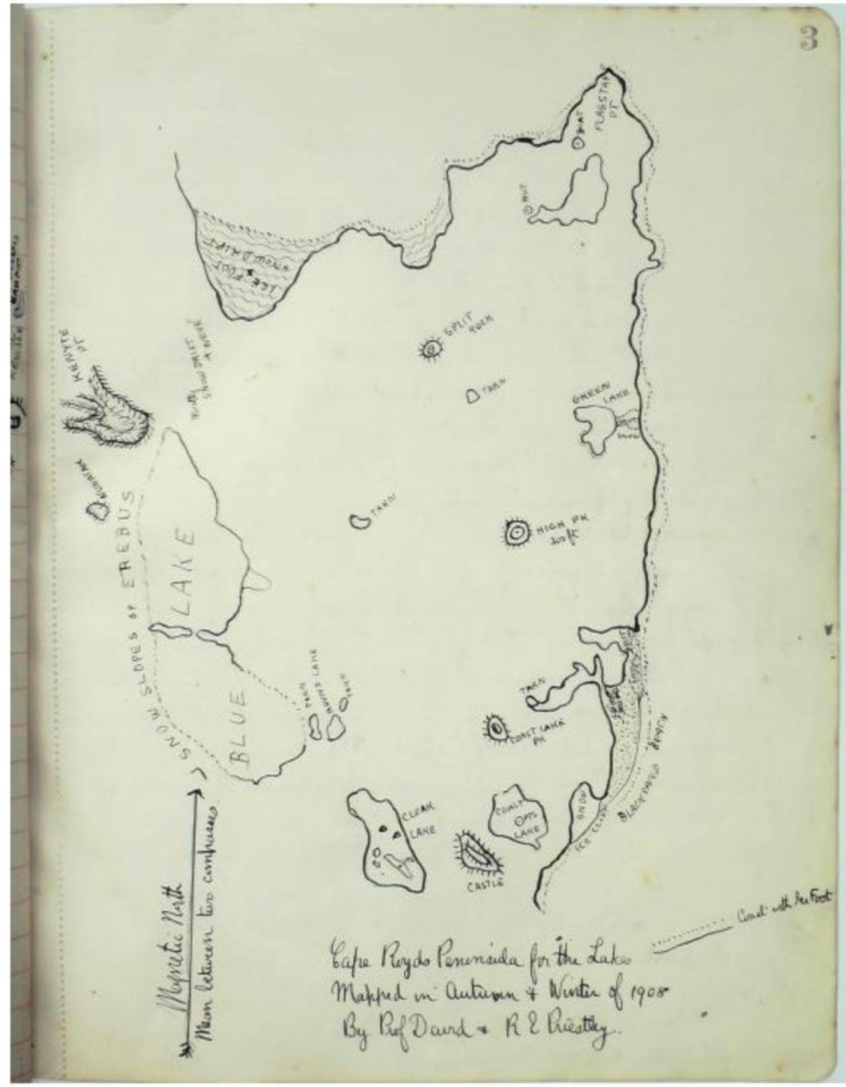


Figure 6: Priestley's sketch map of Cape Royds

Water Chemistry and Physical Properties of the Algal Mats

Twenty-one water chemistry variables were measured at the time of collection or later in the lab. Table 4 summarizes the relevant water chemistry data for all of the samples collected during the 2013/2014 season. The table is organized by region and salinity. See Appendix C for additional cations data as well as all of the available water chemistry for samples taken in 2012/2013 season.

Cape Royds contains both saline and fresh ponds and lakes. For this study, fresh waterbodies are defined as ones having less than 150 mg/L of sodium. Sodium concentrations in the sampled ponds and lakes at Cape Royds ranged from 1,952 mg/L in Pony Lake to 357 mg/L in CR Pond 4 for saline waterbodies, and from 134 mg/L in Coast and Clear Lake to 11.3 mg/L in North Lobe of Blue Lake for fresh waterbodies. Conductivity ranged from 10.8 ms in Pony Lake to 1.3 ms in CR Pond 3 for saline waterbodies, and from 845 µs in Coast Lake to 172 µs in South Lobe of Blue Lake. Chlorine range was 3,377-647 mg/L for saline waterbodies and 228-17.4 mg/L for fresh waterbodies. Magnesium range was 258-50 mg/L for saline waterbodies and 17.2-1.3 mg/L for fresh waterbodies.

The pH values in saline ponds at Cape Royds ranged from 7.4 to 9.5, with the three most saline ponds having pH values above 9. Fresh ponds and lakes had a more narrow range, from 6.7 to 7.4. Water temperature measured at the time of sampling ranged from 1.5° to 10.1° C, with most ponds and lakes being above 4° C. Alkalinity ranged from 1.4 meq/L to 0.1 meq/L for all samples in this region.

In the Cape Royds samples, nitrate concentrations ranged from 6.1 mg/L in Pony Lake to 0.005 mg/L in the North lobe of Blue Lake. Phosphate concentrations ranged from 8.6 mg/L in

CR Pond 5, an order of magnitude higher than any other sample in this region, with the lowest being 0.015 mg/L in the South lobe of Blue Lake. Sulfate ranged from 603 mg/L to 92 mg/L in saline ponds, and from 40 mg/L to 2.8 mg/L in fresh ponds and lakes. Ammonium ranged from 2 mg/L to 0.025 mg/L in saline ponds, and from 0.024 mg/L to 0.005 mg/L in fresh ponds. Dissolved organic carbon concentrations ranged from 38 ppm to 0.6 ppm for lakes and ponds in this region. Silica concentrations ranged from 5,200 ppb in CR Pond 5 to 224 ppb in Pony Lake.

Two ponds sampled on the McMurdo Hut Ridge on the Ross Island were both saline, with sodium concentrations of 582 mg/L in the Lower and 765 mg/L in the Upper pond. Conductivity was 2,936 μs for the Lower and 4,253 μs for the Upper pond. Chlorine concentrations were 854 mg/L and 1,126 mg/L for Lower and Upper pond respectively. Magnesium concentrations were 68 mg/L and 114 mg/L for the Lower and Upper pond respectively.

pH values were measured at 8.7 for the Lower McMurdo Hut Ridge Pond and 8.0 for the Upper pond. Water temperature at the time of collection was 8.6° C for the Lower pond and 6.3° C for the Upper pond. Alkalinity was 1.7 meq/L and 2.2 meq/L for the Lower and Upper pond respectively.

Nitrate concentrations of the McMurdo Hut Ridge Ponds were 0.002 mg/L and 0.005 mg/L for the Lower and Upper pond. Phosphate concentrations were 0.0065 mg/L and 0.0044 mg/L for the Lower and Upper ponds. Sulfate concentrations were 348 mg/L and 418 mg/L for the Lower and Upper pond. Ammonium concentrations were 0.087 mg/L for the Lower pond and 0.045 mg/L for the Upper pond. Dissolved organic carbon concentrations were 4.1 ppm and 5.3 ppm for the Lower and Upper pond respectively. Silica concentrations were 765 ppb in Lower pond and 186 ppb for the Upper pond.

All but one pond in Taylor Valley were fresh. Picture Pond, the only saline pond in this region had sodium concentrations of 2,329 mg/L, which is higher than even the most saline lake at Cape Royds. Sodium concentrations for the fresh ponds in Taylor Valley ranged from 142 mg/L in Nussbaum Riegel Pond to 8.2 mg/L in Spaulding Pond. Conductivity ranged from 648 μs for Marr Pond 3 to 115 μs for Marr Pond 4. Conductivity of Picture Pond at the time of sampling was 8.640 ms. Chlorine ranged from 1,372 mg/L in Picture Pond, 509 mg/L in N.Riegel Pond to 13.4 mg/L in Spaulding Pond. Magnesium ranged from 98 mg/L in N. Riegel Pond to 1.76 mg/L in Many Glaciers Pond.

pH values were measured at the time of sampling and ranged from 10.2 in Picture Pond to 6.6 in Marr Pond 4. Temperatures ranged from 10° C in Spaulding Pond to 2.2° C in Marr Pond 3. Alkalinity, measured in lab later on, was 63.7 meq/L in Picture Pond, and ranged from 0.7 meq/L to 0.2 meq/L for the rest of the ponds Taylor Valley.

Nitrate concentrations in Taylor Valley ponds ranged from 0.011 mg/L in N.Riegel Pond to practically undetectable in Picture Pond. Phosphate concentrations ranged from 0.089 mg/L in Picture Pond to below 0.001 mg/L in Parera and Spaulding Ponds. Sulfate concentrations ranged from 100 mg/L in N.Riegel Pond to 2.7 mg/L in Many Glaciers Pond. Ammonium concentrations ranged from 0.18 mg/L in Picture Pond to 0.015 in Marr Pond 4. Dissolved organic carbon (DOC) was highest in Picture Pond than any other sampled body of water, at 628 ppm. The rest of the ponds in this region had DOC concentrations ranging from 1.8 ppm to 0.8 ppm. Silica concentrations ranged from 2,726 ppb in Marr Pond 3 to 390 ppb in Many Glaciers Pond.

Labyrinth Ponds in the Wright Valley were all fresh ponds, with sodium concentrations ranging from 21 mg/L to 100 mg/L. Conductivity ranged from 161 μs for pond 4 to 962 μs for pond 3. Magnesium ranged from 10 mg/L in pond 4 to 48 mg/L in pond 3. Chlorine ranged from 21.5 mg/L in pond 4 to 196 mg/L in pond 3. Measured pH values at the time of sampling ranged from 7.4 in pond 3 to 8.4 in pond 1 and 4. Water temperature was low, comparing to other regions, ranging from 2.2° C to 3.1° C. Alkalinity was measured and ranged from 0.3 meq/L for pond 1 to 0.8 meq/L for pond 4.

Nitrate concentrations for the four ponds in the Labyrinth ranged from 2.5 mg/L in pond 4 to 23.1 mg/L, higher than most other sampled pond with the exception of Pony Lake and CR Pond 5. Phosphate concentrations ranged from 0.006 mg/L in pond 4 to 0.0006 mg/L in other three ponds. Sulfate concentrations ranged from 41.5 mg/: in pond 1 to 32 mg/L in pond 3. Ammonium concentrations ranged from 0.031 mg/L in pond 4 to undetectable in pond 1 and 2. Dissolved organic carbon ranged from 0.7 ppm to 0.9 ppm. Silica concentrations were quite high, ranging from 2,096 ppb in pond 1 to 4,827 ppb in pond 4.

Principal Component Analysis (PCA) of all of the environmental parameters is shown in Figure 7. Axis 1 was strongly correlated with anion and cation concentrations, whereas Axis 2 is more correlated with alkalinity and nutrient concentrations. Dissolved organic carbon variable was taken out of this analysis because of its very wide range that affected primarily only Picture Pond. This approach allowed for a better resolution of relationships between other environmental variables and the waterbodies. Many of the fresh ponds in Taylor Valley, Labyrinth and Cape Royds show a clear negative relationship to anion and cation concentrations. Picture Pond is clearly separated and appears to have a strong correlation with alkalinity. Saline ponds from Cape Royds show a positive correlation with conductivity and higher concentrations of cations.

Many of the variables are highly correlated with each other. Pearson's correlation coefficient (ρ) for the relationship between sodium and potassium is 0.96, between sodium and magnesium it is 0.91, sodium and chloride it is 0.98, sodium and conductivity it is 0.89, and between sodium and sulfate it is 0.89. Phosphate and nitrite are highly correlated (ρ= 0.97). Sulfate is highly correlated with magnesium (ρ=0.97), calcium (ρ=0.87) and chlorine (ρ=0.91).

Table 3: Ash-free dry mass (AFDM) and Chlorophyll-a (Chl-a) values.

Region	Pond	Conduct.	AFDM (mg/cm^2)	Chlorophyll-a ($\mu g/cm^2$)
Cape Royds	Pony Lake	10830	8.41	46.08
	CR Pond 6	9870	56.48	23.23
	Green Lake	9440	26.78	38
	CR Pond 2	6910	19.47	48.77
	CR Pond 1	5630	46.17	104.43
	CR Pond 5	4910	27.44	105.43
	CR Pond 4	2256	24.1	57.75
	CR Pond 3	1385	42.11	61.04
	Clear Lake	845	32.42	34.11
	Coast Lake	842	45.64	68.82
	Blue Lake N	820	14.41	12.08
	Blue Lake S	173	14.41	18.25
MCM	MCM Upper	4253	14.14	6.46
	MCM Lower	2936	24.98	31.11
Taylor Valley	Picture Pond	8640	34.14	65.13
	Marr 3	648	66.78	13.13
	Spaulding Pond	464	114.23	24.23
	Many Glaciers Pond	398	16.96	30.71
	Parera Pond	263	34.1	9.9
	N. Riegel Pond	184	6.34	3.24
	Marr 4	115	13.39	6.1
Wright	Labyrinth 3	962	34.05	10.13
	Labyrinth 2	411	33.92	9.17
	Labyrinth 4	161	25.81	3.69
	Labyrinth 1	128	87.31	26.89

Table 3 shows the results for Ash-free Dry Mass (AFDM) and Chlorophyll-a (Chl-a) measurements for all samples collected in the 2013/2014 season, as well as the conductivity values for each sample. This table is organized by region as well as conductivity.

Cape Royds ponds had AFDM values ranging from 8.4 mg/cm^2 to 56.5 mg/cm^2. Taylor Valley samples ranged from 6.3 mg/cm^2 to 114.23 mg/cm^2. Despite this difference in range a two-tailed t-test found there to be no significant difference between the regions ($t=-0.74$, $p=0.48$). There was also no significant difference between saline and fresh ponds on Cape Royds ($t=0.49$, $p=0.63$).

Labyrinth region ponds had AFDM values ranging from 25.81 mg/cm^2 in Pond 4 to 87.21 mg/cm^2 in Pond 1. McMurdo Hut Ridge Lower pond had an AFDM value of 24.98 mg/cm^2 and the Upper pond had a value of 14.14. mg/cm^2.

Chlorophyll-a (Chl-a) values for Cape Royds samples ranged from 12.08 μg/cm^2 for the North lobe of Blue Lake to 105.43 μg/cm^2 in CR Pond 5. Taylor Valley samples ranged in Chl-a from 3.24 μg/cm^2 for Nussbuam Riegel Pond to 65.13 μg/cm^{2}in Picture Pond. When compared with a two-tailed t-test Cape Royds samples had significantly higher values than the Taylor Valley samples ($t=2.48$, $p=0.02$). Cape Royds samples had a mean of 51.49 μg/cm^2 and Taylor Valley samples had a mean 21.78 μg/cm^2 of chlorophyll-a. Another two-tailed t-test compared the Chl-a values for saline ponds regardless of region to fresh waterbodies also regardless of the region. Saline ponds were found to have significantly higher Chl-a values than the fresh ponds ($t=2.86$, $p=0.008$), with a mean of 48.04 μg/cm^2 for saline ponds comparing to 20.38 μg/cm^2 for fresh ponds.

Table 4: Summary of Water Chemistry Data for samples collected in 2013/2014 season organized by conductivity within each region.

Region	Pond	Conduct.	Na (mg/L)	Mg (mg/L)	Ca (mg/L)	Cl (mg/L)	NO3 (mg/L)	PO4 (mg/L)	NO2 (mg/L)	SO4 (mg/L)	NH4 (mg/L)	pH	Temp °C	Alkalinity	Si(ppb)	DOC (ppm)
Cape Royds	**Pony Lake**	**10830**	**1952**	258	59	3377	6.149	0.2022	0.156	498	0.472	9.43	4	0.8	224.0	8.7
	CR Pond 6	**9870**	**1873**	187	75.2	2915	0.002	0.0127	0.001	603	0.054	9.15	8.9	1.4	887.1	6.5
	Green Lake	**9440**	**1700**	199	48	2953	0.381	0.0454	0.038	357	0.341	9.47	9.4	1.3	151.6	11.5
	CR Pond 2	**6910**	**1192**	185	39	2189	0.056	0.0308	0.003	319	0.031	7.88	6.3	0.9	1595.3	2.4
	CR Pond 1	**5630**	**886**	122	30	1599	1.499	0.2217	0.044	187	1.89	7.4	6.3	0.6	335.2	5.2
	CR Pond 5	**4910**	**1162**	147	43.5	1951	4.668	8.623	0.654	321	2	8.35	9.1	0.9	5195.7	37.9
	CR Pond 4	**2256**	**357**	49.7	18	647	0.01	0.0221	0.004	91.6	0.053	8.6	8	0.7	1202.4	3.3
	CR Pond 3	**1385**	**416**	62.7	16	785	0.002	0.0245	0.001	110	0.025	7.58	5.4	0.7	1251.1	1.3
	Clear Lake	845	134	16.7	5.1	218	0.054	0.1219	0.002	40	0.015	7.37	2.9	0.3	972.6	0.9
	Coast Lake	842	134	17.2	5.9	222	0.036	0.0616	0.003	32.1	0.115	7.58	10.1	0.2	1051.7	4.8
	Blue Lake N	820	11.3	1.26	0.53	17.4	0.005	0.0159	0	2.79	0.024	6.7	6.3	0.1	286.5	0.6
	Blue Lake S	172.7	28.9	4.05	1.56	48.5	0.006	0.0154	0.001	9.5	0.005	7.52	1.5	0.1	279.9	1.2
MCM	**MCM Upper**	**4253**	**765**	114	64.5	1126	0.005	0.0044	0.001	418	0.045	8.01	6.3	2.2	185.7	5.3
	MCM Lower	**2936**	**582**	67.6	44.8	854	0.002	0.0065	0.001	348	0.087	8.71	8.6	1.7	765.5	4.1
Taylor Valley	**Picture Pond**	**8640**	**2329**	21	11	1372	0	0.0898	0.004	26.8	0.175	10.2	7.1	63.7	1843.3	628.5
	Marr 3	648	66.1	19.9	19.7	138	0.002	0.0011	0.002	48	0.022	7.42	2.2	0.5	2726.4	1.8
	Spaulding Pond	464	8.16	2.8	22.4	13.4	0.002	0.0009	0.001	6.89	0.047	8.28	9.9	0.7	1499.1	1
	Many Glaciers Pond	398	9	1.76	6.13	6.5	0.004	0.0237	0.001	2.46	0.005	7.53	7.4	0.7	379.6	0.8
	Parera Pond	263.2	25.6	8.59	7.53	64	0.004	0.0008	0.001	11.4	0.053	7.31	5.7	0.2	504.8	1.7
	N. Riegel Pond	184	142	97.8	28.5	509	0.011	0.002	0.002	100	0.019	7.04	3.1	0.5	1186.8	1.4
	Marr 4	115.3	9.8	2.59	4.21	21	0.006	0.001	0.002	3.8	0.015	6.59	2.4	0.2	577.7	0.8
Wright	Labyrinth 1	127.8	33.0	11.8	5.1	42.0	3.9	0.0006	0.2	41.5	0.0	8.4	2.2	0.3	2096.5	0.8
	Labyrinth 2	410.9	53.8	24.6	6.0	94.3	11.4	0.0006	0.2	33.1	0.0	7.9	2.4	0.4	2236.0	0.7
	Labyrinth 3	962.0	100.4	47.7	10.7	195.8	23.1	0.0006	0.3	32.0	0.1	7.4	3.1	0.7	3326.9	0.9
	Labyrinth 4	161.3	21.2	10	8.6	21.5	2.503	0.0061	0.022	32.8	0.031	8.44	2.6	0.8	4827.6	0.7

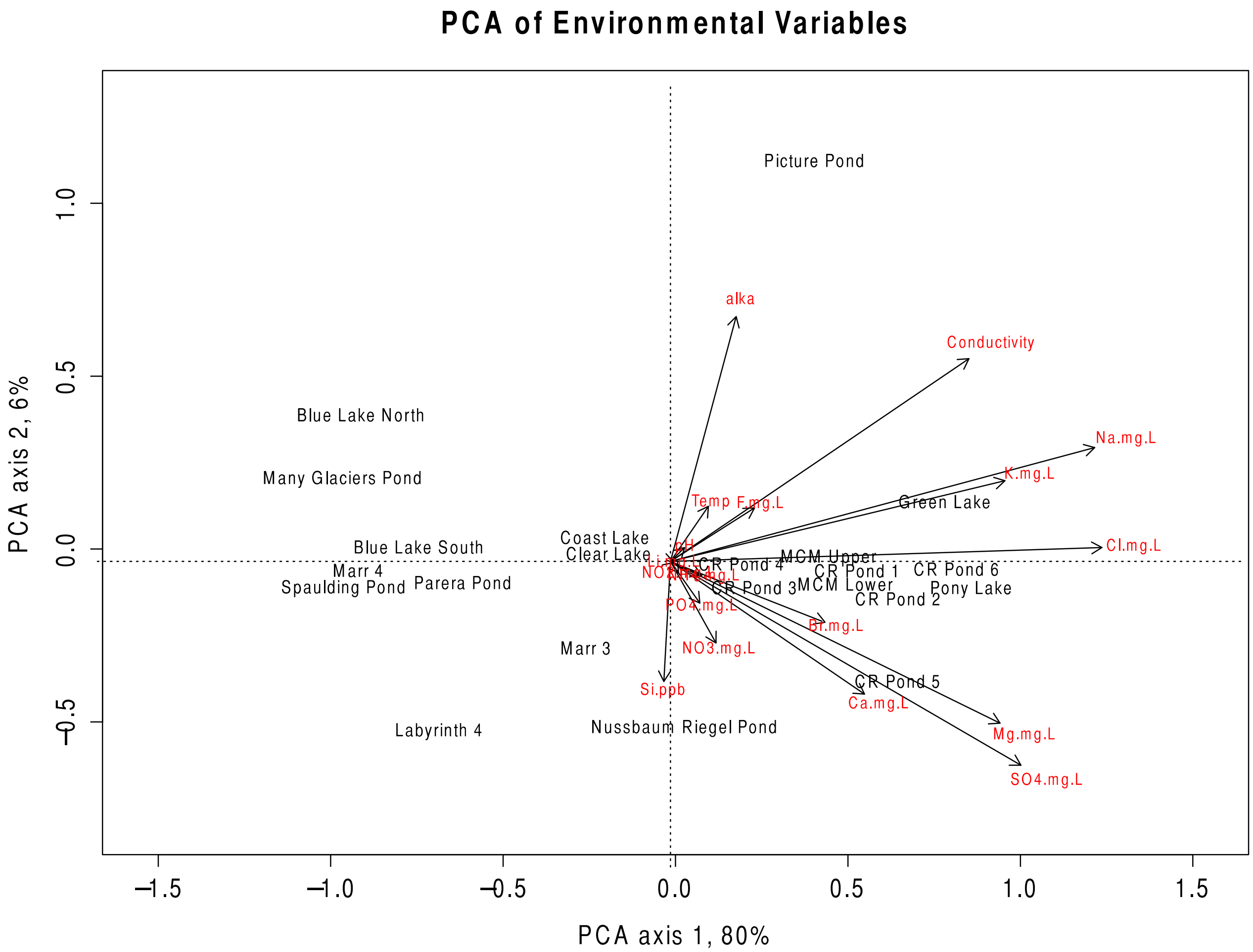


Figure 7: Principal Component analysis of environmental variables

Diatom Community Richness and Diversity

The calculated Shannon's Diversity Index, Richness and Evenness are shown in Table 5 for each of the samples that have a relative abundance counts. For this table, sodium concentrations are shown, instead of conductivity, because some of those values were measured for the 2012/2013 season, but no conductivity data exists for those samples. Missing values are left blank.

A two-tailed t-test was performed on Richness values comparing all of the Cape Royds samples to the Taylor Valley samples. Species Richness of the Cape Royds samples was significantly lower ($p=0.001$) than the Taylor Valley samples. Mean Richness for Cape Royds samples was 7.64 and for Taylor Valley samples 17.4. Diversity values were also significantly lower ($p<0.005$) between Cape Royds waterbodies and Taylor Valley waterbodies. Mean Diversity for Cape Rods was 0.98 and mean for Taylor Valley samples was 1.91. There was no significant difference, however, between saline and fresh ponds at Cape Royds ($p=0.31$). The sample size for McMurdo Hut Ridge Ponds and Labyrinth region was too small to compare them to other regions, however, looking at the table it appears that McMurdo Hut Ridge Ponds represent a middle ground between low diversity and low richness Cape Royds region and high diversity and high richness Taylor Valley region. Labyrinth Pond 4 is has one of the lowest richness and lowest diversity values of all of the collected samples.

Table 5: Shannon-Weiner Diversity Index, Richness and Evenness values for all samples with a relative abundance count

Region	Sample Name	Date Sampled	Na mg/L	Shannon Index	Richness	Evenness
Cape Royds	Pony Lake	24-Jan-13	1491	0.17	5	0.11
	Pony Lake	2-Jan-14	1952	0.15	3	0.14
	Cape Royds Pond 6	2-Jan-14	1873	1.49	8	0.71
	Green Lake	24-Jan-13		0.63	5	0.42
	Green Lake	2-Jan-14	1700	0.9	5	0.56
	Cape Royds Pond 2	21-Dec-13	1192	0.93	6	0.52
	Cape Royds Pond 5	2-Jan-14	1162	0.38	3	0.35
	Cape Royds Pond 1	21-Dec-13	886	0.81	5	0.51
	Clear Lake	24-Jan-13	773	1.34	7	0.69
	Cape Royds Pond 3	21-Dec-13	416	0.9	6	0.5
	Cape Royds Pond 4	21-Dec-13	357	1.76	13	0.69
	Clear Lake	21-Dec-13	134	1.74	13	0.68
	Coast Lake	24-Jan-13	134	0.44	9	0.2
	Coast Lake	21-Dec-13	134	0.84	7	0.43
	Blue Lake S Lobe	24-Jan-13		0.4	9	0.18
	Blue Lake S Lobe	21-Dec-13	28.9	2.11	16	0.76
	Blue Lake N Lobe	24-Jan-13	12.2	1.12	8	0.54
	Blue Lake N Lobe	21-Dec-13	11.3	1.55	15	0.57
MCM	MCM Hut Ridge Lower	2-Jan-14	582	1.79	10	0.78
	MCM Hut Ridge Upper	2-Jan-14	765	1.54	12	0.62
Taylor Valley	Picture Pond	12-Dec-12		1.83	17	0.64
	Picture Pond	5-Jan-14	2329	1.81	20	0.61
	N. Riegel Pond	26-Dec-13	142	2.14	16	0.77
	Marr Pond 3	26-Dec-13	66.1	1.83	12	0.74
	Parera Pond	26-Dec-13	25.6	1.66	11	0.69
	Many Glaciers Pond	17-Dec-13	9	2.38	23	0.76
	Marr Pond 4	26-Dec-13	9.8	1.16	13	0.45
	Spaulding Pond	5-Jan-14	8.16	2.48	27	0.75
Wright	Labyrinth Pond 4	7-Jan-14	21.2	0.68	4	0.49

Diatom Community Composition

Relative abundance counts for all the samples show great variation within and between geographic regions. Figure 8 summarizes the data, with sample names on the x-axis and species names on the y-axis. The size of the dots represents percent of relative abundance of that particular species in the sample. For this analysis, species with relative abundances of less than 1 percent were removed.

As the dot plot shows, there are several species present in the Taylor Valley samples that are completely absent from other regions – *Nitzschia commutata*, *Psammothidium papilio, Fistulifera pelliculosa*, *Navicula* cf. *seibigiana, Muelleria meredionalis, Navicula gregaria, Humidophila australis* and the small, unknown species, only found in the Nussbuam Riegel Pond (see Appendix B). On the other hand, there are no species that are exclusive to Ross Island that do not also appear in Taylor Valley. Labyrinth 4 Pond has an unknown *Luticola* species that does not appear in any other samples. *Navicula shackletoni* is one of the only species that occurs in almost all of the samples, no matter the region or the water chemistry.

Three out of the four ponds in the Labyrinth region could not be analyzed for community composition because of very low abundance on the slides. After examining a whole slide only a few individual valves were found, therefore it was unreasonable to try and get to the 300 valves per sample goal for these counts. The species that were seen on these slides were mostly *Luticola,* and the valves were broken, fragmented most of the time. The one pond, Labyrinth Pond 4 that was counted shows very low diversity and richness, with only 2 species (above 1% abundance) present for the whole count.

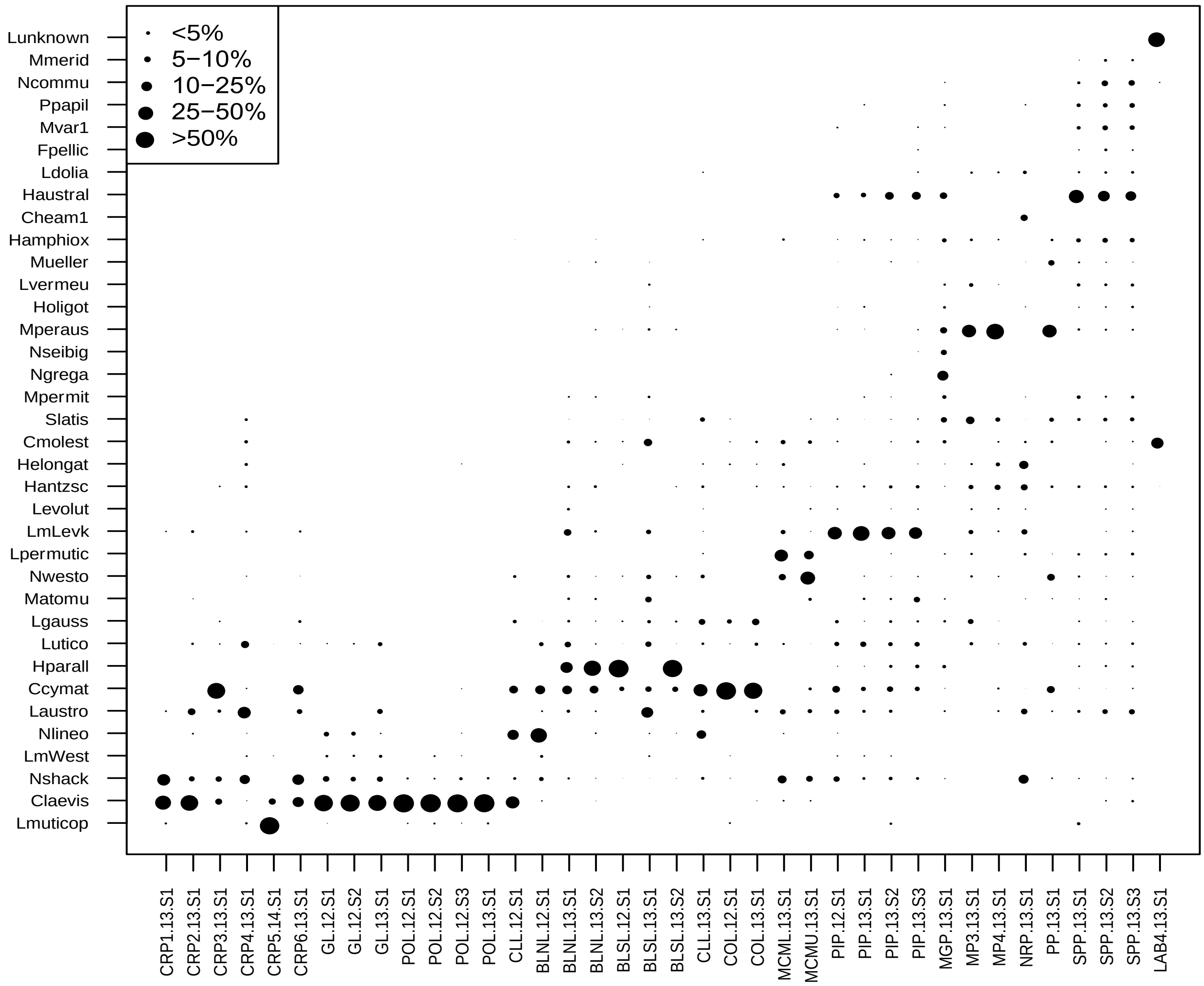
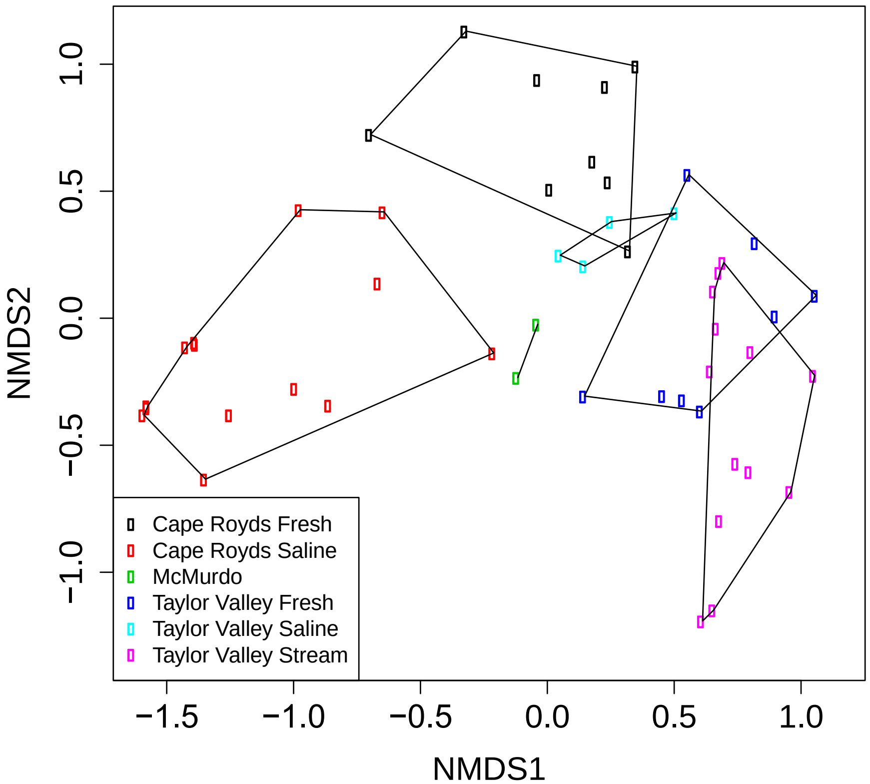


Figure 8: Dot plot representation of relative abundance counts. Ataylor= *Achnanthes taylorensis*, Ccymat= *Chamaepinnularia cymatopleura*, Cheam1= Unknown species, possibly of genus *Chamaepinnularia* (see Appendix B for images), Claevis= *Craspedostauros laevissimus*, Cmolest= *Craticula molestiformis*, Fpellic= *Fistulifera pelliculosa*, Habundan= *Hantzschia abundans*, Amphiox= *Hantzschia amphioxis*, Hantzsc= *Hantzschia* genus, Haustal= *Humidophila australis* , Helangat= *Hantzschia elongata*, Hhyperaus= *Hantzschia hyperaustralis*, Hmuelle= *Hantzschia amphioxis* f. *muelleri*, Holigot= *Halamphora oligotraphenta*, Hparall= *Humidophila contenta* var. *parallela*, Laustro= *Luticola austroatlantica*, Ldolia= *Luticola dolia*, Levolut= *Luticola evoluta*, Lgauss= *Luticola gaussi*, Llaeta= *Luticola laeta*, LmLevk= *Luticola murrayi sensu* Levkov, Lmuticop= *Luticola muticopsis*, LnWest= *Luticola murrayi sensu* West, Lpermutic= *Luticola permuticopsis*, Lunknown= unknown *Luticola* species (see Appendix B for images), Lutico= *Luticola* genus, Lutsp2= *Luticola* sp. 2 (see Appendix B for images), Lvermeu= *Luticola vermeulenii*, Matomu= *Mayamaea atomus*, Mmerid= *Muelleria meridionalis*, Mperaus= *Muelleria peraustralis*, Mpermit= *Mayamaea atomus* fo. *permitis*, Msupra= *Muelleria supra*, Mueller= *Muelleria* genus, Mvar1= *Mayamaea atomus* var.1, Ncommu= *Nitzschia commutata*, Ngrega= *Navicular gregaria*, Nlineo= *Navicula lineola* var. *perlepida*, Nseibig= *Navicula* cf. *seibigiana*, Nshack= *Navicula shackletoni*, Nwesto= *Nitzschia westiorum*, Ppapil= *Psammothidium papilio*, Slatis= *Stauroneis cf. latistauros*

An NMDS analysis of all the counts and some of the streams in Taylor Valley is shown in Figure 9. The samples were defined by region, with Taylor Valley and Cape Royds samples separated into fresh or saline. Fresh was defined in this case as anything under 150 mg/L of sodium. The streams used for this analysis were Aiken and Delta, which both flow directly out of two sampled ponds. Similarly to the cluster analysis, Labyrinth Pond 4 was clearly separated from all other samples and therefore taken out of the final analysis in order to better resolve relationships between samples. All of the Cape Royds saline samples are also clearly separated from other samples. The stream samples partly overlap with Taylor Valley fresh ponds. Cape Royds fresh ponds are also separated from all the other samples. Picture Pond, the only saline pond in the Taylor Valley is closely clustered with Cape Royds fresh ponds, yet somewhat separate from the other Taylor Valley samples.

Figure 10 presents the NMDS analysis but includes the species names that are most closely associated with the certain ponds and regions. *Craspedostauros laevissimus*, *Luticola muticopsis*, *Luticola murrayi* sensu West, *Navicula shackletoni* are strongly associated with the Cape Royds saline ponds. *Chamaepinnularia cymatopleaura* is strongly associated with Cape Royds fresh ponds. *Luticola murrayi* sensu Levkov, *Luticola guassii*, *Nitzschia westorum*, *Hantzschia elangata* and *Craticula molestiformis* are associated with both the Picture Pond in Taylor Valley as well as Cape Royds fresh ponds. *Humidophila parallela*, *Mulleria peraustalis*, *Achnanthes taylorensis*, and *Luticola austoatlantica* are strongly associated with Taylor Valley fresh ponds. *Mayamaea atomus fo. permitis, Psamothidium papilio, Pinnularia borealis, Mayamaea atomus, Humidophila australis, Stauroneis cf. latistauros*, and *Halamphora oligotraphenta* are associated with both Taylor Valley streams and Taylor Valley fresh ponds. And finally, there are several species associated exclusively with the Taylor Valley stream samples – *Navicula cf. seibigiana, Hantzschia hyperaustralis, Hantzschia amphioxys f. muelleri, Fistulifera pelliculosa, Luticola evoluta, Nitzschia commutata, Luticola dolia, Luticola permuticopsis, Mayamaea var.* 1*, Mulleria meridionalis, Hantzschia abundans, and Luticola vermeulenii*.

Because Labyrinth Pond 4 diatom community is so low in richness and one of the species in the sample does not appear in any of the other waterbodies it was deemed to be too much of an outlier and was removed from any of the analyses that included diatom community data. This allows better resolution of the relationships between diatom communities and other variables.



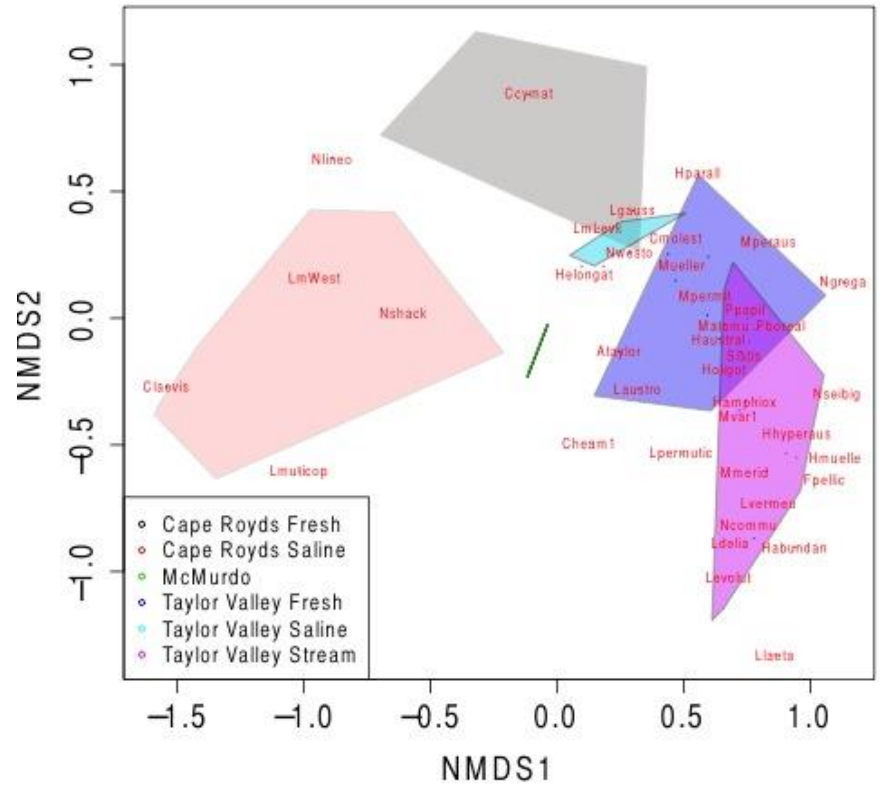


Figure 9: NMDS analysis of diatom community samples

Figure 10: NMDS analysis with species names for each region. Ataylor= *Achnanthes taylorensis*, Ccymat= *Chamaepinnularia cymatopleura*, Cheam1= Unknown species, possibly of genus *Chamaepinnularia* (see Appendix B for images), Claevis= *Craspedostauros laevissimus*, Cmolest= *Craticula molestiformis*, Fpellic= *Fistulifera pelliculosa*, Habundan= *Hantzschia abundans*, Amphiox= *Hantzschia amphioxis*, Hantzsc= *Hantzschia* genus, Haustal= *Humidophila australis* , Helangat= *Hantzschia elongata*, Hhyperaus= *Hantzschia hyperaustralis*, Hmuelle= *Hantzschia amphioxis* f. *muelleri*, Holigot= *Halamphora oligotraphenta*, Hparall= *Humidophila contenta* var. *parallela*, Laustro= *Luticola austroatlantica*, Ldolia= *Luticola dolia*, Levolut= *Luticola evoluta*, Lgauss= *Luticola gaussi*, Llaeta= *Luticola laeta*, LmLevk= *Luticola murrayi sensu* Levkov, Lmuticop= *Luticola muticopsis*, LnWest= *Luticola murrayi sensu* West, Lpermutic= *Luticola permuticopsis*, Lunknown= unknown *Luticola* species (see Appendix B for images), Lutico= *Luticola* genus, Lutsp2= *Luticola* sp. 2 (see Appendix B for images), Lvermeu= *Luticola vermeulenii*, Matomu= *Mayamaea atomus*, Mmerid= *Muelleria meridionalis*, Mperaus= *Muelleria peraustralis*, Mpermit= *Mayamaea atomus* fo. *permitis*, Msupra= *Muelleria supra*, Mueller= *Muelleria* genus, Mvar1= *Mayamaea atomus* var.1, Ncommu= *Nitzschia commutata*, Ngrega= *Navicular gregaria*, Nlineo= *Navicula lineola* var. *perlepida*, Nseibig= *Navicula* cf. *seibigiana*, Nshack= *Navicula shackletoni*, Nwesto= *Nitzschia westiorum*, Ppapil= *Psammothidium papilio*, Slatis= *Stauroneis cf. latistauros*

The results of the hierarchical cluster analysis are shown in Figure 11. The cophenetic correlation coefficient for this analysis was 0.93, which describes how closely the model describes the original pairwise distances between data points. For this analysis, relative abundances counts were used from the 2013/2014 season as well as from the 2012/2013 season. Saline ponds and lakes from Cape Royds are separated from all of the other samples. Most of the freshwater ponds and lakes from Cape Royds clustered separately from other samples, with the exception of Cape Royds 4 and Blue Lake South clustering closer with the McMurdo Hut Ridge Ponds and N. Riegel Pond. Picture Pond, the only saline pond in Taylor Valley clusters closest with Spaulding and Many Glaciers Pond, both of which are geographically closest to Picture Pond, all in the Lake Fryxell basin. The Upland Ponds – Parera Pond and the two Marr ponds also cluster closest together.

It should be noted that the water chemistry and relative abundance counts for samples from Clear Lake varied significantly between the 2012/2013 and the 2013/2014 samples. The sample from the 2013/2014 is in fact fresh, as defined by this study (sodium concentration less than 150 mg/L) and the sample from 2012/2013 is saline (see Appendix x). The sample from 2012/2013 clusters in this analysis with other saline ponds and lakes at Cape Royds. The sample from 2013/2014 clusters with fresh ponds and lakes at Cape Royds.

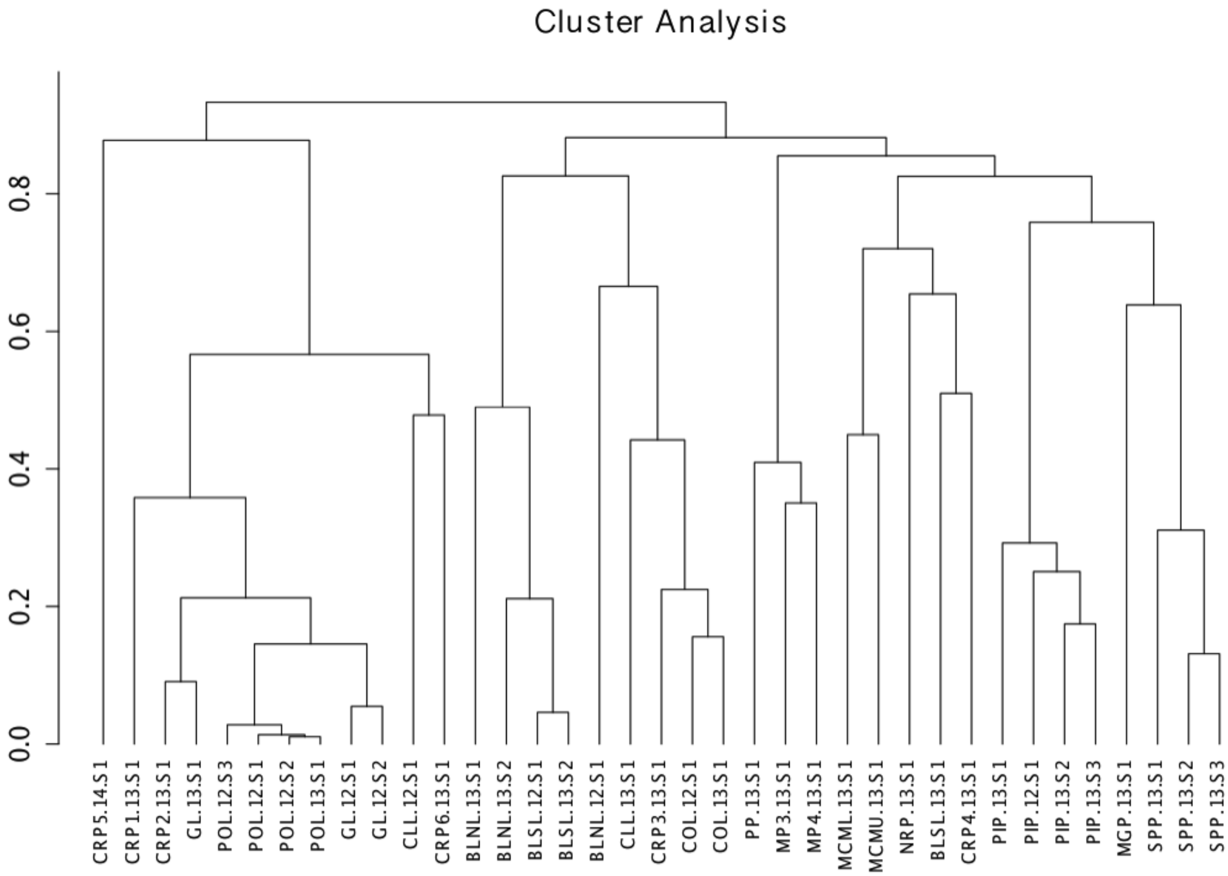


Figure 11: Hierarchical cluster analysis of diatom community samples from ponds and lakes. BLNL.12.S1-Blue Lake North lobe, collected 2012/2013 season. BLNL.13.S1 – Blue Lake North lobe, collected 2013/2014. Blue Lake.13.S2- Blue Lake North lobe, collected 2013/2014, 2nd sample. BLSL.12.S1- Blue Lake South lobe, collected 2012/2013 season. BLSL.13.S1- Blue Lake South lobe, collected 2013/2014 season. BLSL.13.S2- Blue Lake South lobe, collected 2013/2014 ,season, 2nd sample. CLL.12.S1- Clear Lake collected 2012/2013 season. CLL.13.S1- Clear Lake collected 2013/2014 season. COL.12.S1- Coast Lake collected 2012/2013 season. COL.13.S1- Coast Lake collected 2013/2014 season. CRP1.13.S1- Cape Royds Pond 1 collected 2013/2014 season. CRP2.13.S1- Cape Royds Pond 2 collected 2013/2014 season. CRP3.13.S1- Cape Royds Pond 3 collected 2013/2014 season. CRP4.14.S1- Cape Royds Pond 4 collected 2013/2014 season. CRP5.14.S1 – Cape Royds Pond 5 collected 2013/2014 season. CRP6.13.S1- Cape Royds Pond 6 collected 2013/2014 season. GL.12.S1- Green Lake collected 2012/2013 season. GL.12.S2- Green Lake collected 2012/2013 season, 2nd sample. GL.13.S1- Green Lake collected 2013/2014 season. MCML.13.S1- McMurdo Hut Ridge Lower Pond collected 2013/2014 season. MCMU.13.S1- McMurdo Hut Ridge Upper Pond collected 2013/2014 season. MGP.13.S1- Many Glaciers Pond collected 2013/2014 season. MP3.13.S1- Marr Pond 3 collected 2013/2014 season. MP4.13.S1- Marr Pond 4 collected 2013/2014 season. NRP.13.S1- Nussbaum Riegel Pond collected 2013/2014 season. POL.12.S1- Pony Lake collected 2012/2013 season. POL.12.S2- Pony Lake collected 2012/2013 season, 2nd sample. POL.12.S3- Pony Lake collected 2012/2013 season, 3rd sample. POL.13.S1- Pony Lake collected 2013/2014 season. PP.13.S1- Parera Pond collected 2013/2014 season. PIP.12.S1- Picture Pond collected 2012/2013 season. PIP.13.S1- Picture Pond collected 2013/2014 season. PIP.13.S2- Picture Pond collected 2013/2014 season, 2nd sample. PIP.13.S3 – Picture Pond collected 2013/2014 season, 3rd sample. SPP.13.S1- Spaulding Pond collected 2013/2014 season. SPP.13.S2- Spaulding Pond collected 2013/2014 season, 2nd sample. SPP.13.S3- Spaulding Pond collected 2013/2014 season, 3rd sample.

The redundancy analysis (RDA) was first tested with all of the environmental variables, many of which were statistically significant. However, from the previous Pearson's correlation analysis we know that many of the variables are highly correlated. Therefore, only five of the significant variables were chosen for the final analysis – Sodium (Na), Nitrate (NO3), Phosphate (PO4), Ammonium (NH4) and Chlorophyll-a (Chl-a). These variables were both statistically significant ($p<0.005$) in the RDA model and were not correlated with each other. Other variables such as silica, pH, dissolved organic carbon, temperature and alkalinity were not statistically significant. The longitudinal values for the locations of these ponds and lakes were the conditioning terms and explained 16% of variation. The effect of longitudinal variation was removed from the analysis and the chosen environmental variables explained 36% of variation. 51% of the total variation remains unexplained.

Similar to the PCA, the diatom communities of many of the freshwater ponds from Cape Royds and the Taylor Valley show a negative correlation with nutrient and cation concentrations. However, the diatom communities of Many Glaciers Pond and Spaulding Pond now show a positive correlation with phosphate concentrations. The diatom community of Cape Royds Pond 5 and in particular *L.muticopsis*, most abundant species present in that sample, show a strong positive correlation with phosphate concentration. Picture Pond, which was separated from all other samples in the environmental PCA, because of its high alkalinity, is now grouped with

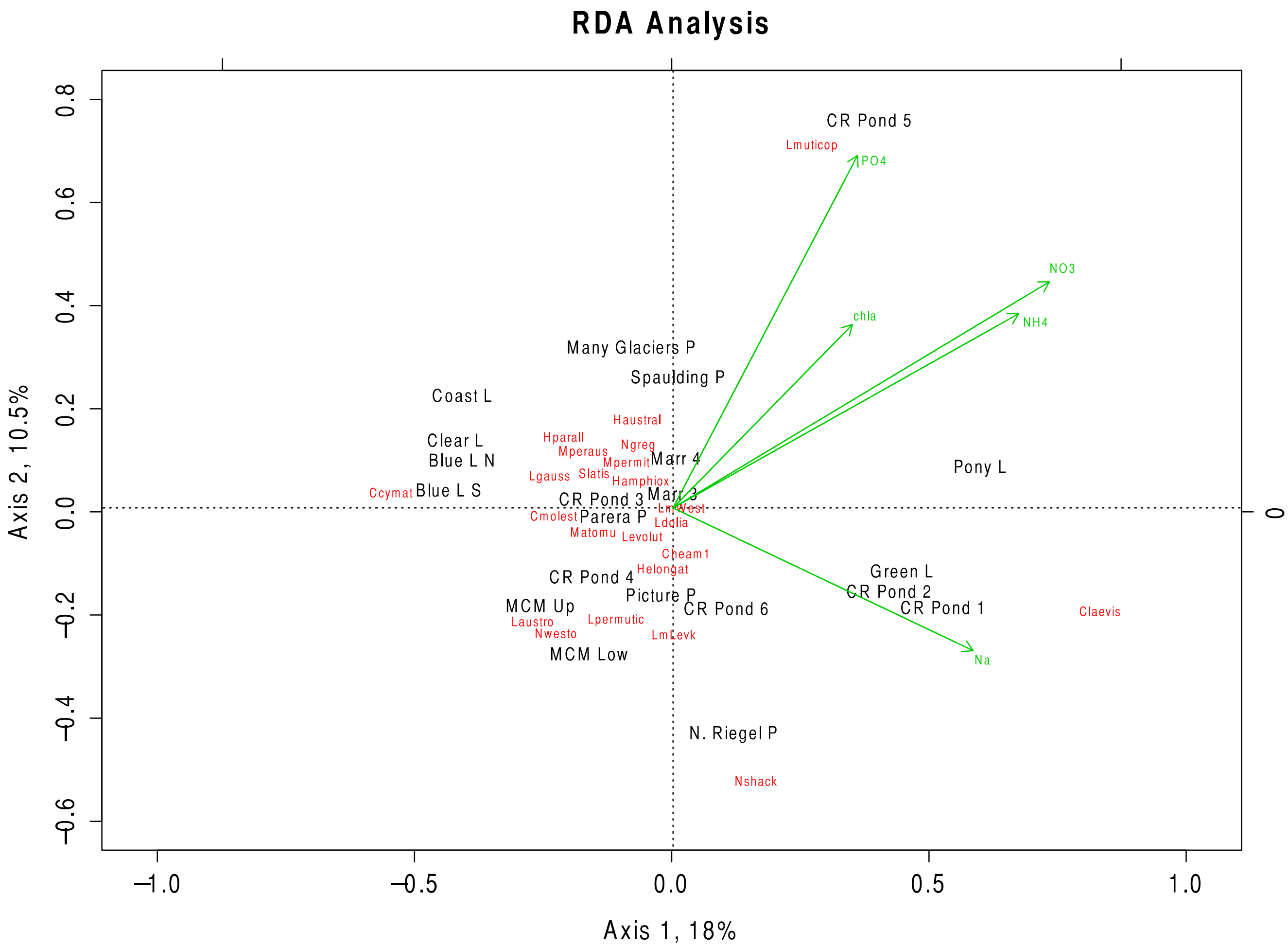


Figure 12: Redundancy Analysis of diatom community data and five environmental variables.

many of the other fresh waterbodies, negatively correlated with phosphate and nitrate concentrations. Some of the species are clearly isolated as preferring freshwater environments – *Craspedostauros laevissimus*, *Craticula molestiformis*, *Luticola gaussii* and *Humidophila parallela*. According to the RDA *C.laevissimus* prefers brackish environments, having a strong correlation with conductivity and sodium concentrations. *Navicula shackletoni* does not show any strong correlations.

Chlorophyll-a appears to be correlated with nitrate and phosphate concentrations, even though when Pearson's correlation was performed on all of the environmental variables, Chl-a had little correlation with either phosphate (ρ=0.39) or with nitrate (ρ=0.24).

In order to determine how the pond communities relate to the stream communities in the Taylor Valley a hierarchical cluster and dot plot analyses were performed, using the same methods. Once again, Labyrinth Pond 4 sample was taken out of the cluster analysis because it separated on its own and its exclusion allowed for better resolution of the relationships between other samples. Community data from Aiken Stream, flowing directly our of Many Glacier Pond, Delta stream, flowing out of Spaulding Pond, Green Creek and Canada Stream located on the western side of Lake Fryxell basin as well as Wormherder Creek in the Lake Bonney basin were included in this analysis. As the Dot Blot below (Figure 13) shows there are some species present exclusively in the streams, such as *Hantzschia abundans*, *Luticola laeta*, *Navicula germanii* and *Pinnulria borealis*. Conversely, *Luticola murrayi* sensu Levkov, *L. murrayi* sensu West, *Hantzschia elongata*, *Craspedostauros laevissimus,* and the two previously unknown species are present exclusively in ponds. It is important to note that there are species in Aiken Stream that are completely absent from Many Glacier Pond sample. This suggests that some species are adapted to flowing water and do not thrive in other environments, such as ponds.

The hierarchical cluster analysis is shown in Figure 14. The cophenetic correlation coefficient for this analysis is 0.89. The stream samples cluster with Many Glacier Pond, Spaulding Pond and Blue Lake samples, however the relationship is not a close one. It is important to note that it appears that lower the richness of samples, the closer they can cluster together. Pony Lake, for example, has communities that are very low in richness and therefore distances of 0.1 for both of the performed clusters in this study. Therefore, it may be difficult to compare samples with high and low richness in the same analysis.

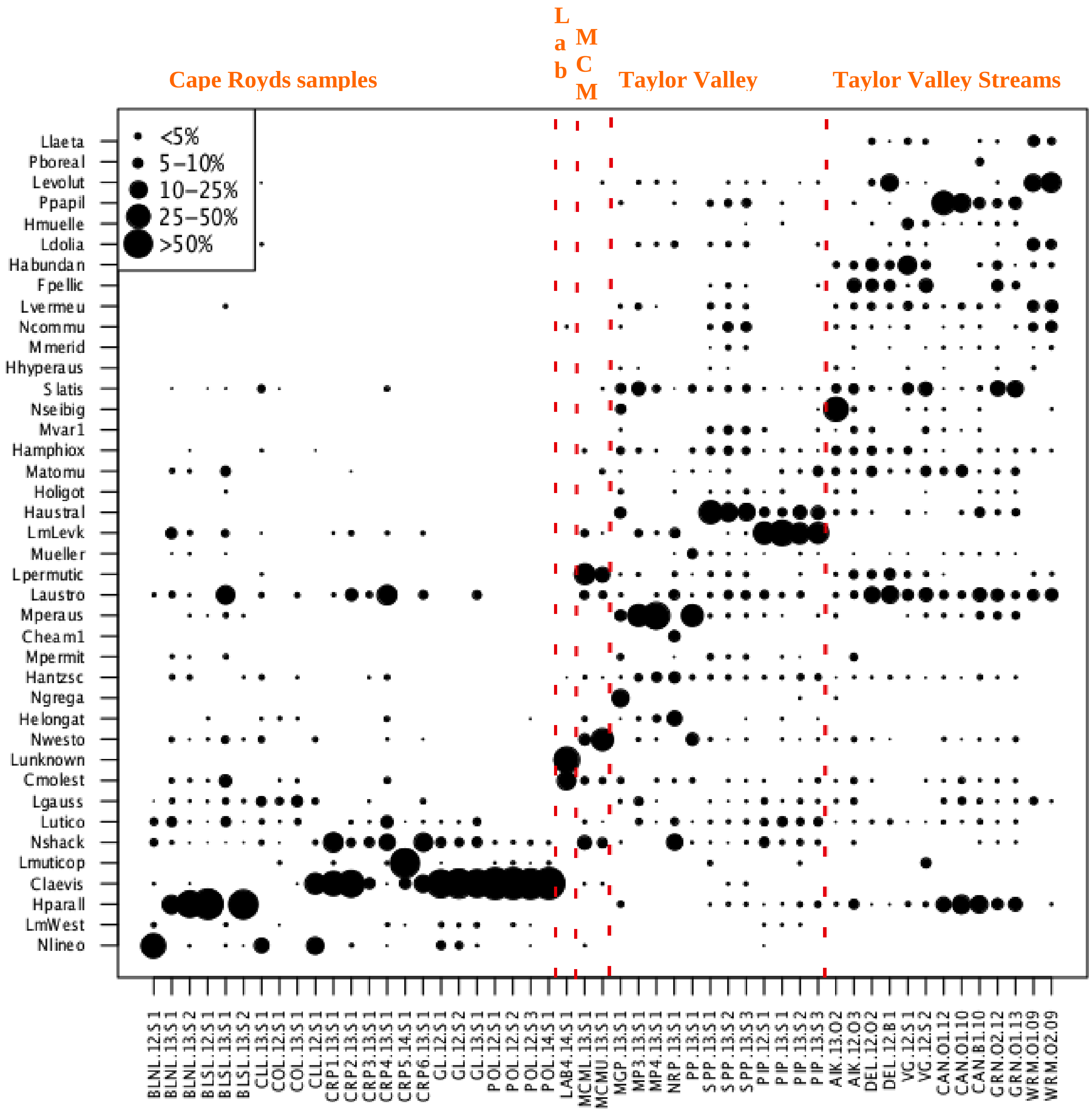


Figure 13: Dot plot representation of relative abundance counts. Ataylor= *Achnanthes taylorensis*, Ccymat= *Chamaepinnularia cymatopleura*, Cheam1= Unknown species, possibly of genus *Chamaepinnularia* (see Appendix B for images), Claevis= *Craspedostauros laevissimus*, Cmolest= *Craticula molestiformis*, Fpellic= *Fistulifera pelliculosa*, Habundan= *Hantzschia abundans*, Hamphiox= *Hantzschia amphioxis*, Hantzsc= *Hantzschia* genus, Haustal= *Humidophila australis* , Helangat= *Hantzschia elongata*, Hhyperaus= *Hantzschia hyperaustralis*, Hmuelle= *Hantzschia amphioxis* f. *muelleri*, Holigot= *Halamphora oligotraphenta*, Hparall= *Humidophila contenta* var. *parallela*, Laustro= *Luticola austroatlantica*, Ldolia= *Luticola dolia*, Levolut= *Luticola evoluta*, Lgauss= *Luticola gaussi*, Llaeta= *Luticola laeta*, LmLevk= *Luticola murrayi sensu* Levkov, Lmuticop= *Luticola muticopsis*, LnWest= *Luticola murrayi sensu* West, Lpermutic= *Luticola permuticopsis*, Lunknown= unknown *Luticola* species (see Appendix B for images), Lutico= *Luticola* genus, Lutsp2= *Luticola* sp. 2 (see Appendix B for images), Lvermeu= *Luticola vermeulenii*, Matomu= *Mayamaea atomus*, Mmerid= *Muelleria meridionalis*, Mperaus= *Muelleria peraustralis*, Mpermit= *Mayamaea atomus* fo. *permitis*, Msupra= *Muelleria supra*, Mueller= *Muelleria* genus, Mvar1= *Mayamaea atomus* var.1, Ncommu= *Nitzschia commutata*, Ngrega= *Navicular gregaria*, Nlineo= *Navicula lineola* var. *perlepida*, Nseibig= *Navicula* cf. *seibigiana*, Nshack= *Navicula shackletoni*, Nwesto= *Nitzschia westiorum*, Pboreal = *Pinnularia borealis*, Ppapil= *Psammothidium papilio*, Slatis= *Stauroneis cf. latistauros*

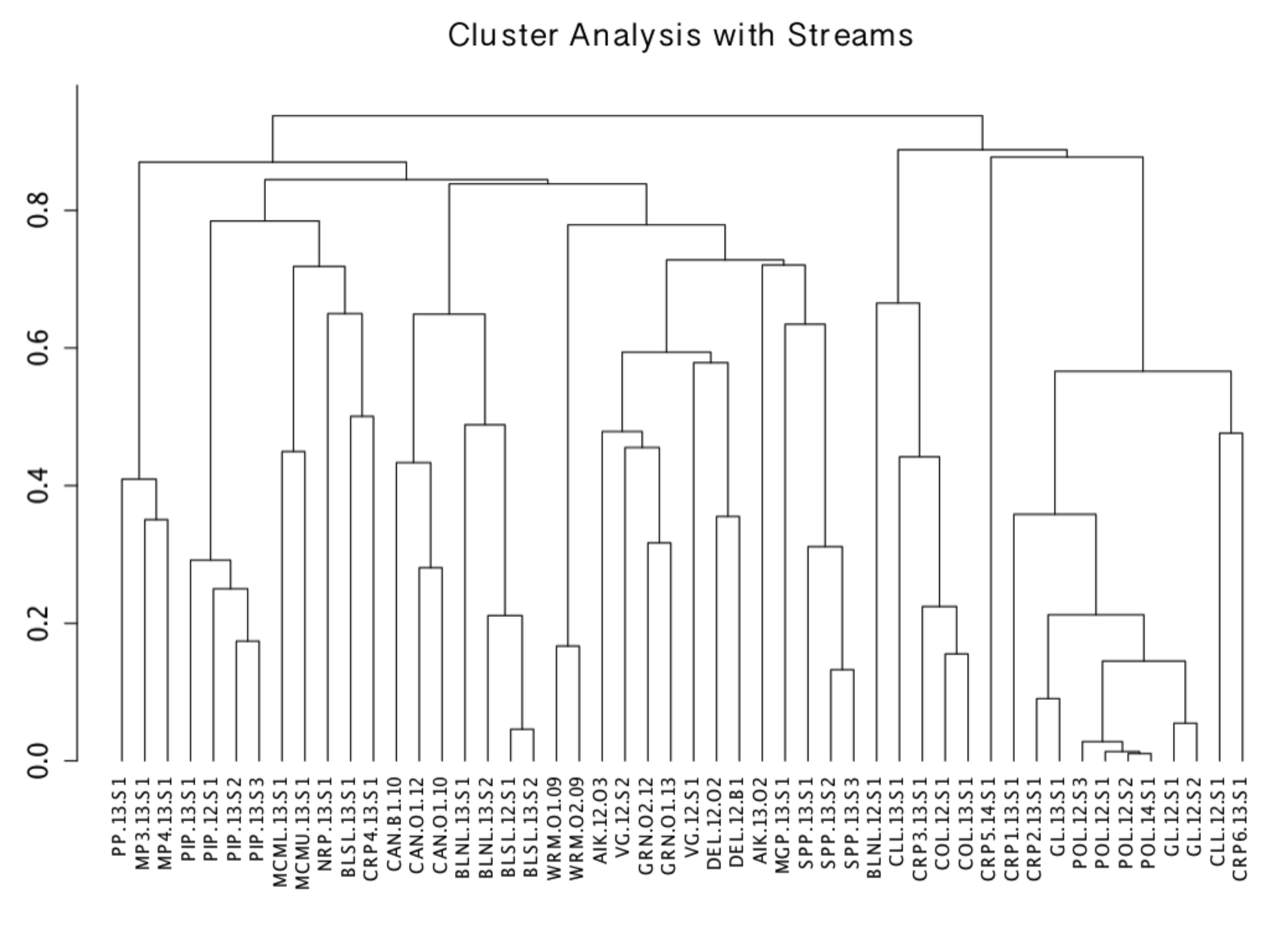


Figure 14: Hierarchical Cluster analysis including Taylor Valley Stream samples. AIK.12.O3- Aiken Stream collected 2011/2012 season, orange mat sample 3. AIK.13.O2- Aiken Stream collected 2012/2013 season, orange mat sample 2. BLNL.12.S1-Blue Lake North lobe, collected 2012/2013 season. BLNL.13.S1 – Blue Lake North lobe, collected 2013/2014. Blue Lake.13.S2- Blue Lake North lobe, collected 2013/2014, 2nd sample. BLSL.12.S1- Blue Lake South lobe, collected 2012/2013 season. BLSL.13.S1- Blue Lake South lobe, collected 2013/2014 season. BLSL.13.S2- Blue Lake South lobe, collected 2013/2014 ,season, 2nd sample. CAN.B1.10- Canada Stream collected 2009/2010 season, Black mat sample 1. CAN. O1.12- Canada Stream collected 2012/2013 season, orange mat sample 1. CAN.O1.10- Canada Stream collected 2009/2010 season, orange mat sample 1. CLL.12.S1- Clear Lake collected 2012/2013 season. CLL.13.S1- Clear Lake collected 2013/2014 season. COL.12.S1- Coast Lake collected 2012/2013 season. COL.13.S1- Coast Lake collected 2013/2014 season. CRP1.13.S1- Cape Royds Pond 1 collected 2013/2014 season. CRP2.13.S1- Cape Royds Pond 2 collected 2013/2014 season. CRP3.13.S1- Cape Royds Pond 3 collected 2013/2014 season. CRP4.14.S1- Cape Royds Pond 4 collected 2013/2014 season. CRP5.14.S1 – Cape Royds Pond 5 collected 2013/2014 season. CRP6.13.S1- Cape Royds Pond 6 collected 2013/2014 season. DEL.12.O2- Delta Stream collected 2011/2012 season, orange mat sample 2. DEL.12.B1- Delta Stream collected 2011/2012 season, black mat sample 1. GL.12.S1- Green Lake collected 2012/2013 season. GL.12.S2- Green Lake collected 2012/2013 season, 2nd sample. GL.13.S1- Green Lake collected 2013/2014 season. GRN.O2.12- Green Creek collected 2011/2012 season, orange mat sample 2. GRN.O1.13 – Green Creek collected 2012/2013 season, orange mat sample 1. MCML.13.S1- McMurdo Hut Ridge Lower Pond collected 2013/2014 season. MCMU.13.S1- McMurdo Hut Ridge Upper Pond collected 2013/2014 season. MGP.13.S1- Many Glaciers Pond collected 2013/2014 season. MP3.13.S1- Marr Pond 3 collected 2013/2014 season. MP4.13.S1- Marr Pond 4 collected 2013/2014 season. NRP.13.S1- Nussbaum Riegel Pond collected 2013/2014 season. POL.12.S1- Pony Lake collected 2012/2013 season. POL.12.S2- Pony Lake collected 2012/2013 season, 2nd sample. POL.12.S3- Pony Lake collected 2012/2013 season, 3rd sample. POL.13.S1- Pony Lake collected 2013/2014 season. PP.13.S1- Parera Pond collected 2013/2014 season. PIP.12.S1- Picture Pond collected 2012/2013 season. PIP.13.S1- Picture Pond collected 2013/2014 season. PIP.13.S2- Picture Pond collected 2013/2014 season, 2nd sample. PIP.13.S3 – Picture Pond collected 2013/2014 season, 3rd sample. SPP.13.S1- Spaulding Pond collected 2013/2014 season. SPP.13.S2- Spaulding Pond collected 2013/2014 season, 2nd sample. SPP.13.S3- Spaulding Pond collected 2013/2014 season, 3rd sample. VG.12.S2- Von Guerard Stream collected 2011/2012 season, orange mat sample 2. VG.12.S1- Von Guerard Stream collected 2011/2012 season, orange mat sample 1. WRM.O1.09 – Wormherder Creek collected 2008/2009 season, orange mat sample 1. WRM.O2.09- Wormherder Creek collected 2008/2009 season, orange mat sample 2.

DISCUSSION

In this study we test the hypothesis that water chemistry plays a significant role in defining diatom community structure and that individual species show preference for certain environmental conditions. The results of this study, however, tell a more complicated story. The fact that Taylor Valley samples contain species that are absent from other regions suggests that universal dispersal is not occurring. Picture Pond, the most saline of all sampled waterbodies, has a diatom community most similar to fresh ponds in the Taylor Valley. These two results alone tell us that water chemistry is not the only factor that defines diatom communities in lakes and ponds in the McMurdo Dry Valleys and nearby Ross Island.

Diatom community of Picture Pond in Taylor Valley is grouped closely with other ponds in that region by both the NMDS analysis and the RDA analysis. However, this is the most saline of all sampled bodies of water. This pond has high diversity and richness and the species present there are also present in ponds with very low salinity. At the time of sampling there appeared to be no apparent inflow or outflow for this pond. In addition, the soil surrounding the pond had a visible film of salt. This points to the fact that this pond is drying out. It is possible that Picture Pond, as it is called in this study, used to receive meltwater from the nearby Commonwealth Glacier, but this inflow was somehow cut off in recent time.

Therefore, the diatom community that appears in Picture Pond today is a remnant of a time when this body of water was as fresh as the other ponds in the Taylor Valley. This is consistent with the historical processes theory of biogeography (Vyverman *et al.*, 2007), rather than the ubiquity hypothesis (Baas-Becking 1934, Finlay 2002). It suggests that the previous pool of diatoms present in a body of water may be more important in determining the diatom community in the future. It would be important to find out when this cut-off from inflow occurred. One of the potential studies that could accomplish that would be to use satellite imagery available for the last twenty or more years in order to determine if the size of the pond has changed in that period of time. Knowing whether this change from freshwater to brackish water that is high in DOC occurred in the last ten, twenty or a hundred years would inform us about the ability of the particular species of diatoms in Picture Pond to adapt to changes in water chemistry.

Labyrinth Ponds in the Wright Valley tell another interesting story. This area is quite isolated, farther away from large lakes and streams than other sampled habitats. The ponds are low in phosphate in high in nitrate. Labyrinth Pond 4, the only one with an abundance of diatoms present, has the highest phosphate concentration. Therefore, ponds 1-3 may be phosphate-limited. The isolation of this area can also play a role in the low richness and diversity of this community. If diatoms are dispersed via wind then it is possible that these ponds are too isolated to continually receive a variety of other species. High abundance of an unknown species of *Luticola* (see Appendix B) not present anywhere else out of the sampled regions also supports this conclusion.

Craspedostauros laevissimus was characterized by Sabbe *et al*. (2003) as a brackish water species. This is consistent with the diatom community results from Cape Royds, where the species dominates and thrives in samples with sodium concentrations higher than 1.5 g/L. However, this species is completely absent from Picture Pond in Taylor Valley even though this pond is brackish. This species was only seen in Spaulding Pond in the Taylor Valley and in abundance of less than 5%, so it is possible that this species simply never dispersed to Picture Pond.

Navicula shackletoni is present almost ubiquitously across all of the ponds and lakes and more rarely in the streams. This species is a South Victoria Land endemic and was first described by West & West (1911). This species is clearly well adapted to a wide range of habitats and chemical variables.

Navicula lineola var. perlepida was described as a marine diatom common in the Artic Ocean (Witkowski, 2000), but in the Antarctic it has been seen in inland, quite saline lakes (Antarctic Freshwater Diatoms website). However, in this study this species was abundant in one of the freshest lakes at Cape Royds – North lobe of Blue Lake, as well as in Clear Lake and seen in South Lobe of Blue Lake, Green Lake and Picture Pond. Therefore, this species may have a wider range of habitat than previously thought.

The fact that there are several species present exclusively in the streams and not in the ponds and vice versa suggests that certain species are better adapted to flow conditions. For example, *Hantzschia abundans* is present in Aiken stream, which flows directly out of Many Glaciers Pond where this species is absent. On the other hand, both *Luticola murrayi sensu Levkov* and *Luticola murrayi sensu West* are present in ponds across the Taylor Valley but are hardly if ever seen in any of the streams.

This study highlights the importance of dispersal and geography in defining diatom communities in this region of Antarctica. The fact that the ponds in the Taylor Valley have higher richness than the fresh ponds at Cape Royds suggests that interactions (via wind) between various habitats such as the streams, large lakes, cryoconite holes on the glaciers and the ponds in the Taylor Valley bring a variety of species to these habitats and therefore increase diversity. On the other hand, fresh ponds on Cape Royds are more isolated from other freshwater habitats and do not receive the same input of species.

Out of the chemical variables that were examined in this study salinity, alkalinity, concentrations of nitrate, ammonium and phosphate played the most important roles in defining diatom community structure. At higher salinity and nutrient concentrations, some species appear to thrive (such *as C.laevissimus*), outcompeting others. This is consistent with a similar study done on the Antarctica Peninsula that found that salinity and nutrient gradients had the biggest influence on diatom community structure (Kopalova *et al*,. 2013a).

The results of this study help establish habitat ranges for individual species, which can inform paleolimnology work in this region. A more extensive study that includes more ponds throughout the Dry Valleys, Ross Island and other nearby regions can help better establish habitat preferences of diatom species.

This study did not consider mat type in sampling and the other types of algae present in the mat were not considered. A study that examined these two variables could also help establish if the diatom community structure changes with mat type. The biovolume of diatoms per sample was also not considered in the study. This variable could be important in determining how chemical variables affect diatom abundance.

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APPENDIX A

PHOTOS OF SAMPLING SITES AND ALGAL MAT TYPES

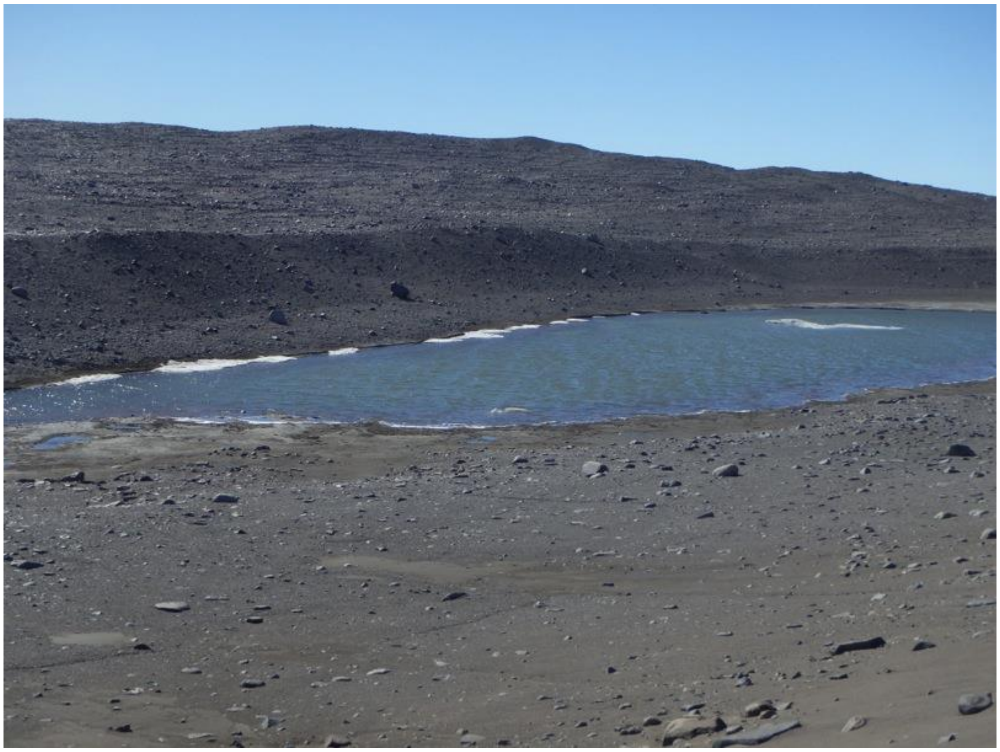

Figure 1: Picture Pond, Taylor Valley

Figure 2: Salt deposits on the soil around Picture Pond

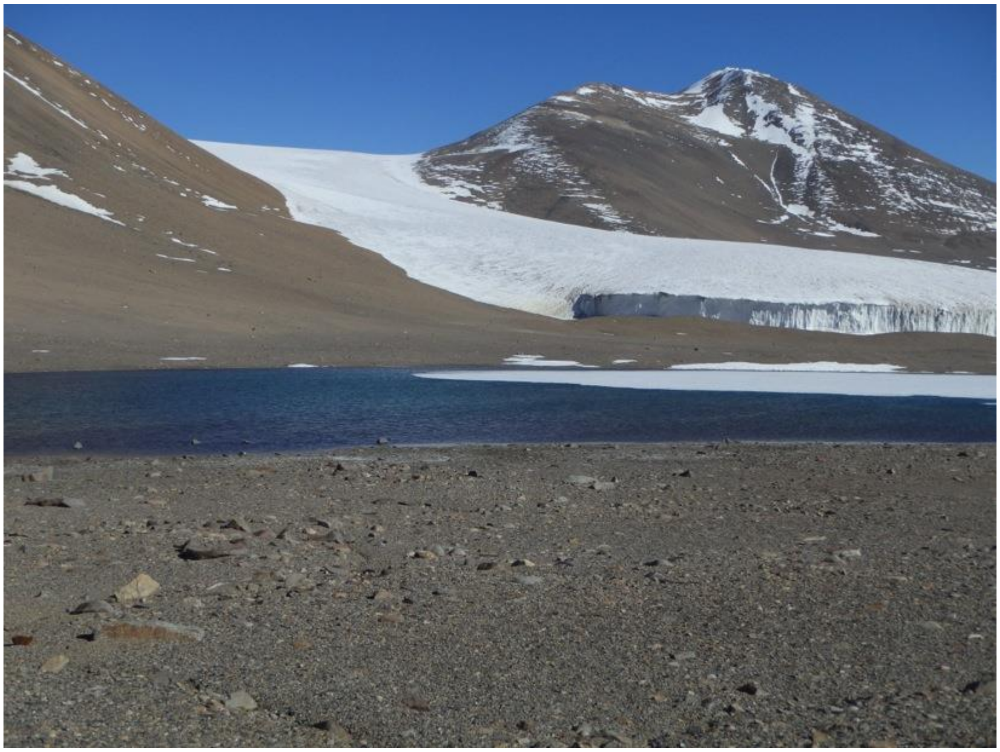

Figure 3: Spaulding Pond, Taylor Valley

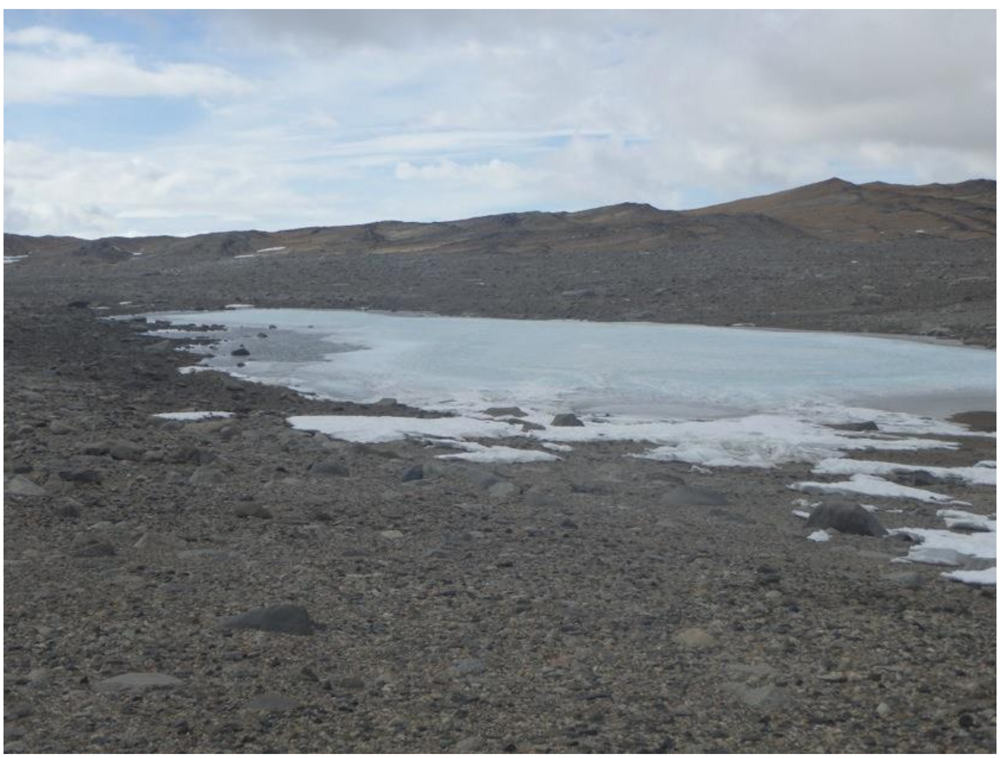

Figure 4: Nussbaum Riegel Pond, Taylor Valley

Figure 5: Labyrinth Pond 1, Wright Valley

Figure 6: Labyrinth Pond 2, Wright Valley

Figure 7: Mat type in Labyrinth Pond 2

Figure 8: Labyrinth Pond 3, Wright Valley

Figure 9: Labyrinth Pond 4, Wright Valley

Figure 10: Clear Lake, Cape Royds.

Figure 11: Coast Lake, Cape Royds. Credit:Adrian Howkins.

Figure 12: Appearance of floating mats in Coast Lake, Cape Royds.

Figure 13: Green Lake, Cape Royds. Credit:Adrian Howkins.

Figure 14: Appearance of algal mats in Green Lake, Cape Royds. Credit: Adrian Howkins.

Figure 15: Cape Royds Pond 1. Credit: Adrian Howkins.

Figure 16: Cape Royds Pond 5. “Almost dried-up lake”. Credit: Adrian Howkins

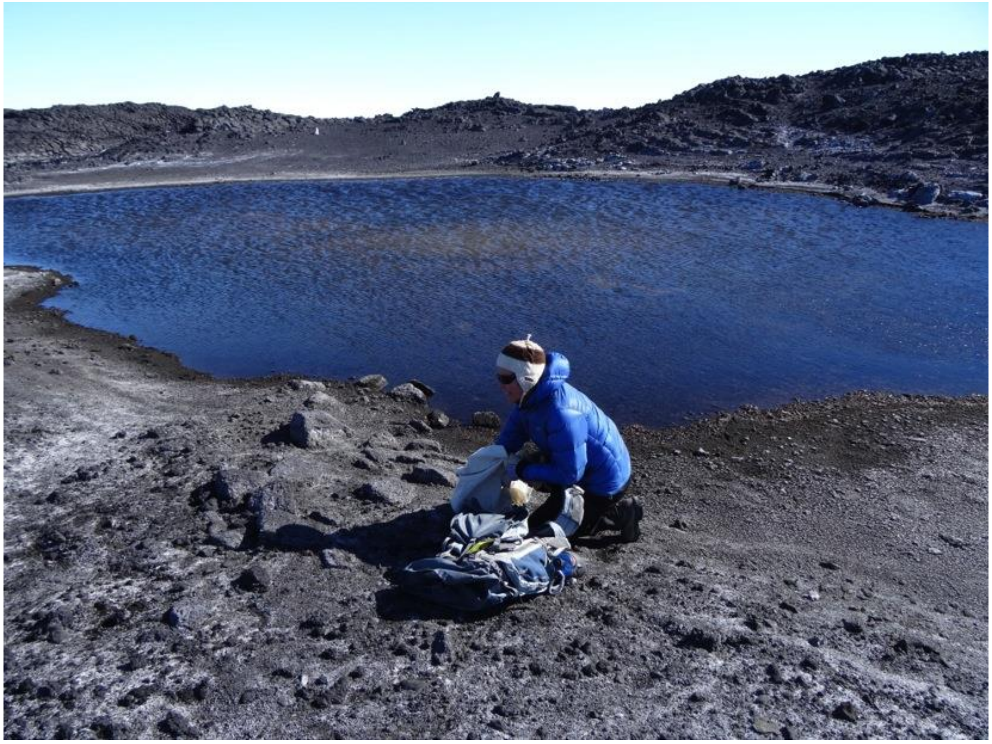

Figure 17: Cape Royds Pond 6. Credit: Adrian Howkins.

Figure 18: McMurdo Hut Ridge Lower Pond, Ross Island

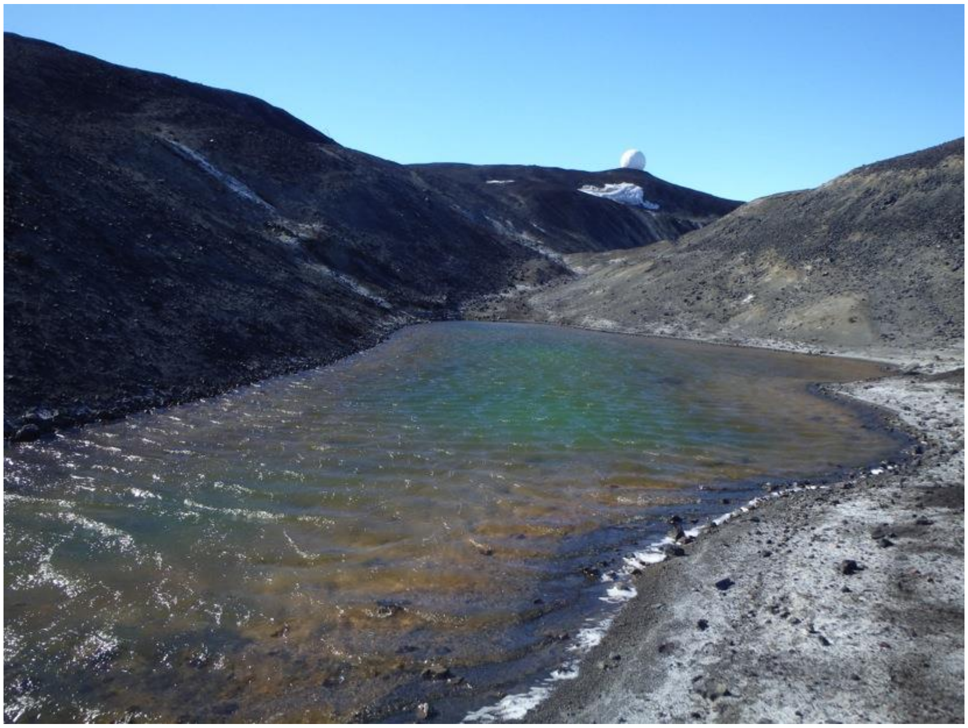

Figure 19: McMurdo Hut Ridge Upper Pond

APPENDIX B

UNKNOWN SPECIES FOUND DURING THIS STUDY

UKNOWN LUTICOLA SPECIES FOUND IN LABYRINTH POND 4

This species comprised roughly half of the relative abundance count for this sample. It is similar in shape to *Luticola gaussii* but in order to insure that this was a different species from L.gaussii a short study was performed on the length to width ratios of individuals present in Labyrinth Pond 4. 20 individuals of varying size were measured in length and in width and results were graphed (Figure 1).

Sample #	Length	Width
1	31.2	8.57
2	21.2	6.93
3	21.47	7.53
4	21.29	7.18
5	25.53	7.91
6	25.01	7.92
7	36.92	10.41
8	29	8.74
9	29.75	9.06
10	21.73	7.44
11	20.6	7.7
12	25.06	8.27
13	24.61	8.23
14	21.21	7.81
15	28.06	8.49
16	27.16	8.43
17	23.11	7.54
18	27.84	8.35
19	45.26	10.56
20	28.49	9.2

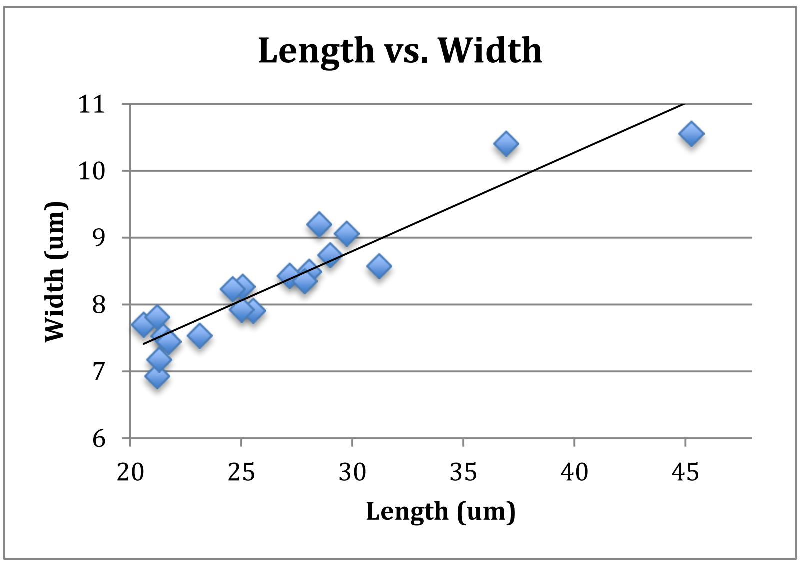

Figure 1: Measured lengths and widths for each sample (left) and graphical representation of the data (above).

The fact that there is a linear relationship between length and width of the individuals measured is a good indication that this is a population of one species, rather than several species.

Luticola guassii is described as being 12-26 μm in length and 6-9.5 μm in width. However, this unknown species is clearly larger in both length and width. At its smallest recorded width of 6.9 μm it was 21.2 μm, which is in the larger range by *L.gaussii*. Therefore, this is most likely a new species.

Below are several SEM images (Figure 2) of this unknown species and a plate of light microscope images (Figure 3).

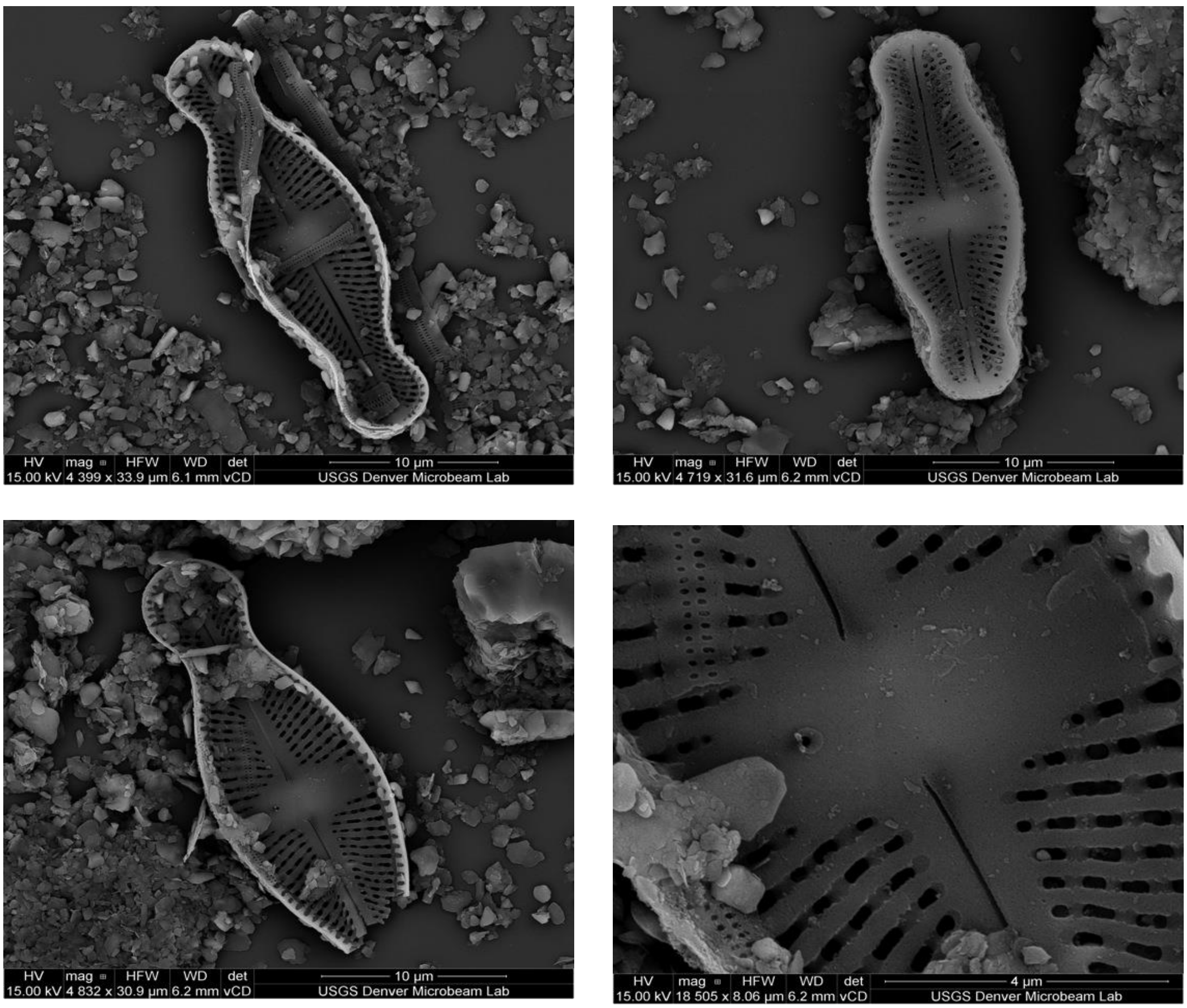

Figure 2: SEM images of unknown *Luticola* species from Labyrinth Pond 4, Wright Valley. Credit: Sarah Spaulding.

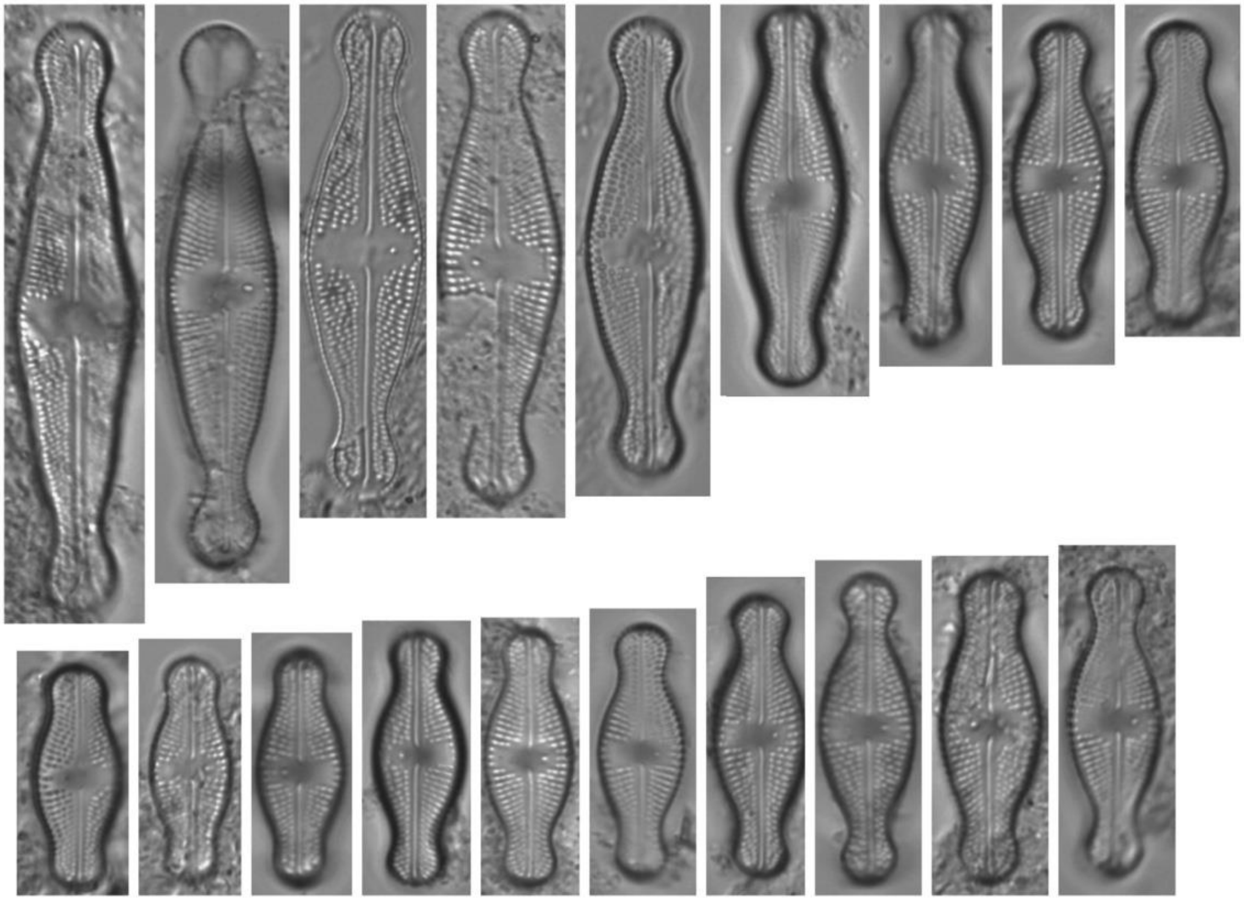

Figure 3: Light microscope images of unknown *Luticola* species from Labyrinth Pond 4, Wright Valley

UNKNOWN SPECIES FOUND IN NUSSBAUM RIEGEL POND, TAYLOR VALLEY

Another unknown species was found in the Nussbaum Riegel Pond. It comprised about 12 percent of the relative abundance count. Below are SEM (Figure 4) and light microscope images (Figure 5) of this unknown species. In the light microscope images the samples vary from 17.5 to 9 μm.

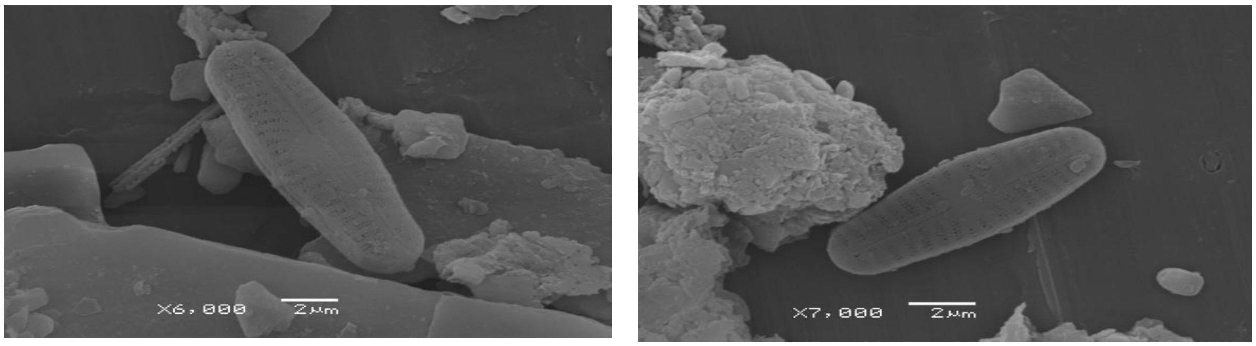

Figure 4: SEM images of unknown species from Nussbaum Riegel Pond, Taylor Valley. Credit: Kateřina Kopalová

Figure 5: Light microscope images of unknown species from Nussbaum Riegel Pond, Taylor Valley.

APPENDIX C

REMAINING WATER CHEMISTRY DATA FOR SAMPLES COLLECTED IN 2013/2014 SEASON AS WELL AS ALL DATA AVAILABLE FOR SAMPLES FROM THE 2012/2013 SEASON

Table 1: Collection data for samples taken during the 2012/2013 season

Sample	Latitude	Longitude	Collection Date
Blue Lake South Lobe	-77.54594	166.18219	Jan-24-13
Blue Lake North Lobe	-77.54417	166.17249	Jan-24-13
Clear Lake	-77.54225	166.16216	Jan-24-13
Coast Lake	-77.54224	166.14967	Jan-24-13
Pony Lake	-77.55283	166.16721	Jan-24-13
Green Lake	-77.54947	166.1562	Jan-24-13

Table 2: All available water chemistry data for samples collected during the 2012/2013 season

Sample	pH	Li mg/L	Na mg/L	K mg/L	Mg mg/L	Ca mg/L	F mg/L	Cl mg/L	Br mg/L	SO4 mg/L	Si mg/L	PO4
Blue Lake South Lobe	7.64		12.2	2.41	1.04	0.67	0.275	19.70		2.47	0.42	16.1
Clear Lake	8.63	0.049	773	166	67.6	22.6	2.551	1320.9	3.84	200	1.68	50.3
Pony Lake	8.96	0.021	1491	192	173	42.9	1.164	2680.2	7.86	323	0.81	308

Table 3: Water chemistry data for samples collected in the 2013/2014 season that was not included in the main body of the thesis

Region	Pond	Li (mg/L)	K (mg/L)	F (mg/L)	Br (mg/L)	NO3 + NO2 (mg/L)	Anions (meq/L)	Cations (meq/L)
Cape Royds	Blue Lake North	0.000	1.930	0.200	0.100	0.005	0.562	0.671
	Blue Lake South	0.000	2.240	0.200	0.100	0.006	1.580	1.725
	Clear Lake	0.000	18.500	0.700	0.500	0.054	7.030	7.933
	Coast Lake	0.000	13.600	0.700	0.700	0.036	6.990	7.881
	CR Pond 1	0.014	74.000	0.600	5.900	1.499	49.210	51.957
	CR Pond 2	0.012	97.000	1.000	5.900	0.056	68.521	71.513
	CR Pond 3	0.000	52.100	0.900	1.700	0.002	24.489	25.366
	CR Pond 4	0.000	33.700	0.900	1.900	0.010	20.223	21.407
	CR Pond 5	0.070	84.300	2.900	6.500	4.668	62.200	66.963
	CR Pond 6	0.080	145.000	5.100	7.700	0.002	95.151	104.369
	Green Lake	0.090	249.000	2.500	5.800	0.381	90.919	99.074
	Pony Lake	0.000	224.000	1.400	9.600	6.149	106.217	114.796
MCM	MCM Lower	0.010	35.300	0.900	0.900	0.002	31.384	34.005
	MCM Upper	0.060	26.000	1.000	0.000	0.005	40.517	46.579
Taylor Valley	Many Glaciers Pond	0.002	2.040	0.100	0.000	0.004	0.241	0.895
	Marr 3	0.009	11.000	0.450	0.000	0.002	4.908	5.777
	Marr 4	0.002	2.760	0.170	0.000	0.006	0.670	0.921
	Nussbaum Riegel Pond	0.010	39.500	0.640	0.200	0.011	16.489	16.650
	Picture Pond	0.000	127.000	4.400	0.000	0.001	39.483	106.790
	Parera Pond	0.002	3.860	0.090	0.000	0.004	2.047	2.294
	Spaulding Pond	0.002	2.130	0.050	0.000	0.002	0.523	1.757
Wright Valley	Labyrinth 1	0.000	0.720	0.401	0.000	5.601	2.347	2.679
	Labyrinth 2	0.000	1.032	0.551	0.000	13.431	4.188	4.696
	Labyrinth 3	0.000	1.370	0.993	0.000	27.774	7.890	8.866
	Labyrinth 4	0.000	0.910	0.900	0.000	2.503	1.489	2.180