INFLUENCE OF NUTRIENT ENRICHMENT ON STRUCTURING DIATOM COMMUNITIES IN A GLACIAL MELTWATER STREAM, MCMURDO DRY VALLEYS, ANTARCTICA

Joshua Darling
Joshua.Darling@Colorado.EDU

Follow this and additional works at: http://scholar.colorado.edu/honr_theses
Part of the Fresh Water Studies Commons

Recommended Citation
Darling, Joshua, "INFLUENCE OF NUTRIENT ENRICHMENT ON STRUCTURING DIATOM COMMUNITIES IN A GLACIAL MELTWATER STREAM, MCMURDO DRY VALLEYS, ANTARCTICA" (2015). Undergraduate Honors Theses. Paper 794.
INFLUENCE OF NUTRIENT ENRICHMENT ON STRUCTURING DIATOM COMMUNITIES IN A GLACIAL MELTWATER STREAM, MCMURDO DRY VALLEYS, ANTARCTICA

By
Joshua Darling
University of Colorado at Boulder

A thesis submitted to the
University of Colorado at Boulder
in partial fulfillment
of the requirements to receive
Honors designation in
Environmental Studies

Defended 31 March 2015

Thesis Advisors:

Diane McKnight, Civil, Environmental and Architectural Engineering, Committee Chair
Dale Miller, Environmental Studies
Sarah Spaulding, Institute of Arctic and Alpine Research (INSTAAR)

© 2015 by Joshua Darling
All Rights Reserved
ABSTRACT

In the arid McMurdo Dry Valleys of East Antarctica, glacial meltwater streams flow for 6-10 weeks during the austral summer. Harbored in these meltwater streambeds are diatom communities, which are part of a microbial mat matrix. These mat assemblages endure desiccating winters and become reactivated upon rehydration during the austral summer. Water is considered the major limiting resource in the dry valley stream ecosystems, and the variable flow of meltwater has been shown to regulate the biomass and growth of these algal mats. However, other environmental variables could influence the structure of these mat communities. In this thesis, the influences of nutrients are examined as a regulatory control on diatom community structure. This thesis draws from previous experimentation using Nutrient Diffusing Substrates (NDS) with nitrate and phosphate amendments that were left in Green Creek for algae to colonize. Characterization of diatom communities that grew on NDS units showed that nitrate enrichments significantly altered diatom relative abundance, with an increase in *Fistulifera pelliculosa* to 21% relative abundance in nitrate treatments compared to other nutrient amendments, which had less than 5% *F. pelliculosa* abundance. Other nutrient amendments showed only a marginal influence on diatom relative abundance. In addition, nitrate and phosphate amendments showed greater average diatom densities relative to the control treatments, with the greatest densities occurring in nitrate amendments. These results suggest that nutrients influence diatom growth and accrual, although stream hydrology and geomorphology likely have a greater influence on regulating the structure of these diatom communities within the microbial mat matrix. Moreover, the results from this thesis can help to predict the response by diatom communities to expected landscape changes in McMurdo Dry Valley streams as a function of climate change, such as increase flow and subsequent nutrient enrichment.

KEYWORDS: diatoms, algae, nutrients, climate change, colonization, streams
I want to thank Dr. Diane McKnight for providing me with many opportunities to explore aquatic ecology through hands-on learning in her lab. The advice I have received from Dr. McKnight has been particularly valuable, and I wish to extend my many thanks. In addition, I want to recognize Dr. Sarah Spaulding for her passion and expertise in the world of diatoms and algae. Further, Dale Miller has provided excellent advice and encouragement throughout the duration of this project.

Tyler Kohler, who initially conceived of this project and completed the in-field portion, made the work pertaining to this thesis possible. I am very grateful for the guidance and expertise that Tyler has brought to this project. In addition, I want to thank Dr. Pat Kociolek, who allowed me to take part in his freshwater phycology class to learn more about the taxonomy of diatoms.
CONTENTS

CHAPTER 1 | INTRODUCTION .................................................................................................................. 1
  PURPOSE AND SCOPE .......................................................................................................................... 1
  FORMAT OF THESIS ............................................................................................................................ 3

CHAPTER 2 | BACKGROUND .................................................................................................................. 4
  GREATER McMURDO DRY VALLEYS ECOSYSTEM .................................................................. 4
  McMURDO DRY VALLEYS STREAMS ......................................................................................... 6
  ALGAL MAT COMMUNITIES: CHARACTERISTICS AND DISTRIBUTION ..................................... 8
  DIATOMS ........................................................................................................................................ 11
  McMURDO DRY VALLEY STREAM DIATOMS ........................................................................ 13

CHAPTER 3 | METHODS ....................................................................................................................... 19
  GREEN CREEK: SITE DESCRIPTION ........................................................................................... 19
  NDS COLONIZATION ..................................................................................................................... 22
  DIATOM ENUMERATION ............................................................................................................... 24
  DIATOM COMMUNITY CHARACTERIZATION AND ANALYSIS .................................................. 24
    Species Presence .......................................................................................................................... 25
    Diversity ....................................................................................................................................... 25
    Density ....................................................................................................................................... 25
    Relative Abundance ................................................................................................................... 26

CHAPTER 4 | RESULTS .......................................................................................................................... 27
  SPECIES PRESENCE ....................................................................................................................... 27
  DIVERSITY ...................................................................................................................................... 28
  DENSITY ....................................................................................................................................... 29
  RELATIVE ABUNDANCE ............................................................................................................... 31

CHAPTER 5 | DISCUSSION ....................................................................................................................... 35

APPENDIX .......................................................................................................................................... 38

BIBLIOGRAPHY .................................................................................................................................. 40
Chapter 1 | INTRODUCTION

Purpose and Scope

The purpose of this thesis is to assess how nutrient loading influences the establishment of diatom (Bacillariophyta) taxa in a glacial meltwater stream located in Taylor Valley, of the McMurdo Dry Valleys, Antarctica. Diatoms are a type of unicellular algae and are fundamental primary producers found in marine and freshwater systems the world over. The algal group is valued as a useful bio-indicator of environmental change. And, in regions sensitive to small climatic changes, such as the McMurdo Dry Valleys (MDV), diatom monitoring can be a useful tool for understanding the ecological response to chemical and physical controls in a dynamic system. This thesis addresses the response of colonizing diatom assemblages to nutrient enrichment to better understand the ecological structure and function of these diatom communities.

For most aquatic systems, it can be expected that an increase in the major limiting nutrients for that system will result in increased growth. However, is not always explicitly known how diatom communities will respond to nutrient loading—especially in the context of the oligotrophic Antarctic streams, where diatom communities represent only a small portion of the microbial mat biomass, and where nutrient concentrations in the mat matrix can be significantly controlled by the pre-existing microbial mat communities. Many of the diatom taxa present in the MDV streams are considered endemic to the MDV region and have evolved in harsh environmental conditions. Furthermore, understanding how the MDV stream diatom community structure is influenced by nutrient enrichment will provide more insight into the microbial mat ecology of the MDV region.

The stream of interest in this thesis, Green Creek, is nitrogen limited (Gooseff et al., 2004),
and so it can be hypothesized that diffused nitrate treatments will result in stimulated algal growth. Yet, it is still unknown how the community structure of these diatom assemblages will change with regard to different treatments.

This thesis will examine the significance of nitrate and phosphate to the establishment of diatom communities onto nutrient diffusing substrata (NDS) over the course of a flow season (~20 days). The scope of this thesis is to quantify the diatom taxa that colonized onto NDS structures and determine if nutrient amendments influence the accumulation of certain taxa and overall diatom community structure. Understanding how diatom assemblages respond to nutrient enrichment, rather than other algal assemblages within the mat matrix, is important because diatoms can be used as a proxy for ecological and environmental monitoring due to specific taxonomic responses to climate variation. In addition, diatoms have a silica-composed frustule (cell wall), which can be preserved for millennia, and thus diatoms can be looked at in a paleoecological context to reconstruct historical climates and environmental conditions.

Furthermore, the responses to nutrient enrichment by certain diatom taxa can tell us more about the individual ecologies of these taxa. And understanding how diatom assemblages respond to amended nutrient regimes will provide insight into understanding how environmental change may alter the MDV stream microbial communities.

For this thesis, diatoms were enumerated from algal material that colonized onto 32 artificial nutrient diffusing substrate structures, which were deployed along a reach of Green Creek during the 2012/2013-flow season. The 32 NDS structures were divided into 8 units with 4 different nutrient diffusing treatments. The 4 nutrient treatments tested: nitrate (NO$_3^-$), phosphate (PO$_4^{3-}$), nitrate + phosphate (NO$_3^-$ + PO$_4^{3-}$), and a control treatment that lacked nutrient salts. Thus, in total algal mats colonized onto 32 separate artificial nutrient releasing substrates left in Green
Creek during the flow season. In the laboratory, diatoms were isolated from other algae and bacteria that colonized onto the substrates and were counted and identified at a species-level resolution, using light microscopy. Accordingly, here I will share my observations to determine if nitrate and phosphate concentrations influence the accrual of Antarctic stream diatom taxa.

This thesis aims to address the question: Do enriched treatments of nitrate (NO$_3^-$) and phosphate (PO$_4^{3-}$) alter the relative abundance, density, and diversity of diatom flora that colonized onto nutrient diffusing substrates during a flow season (20 days)?

**Format of Thesis**

This thesis will begin with a background chapter and literature review that delves into the unique McMurdo Dry Valleys. The ecological controls on the dry valley stream ecosystem—such as hydrologic regime, nutrient flux of streams, and algal community composition and distributions—will be examined. Chapter 3 outlines the methods used to assess the influence of nutrients on diatom communities. Chapter 4 reveals the results from this study, and Chapter 5 integrates the results into a discussion on the broader patterns of diatom colonization with regard to different nutrient treatments.
Chapter 2 | BACKGROUND

The McMurdo Dry Valley region is characterized by extremely harsh environmental conditions, and represents an ecosystem that persists near environmental limits. Since its inception as a Long-Term Ecological Research (LTER) site in 1992, many scientists have collaborated with the McMurdo Dry Valleys LTER (MCM LTER) program in attempts to further understand the basic ecological processes of the region, and to investigate how the sensitive environment may respond to climatic changes. As a National Science Foundation LTER site, a wealth of literature and data is available on the McMurdo Dry Valleys region. Herein I will synthesis much of the literature pertaining the McMurdo Dry Valley region to provide a background understanding for the context of this thesis. Following, I will describe the generalities of periphyton growth and nutrient limitation.

Greater McMurdo Dry Valleys Ecosystem

The McMurdo Dry Valleys (MDV) cover a 4800 km² area located in Southern Victoria Land, Antarctica. In 1992 the McMurdo Dry Valleys Long-Term Ecological Research (MCM LTER) was established, and the areas ecology has been extensively studied. The seemingly arid and barren region holds the largest ice-free expanses on the Antarctic continent (Fountain et al., 1998), and represents the coldest and driest desert on Earth (McKnight et al. 1999). Soil and bedrock loom over the landscape in lieu of ice, and provide a canvas for perennially ice-covered lakes, ephemeral streams, valley glaciers, and Transantarctic Mountain peaks.

Within the MDV, water is the critical component that facilitates the functioning polar ecosystem. The hydrologic reservoirs of the MDV are discussed herein. First, the valley floors of the MDV receive very little precipitation. Of the precipitation that does fall in the MDV, most falls as snow or is blown in from the polar plateau during winter and does not exceed 50 mm in
Maximum precipitation occurs near the margins of the MDV, where uplifting takes place near the coast of the Ross Sea, and a gradient of decreasing precipitation occurs moving inland from the coast (Fountain et al., 2010). Snow accumulation however, does not last long, and quickly sublimates or blows elsewhere due to katabatic winds that descend from the polar plateau. Sublimation exceeds precipitation in the MDV, and thus the climate is very arid (Fountain et al. 2010).

A thick layer of permafrost underlies the MDV, and is an important feature of the landscape. An ice-cemented permafrost layer, which remains frozen throughout the year— with sufficient moisture content to cement soil partials together— is present at around 60 cm depth below surface soils (Campbell et al., 1998). Campbell et al. (1998) found the average moisture content of the ice-cemented permafrost in the region to be about 40 percent. An active layer of permafrost sits above the ice-cemented layer, but is dry-frozen; meaning moisture content is too low to cement soil partials, where moisture content is only around 1.5 to 3 percent (Campbell et al., 1998). Moreover, permafrost is likely to play an important role as the MDV region warms in the coming decade. Swanger and Marchant (2007) propose that, as a result of climate warming, permafrost degradation is likely to happen, and leach nutrients and salts saturated in the permafrost into the greater MDV ecosystem. In addition Fountain et al. (2014) anticipate that climate warming will drive landscape changes in the MDV, resulting in greater permafrost thaw and more glacial melt, which will enhance connections between surface water, and soils/sediments. This, they postulate, will increase the flux of nutrients, solutes, and particulates into the stream ecosystem and will result in a subsequent response to the structure and function of the regions hydrology, geochemistry, and biological communities (Fountain et al., 2010).

Glaciers provide the main source of water to the MDV ecosystem during the austral summer.
Glacial meltwater is a product of warming air-temperature and incoming solar radiation, which increase the energy balance of the alpine glaciers to produce a subsequent pulse of melt, flowing from the glacial terminals into previously formed stream channels, or glacial melt ponds (Gooseff et al. 2011). In addition, glaciers provide a source of nutrients to the streams, especially during initial spring melt, when the particulate matter that accumulated onto the glacier during the winter flushes off the ice and into the streams (Howard-Williams et al., 1998). The glaciers only produce meltwater for 6-10 weeks during the austral summer and during this short time period, water, energy, and matter (such as, sediments, salts, nutrients, and algae) are distributed to communities of microbial and algal biota that persist in the soils, streams, and lakes of the MDV (Gooseff et al., 2011).

*McMurdo Dry Valleys Streams*

Glacial meltwater streams are vital for the greater MDV ecosystem for distributing and regulating the amount of water and flux of nutrients to the lakes, and soils along the stream margins. Stream flow can vary greatly on a daily timescale depending on temperature and incoming solar radiation, which produces subsequent glacial melt. McKnight et al. (1999) showed that stream flow varies as much as 5-10 fold during a single day depending on temperature, solar declination, and topographic features. For example, Huey Creek, which drains into Lake Fryxell can range from merely a trickle of 5 L/s in the morning to 80 L/s later in the day when temperatures increase and more sun is exposed to the glacier face. Moreover, the turbidity of the stream increases with greater flow, carrying more sediment into the system.

During cold spells, when melt water is not being fed into the stream channel, the hyporheic zone—the saturated bands alongside and beneath the stream, which interacts with water in the main channel, and where weathering of minerals occur—will withdrawal stored water back into stream (McKnight et al., 1999 & 2004). Moreover, the hyporheic zone influences the hydrology
and nutrient flux of the stream channel. The role of the hyporheic zone, however, depends on the stream length and geomorphology. Nonetheless, hyporheic exchange and algal mat assimilation of nutrients are critical components to the biogeochemical cycling in Antarctic streams.

McKnight et al. (2004) examined the nutrient dynamics of MDV meltwater streams controlled by the hyporheic zone and microbial processes; this study found that in streams with abundant algal mat coverage, stream nitrate and phosphate concentrations were lower than in streams that scant algal mat coverage. In addition, streams with abundant algal mats had greater nitrate and phosphate concentrations in the hyporheic zone than in the water column. McKnight et al. (2004) showed that nitrate uptake happens in both the main channel and in the hyporheic zone, where algal mats are responsible for autotrophic uptake in the main channel, and in the hyporheic zone, microbial uptake takes place. Moreover, microbial processes in the hyporheic zone transform and reduce nitrate through reduction and denitrification (McKnight et al., 2004; Gooseff et al., 2004).

Phosphate uptake happens only in the main channel by algal mat assimilation (McKnight et al., 2004). The dissolution of leached aerosols and mineral weathering are likely to occur within the hyporheic zone, and then diffuse into streams (Lyons et al., 1998). And so, a source of nutrients for the algal mat communities is attributed to the hyporheic zone. Additionally, the source of nutrients to downstream lake ecosystems is heavily dependent upon the abundance of algal mats within the stream and the extent of the hyporheic zone, both which are attributed to nutrient transformations and uptake (McKnight et al., 1999, McKnight et al., 2004, Gooseff et al., 2004).
**Algal Mat Communities: Characteristics and Distribution**

Many of the ephemeral streams in MDV contain algal mats that are attached to the streambed substrate. These mats can be several centimeters thick and may cover substantial reaches of MDV creeks (Howard-Williams and Vincent, 1989). Here the algal mats are seasonally reactivated, and represent hot spots of primary production in a region otherwise devoid of life. The mat assemblages present in these streams have adapted to the arid and harsh environment; being able to survive long periods of desiccation in winter and variable stream flow in summer. After cold, dark, and desiccating winters, the algal mats are revived with the occurrence of flowing liquid water (McKnight et. al., 2007). With an influx of solar radiation, the glaciers begin to melt. Soon after melt is initiated, stream flow is regenerated, and within 20 minutes of the algal mat communities becoming wetted, they start to photosynthesize (Vincent and Howard-Williams, 1986). This phenomenon, however on a longer temporal scale, has been shown to occur in old relict streambeds, even after several decades of receiving no flow (McKnight et al., 1999; McKnight et al., 2007).

Water limits the biological function and primary production within the MDV streams. The seasonally re-activated algal mat community, attached to the substrates of the ephemeral streams, consists of bacteria, Archaea, and Eukaryota (McKnight et al. 1999; Stanish and Spear, 2013). Within these algal mats, eukaryotic diatom taxa are found—a group of micro algae sensitive to stream water chemistry and specific ecological conditions, and thus are used as a metric for water-quality in many aquatic systems (Stevenson and Smol, 2003). The structure of these microbial mat communities consists mainly of filamentous cyanobacteria, diatoms, chlorophyta, mosses, and other heterotrophic and chemoautotrophic bacteria (Alger et al., 1997; Fountain et al. 2014, McKnight et al. 1999). The largest organisms are nematodes, tardigrades, and rotifers, however these organisms are sparse and show little biodiversity (McKnight et al. 1999; Alger et
Alger et al. (1997) extensively surveyed the characteristics and distribution of algal mats within the dry valley streams. Broad patterns were observed in relation to the location and type of mats found within the streambeds. Mats were categorized by color and analyzed for algal species composition for each categorized mat type. Algal mats display different colors due to the photosynthetic and accessory pigments of the mat constituents (McKnight et al., 1999).

Observations made by Alger et al. (1997) showed that the middle of the streambed was generally a heterogeneous mix of orange, red, or green mats. Where the primary cyanobacteria species present in the orange and red mats are composed of *Oscillatoria* and *Phormidium*, and house more a diverse assemblage of species. Green mats are more dominated by a green algae, *Prasiola calophylla*, and do not exhibit diverse alga assemblages. Further, black mats were found at the stream margins and were dominated by the cyanobacteria *Nostoc*—an N-fixing cyanobacterium (Alger et al., 1997). Broad patterns have been shown to relate the abundance of cyanobacteria and green algae to different colored mats and location (Alger et al., 1997), however the habitat controls for diatoms are not restricted to the same constraints for cyanobacteria and green algae (Stanish et al., 2012a). Furthermore, subsequent studies on individual diatom ecologies are needed to better understand the controls on diatom community structure.

Stream geomorphology can influence the community structure within the microbial mats. In steep stream reaches, a jumbled composition of large rocks makes up the streambed substrate, with scant algae presence in the main channel (McKnight and Tate, 1997). In stream reaches with a moderate gradient a flat stable stone pavement provides a favorable habitat for algal mat assemblages (McKnight and Tate, 1997; Alger et al., 1997). Stable stone pavement limits the
turbulent flow and abrasion and provides more laminar flow, further bolstering microbial habitat quality (Alger et al., 1997). However, reaches with stable stone pavements, and thus more abundant algal growth, are dependent upon a saturated alluvium in the parafluvial zone that is capable freeze-thaw processes (McKnight and Tate, 1997). Saturated ground promotes the formation of a pavement through freeze-thaw cycles over time; and thus, sites with stable pavements are typically found below melt ponds or flat areas with a saturated alluvium (Alger et al., 1997). Hence, stream reaches with a moderate gradient and a stable stone pavement provides a favorable habitat for algal mats. Similarly, stream reaches with uneven substrata are typically deficient of moisture; such that the streambed is not saturated when freezing temperatures occur at the end of the austral summer, and stable pavements are unable to form, precluding algal growth (Alger et al., 1997). Indeed, substrate type and gradient are functional components to algal mat habitat.

High flow events can increase the turbidity of the stream, adding particulates and nutrients into the stream, while also subsequent mat scouring can occur—both phenomena can be linked to biomass accrual and reduction, respectively (Cullis et al., 2014). Fountain et al. (2014) described the MDV ecosystem, especially the ephemeral stream ecosystems to be very sensitive to marginal changes in climatic conditions or altered physical constraints. Also, expressed by McKnight and Tate (1997), the stream ecosystems are not in a steady state, and warming events will alter the hydrologic processes of the streams. The predicted effects of climatic warming can be associated with increased stream flow, or altered hydrologic flow regime (Fountain et al., 2014). This predicted change in the hydrologic regime, as a function of climate warming, will likely alter stream microbial communities (Fountain et al., 2014; Kohler et al., 2014, submitted for publication). Fountain et al. (2014), postulate that an increase in stream flow will cause a
subsequent increase in nutrient availability, with stimulated algal primary production expected. In these conditions, endemic organisms adapted to intermittent flow could be outcompeted by generalist species, which are more resilient to higher-flow conditions (Fountain et al., 2014; Stanish et al., 2011). Moreover, the hydrology and geomorphology of the stream ecosystem are considered important variables controlling diatom and algal community structure. However, other mechanisms that regulate algal biomass, such as nutrient availability, have been less studied.

**Diatoms**

Diatoms are a group of unicellular micro-algae found in most aquatic habitats; the algal group is classified as *Bacillariophyta*. Generally, diatoms are relatively small; cell sizes can range from 2 to greater than 200 microns. Diatoms represent a rather large biological group, with over 250 genera and an estimated 200,000 different species (Mann and Droop 1996). However, of the 200,000 estimated species, only about 12% have been described (Julius and Theriot 2010). As a group, diatoms are attributed with producing more than 40% of global net primary production (Nelson et al., 1995), and diatoms account for 25% of Earth’s total oxygen production (Werner, 1977).

Diatom morphologies are precise and species specific. They possess highly ornate silica frustules, which are made of inorganic biogenic silica. The frustules are composed of two values, the epitheca and the hypotheca, which fit together like a petri dish. Moreover, diatoms reproduce primarily asexually, with quick growth rates. During division, the epitheca and the hypotheca of the initial cell divide, and both parts become the epitheca of each succeeding cell. Thus, average cell size decreases over time. This division process was described over a century ago, and is referred to the MacDonald-Pfitzer rule (MacDonald 1869; Pfitzer 1869, 1871). Moreover, to reestablish cell size and maintain populations, sexual reproduction takes place after a cell reaches
a minimum size threshold, forming another initial cell, or auxospore, restoring the maximum size of the cell. This cyclical asexual-sexual process of size reduction and enlargement has been coined as the diatom sex clock, a life strategy that likely explains the existence and perseverance of diatoms over time (Lewis 1984).

Within the class *Bacillariophyta*, two divisions of hierarchical orders exist based on the frustule morphology: *Coscinodiscophyceae* and *Pennales*, or centric and pennate, respectively. The frustule symmetry of centric diatoms is radially formed, where pennate diatoms show a frustule symmetry that is bilateral. Most freshwater diatoms—like those found in Antarctic streams—are pennate in symmetry, while many centric diatoms are found in marine environments.

The inorganic silica cell-wall frustules of diatoms do not easily decompose, allowing diatoms to be preserved in geologic time. Accordingly, diatoms are commonly used as a metric to assess environmental and ecological conditions of the past and the present. For example, specific diatoms taxa are sensitive to environmental variables, such as water chemistry, hydrology, or nutrient regime, which dictate species presence and abundance (Alger et al., 1997; Kohler et al., 2015; Stanish et al., 2011; Stevenson et al., 1996). Hence by examining the presence and abundance of certain diatom taxa in known environmental conditions, species preferences and their sensitivity to certain conditions can be better understood. Furthermore, the presence and abundance of diatoms in modern environmental conditions can be applied to reconstruct the historical environmental conditions from diatoms preserved in sediment cores from lakes and oceans (Spaulding et al., 1997; Verleyen et al., 2009). Moreover, in the context of this thesis, understanding how nutrients influence the structure of colonizing diatom assemblages onto nutrient diffusing substrates will provide information on the species sensitivity to nutrient
McMurdo Dry Valley Stream Diatoms

The diatom assemblages present in MDV stream algal mats are characterized by abundant endemic species, but low overall diversity (Alger, 1999; Esposito et al, 2006). In all, the dry valley stream diatom taxa are relatively few, with 45 total species (Spaulding et al., 2014). Many scientists have described the taxonomy of the MDV diatom flora (Alger, 1999; Esposito et al., 2008; Kohler et al., submitted 2015; Sabbe et al., 2003; Van de Vijver et al., 2011a; 2011b; and 2012: Spaulding et al., 2015). And hence the many publications describing the MDV diatoms, a taxonomic resource was developed by MCM LTER to synthesize the literature on MDV diatoms, and list up-to-date and consistent taxonomic descriptions of the diatoms present in the MDV and the greater Antarctic region (Spaulding et al., 2015).

Most of the MDV stream diatom assemblages are represented by naviculoid taxa (such as Luticola, Navicula, Chamaepinnularia, Muelleria, Stauroneis, and Fistulifera; Figure 1). However, other morphological groups such as amphorid, nitzschioid, and monoraphids are present in the MDV mat assemblages. Also, it is worth noting that many morphological groups are not represented in MDV stream diatom flora. The diatoms that inhabit the MDV streams are mostly aerophilic genera that are also found in soils and mosses, and capable of persisting during periods of desiccation (Esposito et al., 2006; 2008). Esposito et al. (2006) found that the abundance of endemic diatoms increases with harsher conditions, such as intermittent low-flow periods. In addition, diatoms of the MDV stream ecosystems not only need to withstand harsh environmental conditions (low flow and desiccation/ dark winters), but also must able to complete their life cycle during the highly variable and short flow season during the austral summer. Hence, many of the MDV diatom taxa have local adaptations for withstanding
Figure 1.A. Illustrations of diatom taxa that were observed in this thesis, and that are present in Green Creek in the McMurdo Dry Valleys, Antarctica. Illustrations were drawn based on personal observation, and from descriptions by Esposito et al. (2008), Kohler et al. (2015), and the Antarctic Freshwater Diatoms website, Spaulding et al. (2015). Cell sizes were drawn based on average dimensions for each species. Scale bar is 10 µm.
Figure 1. B. Illustrations of diatom taxa that were observed in this thesis, and that are present in Green Creek in the McMurdo Dry Valleys, Antarctica. Illustrations were drawn based on personal observation, and from descriptions by Esposito et al. (2008), Kohler et al. (2015), and the Antarctic Freshwater Diatoms website, Spaulding et al. (2015). Cell sizes were drawn based on average dimensions for each species. Scale bar is 10 µm.
isolation in sporadic desert streams and arid environmental conditions. Moreover, the physical characteristics of the streams control the structure of the diatom communities.

**Controls on Stream Diatom Communities**

The hydrologic regime of the dry valley streams can fluctuate greatly in short time intervals; where flow is dependent upon the dynamic air-temperatures and solar radiation controlling glacial melt. Further, it has been shown that benthic algal mat communities in Antarctic streams are more influenced by hydrologic regime than nutrient regime (Esposito et al., 2006; Stanish et al., 2011; 2012b; Howard-Williams et al. 1986). Stanish et al. (2011) revealed that diatom community composition is dependent upon hydrologic regime, and further discussed the habitat preferences of diatoms in relation to species traits such as size, motility, and hydrologic flow regime. For example, smaller sized generalist diatom genera, such as *Psammothidium* spp. and *Diadesmis* spp. were found to benefit from higher-flow streams, indicating the ability for these diatoms to tolerate flow inundation while also sustaining nutrient uptake and fast growth rates (Stanish et al. 2011). Also, another small generalist diatom species, *Fistulifera pelliclosa*, is generally dispersed downstream during intermittent high-flow periods from small meltwater ponds sitting near the base of glaciers, and colonizes onto mats downstream (Stanish et al. 2011). The distribution and resilience of the small-sized generalist diatom population is greatly influenced by a high-flow regime. However, diatom species that are more common to the Antarctic region, and that are considered endemic, are more adapted to the varying hydrologic regimes and extreme environmental conditions (Esposito et al., 2006; 2008; Stanish et al., 2011). The genus *Luticola* is considered to be the most diverse and abundant group of diatoms within the MDV, characterized by high rates of endemism, with 9 taxon considered endemic to the MDV region (Esposito et al., 2008; Kohler et al., submitted 2015; Stanish et al., 2011; 2012b).
Further, it was found that *Luticola* spp. are more abundant in highly variable, low-flow streams indicating that regional adaptations have occurred within this genus (Esposito et al., 2008; Stanish et al., 2011). Similarly, the diatom genus *Hantzschia*, a genus with some Antarctic endemic species, was also found to prefer low-flow streams, or intermittently wetted habitats along the stream margins (Stanish et al., 2011). A later study by Stansh et al. (2012b) confirmed that endemic diatom species are more resilient to intermittent flow periods and frequent drying events. Based on the results presented by Stanish et al. (2011; 2012b), it can be concluded that diatom community structure is greatly influenced by hydrologic regime.

Most of the research pertaining to the mechanisms that govern the structure of diatom assemblages in MDV streams has focused on physical controls, such as hydrology (Stanish et al., 2011; 2012b; Esposito et al., 2008), streambed substrate composition (Alger et al., 1997), and temperature (Garland, 2013). Nutrient limitation, as a means for governing diatom community structure, has been less studied. However, hydrologic processes influence nutrient processes. For example, in a general stream ecosystem context, biological nutrient uptake and recycling is greatly influenced by hydrologic processes, such as the exchange of water between streams and solute-rich, interstitial or hyporheic waters (Allan, J, 1995). In the context of dry valley streams, the hydrologic regime regulates the exchange between solute-rich hyporheic water and the stream water (McKnight et al., 1999; Gooseff et al., 2011). Furthermore, the exchanges of nutrients form the hyporheic zone and the subsequent uptake by benthic algal mat communities can be associated with the hydrologic regime. However, isolating nutrients to determine the response by algae or diatom assemblages has been less explored. Previous exploration on the role of nutrients in dry valleys streams has shown that nutrients have little effect on photosynthetic rates (Howard-Williams, 1989) or biomass accrual (Stanish et al., 2011; Alger et
al., 1997). However, these studies did not consider the affects of nutrients on colonizing mat communities, where nutrients may play a greater role in structuring communities since microbial mats are known to regulate their own nutrient conditions.

Thus this thesis aims to address how diatoms respond to isolated nutrient treatments during colonization, to understand taxonomic sensitivity of nutrients at a species level resolution. Exploring how diatom communities respond to nutrient amendments can be useful for the LTER diatom-monitoring program, to understand how individual species may respond to amended nutrient concentrations. This knowledge can be useful for predicting how microbial communities may respond to the destruction of solute-rich permafrost and increased flow, as a consequence of climate change.
Chapter 3 | METHODS

A common method for assessing nutrient limitation in running waters is to use Nutrient Diffusing Substrates (NDS). NDS units release nutrients into the water column from a nutrient saturated-medium held in containers, nutrients diffuse through artificial substrates, which algae colonize onto. NDS can be used in situ to determine different species responses to amended and isolated nutrient regimes. This thesis utilizes algal mat material that grew on NDS units that were deployed in Green Creek, during the 2012/2013 austral summer. Diatom communities were isolated from other algae, then analyzed under a microscope to determine species limitation to nutrient amendments.

**Green Creek: Site Description**

Nutrient Diffusing Substrate (NDS) colonization was conducted in Green Creek, a glacial-fed stream that links Canada glacier to the perennially ice-covered Lake Fryxell, a closed-basin lake. NDS units were placed in a reach of the creek just below the MCM LTER F9 gauging station, which continuously measures stream chemistry and hydrology; these data can be accessed via the MCM LTER website, and are shown in Figure 2 and Table 1 for the 20-day colonization period. The 1.2-kilometer stream is located on the west side of Lake Fryxell and drains a glacial melt pond at the base of Canada Glacier (Map of location, Figures 3A & 3B). The stream channel of Green Creek is wide with a shallow gradient and a low stream bank. The streambed substrate is composed of a stable stone pavement with abundant and thick algal mat coverage throughout most its reach. Furthermore, because the stream drains a melt pond, stream flow is less influenced by periods of cloud cover, which, for most other MDV streams, can suddenly turn off stream flow. Thus, the stream is less likely to experience lengthy periods of desiccation. Still, however, discharge varied throughout the duration of NDS colonization (Figure 2); average
maximum discharge occurred at the start of the experiment (288 L/s), and decreased throughout the 20-days, with no flow occurring on the last day of the colonization experiment. Stream temperature (Figure 2) remained relatively stable with small diel changes (2-6°C). The justification for testing treatments of nitrate and phosphate is that these nutrients generally vary within dry valley streams, and thus can provide insight into algal community colonization. Furthermore, Green Creek was chosen because it contains abundant algal mat coverage and has a reduced chance of desiccation.

**FIGURE 2.** Green Creek discharge [L/s] (solid line) and water temperature [°C] (dashed line) during the 20-day NDS colonization experiment, 2 January 2013 to 22 January 2013. Data were derived from MCM LTER online database: www.mcmlter.org.

**Table 1.** Abiotic characteristics of Green Creek during NDS colonization experiment

<table>
<thead>
<tr>
<th>DATE &amp; TIME</th>
<th>pH</th>
<th>°C</th>
<th>Conductance (µS)</th>
<th>N-Nitrate</th>
<th>N-Nitrite</th>
<th>N-Ammonium</th>
<th>P-Phosphate</th>
<th>Si</th>
<th>SO4</th>
<th>DOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec 11 2012 at 12:45 PM</td>
<td>6.87</td>
<td>2.50</td>
<td>31.50</td>
<td>36.14</td>
<td>2.07</td>
<td>&lt;5</td>
<td>4.13</td>
<td>308.86</td>
<td>1121.7</td>
<td>199.88</td>
</tr>
<tr>
<td>Dec 18 2012 at 12:19 PM</td>
<td>6.89</td>
<td>5.90</td>
<td>27.30</td>
<td>17.48</td>
<td>0.97</td>
<td>&lt;5</td>
<td>3.45</td>
<td>409.82</td>
<td>897.98</td>
<td>319.89</td>
</tr>
<tr>
<td>Dec 26 2012 at 3:30 PM</td>
<td>7.32</td>
<td>8.40</td>
<td>45.50</td>
<td>13.08</td>
<td>2.09</td>
<td>&lt;5</td>
<td>4.04</td>
<td>940.13</td>
<td>935.66</td>
<td>615.12</td>
</tr>
<tr>
<td>January 2 2013 at 9:15PM</td>
<td>7.54</td>
<td>4.60</td>
<td>24.40</td>
<td>16.29</td>
<td>&lt;0.7</td>
<td>&lt;5</td>
<td>6.29</td>
<td>277.29</td>
<td>745.10</td>
<td>&lt;100</td>
</tr>
<tr>
<td>January 11 2013 at 11:21 AM</td>
<td>7.19</td>
<td>7.20</td>
<td>36.30</td>
<td>11.43</td>
<td>1.87</td>
<td>&lt;5</td>
<td>2.71</td>
<td>635.31</td>
<td>780.60</td>
<td>205.73</td>
</tr>
<tr>
<td>January 15 2013 at 1:00PM</td>
<td>7.97</td>
<td>7.50</td>
<td>34.90</td>
<td>1.87</td>
<td>&lt;0.7</td>
<td>&lt;5</td>
<td>3.49</td>
<td>621.00</td>
<td>933.71</td>
<td>112.85</td>
</tr>
</tbody>
</table>

Note: All data were derived from MCM LTER online database, recorded from F9 gauging station, Green Creek, McMurdo Dry Valleys, Antarctic.

**TABLE 1.** Green Creek stream chemistry and temperature at weekly time-points during the NDS colonization experiment that took place during the 2012/2013-flow season. Data were derived from MCM LTER online database: www.mcmlter.org.
FIGURE 3A. Map of the Lake Fryxell basin in Taylor Valley, Antarctica. The black arrow points to Green Creek, and the black circles indicate stream-gauging stations in operation by the MCMLTER project. Figure adopted from Kohler et al. (2015).

FIGURE 3B. Map of Green Creek showing sample locations, where NDS structures were deployed. Contour interval is 1 meter. Map manipulated from from Gooseff et al. (2004) to show sampling location for this experiment.
**NDS colonization**

Tyler Kohler, Environmental Studies Ph.D. candidate, completed the in-field portion of this project during the 2012/2013 sampling season. He has since transferred the samples to me for further analysis. The following paragraph describes the work completed by Kohler et al. The subsequent paragraphs, however, describe the work that I have completed.

To assess how nutrients influence the relative abundance of diatom taxa in Green Creek, Nutrient Diffusing Substrates (NDS) were used (modified from Tank et al., 2006). NDS units were constructed and placed in the thalweg of Green Creek (see Figure 4 to reference a NDS structure illustration). Each NDS unit held 4 nutrient-releasing cups, with 4 different treatments diffused to the artificial substrate (glass frit). The nutrient-releasing cups were made from 30ml Fisherbrand © Polyethylene Hinged-lid Containers and filled with agar (a natural algal bi-product) and nutrient salts. A 2.2cm diameter hole was cut into the lids of the cups. These holes were then plugged with 2.75cm diameter fritted glass discs; these discs act as the porous artificial substrate for algal material to accumulate on. Eight NDS units were made (32 total samples), each held 4 nutrient releasing cups, each cup had a treatment of nitrate (NO$_3^-$), phosphate (PO$_4^{3-}$), nitrate + phosphate (NO$_3^- + $PO$_4^{3-}$), and a control. The chosen molar concentration for each treatment was set as 0.5 M, as outlined in table 10.2 of Methods in Stream Ecology (Hauer, 2007). The 4 different nutrient-releasing cups were bonded to a Plexiglas sheet. Clear Plexiglas was used to limit the energy absorption of incoming solar radiation. These nutrient-releasing units were then staked into the substratum of Green Creek, with barn nails, in a reach just below the F9 gauging station. In total, 8 units, or 32 treatments, were left to incubate in Green Creek starting on 2 January 2012.
The units were left in the stream until the end of the flow season (22 January 2012) to allow time for microbial colonization of the glass frits. The frits were then collected, and the algal material was sent to University of Colorado, Boulder for analysis. Frits from 5 NDS units were used for determining Chlorophyll-a (Chl-a) concentrations, as a method for estimating changes in the algal biomass of photosynthetic communities (Serôdio, 2001). Chl-a was measured with a Turner Designs 10-AU fluorometer, and values were manipulated to represent Chl-a over the entire frit area. These samples were then retained and used to determine diatom community structure and characterization; however, the samples used for Chl-a analysis were not used to determine diatom density because the density could have been altered during the process of measuring Chl-a.

**FIGURE 4.** Illustration of a Nutrient Diffusing Substrate (NDS) unit. NDS units were deployed in Green Creek from 2 January 2013 to 22 January 2013. A control (C) treatment without nutrient amendments, and nutrient treatments of phosphate (P), nitrate (N), and nitrate + phosphate (N+P) were diffused from 30mL cups for 20 days. Nutrients diffused through porous fritted-glass substrata that algae attached to and grew on. At the end of the flow season frits were removed and sent to University of Colorado at Boulder for further analysis.
**Diatom Enumeration**

To characterize the diatom taxa that colonized onto the nutrient-releasing artificial substrates, the accumulated algal mat material was transferred to 50mL centrifuge tubes and digested with 25mL of 30% hydrogen peroxide (H$_2$O$_2$) solution at low heat to remove organic matter from the sample material. Since diatom frustules are composed of inorganic biogenic silica, the H$_2$O$_2$ solution does not oxidize diatom frustules. After digestion, the samples were rinsed with distilled water several times until a neutral pH was reached. Next, mounted microscope slides were made. With the digested material from each sample, a 1mL aliquot was removed and dried onto glass microscope coverslips. The coverslips were then mounted onto glass slides using Zrax© (developed by W.P. Dailey, Philadelphia, U.S.A), a high refractive index mounting media. For each nutrient treatment, mounted microscope slides were then examined using an Olympus Vanox light microscope at 1250x magnification until ≥ 300 valves were counted for each treatment sample. Diatoms were identified to species following descriptions from Esposito et al. (2008), Kohler et al. (submitted, 2015) Kopalova et al. (2011, 2012), Sabbe et al. (2003), Van de Vijver et al. (2011a, 2011b, and 2012), Zidarova et al. (2010), and the Antarctic Freshwater Diatoms website: huey.colorado.edu/diatoms (Spaulding et al., 2014).

**Diatom Community Characterization and Analysis**

Several diatom community characteristics were analyzed to determine the response of colonizing diatoms to treatments of nitrate and phosphate. First, the average frequency that species were present in different treatments was determined. Second, species diversity was calculated between nutrient treatments using a Shannon-Weaver index. Third, the density, or number of cells per unit area was calculated. Lastly, the relative abundance of species between treatments was quantified.
Species Presence

To show a general trend in species presence between treatment samples, the frequency by which species were seen in all 32 samples, regardless of nutrient treatment, was determined. Frequency was also determined between each treatment to compare how treatment samples contribute to overall frequency in all treatments, and how treatments differ in species presence. Species were ranked sequentially by their presence in a sample from most frequent to least frequent.

Diversity

Using diatom counts species richness ($S$) was calculated, which is equal to the total number of species present in each treatment. Also, the community diversity ($H'$) of each sample was calculated using a Shannon-Weaver index (Shannon and Weaver 1949):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Where $p_i$ is the relative abundance of species, $i$. And $S$ is the species richness. Evenness was considered by calculating $\ln(S)$, which is equal to the ratio of $H'$ to $H'_{\text{max}}$ (Pielou, 1966).

Density

In addition to species presence, the diatom density (number of valves per cm$^2$) between treatments was examined. This was determined by converting the number of valves counted per field of view (FOV), per treatment, then averaged for each treatment. A field of view is the diameter of the circle of light when looking into the microscope. As aforementioned, each treatment sample was enumerated until at least 300 valves were counted. And so, the amount of valves per unit area was calculated by considering the number of FOVs it took to reach the 300-valve threshold. Diatom valve density was averaged for each treatment, and standard error was calculated to determine the difference in the number of cells per unit area between nutrient
treatments. In addition a two-tailed T-test was used to determine significance between treatments. Densities were only calculated for 3 treatment structures (12 total slides, with 3 slides counted for each treatment) because the remaining samples were used to determine chlorophyll-a concentrations, instead of density.

Relative Abundance
To determine the influence of nutrient loading on composing diatom assemblages, the relative abundance of diatom taxa was considered between treatments. First, the number of each taxon counted per nutrient treatment was averaged and the proportion of representing taxa was then calculated for each treatment. Using the average proportion of species present in each sample, a stacked bar plot was generated to show the relative changes in community composition between nutrient treatments. The generated plot was constructed with a mixed species- and genus-level resolution to highlight trends between treatments, and decrease clutter within the plot. Species were shown only if taxon within a genus contributed greater than 4 percent relative abundance in a given treatment. Furthermore, species were lumped into their genus if the majority of the taxon within that genus contributed less than 4 percent relative abundance. Following the same criteria, a Redundancy Analysis (RDA) was then plotted to illustrate patterns in colonizing diatom taxa across varying nutrient treatments, and a PERMANOVA statistical analysis was performed on these data.
Chapter 4 | RESULTS

Species Presence

Four species were common and present in all 32 samples regardless of nutrient treatment: *Humidophila australis, Luticola austroatlantica, Mayamaea atomus, and Muelleria peraustralis* (Figure X). The microbial communities colonizing treatments of phosphate (P) and nitrate + phosphate (N+P) each included 10 diatom species in all treatment slides (n=8). The control (C) treatment had 11 species that were present in all C slides (n=8). And the nitrate (N) treatment had 12 species present in all N slides (n=8). However the species present varied between treatments. For example, in comparing all treatments, *Navicula shakletoni* was present in all P treated samples. However, *N. shakletoni* was present, but not in all of the slides of other nutrient treatments and controls. A few species were not present in some of the treatments, but present in other treatments. For example, *Mayamaea atomus var. #1* was present in some of the N, P, and N+P treatment slides, but not present in any C slides. Another example, *Muelleria supra* was only present in N and N+P slides, but not present in any P or C slides. And, *Navicula gregaria* was present in N, P, and C treatments, but was not present in N+P treatments. Figure 5 shows the presence of species in treatment slides, and ranks the species presence for each treatment.

Between treatments, species richness stayed relatively comparable with 32 ± 1 species present in each treatment; C and P treatments had 32 species present, N treatment had 31, and N+P treatment had 33 species present (Table 2). Reference Appendix 1.a for species presence and frequency plots for each treatment.
Diversity

The Shannon-Weaver diversity index ranged from 2.65 to 2.75 among nutrient treatments and showed no significant difference when comparing treatments against the control. Using a two tailed T-test; all P values calculated were greater than 0.05, and therefore no significant difference was found in diversity between nutrient amendments. The overall species richness

**FIGURE 5.** Diatom species presence in all 32 NDS samples, with 8 samples per treatment, ranked sequentially from most frequent to least frequent. Species were marked present if observed at least once in each representative treatment sample. NDS treatments of: nitrate + phosphate (N+P), nitrate (N), phosphate (P), and a control (C). Appendix 1 separates species presence for each treatment.
showed no significant difference and remained alike between all treatments with 32 ± 1 species present on all NDS substrata (Table 2).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Shannon-Weaver Diversity</th>
<th>Diversity Standard Error</th>
<th>Average Species Richness</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2.69</td>
<td>0.78</td>
<td>32 ± 1</td>
</tr>
<tr>
<td>P</td>
<td>2.72</td>
<td>0.75</td>
<td>32 ± 1</td>
</tr>
<tr>
<td>N</td>
<td>2.65</td>
<td>0.77</td>
<td>31 ± 1</td>
</tr>
<tr>
<td>N+P</td>
<td>2.75</td>
<td>0.68</td>
<td>33 ± 1</td>
</tr>
</tbody>
</table>

**TABLE 2.** Shannon-weaver species diversity, standard error in diversity, and average species richness for nutrient treatments of phosphate (P), nitrate (N), nitrate + phosphate (N+P), and a control treatment

**Density**

Diatom density, which corresponds to the number diatom valves per cm², increased with nutrient amendments (Figure 6). The greatest average density was in N+P treatments (28,000 valves per cm²), however the variance in N+P treatments was quite large, standard error = 13,074 valves per cm². Furthermore, N treatments had a relatively small standard error, 2281 valves per cm², with greater densities relative to the control treatment (25,075 valves per cm²). In addition, diatom valve density in P treatments was also greater than C treatments (23,374 valves per cm²), with a standard error of 4500 valves per cm². Control treatment valve density was less than any of the amended treatments, with 14471 valves per cm², and a standard error of 5470 valves per cm². No significant difference was found, however, between treatment densities, with P-values all greater than 0.05. It is important to note however that diatom valve densities were only calculated for 3 slides per treatment. The small sample size and high variability is likely the reason for the lack of significant difference in density among treatments. Moreover, these calculations do not account for the variance in diatom size, which could show a more significant difference between treatments, and compare better to chlorophyll-a concentrations (Figure 7).
**FIGURE 6.** Average diatom valve densities [valves cm$^{-2}$] for each nutrient treatment, with standard error bars. Sample size = 3 slides per treatment (n=3).

**FIGURE 7.** Average chlorophyll-a concentrations [µg cm$^{-2}$] for each nutrient treatment, with standard error bars. Sample size = 5 slides per treatment (n=5).
Relative abundance

Diatom species relative abundance showed a marked difference in N treatments compared to other nutrient amendments. This change was largely driven by *Fistulifera pelliculosa*, a lightly silicified, small diatom (typically < 10µm) that may originate from upstream ponds. *Fistulifera pelliculosa* only represented a small proportion of relative species abundance in C, P, and N+P treatments, with 2.8%, 1.7%, and 3.4%, respectively. However, in the N treatments, the proportion of *F. pelliculosa* increased to represent 21% relative abundance. Also, N treatments showed a slight proportional decrease in other small diatoms relative to C, P, and N+P samples. For example, the abundance of *Diadesmis arcuata var. parallela*, *Humidophila australis*, and *Psammothidium papilio* decreased in N treatments.

The P treatments revealed minor differences relative to other treatments: *Luticola austroatlantica*, and *P. papilio* decreased, compared to C and N+P treatments, and there were marginal increases in *Humidophila spp.*, *Mayamaea spp.*, *Stauroneis latistauros*, and *Chamaepinnularia deltaica* relative to all treatments. The C and N+P amendments showed very similar relative abundances, with less than 1% difference in the proportion of taxon between each treatment. *P. papilio* abundance, however, showed the greatest difference between C and N+P treatments, with 2.7% less in N+P samples compared to C samples.

Using a redundancy analysis (RDA), N treatments showed a significant control on colonization diatom community members (PERMANOVA, P value = 0.04), whereas P treatments were found to significantly alter the relative abundance of diatom colonizing diatom assemblages (PERMANOVA, P value = 0.084). Figure 8A shows relative abundances between treatments, and Figure 8B shows the same relative abundance plot, but weighted without *F.*
*pelliculosa* to highlight the more marginal differences in abundances between treatments. Figure 9 is the RDA on diatom relative abundance separated by nutrient treatments.

FIGURE 9. Redundancy Analysis (RDA) of diatom relative abundance separated by nutrient treatments. Points represent slides counted. Abbreviations for diatom taxa: Ccymat, Chamaepinnularia deltica; Cmole, Craticula molestiformis; Depar, Diadesmis contenta var. parallela; Fpell, Fistulifera pelliculosa; Hamph, Hantzschia amphioxys; Harcu, Humidophila acuata; Haust, Humidophila australis; Humid, Humidophila spp; Laustrt, Luticola astroatlantica; Matom, Mayamaea atomus; Mfper, Mayamaea atomus fo. permitis; Mpera, Muelleria peraustralis; Ppapi, Psammothidium papilio; Slatis, Stauroneis latistauros.
Chapter 5 | DISCUSSION

For most aquatic systems, phosphate, nitrate, and silica are deemed the most crucial nutrients for algal growth and primary production (Allan, J. 1995). And following, from Liebig’s law of the minimum it can be expected that the nutrient in shortest supply relative to demand will limit biomass growth. Furthermore, this suggests that different species in a community can be limited by different nutrients. In dry valley streams, and most lotic systems, silica is not necessarily considered limiting for diatom growth (Stanish et al., 2011, Allan, J. 1995). In the Lake Fryxell basin of Taylor Valley, streams are enriched with phosphate and depleted in nitrate (Welch et al., 2010). In addition, McKnight et al (2004) showed that rapid nitrate uptake by algal mats occurs in Green Creek. The chlorophyll-a concentrations presented here show consistent results, indicating that nitrate limits algal growth. Therefore, it comes as no surprise that nitrate enrichments stimulated diatom growth in the Lake Fryxell basin. It would be interesting, however, to complete this experiment in the P-limited Lake Bonney basin.

Here the results suggest that enriched nutrient concentrations marginally influence diatom assemblages. Nitrate treatments showed the greatest significant change in diatom relative abundance, with *Fistulifera pelliculosa* taking up 21% average relative abundance in N treatments, compared to less than 5% in other treatments. Subsequently, the relative abundance of larger diatoms (*Muelleri* and *Hantzschia spp.*, and *Stauroneis latistauros*) showed a marginal decrease in N treatments. This result could be attributed to differences in nutrient uptake based on size and surface area-to-volume ratios (Lavoie et al., 2006), leading to competitive interactions within the establishing assemblages (Allan, 1995).

There are likely other stochastic dispersal mechanisms occurring in the composition of these diatom assemblages on NDS units, regardless of the nutrient treatments, such as stream flow...
variability. However, it is still reasonable to consider nutrients as a mechanism for regulating community structure. Stanish et al. (2011) described *Fistulifera pelliculosa* distribution as being greater during high-flow periods as the diatoms move downstream from melt ponds and colonizing microbial mats. However, the results from this thesis suggest that *Fisulifera pelliculosa* abundance could also be a function of enriched N concentrations. These results follow from literature that describe *Fistulifera* abundance to locally increase in eutrophic waters (Kociolek and Spaulding, 2003). However, this relationship is only hypothesized and stream flow dispersal, nitrogen availability, or both may control *Fistulifera* abundance.

Algal mats are known to regulate their own nutrient conditions in MDV streams (Gooseff et al., 2004; McKnight et al., 2004). Therefore it could be likely that nutrients are more important during the initial colonization and development of algal assemblages, and enriched nutrients may have less of an influence on established mats. Furthermore, this study was designed to provide an understanding of the initial colonization process in diatom assemblages with isolated nutrient amendments. Nutrients amendments showed little effect on the diversity and richness of diatom communities on NDS units. Moreover, nitrate showed a significant control on altering community structure, whereas phosphate did not significantly control diatom communities.

Fountain et al. (2014) postulate that new patterns in nutrient enrichment will likely take place in MDV streams as a result of a warming climate, with subsequent changes in stream diatom communities. Corresponding to nutrient enrichment and greater stream flow, the abundance of MDV endemic diatoms will likely diminish with augmented abundances of smaller generalist species (Fountain et al., 2014; Stanish et al., 2011; 2012b). Likewise, this thesis found a shift in the community structure of N enriched treatments. However, as distinguished by Capps et al. (2011), different types of NDS structures can result in different outcomes in colonizing
community structure. Therefore more experimentation may be useful to solidify the results found in this thesis.

Although the MDV stream diatom assemblages only represent a small portion of total biomass of the algal mat matrix, diatoms are important components for ecological monitoring. Exploring the response to nutrient enrichment by certain diatom taxa can further delineate the individual ecologies of these taxa. And furthermore, the results from this thesis can be incorporated into paleoecological models to reconstruct climates of the past, and predict the response to future changes in climate and ecosystem function. In addition, these results help to further our understanding of biogeochemical cycling, and hydrologic connectivity in the McMurdo Dry Valley ecosystem.
Appendix 1. Shows the diatom species presence for each treatment with 8 sample slides for each treatment. Species were marked for each treatment if species were seen once in each slide.
BIBLIOGRAPHY


Compass, 5(9):666-681


Kohler, T., Kopalová K., Van de Vijver, B., & Kociolek, P. (Submitted, 2015). The genus Luticola D.G.Mann (Bacillariophyta) from the McMurdo Sound Region, Antarctica, with the description of 4 new species. *Journal?*


Van de Vijver, B., Zidarova, R. and de Haan, M.(2011). Four new Luticola taxa (Bacillariophyta) from the South Shetland Islands and James Ross Island (Maritime
Antarctic Region). *Nova Hedwigia* 92: 137-158.

Van de Vijver, Bart; Zidarova, Ralitsa; Sterken, Mieke; et al.(2011) Revision of the genus *Navicula* s.s. (*Bacillariophyceae*) in inland waters of the Sub-Antarctic and Antarctic with the description of five new species. *Phycologia. Vol.* 50 (no. 3): 281-297


