DATA ANALYSIS FOR OPTIMIZATION OF MARS TERRAFORMING: A GIS FRAMEWORK

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ABSTRACT

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This study has developed a GIS framework that uses spatial environmental and climate data to better understand areas on Earth that share the most environmental similarities to Mars. The purpose of developing this framework is to determine which vegetation is most likely to survive in closed bioregenerative life support systems on Mars, using as many in-situ materials and environmental elements as possible. Using remotely sensed climate data, digital elevation models, and vegetation occurrence data sourced from the Global Biodiversity Information Facility, three Mars-like study areas on Earth were analysed (the Antarctic Peninsula, Ellesmere Island, and Devon Island). This study found that plants that are part of the Bryophyte and Tracheophyta phyla are worthy of further research in regard to possible vegetation candidates that could be brought to Mars. In addition, the most promising candidate of the entire study is the genus Poa, which is found in the phylum Tracheophyta.

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CHAPTER 1

INTRODUCTION

For several decades' humans have been fascinated with the idea of travelling to Mars, and with technological developments and improvements, the idea of sending human missions to Mars has become more realistic and plausible (Genta, 2017). This study aims to provide a contribution to research using a GIS approach that will enable humans to travel to Mars in the foreseeable future. The objectives of this study are to use environmental and climate data from Earth to develop and test a framework that will allow future researchers to spatially understand locations on Earth that share environmental and climactic conditions that are similar to those found on Mars. This framework has also been developed to allow future researchers to use the environmental and climactic conditions in these Mars-like locations on Earth to understand which genera of vegetation growing in these areas are most likely to survive missions to Mars. The genera of vegetation identified in this study has the potential to be brought to Mars for the purposes of both water an oxygen recycling, however the genera identified in this study is not recommended to be brought to Mars for the purpose of human consumption.

Mars, the fourth planet from the sun, also known as 'the red planet,' has fascinated humans for centuries. Since Galileo Galilei first observed Mars with a telescope, humans have been conducting research to learn more about the planet (NASA Mars Exploration Program, n.d.)[1]. At this point, government led space programs, like NASA, have learned a considerable amount of information about Mars. Currently, the Mars Exploration Program, led by NASA, has five operating missions on the planet that are attempting to answer questions such as, is there presently life on Mars? (NASA Mars Exploration Program ,n.d.). However, so far, there has not been any discovery of life on the planet (NASA Mars Exploration Program, n.d.).

Although no evidence of life on Mars has been discovered, the idea of life on Mars is seen with renewed excitement as the concept of terraforming Mars becomes a more plausible theory (New Delhi 2018). However, unlike popular science fiction depictions of terraforming, where an entire planet is transformed to become more Earth-like, the terraforming that humans are realistically capable of in the foreseeable future involves the introduction of Earth-like conditions and elements in small, closed systems on Mars (Todd, 2006).

[1] Follow link to see more: https://mars.nasa.gov/#mars_exploration_program

There is currently a considerable amount of interest in exploring Mars and developing technology that will enable humans to explore the planet. Organizations such as the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and SpaceX all have plans for several upcoming missions to the planet. NASA currently has an unmanned lander (InSight) that was set to reach the planet on November 26th, 2018. The purpose of this mission is to understand levels of tectonic activity on the planet as well as how the planet has formed and evolved (Mars InSight Mission, n.d.)[2]. NASA is also in the process of preparing another mission to Mars, sending the Mars 2020 Rover to robotically explore the planet. The purpose of this mission is to understand if life has ever occurred on Mars, to better understand the geology and climate on Mars, and to plan for future human mission to Mars (Mars 2020 Rover, n.d.)[3]. The ESA is also in the process of preparing a mission to Mars that will launch in 2020 called ExoMars, 2020. This mission will send both a lander and a rover that will collect rock samples, as well as define the planets subsurface characteristics, and search for water (European Space Agency, 2016)[4]. In addition to missions planned by NASA and ESA, a private company called SpaceX is quickly working to sending a crew to Mars. SpaceX plans to send a cargo mission to Mars as early as 2022 in order to prepare for a second mission, sending both cargo and a crew to Mars as early as 2024 (SpaceX, 2017)[5]. The hope is that this study will provide a contribution to the work currently being undertaken by organizations like NASA, ESA and SpaceX.

The goal of this study is to develop a framework that uses spatial environmental and climate data from Earth to better understand areas on Earth that share the most environmental similarities to Mars. The primary purpose of this study is to develop and test a GIS framework that can also be used as a tool by future researchers when attempting to determine which vegetation is most likely to survive in a Mars-like atmosphere. This study falls into the category of Geographic Information Science, as it uses a Geographic Information System to conduct research by testing a framework in a scholarly manner. As further research is done by organizations such as NASA, ESA and SpaceX this framework can be adapted to explore

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[2] Follow link to see more: https://mars.nasa.gov/insight/
[3] Follow link to see more: https://mars.nasa.gov/mars2020/
[4] Follow link to see more: http://exploration.esa.int/mars/56504-missions-to-mars/
[5] Follow link to see more: https://www.spacex.com/mars

vegetation found in regions on Earth that share environmental similarities to Mars that may not be evaluated in this study. By using data analysed within a GIS approach, this study will allow the identification of plants that are a best fit to be taken to Mars for the purpose of terraforming the planet in a closed bioregenerative life support systems.

PAST, PRESENT AND FUTURE MISSIONS TO MARS

Mission	Location/Agency	Launch Date	Land/Flyby Date	Mission Type
Marsnik 1 (Korabl 4)	USSR	10 October 1960	Did not reach Earth orbit	Mars flyby
Marsnik 2 (Korabl 5)	USSR	14 October 1960	Did not reach Earth orbit	Mars flyby
Sputnik 22 (Korabl 11)	USSR	24 October 1962	Achieved Earth orbit only	Mars flyby
Mars 1 (Sputnik 23)	USSR	1 November 1962	Radio failed 170 million km from Earth	Mars flyby
Sputnik 24 (Korabl 13)	USSR	4 November 1962	Achieved Earth orbit only	Mars flyby
Mariner 3	US	5 November 1964	Did not reach Earth orbit	Mars flyby
Mariner 4	US	28 November 1964	14/15 July 1965	Mars flyby
Zond 2	USSR	30 November 1964	6 August 1965	Mars flyby
Mariner 6	US	25 February 1969	31 July 1969	Mars flyby
Mariner 7	US	27 March 1969	5 August 1969	Mars flyby
Mars 1969A	USSR	27 March 1969	Did not reach Earth orbit	Mars orbiter
Mars 1969B	USSR	2 April 1969	Did not reach Earth orbit	Mars orbiter
Mariner 8	US	9 May 1971	Lost during launch failure	Mars orbiter
Kosmos 419	USSR	10 May 1971	Achieved Earth orbit only	Mars orbiter
Mars 2	USSR	19 May 1971	27 November 1971	Mars Orbiter and Lander
Mars 3	USSR	28 May 1971	2 December 1971	Mars Orbiter and Lander
Mariner 9	US	30 May 1971	14 November 1971	Mars orbiter
Mars 4	USSR	21 July 1973	Did not enter Mars orbit – passed Mars 10 February 1974	Mars orbiter
Mars 5	USSR	25 July 1973	12 February 1974	Mars orbiter
Mars 6	USSR	5 August 1973	12 March 1974	Mars flyby module and lander
Mars 7	USSR	9 August 1973	9 March 1974 – missed Mars by 1300km	Mars flyby module and lander
Viking 1	US	20 August 1975	19 June 1976	Mars orbiter and lander
Viking 2	US	9 September 1975	7 August 1976	Mars orbiter and lander

Phobos 1	USSR	7 July 1988	Contact lost before it reached Mars	Mars orbiter and Phobos lander
Phobos 2	USSR	12 July 1988	30 January 1989	Mars orbiter, Phobos lander, and Phobos hopper
Mars Observer	US	25 September 1992	Contact lost before it reached Mars	Mars orbiter
Mars Global Surveyor	US	7 November 1996	12 September 1997	Mars orbiter
Mars 96	Russia	16 November 1996	Did not reach Earth orbit	Mars orbiter, two landers and two penetrators
Mars Pathfinder and Sojourner	US	4 December 1996	4 July 1997	Mars lander and rover
Nozomi	Japan	3 July 1998	14 December 2003 – missed Mars by 1000km	Mars orbiter
Mars Climate Orbiter (Mars Surveyor ’98 Orbiter)	US	11 December 1998	23 September 1999 – destroyed upon arrival to Mars	Mars orbiter
Mars Polar Lander (Mars Surveyor ’98 Lander) / Deep Space 2	US	3 January 1999	3 December 1999 – contact lost upon arrival to Mars	Mars lander and two penetrators
2001 Mars Odyssey (formerly Mars Surveyor 2001 Orbiter)	US	7 April 2001	24 October 2001	Mars orbiter
Mars Express / Beagle 2	ESA/UK	2 June 2003	25 December 2003	Mars Express orbiter and Beagle 2 lander
Mars Exploration Rovers A (Spirit) and B (Opportunity)	US	10 June 2003	4 January 2004	Mars Landers and Rovers
Mars Reconnaissance Orbiter	US	12 August 2005	10 March 2006	Mars orbiter
Phoenix Mars Lander	US	4 August 2007	25 May 2008	Mars lander
Phobos-Grunt / Yinghuo-1	Russia/China	8 November 2011	Did not reach Earth orbit	Mars lander and orbiter
Mars Science Laboratory / Curiosity rover	US	26 November 2011	6 August 2012	Mars lander and rover
Mars Orbiter Mission (Mangalyaan)	India	5 November 2013	24 September 2014	Mars orbiter
Mars Atmosphere and Volatile EvolutioN (MAVEN)	US	18 November 2013	22 September 2014	Mars orbiter
ExoMars 2016 / ExoMars Trace Gas Orbiter and Schiaparelli	ESA/Russia	14 March 2016	19 October 2016	Mars orbiter and schiaparelli
InSight	US	5 May 2018	26 November 2018	Mars lander
ExoMars 2020	ESA/Russia	Launch planned for 2020		Mars lander, rover, and surface platform
Mars 2020	US	Launch planned for 2020		Mars Rover
Space X Mission to Mars	Space X	Launch planned for 2022		Mars cargo Mission

Table 1. Past, Present, and Future Missions to Mars (Mars InSight Mission n.d.), (European Space Agency, 2016), and (SpaceX, 2017)

CHAPTER 2
LITERATURE REVIEW

"The aim of terraforming is to alter a hostile planetary environment into one that is Earth-like" (Beech, 2009) and there are a number of reasons why Mars is likely the best candidate for terraforming which will be discussed in section 2.1 of the literature review. Although Mars is likely the best candidate for terraforming, there are three conditions to terraforming; the first organisms brought to Mars must utilize the Martian soil and available sunlight and must also be oxygen producing organisms; any organisms that are transported to Mars for the purpose of terraforming should be sourced from locations on Earth where availability of water is limited; and because Mars does not have an ozone layer, organisms that are brought to Mars must have the ability to withstand an increase in solar ultraviolet radiation (Todd, 2006). In addition, any bases built on Mars must be fabricated in a manner that allows them to tolerate the extreme environment, while using as many in-situ materials and resources as possible (Naser and Chehab, 2018).

This literature review has been written is seven sections that discuss the current state of literature on; the environment on Earth and Mars; terraforming Mars; work that has been done on plant response to environmental conditions found on Mars and the International Space Station; identifying locations on Earth that are environmentally similar to Mars; how GIS has been used as a tool to perform vegetation analysis in polar regions on Earth; suitability analysis using remotely sensed climate images, Digital Elevation Models and regression analysis; and transporting vegetation to Mars.

2.1 THE ENVIRONMENT ON EARTH AND MARS

On average, there are approximately 79 million kilometers between the Earth and Mars, and there are several environmental similarities between the two planets (Attwood, 2018). Based on the criteria listed in the Earth Similarity Index[6], Mars falls within the habitable zone of the solar system and current conditions on Mars may allow extremophile species to inhabit the planet (Jagadeesh et al., 2017). In addition to falling within the habitable zone of our solar

[6] The Earth Similarity Index is used to categorize planets that are most similar to Earth and the criteria that are used to measure this index are a planets radius, density, escape velocity and surface temperature (Jagadeesh et al. 2017).

system, Mars is likely the best candidate for terraforming for a number of reasons; the energy required to reach Mars is comparable to the energy required to reach the Moon (Genta, 2016); there is a present atmosphere comprised of carbon dioxide (92%), argon (< 2%), nitrogen (< 2%) and other compounds, including oxygen, carbon monoxide and water vapor (< 1%) (Haberle et al., 2017); terrestrial Mars contains both macronutrients (Oxygen, Carbon, Hydrogen, Nitrogen, Potassium, Phosphorus, Calcium, Magnesium, and Sulphur) and micronutrients (Iron, Manganese, Zinc, Copper, Molybdenum, and Boron) that are similar to those found on Earth (Mangold et al., 2016); and Martian water in the form of stable regolith ice has been discovered at high latitudes of the planet and extensive research is being done on the Mars water cycle as well as Martian water extraction for the purpose of supplying water to human missions to the planet (Wasilewski, 2018). In addition to water in the form of regolith ice at the poles, water is present in the Martian atmosphere in the form of water vapor which is significantly more abundant in the northern hemisphere of the planet due to the abundance of ice in the ice cap of the northern pole (Haberle et al., 2017).

One of the notable differences between Earth and Mars that is important to acknowledge is the relatively regular occurrences of global dust storms that are present on Mars. Guzewich and others (2019) discuss the most recent observations of a Martian global dust storm collected by the Viking Landers, which lasted for approximately 100 Martian sols[7]. A finding of these observations which is important to note in the literature review of this study is that the opacity in the Gale Crater began to decline several weeks before the storms dust lifting began to cease (Guzewich et al., 2019). This is an important finding as it shows that the Gale Crater, an area of low elevation, experienced impacts of the global dust storm that were less severe and lasted for a shorter period of time compared to areas found at higher elevations.

2.2 BIOREGENERATIVE LIFE SUPPORT SYSTEMS

In order for humans to survive a mission to Mars they must use resources found on the planet in bioregenerative life support systems in order to have access to the materials that are necessary to support human life (Murukesan et al., 2016). There is existing research on the topic of transporting vegetation to Mars and supporting vegetation in a contained environment. There

[7] A Martian sol is equal to 24 hours and 37 minutes (NASA Mars Exploration Program n.d.)

are several benefits of transporting plants to Mars and a lot has been learned from research done on bioregenerative life support systems that enable vegetation to grow and reproduce in a closed system. Bioregenerative life support systems are capable of sustaining vegetation in a closed system and the benefits of this system include the conversion of CO_2 into breathable O_2, and the possibility of recycling waste water (Wheeler, 2010). This enables a closed system not only for plants but for water as well. In addition to the life support benefits enabled by bioregenerative life support systems, there are also ethical benefits of limiting planetary exploration contained to small closed systems. If native life were to be discovered on a planet [Mars] during a human mission to the planet, it would be possible to remove the contaminated materials brought to the planet and sterilize any life forms brought by humans with UV radiation sterilization so that species native to Mars may evolve naturally (McKay, 2018).

There are several important factors that enable plants to survive in bioregenerative life support systems, including light energy (either natural solar energy or artificial light energy), the need for advanced hydroponic systems, and that CO_2 rich environments coupled with adequate light energy and advanced hydroponic systems could enable plants to produce higher yields in closed systems than in natural environments (Wheeler, 2010). Although this article stresses the importance of hydroponic systems, the benefits of growing vegetation in Martian soil include; carbon dioxide sequestration, the production of food and oxygen, and water filtration (Maggi and Pallud, 2010).

Bioregenerative life support systems are already being implemented on the International Space Station. Currently, the bioregenerative life support systems that are used on the International Space Station use algal growth, are able to recover 50% of oxygen used and 70% of water used in the system (Neiderwieser et al., 2018). Although algal growth is successfully being used in bioregenerative life support systems it is important to continue to expand the diversity of vegetation used in these systems. An additional benefit to plant growth in space or desert areas on Earth is human exposure to vegetation. In desert areas on Earth exposure to vegetation has been shown to have positive impacts on mental health and overall well-being. Respondents to a survey conducted at the Neumayer Station (a German research station located in Antarctica) stated that fresh fruit and herbs grown on the station overwhelming increased their 'overall well-being' (85%), 'mental health' (83%), and provided a 'positive psychological benefit' (61%) (Mauerer et al., 2016).

2.3 PLANT GROWTH ON THE INTERNATIONAL SPACE STATION

Vegetation has already been transported off of Earth and on to the International Space Station (ISS) (Massa et al., 2016). There is ongoing research that is being done in the Columbus Laboratory on the ISS (contributed to the International Space Station by the European Space Agency). The purpose of the research is to develop a better understanding of how vegetation can respond to altered light conditions, and how gravity can impact plant development. Specifically, this research will show how microgravity will impact plant genes (cell division), plant growth, and plant adaptation (Kittang, 2013). There is a great deal of importance with growing plants on the ISS and the objectives of these experiments include; plant response to gravitational force; understanding the role of gravity and microgravity on plant development; understanding the role of gravity and microgravity on metabolic and transport processes in plants; understanding how microgravity and other space conditions (e.g. radiation) interact; and understanding plant response in recycling (bioregenerative) life support systems (Williams, 2009). There is also an experiment that is currently taking place on the ISS which seeks to test bryophyte (moss) response to micro- and zero-gravity conditions. This research group from Hokkaido University has already found that the mosses tested responded to hyper gravity conditions (produced through a centrifuge) by increasing their population numbers more rapidly than in gravity conditions found on Earth. The hope for this experiment is that it could lead to genetically engineered plants (engineered to respond to gravity that is different to the conditions found on Earth) that could be brought to the Moon or Mars for terraforming in bioregenerative life support systems (Fujita et al., 2016).

Although there has been considerable work done on researching plant growth on the ISS, there is very little that is known about the effects of reduced gravity on plant growth. In order to gain a better insight to how plants will respond to reduced gravity environments, (i.e. gravity on Mars), future studies on plant growth on the ISS should be done in laboratories with centrifuges which will have reduced gravity rather than microgravity (Kiss, 2014). The continuation of researching plant growth on the ISS will provide important knowledge that will be useful for transporting vegetation to Mars.

2.4 PLANT GROWTH IN MARS-LIKE ENVIRONMENTS

There is currently a project that is being developed to bring microorganisms to Mars and terraform in a small closed system. Eugene Boland, who is the chief scientist at Techshot (a private space research facility), is working with NASA to develop a project called ‘terraforming in a bottle’. This project involves sending microorganisms on an unmanned mission to Mars and using soil and frozen water (warmed into liquid water by the Mars Rover) found on Mars to support the microorganisms. The purpose of this experiment is to determine if the microorganisms can begin to produce oxygen in a closed system on Mars, while using resources from the planet (David, 2015). Another study has tested photosynthetic organisms in closed systems with near 100% CO_2 and low N_2 conditions to mimic the atmosphere on Mars and determine if the organisms were able to survive. This study showed that if temperature is adjusted, there is protection against radiation, and water is maintained in liquid form, the photosynthetic organisms were able to survive the Mars-like atmospheric conditions (Murukesan et al., 2016).

Mars soil simulant coupled with light levels similar to levels on Mars has also been used to successfully grow plants for the purpose of consumption, including kale, sweet potatoes and lettuces. A group of undergraduate students at Vilanova University working on a project to grow plants in Mars soil simulant and light conditions who were successful in growing kale, sweet potatoes, and lettuces. The professor teaching the course, Edward Guinan, states in this article that the students chose to grow plants that they enjoyed eating and suggests that further work should be done to investigate other plants that may have a better response to the Mars soil simulant and light conditions (Cartier ,2018). In addition to this study, there has been an experiment that compared low grade Earth soil simulant, Moon soil simulant and Mars soil simulant and measured the production of biomass in each soil simulant. This study found that differences in plant species impacted germination and biomass; however, plants grown in the Mars soil simulant actually produced the highest biomass compared to the Earth and Moon soil simulants (Wamelink et al., 2014). Additional research has been done to gain further insight in to plant response to Mars-like environmental conditions through the development of a new Martian regolith simulant. This Mars-like regolith simulant has been developed by combining individual components found in Martian regolith and the researches have created a simulant that in regard to mineralogy is more similar to Martian regolith than other previously developed simulants

(Cannon et al., 2019). This work will allow researchers to gain further insight to the impacts of Martian regolith on plant growth.

2.5 IDENTIFYING MARS-LIKE PLACES ON EARTH

As mentioned previously, Mars falls within the habitable zone of our solar system (Jagadeesh et al., 2017), and there are locations on Earth that are more similar to Mars than other locations. An article written by Bret Israel for Live Science entitled "7 Most Mars Like Places on Earth" uses data collected from NASA to identify the top seven locations on Earth that have environmental conditions most similar to those found on Mars. These locations include the Atacama Desert (Chile), Lake Vostok (Antarctica), Pico do Orizaba (Mexico), Ellesmere Island (Canada), Devon Island (Canada), Dry Valleys (Antarctica), and Death Valley (United States) (Israel 2012). A review conducted by Preston and Dartnell (2014) sought to catalogue terrestrial field sites that are analogues to regions found on Venus, Mars, Europa, Enceldus and Titan and summarize the physiochemical environmental conditions in each identified location. These authors showed that the Pilbara Region (West Australia), Rio Tinto (Spain), The Golden Deposit (Canada), Yellowstone National Park (United States), Haughton Impact Structure, Devon Island (Canada), Dongwanzi Ophiolite Complex (China), Axel Heiberg Island (Canada), Beacon Valley (Antarctica), Sub-glacial Volcanism (Iceland), Kamchatka (Russia), Bockfjord Volcanic Complex (Svalbard), Kilimanjaro (Tanzania), The Atacama Desert (Chile), The Antarctic Dry Valleys (Antarctica), The Mojave Desert (United States), The Namib Desert (Namibia), Ibn Battuta Centre Sites (Morocco), and Qaidam Basin (Tibet) are locations on Earth that are analogues to early, middle and present Martian conditions (Preston and Dartnell, 2014).

In addition to the locations mentioned above, high altitude and/or glaciovolcanic hydrothermal environments are particularly good environments to explore to find locations on terrestrial Earth that are environmentally similar to Mars. This is because of the low temperatures and high level of radiation intensity found in these areas are consistent between Earth and Mars (Barbieri and Cavalazzi, 2014). Although this focus of this study is to explore plants that live in Mars-like environments, microbial life found at high volcanic elevations are also being studied to explore life forms that live in Mars-like environments. There is also importance in studying extremophile microbial life found at extremely high elevations on volcanos in Atacama to gain insight to the extreme environmental conditions as well as limitations to the survival of extremophile microbial species. This location is considered Mars-like because of the extreme temperature fluctuations, the high levels of UV radiation, and the soils are characterised as acidic, oligotrophic, and are exposed to a low-pressure atmosphere (Schmidt et al., 2018).

Conducting research in specific regions on Earth that have similar conditions to other planets in our solar system in order to advance research in the fields of astrobiology and planetary exploration is another important aspect of extraterrestrial exploration. It is important to understand that regions on Earth that share environmental or geological similarities to other planets do not replicate the exact conditions of another planet. The value in studying these regions is that they mimic environmental and geological conditions found on other planets and can be used as a tool gain some insight on conditions found on other planets (Martins et al., 2017).

2.6 GIS AND POLAR VEGETATION ANALYSIS

GIS are an important tool that that have been used by many researchers to spatially understand many environmental characteristics, including vegetation distribution in the polar regions on Earth. Using GIS to map and classify vegetation that is growing in both the Arctic and Antarctic has been a tool used to better understand the impacts of climate change, biodiversity, and invasive species impacts on native vegetation. Remotely sensed images of the American Arctic (Alaska) have been used to produce maps which are able to estimate the canopy volume and biomass of shrub vegetation (Greaves et al., 2016). In addition, low-altitude unmanned aircraft systems (UAS) images have been used to create maps of polar vegetation that can be used to assess the health of the vegetation as they respond to environmental shifts and stresses. The authors of this article describe that the benefit to using low-altitude unmanned aircraft systems has improved the resolution of the remotely sensed images and has allowed them to avoid challenges typically experienced with remotely sensed images sourced from satellites like cloud cover (Malenovsky et al., 2017).

There are existing studies that are merging field observation data and remote sensing data to better understand vegetation in the Arctic and Antarctic. In the Siberian Arctic tundra, both field observation data and remote sensing data have been used to explore the connection between spatial variation and soil and plant attributes (Mikola et al., 2018). The Global Biodiversity Information Facility has also been used to explore invasive species distribution in the Antarctic. In a study conducted on invasive species impacts on Antarctic vegetation, data collected from the Global Biodiversity Information Facility was used to explore the potential ranges of two invasive grass species as they spread throughout Antarctica. This study used GIS to map ice free areas in Antarctica to build a model and explore the potential of invasive species distribution (Pertierra et al., 2016).

2.7 SUITABILITY ANALYSIS USING REMOTELY SENSED CLIMATE IMAGES AND DIGITAL ELEVATION MODELS

There are several studies that have been done that use remotely sensed images to perform a suitability analysis. This type of study allows the researcher to determine specific locations within a large area that are most suitable for a given need based on various environmental or anthropogenic factors. A suitability analysis was done using digital elevation model (DEM) data and climactic data to map areas that are most suitable for wetlands based on the water table depth. This study proved that with high resolution remotely sensed images, a highly accurate global map of suitable wetland areas could be made with a relatively low number of datasets (Peng and Peng, 2014). In addition, soil and topographic data from the Taftan Mountain was used to perform a suitability analysis to understand the potential distribution of vegetation. This suitability analysis was done so that the researchers were able to predict potential areas for plant species habitat in that region. The researchers found that when their results were compared to the actual distribution maps of the plant species included in the study, their suitability analysis methods accurately showed the estimated distribution of the plant species (Piri Sahragard et al., 2018). Environmental suitability modeling is a method that was used to determine areas where fire and climate conditions are most likely to be positive for a woody vegetation community. This study used "raster grids for 1900 to 1929 mean fire probability (natural-log transformed to increase normality), annual precipitation, January minimum temperature, July maximum temperature, and community point data" (Stroh et al., 2018) to perform the suitability analysis. This environmental suitability model was able to predict areas where the balance of fire and climate are most suitable for three woody plant communities in the United States (Stroh et al., 2018). A suitability analysis was also performed to identify potential areas for wetland restoration or creation using only topographic data and land use data. Although the suitability analysis was performed using only slope and elevation data, the authors stress the importance of also using additional data, such as soil surveys, to be able to more accurately identify the most suitable areas for wetland restoration or creation (Uuemaa et al., 2018). Incorporating a regression analysis to perform a suitability analysis has been done by using both raster and vector layer data as independents in a regression analysis to identify habitat suitability for the Nilgiri Laughingthrush. This was done to improve management of this species by developing a spatial understanding of the species and habitat locations (Zarri et al. 2008). In addition, a regression analysis has been used in tandem with remotely sensed images and geographic information systems to develop a habitat suitability index. This was done to understand the locations on suitable habitats for Bos Gaurus in India (Imam and Kushwaha, 2013).

The literature shows that remotely sensed images, including digital elevation models, are data sources necessary for performing a suitability analysis. In addition, performing a suitability analysis is a reliable method that can be used to identify specific locations within a large area that are most suitable for a given need. In the case of this study, a suitability analysis is performed to identify locations within the selected study areas that consistently have the lowest minimum temperatures, the lowest levels of precipitation, the highest levels of solar radiation and the lowest levels of elevation. Identifying these locations allows the researcher to determine which areas within the selected study areas are most Mars-like, i.e. which areas in regard to the particular environmental conditions mentioned above are most similar to the environmental conditions found on Mars. It is also important to note that the use of digital elevation models to identify areas that have the lowest levels of elevation on Earth has been done to account for the protection that areas of low elevation on Mars provide during global and local dust storms of the planet (mentioned in Section 2.1 The Environment on Earth and Mars of this literature review). It is possible that when humans travel to Mars, vegetation that is brought with them will need to be sourced from areas on Earth that are at a low elevation because humans on Mars may need to reside in low elevation areas to find protection from the dust storms.

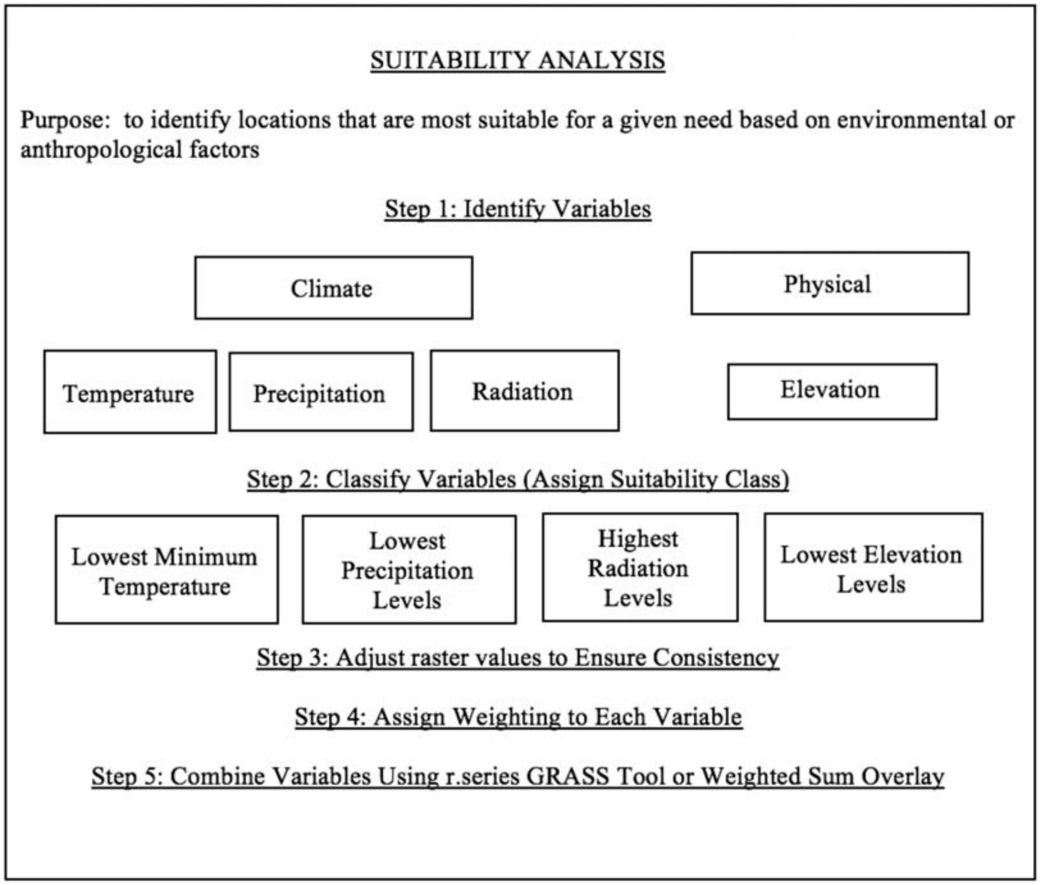

Diagram 1. Suitability Analysis

2.8 TRANSPORTING VEGETATION TO MARS

Developing an understanding of the vegetation that can thrive and reproduce in Mars-like environments on Earth is an important step to transporting vegetation to Mars for the purpose of terraforming in closed bioregenerative life-support systems. However, it is also important to develop and understanding which plant seeds are best suited to the long space flight to Mars. There are important factors for growing plants on the International Space Station, and on future space missions that are related to the seeds of the plants grown. The authors of this article stress that it is and will continue to be important to source plants that; produce large quantities of seeds that take up minimal space, are relatively low maintenance to grow, and require minimal electricity (i.e. can survive at lower temperatures and with relatively little water) (Meinen et al., 2018). The impacts of solar radiation and the environmental conditions found in outer space have been analyzed to see how they impacted seed production in plants. The researchers studying this found that seeds that developed higher up on the plant were more likely to die or become unviable than the seeds located lower on the plant (Nivokiva et al., 2015). This suggests that vegetation that grows relatively low to the ground is perhaps more likely to produce viable seeds (when grown in outer space or extraterrestrial environments) compared to taller vegetation. The impacts of removing oxygen from plant environments while seeds are germinating has also been examined to determine how seeds may respond in outer space or extra-terrestrial environments where oxygen is limited. These researchers found that in oxygen deprived environments dicots (plants that have two seed leaves inside the seed coat) were less likely to survive than monocots (plants that have one seed leaf inside the seed coat) due to their sensitivity to hypoxia (Tang et al., 2014).

CHAPTER 3
METHODOLOGY

3.1 SUITABILITY ANALYSIS

In order to identify specific locations within the selected study areas that would be most appropriate for the vegetation analysis, a suitability analysis was performed for each study area. The goal of the suitability analysis was to identify which areas within the selected study areas consistently had the lowest levels of precipitation, the lowest minimum temperatures, the highest levels of solar radiation, and the lowest elevation levels.

As mentioned in the literature review a suitability analysis allows the researcher to determine specific locations within a large area that are most suitable for a given need based on various environmental or anthropogenic factors. This can be compared to a propensity analysis which allows the researcher to determine and evaluate the spatial characteristics that cause changes in land-use (Vorel and Grill, 2015). A suitability analysis was selected for this study because it was important to determine specific locations that shared environmental/climactic conditions to Mars, whereas understanding how land-use had changed in the study areas was not relevant to this study. This suitability analysis measured and compared multiple variables, including minimum temperature, precipitation, solar radiation and elevation geospatial data. Because more than two variables were analyzed for this section of the study this suitability analysis is considered a multivariate analysis (Bodaghabadi et al., 2019)

The dataset for this section of the study was downloaded from two sources, first Wordclim2: New 1-km spatial resolution climate surfaces for global land areas[8], a website that compiles world climate data gathered from 1970-2000 was acquired. Through Worldclim2, global GeotTiff images containing data with global minimum temperature (°C), global precipitation (mm/month) and global solar radiation (kJ m-2 day-1) was acquired. The second source used was used was USGS (United States Geological Survey)[9]. USGS was used to obtain the GMTED2010 (Global Multi-Resolution Terrain Elevation Data) dataset, which contained global GeoTiff images containing elevation data.

The first step of the suitability analysis required that the global minimum temperature, precipitation, and solar radiation datasets were clipped to be closer to the boundaries of the selected study areas. To perform the suitability analysis of Ellesmere Island and Devon Island, the global minimum temperature, precipitation and solar radiation datasets were clipped so that only the data for Nunavut Territory, Canada was used. For the suitability analysis of the Antarctic Peninsula, the data was clipped so that only the data for the continent of Antarctica was used. The GMTED2010 dataset was downloaded from a global grid, meaning that only the data connected to the study areas was acquired. However it was still necessary to clip this data set so that the datasets would eventually be able to be combined using the r.series GRASS tool in QGIS. In addition to clipping all of the data sets, the projection was also set for each dataset in each study area. This was done so that when all of the datasets were combined in the suitability analysis the data would not be distorted. For the Ellesmere Island and Devon Island datasets the projection was set to NAD83 / Statistics Canada Lambert EPSG:3347, and for the Antarctic Peninsula the projection was set to WGS84 / Antarctic Polar Stereographic EPSG:3031.

In order to ensure that each month of minimum temperature data from the Nunavut dataset was comparable, the lowest 15 degrees Celsius for each month was set by adjusting the maximum value for the dataset. In order to ensure that data from the Antarctica dataset was comparable, the highest 15 degrees Celsius for each month was set by adjusting the minimum value for the dataset. This was done to ensure consistency when merging the monthly datasets, as

[8] Follow link to see more: http://worldclim.org/version2
[9] Follow link to see more: https://www.usgs.gov/land-resources/eros/coastal-changes-and-impacts/gmted2010?qt-science_support_page_related_con=0#qt-science_support_page_related_con

each month of the year has different minimum and maximum values for temperature. For the Nunavut dataset, the lowest 15 degrees were classified because the selected study areas (Ellesmere Island and Devon Island) are located in the most northern part of the dataset (in the northern hemisphere), and therefore in the coldest part of the dataset. Whereas for the Antarctica dataset, the highest 15 degrees were classified because the selected study area (the Antarctic Peninsula) is located in the most northern part of the dataset (in the southern hemisphere), and therefore in the warmest part of the dataset. This was also done to account for the extreme temperature difference between the Antarctic Peninsula and the centre of the continent of Antarctica. If the lowest 15 degrees of this dataset had been used, it would have only showed temperature variation on the continent of Antarctica and not on the Antarctic Peninsula.

In order to ensure that each month of precipitation data for both the Nunavut and Antarctica datasets were comparable, the minimum and maximum values were adjusted to 0mm precipitation/month to 50mm precipitation/month. This was done to ensure consistency when merging the monthly datasets, as each month of the year has different minimum and maximum values for precipitation.

In order to ensure that each month of solar radiation data for both the Nunavut and Antarctica datasets were comparable, the minimum and maximum values for each month were adjusted to 0 kJ m-2 day-1 to 43736 kJ m-2 day-1 (the minimum and maximum values of the entire monthly dataset). This was done to ensure consistency when merging the monthly datasets, as each month of the year has different minimum and maximum values for solar radiation levels.

When adjusting the minimum and maximum values for each dataset the Equal Interval Mode was used. This was done so that the range of values remained the same regardless of where the values were on the dataset, also this was done so that it was possible to change the number of classes. If the Quantile Mode had been used, the range of values would have increased as the pixel values on the dataset increased, and if the Continuous Mode had been used, it would not have been possible to change the number of classes. Once the minimum and maximum values had been adjusted for each month of minimum temperature, precipitation and solar radiation data the layer was saved as a rendered image so that the minimum and maximum values would remain consistent when combining the datasets. This reassigned the value of each pixel to a value between 0-200 while maintaining the pixel distribution of the rendered images.

The pixel values were reassigned to a range between 0-200 because this was the default setting in QGIS when saving raster GeoTIFF images as rendered images. This was a necessary step as it allowed the minimum temperature, precipitation and radiation datasets to be comparable when performing the suitability analysis. Before the raster images were saved as rendered images the range of pixel values was different for each data set (i.e. a raster image representing month of minimum temperature had a pixel value range from -10°C to 5°C and another raster image representing a month of precipitation had a pixel value rage from 0mm precipitation/month to 50mm precipitation/month). By saving each raster image as a rendered image, each image had the same range of pixel values, which enabled them to be compared when merging all of the monthly rendered images as well as performing the suitability analysis.

The second step of the suitability analysis was to merge all of the monthly rendered image data for each study area using the raster merge tool. This was done so that there would be one raster GeoTiff image that contained all of the monthly temperature, precipitation or radiation data for each study area. The GMTED2010 dataset did not contain separate monthly data, so it was unnecessary to change the minimum and maximum values. However, because the dataset was obtained from a global grid, each cell in the grid needed to be merged so that the dataset became a single raster layer. Once the GMTED2010 dataset was merged it was then clipped to the same boundaries as the minimum temperature, precipitation and solar radiation datasets. Once all of the monthly temperature, precipitation and radiation data were merged, the raster layers needed to be converted from multiband images to singleband images. This was done using the raster calculator which averaged the Red, Green and Blue colour band pixel values and produced a new singleband GeoTiff image. This was important because it would allow the r.series GRASS tool to determine the average values of each pixel when combining the minimum temperature, precipitation, solar radiation and elevation layers in the suitability analysis.

After the solar radiation dataset was converted to singleband GeoTiff image, the singleband grey pallet was reversed from black to white, to white to black. This was done so that the solar radiation dataset could be changed from a singleband grey pallet to a singleband pseudocolour pallet where the highest levels of solar radiation would appear as blue (rather than red), with a minimum value of 0, and the lowest levels of solar radiation would appear as red (rather than blue), with a maximum value of 200. This step was required to ensure that when the radiation data was combined with the temperature, precipitation and elevation there was consistency between the datasets. Ultimately showing that the 5 equal interval classes used to perform the suitability analysis would depict blue (most suitable) as the lowest minimum temperature, the lowest levels of precipitation, the highest levels of solar radiation and the lowest levels of elevation, and the pixel value range would be between 0-200.

The solar radiation dataset was also edited at this stage to show only the levels of solar radiation relevant to the study areas, 0-9372 (kJ m^{-2} day^{-1}) for both Nunavut Territory and the continent of Antarctica. This was done so that the distribution of solar radiation within the selected study areas could be clearly represented in the maps. This was again, saved as a rendered image so that the minimum and maximum values would remain consistent when combining the datasets. This again reassigned the value of each pixel to a value between 0-200 while maintaining the pixel distribution of the rendered images. In order to ensure that the pixel values in each raster layer could be averaged in the r.series GRASS tool the "align raster's" tool was used. This was done to ensure that each layer had the same number of pixel rows and columns.

The third step of the suitability analysis was to combine the minimum temperature, precipitation, solar radiation and elevation data for each study area. This was done using the r.series GRASS tool, which "makes each output cell value a function of the value assigned to the corresponding cells in the input raster layers". This tool averaged the minimum temperature, precipitation, solar radiation and elevation data values for each pixel. The result of this process was a new raster layer that depicted the result of the suitability analysis with a singleband grey pallet. In addition, the elevation data raster layer was added separately as a Hillshade overlay. The Hillshade overlay was adjusted to have an altitude of 45 degrees and an azimuth of 0 degrees for the Antarctic Peninsula and 180 degrees for Ellesmere Island and Devon Island. This was done to show which areas would and would not receive direct sunlight, due to their elevation during the summer months. Temperature shifts, precipitation levels, solar radiation levels and elevation levels are all factors that influence vegetation growth and can influence the type of vegetation that is able to grow in a given area. In this study however, temperature, precipitation, radiation and elevation were given equal weighting when applied to the suitability analysis maps. This was done because research done on the environmental and climactic conditions found on Mars (identified in the literature review) did not indicate that any of these environmental/climactic conditions was more prominently different from the others on Mars. Work identified in the literature review indicated that; overall Mars has significantly lower temperatures than those found on Earth, Mars has very little water compared to Earth, Mars has much higher levels of solar radiation than what is found on Earth, and locations on Mars that are at a low elevation will be promising locations for humans to locate bases sue to their protection from global dust storms. The purpose of this suitability analysis was to identify locations in the study areas that consistently had the lowest minimum temperatures, the lowest levels of precipitation, the highest levels of radiation and the lowest levels of elevation. This allowed the researcher to identify the locations within the study areas that, in terms of environmental and climactic conditions, were most similar to Mars.

The ordinal combination method was used to create a rating system for each dataset. This was done by changing the colour scheme of the dataset from a singleband grey pallet to a single band pseudocolour pallet. In the singleband pseudocolour pallet five colours were used to classify each section of the dataset. The colours that were chosen were red, orange, yellow, green, and blue, with blue being the most suitable and red being the least suitable. The combined datasets showed the distribution of areas that had the lowest temperatures, the lowest levels of precipitation, the highest levels of radiation and the lowest levels of elevation.

Once these maps were produced the number of equal interval classes was reduced from 5 classes to the 3. The colours that were chosen were red, yellow and blue, with blue being the most suitable and red being the least suitable. This was done so that the distribution of minimum temperature, precipitation, solar radiation and elevation within the selected study areas could be clearly represented in the maps. This was also done so that when the vegetation vector points were added to the maps the raster values added to the attribute table could be categorized as most suitable, moderately suitable and least suitable.

3.2 COMBINING SUITABILITY ANALYSIS AND VEGETATION OCCURRENCE DATA

To perform the vegetation analysis, vegetation occurrence data was obtained for the Global Biodiversity Information Facility, a website that compiles georeferenced vegetation occurrence data from around the world. Datasets were selected by using the map function in the Global Biodiversity Information Facility website to draw polygons that surrounded each of the study areas. The website then produced tables showing all vegetation occurrence data in the selected areas, including the scientific name, longitude and latitude coordinates, the date the data was recorded, the name of the dataset the data was obtained from, and the kingdom, phylum, class, order, family and genus names for each plant. These tables were then moved to excel files and saved as csv files.

The nest step of the study was to link the maps used to perform the suitability analysis with the vegetation occurrence data. This was done so that the ranking used in the suitability analysis (red areas were least suitable, yellow areas were moderately suitable and blue areas were most suitable) could be applied to each row of the vegetation occurrence data. The vegetation occurrence data was added as a delimited text layer to QGIS so that each row of plant occurrence data would be represented by a point on the suitability analysis maps. This delimited text layer was then saved as a shapefile so that the raster pixel values from the suitability analysis could be added to the vegetation point data attribute table. To add the raster cell values to the vegetation point attribute table, the SAGA geoalgorithm "add raster values to point" was used. This geoalgorithm pulled the value of the raster cell that each vector point was over top of and added the pixel value (obtained through the suitability analysis) to the attribute table of the vector point shapefile. Once this step was complete, each shapefile was then saved as a .xlsx spreadsheet so that the vegetation data could be analysed. This section of the methodology has also been depicted in Diagram 2.

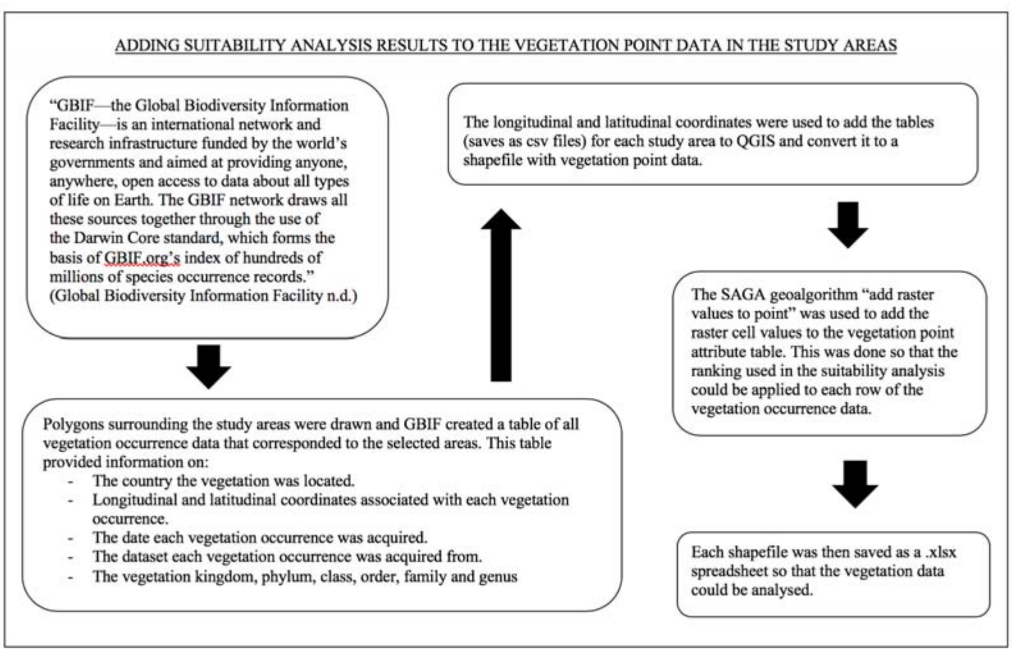

Diagram 2. Adding Suitability Analysis Results to the Vegetation Point Data in the Study Areas

3.3 VEGETATION DATA ANALYSIS

After the raster values had been added to the vegetation data in each study area, a new set of spreadsheets was produced with the suitability analysis pixel value added as a column. To replicate the ranking system used in the suitability analysis, the spreadsheet for each study area was divided into three separate spreadsheets. Each spreadsheet represented the values determined in the suitability analysis and were relabeled to reflect the value range. Blue was labeled suitability 1, yellow was labelled suitability 2, and red was labelled suitability 3 (red areas were least suitable, yellow areas were moderately suitable and blue areas were most suitable).

To perform the data analysis, the suitability 1 (most suitable) datasets were edited and then compared to the total dataset for each study area. It was important to edit the spreadsheets so that only vegetation occurrence that had been recorded between the years 1970-2000 was included. This is because the climate data for minimum temperature, precipitation and solar radiation had been collected between 1970-2000. In order to compare the suitability 1 datasets to the total dataset for each study area the vegetation occurrence data was counted to determine the number of each genus of plants. The count value was added as a new column to the spreadsheet. Once the count of each genus was determined all duplicate data was removed. The count column was then summed to determine a total value for each dataset. This was then used to determine the percentage of each genus found in each dataset. This was done separately for each suitability 1 dataset and each total dataset for each study area, producing a total of 6 indexes. It was important to represent each plant genus as a percentage so that the suitability 1 datasets could be accurately compared to the total datasets for each study area. The purpose of comparing the suitability 1 datasets to the total datasets for each study area was to determine if each genus growing in suitability 1 areas represented the proportional distribution of all genera in each study area or if these genera were more likely to grow in the suitability 1 areas compared to the overall study area. Suitability 1 areas were used for both Ellesmere Island and the Devon Island study areas, however suitability 2 areas were used for Antarctic Peninsula. This is because the Antarctic Peninsula study area did not contain any vegetation occurrences located in the suitability 1 areas.

Once the percentage of each genus found in the suitability 1 (or suitability 2 for the Antarctic Peninsula) dataset and the total dataset was determined, the percentages of each genus were subtracted from each other. The percentage of genera found in suitability 1 (or suitability 2) areas was subtracted from the percentage of genera found in the total dataset for each study area.

This showed a percentage increase or decrease of the occurrences of each genus compared to the overall study area. Positive percentage values represented genera that had proportionally more occurrences in the suitability 1 (or suitability 2) areas compared to the overall study area. Negative percentage values represented genera that had proportionally fewer occurrences in the suitability 1 (or suitability 2) areas compared to the overall study area.

This index showing positive and negative percentage values for each genus in each study area was converted to both a table and a bar graph. A table was included so that the percentage values could be connected to each plant's phylum, class, order, family and genus. A bar graph was included so that the genera that had proportionally more occurrences in the suitability 1 (or suitability 2) areas could be clearly depicted. This section of the study ultimately determined which genera in each study area are best suited to live in areas that have low temperatures, low levels of precipitation, high levels of solar radiation and low levels of elevation.

To further refine the list of plant genera that are best suited to live in Mars-like environments on Earth an additional graph was created that showed plant genera that had proportionally more occurrences in the suitability 1 (or suitability 2) areas and also occurred in multiple study areas.

3.4 REGRESSION ANALYSIS

In order to determine which suitability area the vegetation occurrence data was most likely to be gathered from, a regression analysis was also performed on the total dataset from each study area. The regression analysis was performed to determine if there was a relationship between the level of suitability and the number of vegetation occurrence points (i.e. as the locations become more Mars-like do the number of vegetation occurrence points increase or decrease?). This was done by counting the number of vegetation occurrences for each suitability pixel value. This generated two columns in excel, one showing the suitability analysis pixel value, and the other showing the number of vegetation occurrence points associated with each different pixel value. These columns were then used to create scatter plot graphs for each study area and a line of best fit was added to determine if there was a negative or positive relationship between the level of suitability and the number of vegetation occurrence points collected by the Global Biodiversity Information Facility. In addition, a regression analysis was performed using the "Data Analysis Regression" tool in excel which produced a "Regression Statistics" table.

When performing the regression analysis, the data was normalized. Normalization was used so that the suitability analysis pixel values and the number of vegetation occurrence points associated with each pixel value, two variables that are unalike, could be compared and the relationship between these unalike variables could be understood. Because the data was normalized, then all of the variables have the same standard deviation whereas if the data had been standardized than the variables would only be represented as they deviated from the mean of the dataset's distribution (Allen, 1997) and (Ciaburro, 2018).

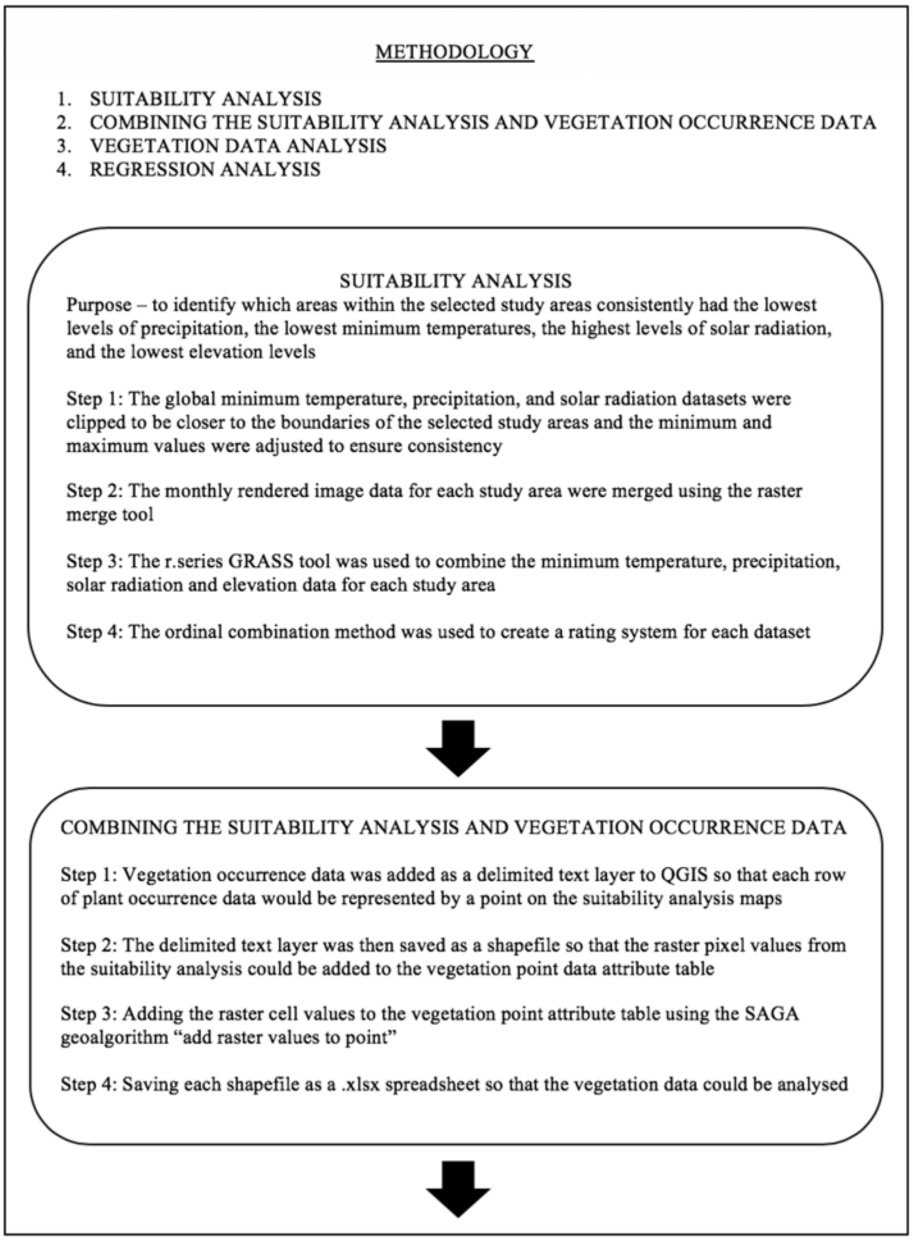

Diagram 2. Methodology – page 1

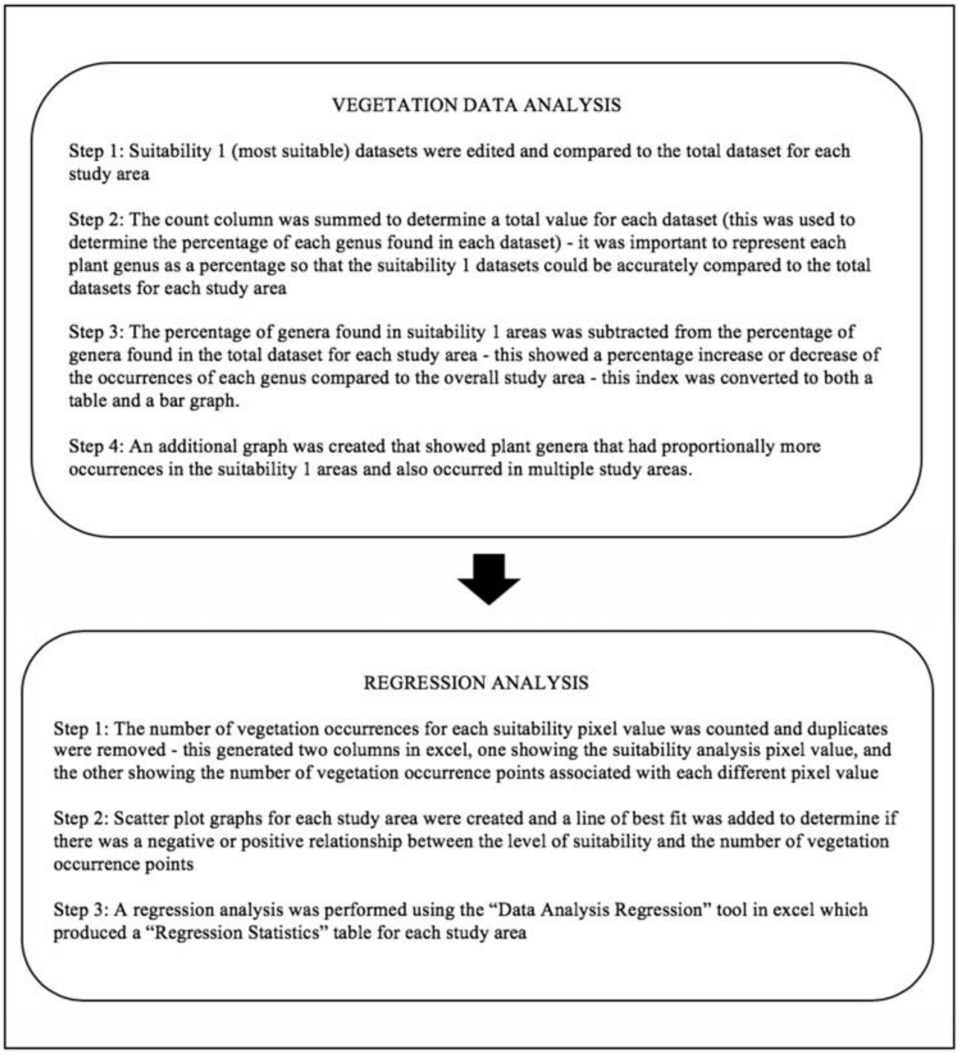

Diagram 3. Methodology – page 2

CHAPTER 4
RESULTS

4.1 SUITABILITY ANALYSIS

Before the suitability analysis could be performed, three maps for each study area were produced. For the Antarctic Peninsula, maps showing the merged monthly minimum temperature (Figure 1), the merged monthly precipitation between 0-50mm/month (Figure 2), and the merged monthly solar radiation between 0-9372 KJ m^{-2} day^{-1} (Figure 3) were produced. For Ellesmere Island, maps showing the merged monthly minimum temperature (Figure 5), the merged monthly precipitation between 0-50mm/month (Figure 6), and the merged monthly solar radiation between 0-9372 KJ m^{-2} day^{-1} (Figure 7) were produced. For the Devon Island, maps showing the merged monthly minimum temperature (Figure 9), the merged monthly precipitation between 0-50mm/month (Figure 10), and the merged monthly solar radiation between 0-9372 KJ m^{-2} day^{-1} (Figure 11) were produced. Each of these maps showed the range of merged monthly minimum temperature, precipitation or solar radiation as thematic maps, using five colours to classify the range of data. The raster layers that were generated to create these maps were used to create the suitability maps for each study area. Additionally, digital elevation model data was added to the minimum temperature, precipitation and solar radiation data to produce the final suitability maps (Antarctic Peninsula – Figure 4, Ellesmere Island – Figure 8, and Devon Island – Figure 12).

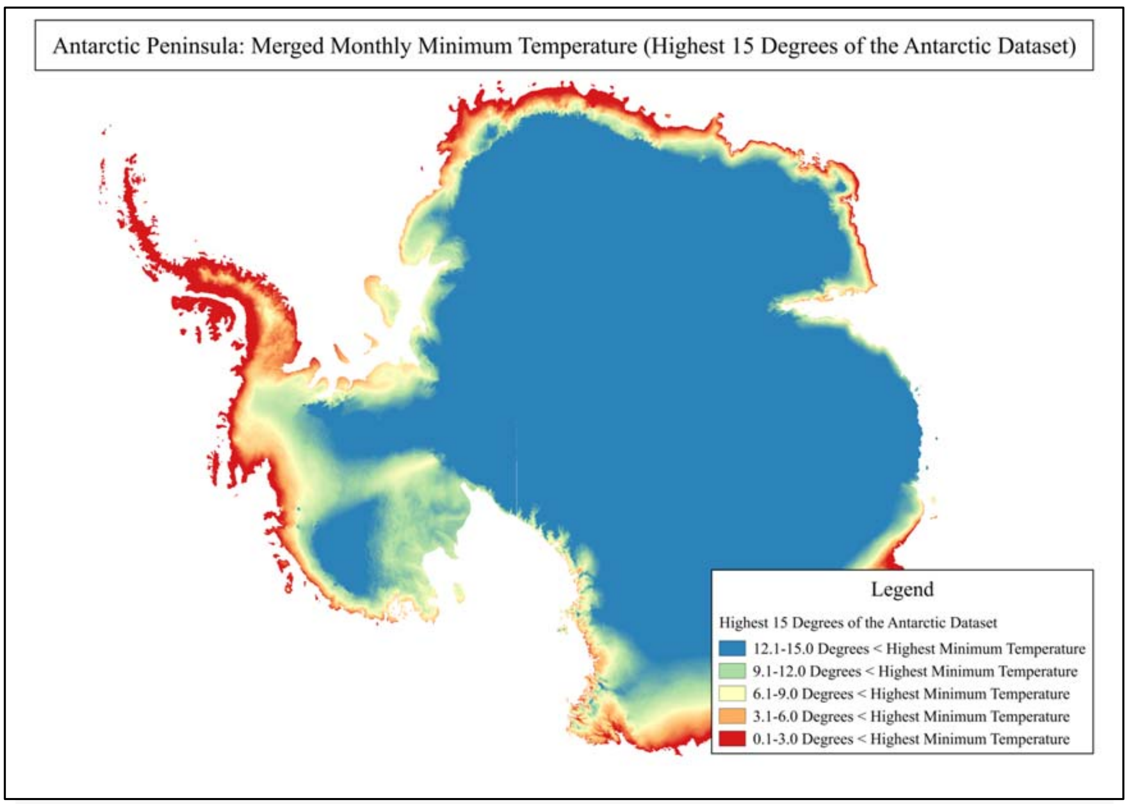

Figure 1. Antarctic Peninsula Merged Monthly Minimum Temperature (1970-2000)

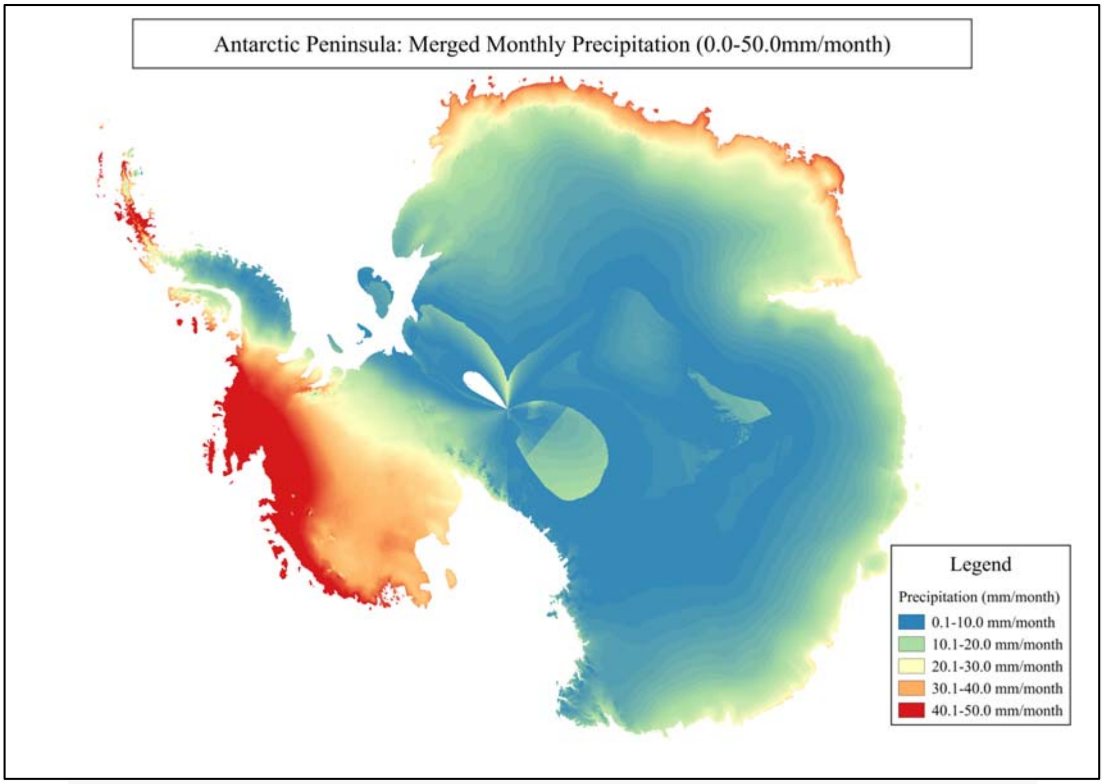

Figure 2. Antarctic Peninsula Merged Monthly Precipitation (1970-2000)

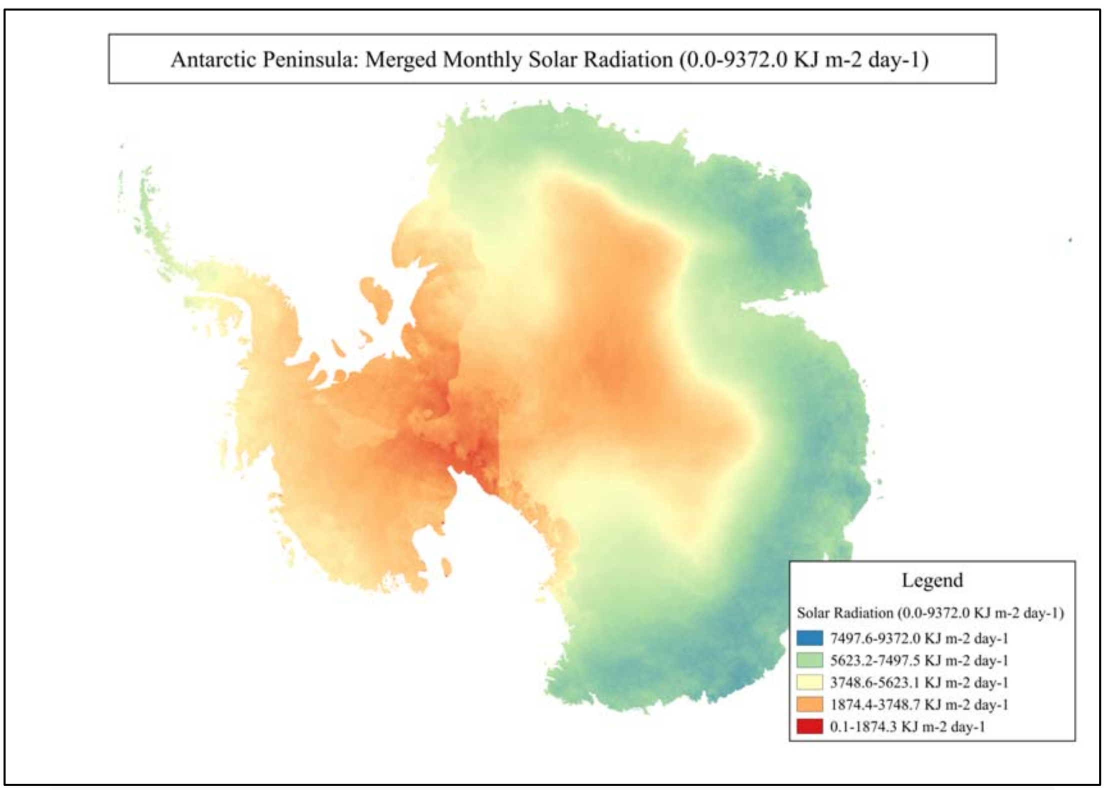

Figure 3. Antarctic Peninsula Merged Monthly Solar Radiation (1970-2000)

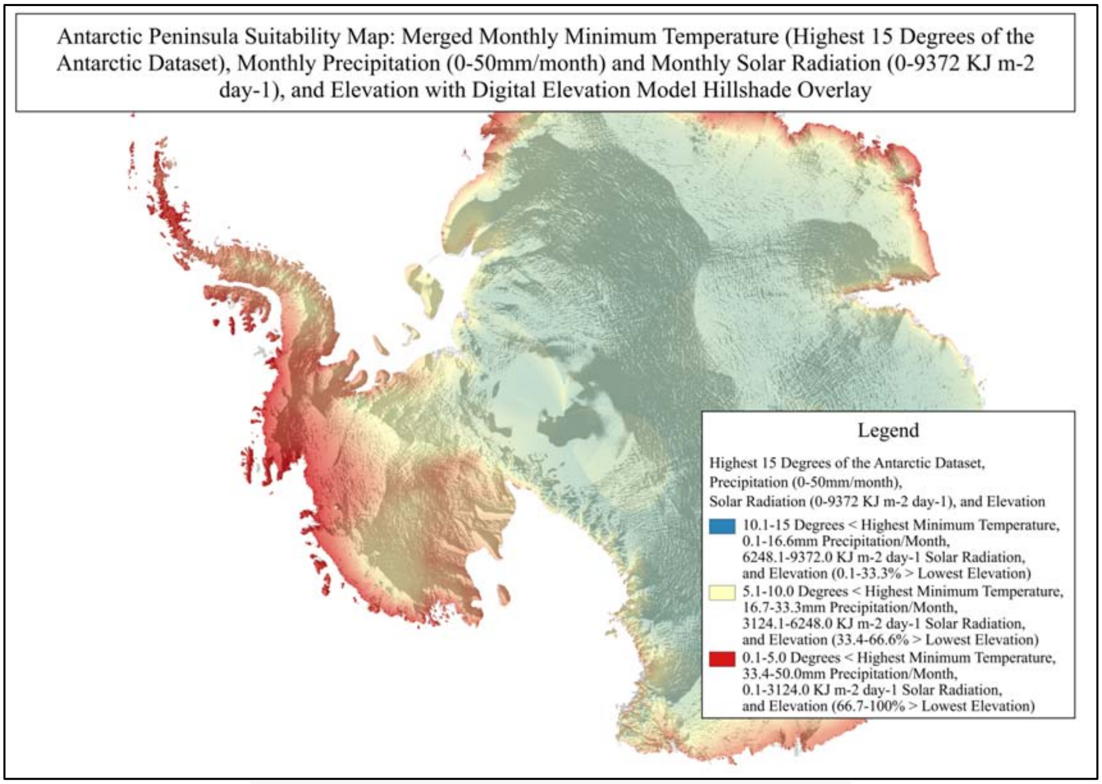

Figure 4. Antarctic Peninsula Suitability Map

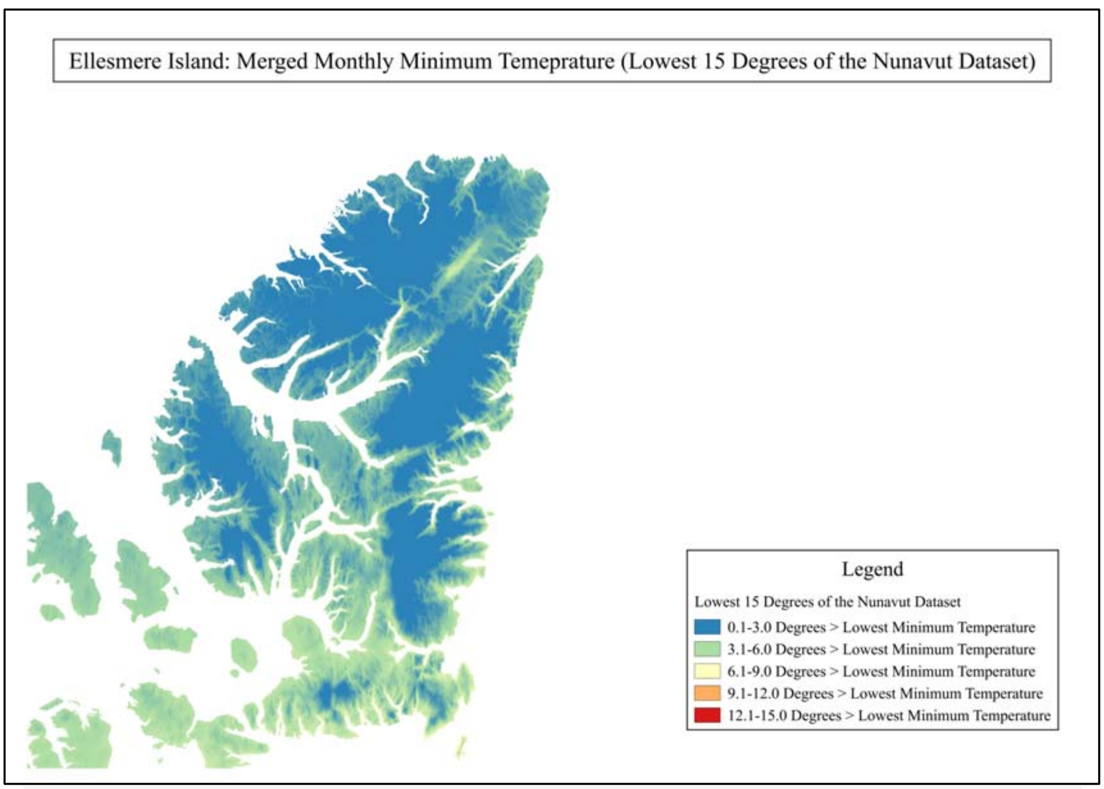

Figure 5. Ellesmere Island Merged Monthly Minimum Temperature (1970-2000)

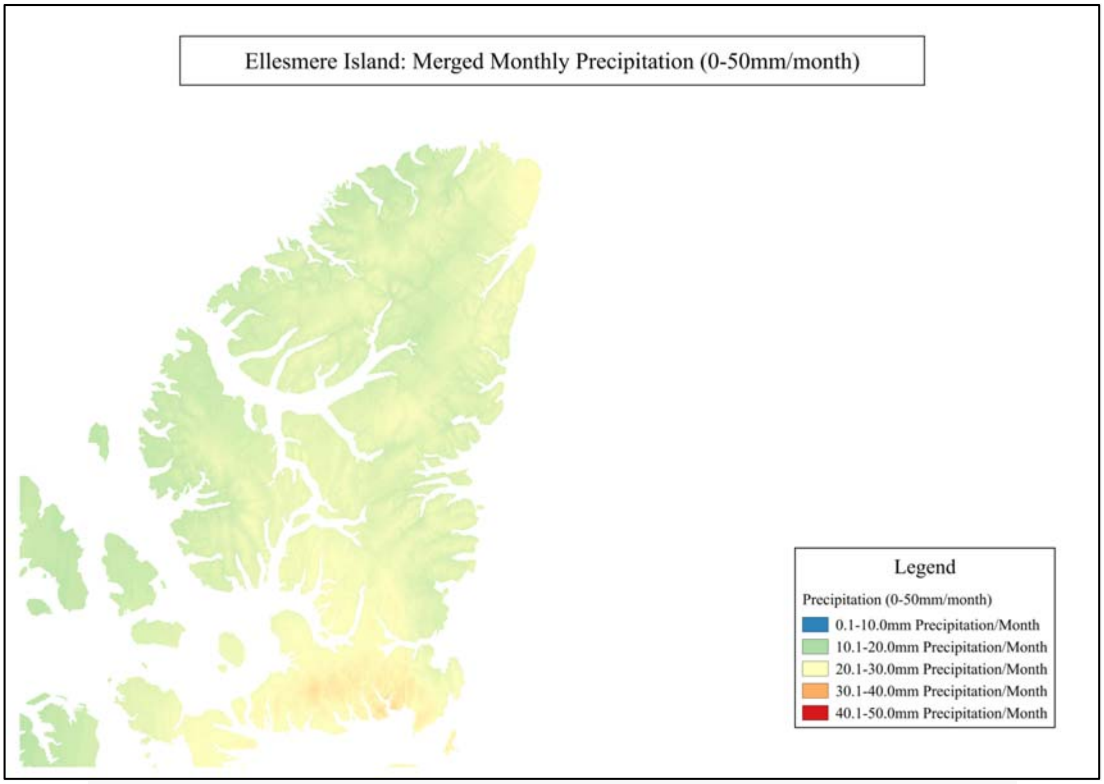

Figure 6. Ellesmere Island Merged Monthly Precipitation (1970-2000)

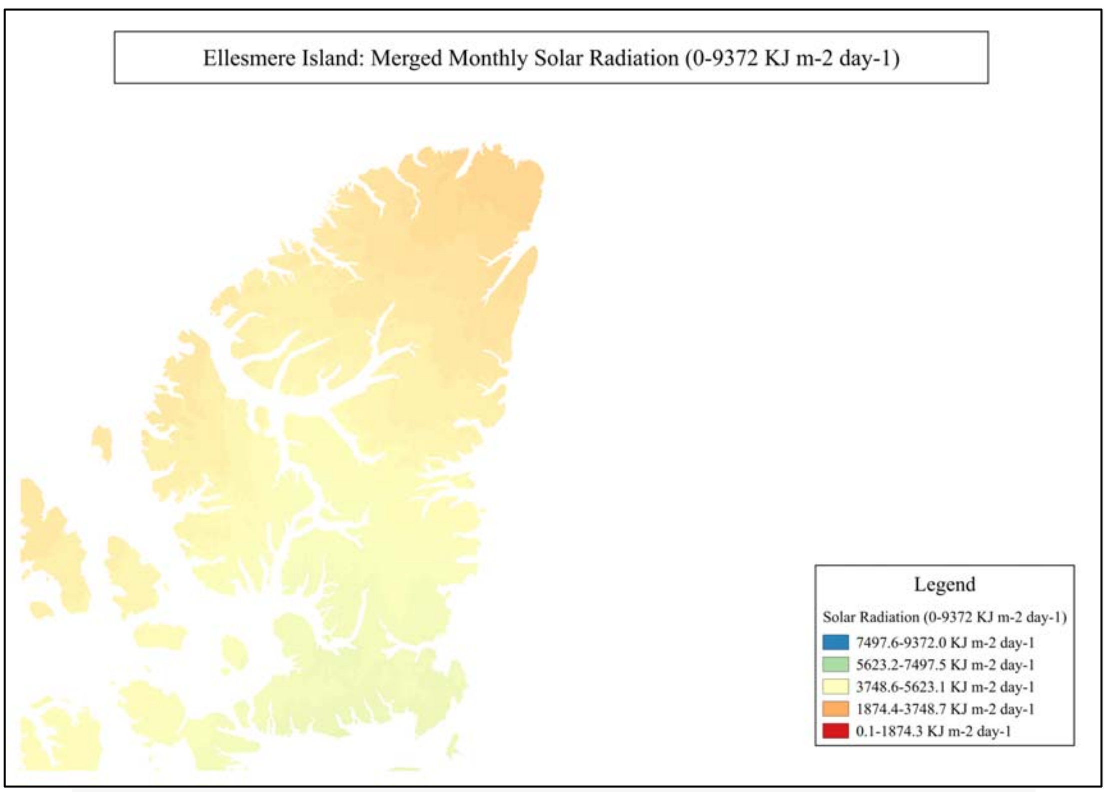

Figure 7. Ellesmere Island Merged Monthly Solar Radiation (1970-2000)

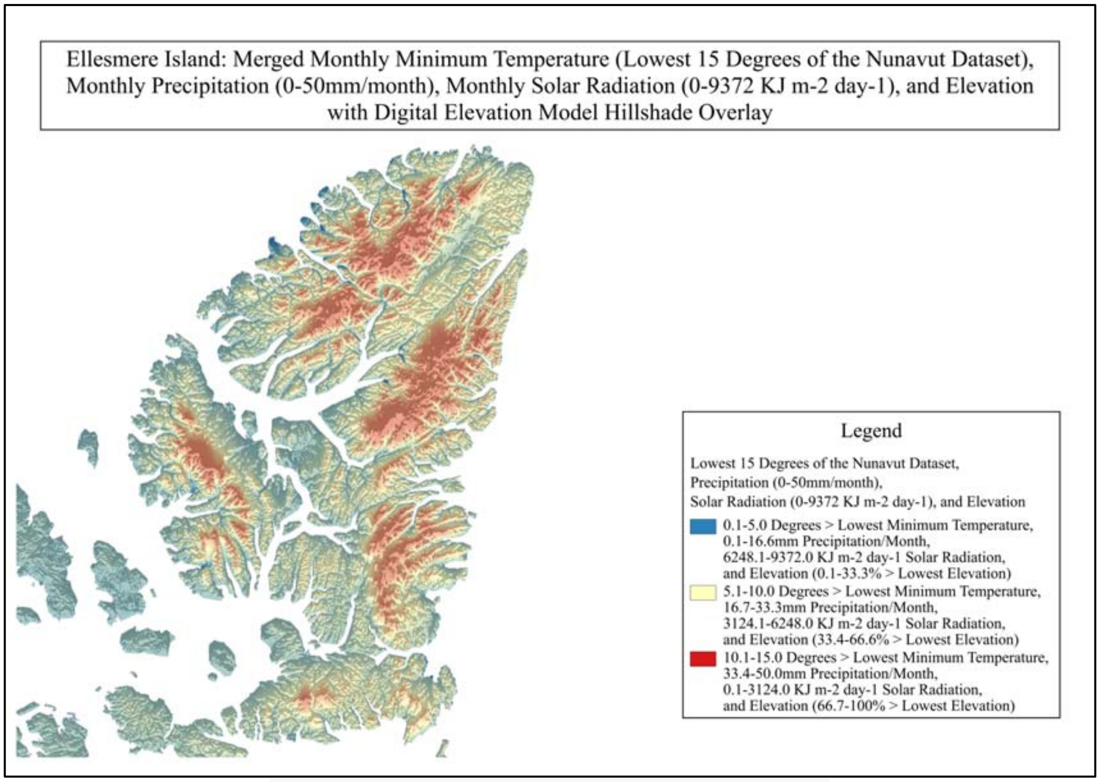

Figure 8. Ellesmere Island Suitability Map

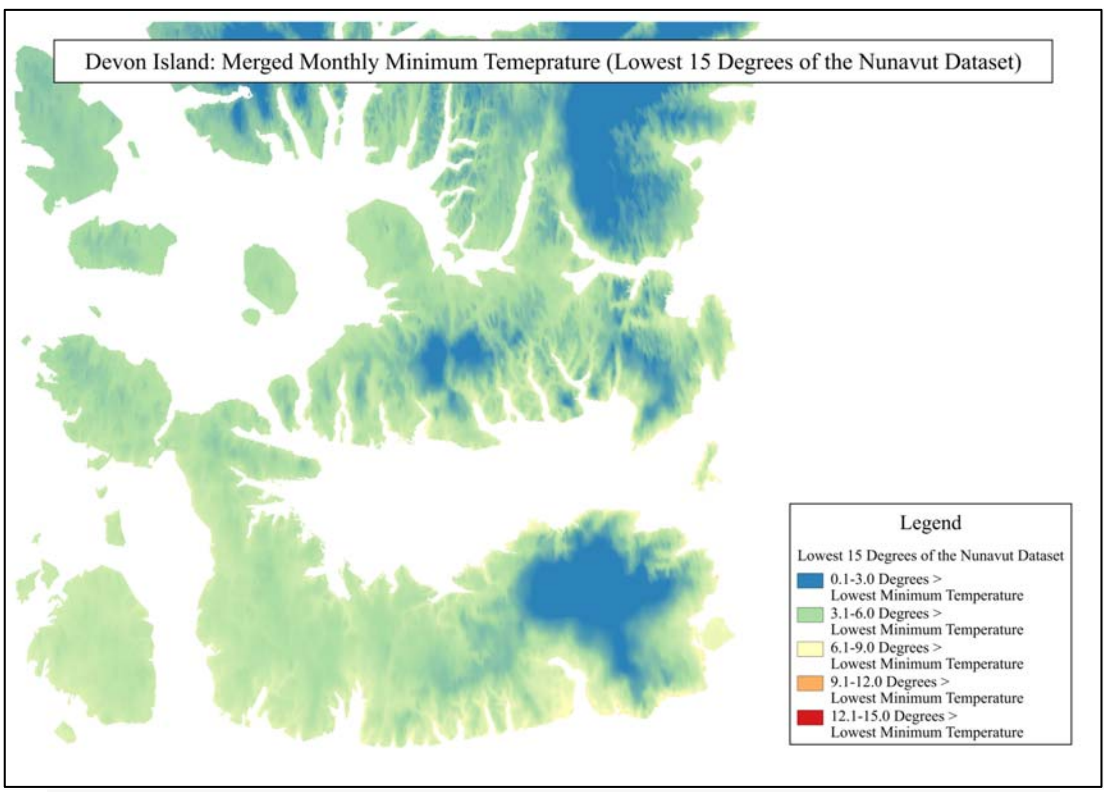

Figure 9. Devon Island Merged Monthly Minimum Temperature (1970-2000)

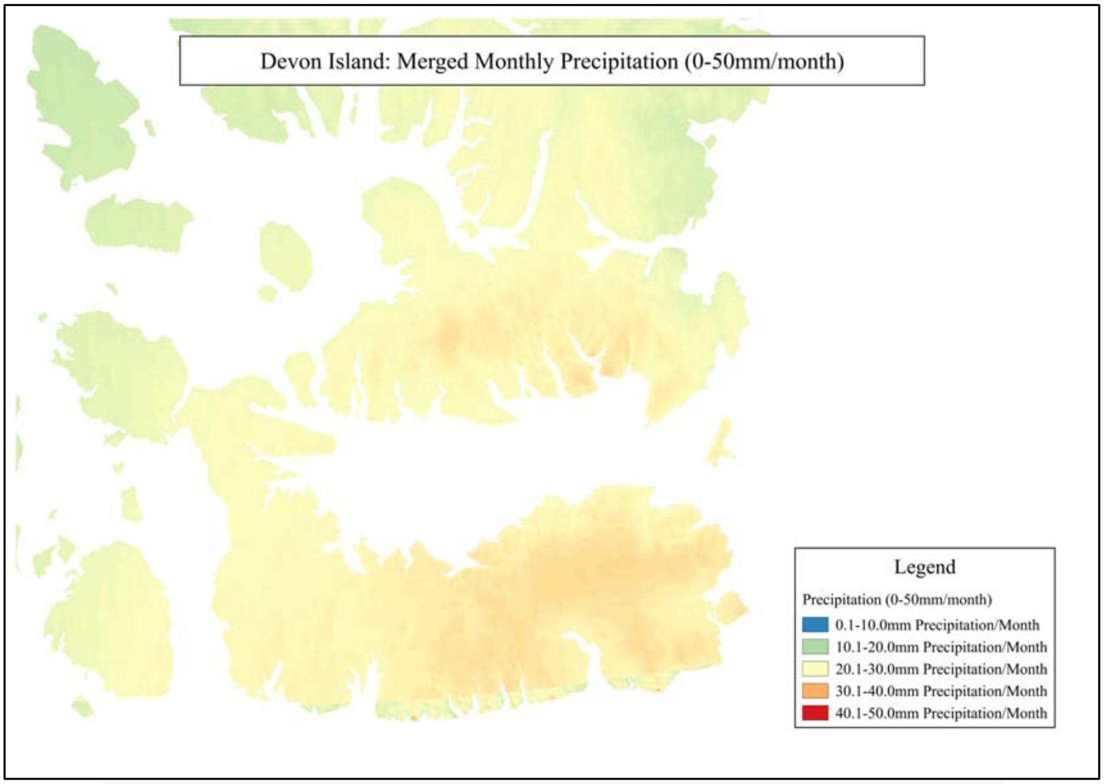

Figure 10. Devon Island Merged Monthly Precipitation (1970-2000)

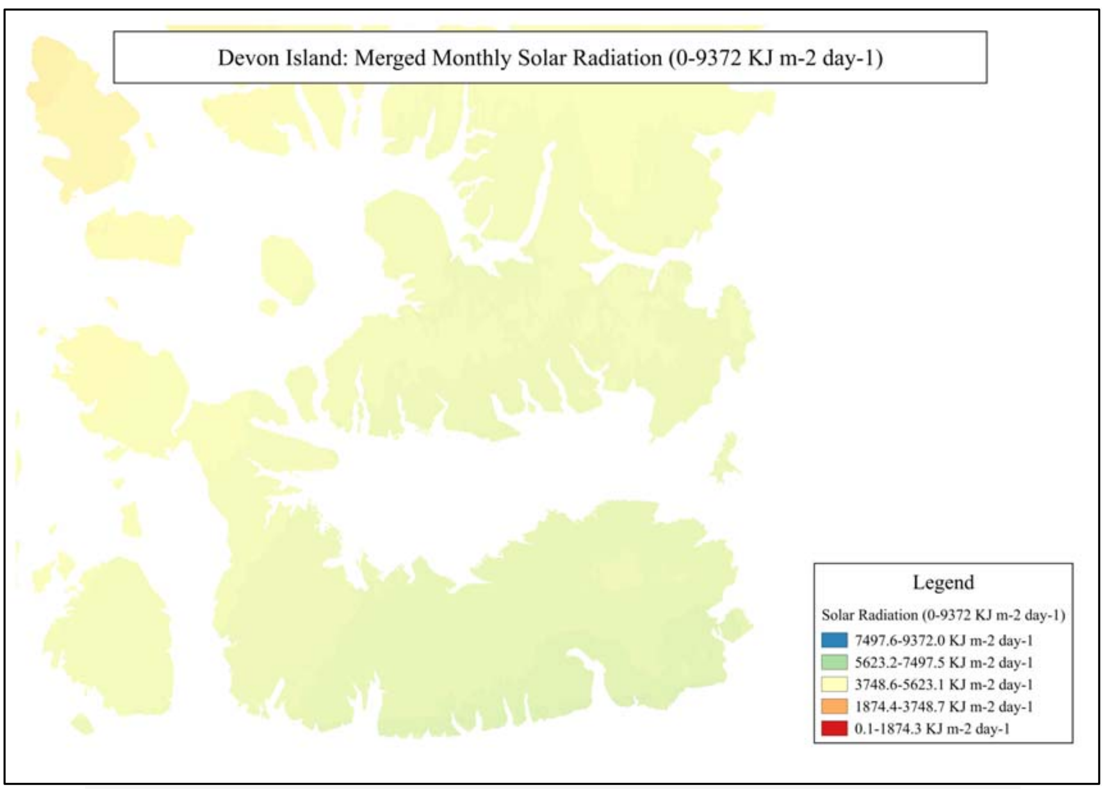

Figure 11. Devon Island Merged Monthly Solar Radiation (1970-2000)

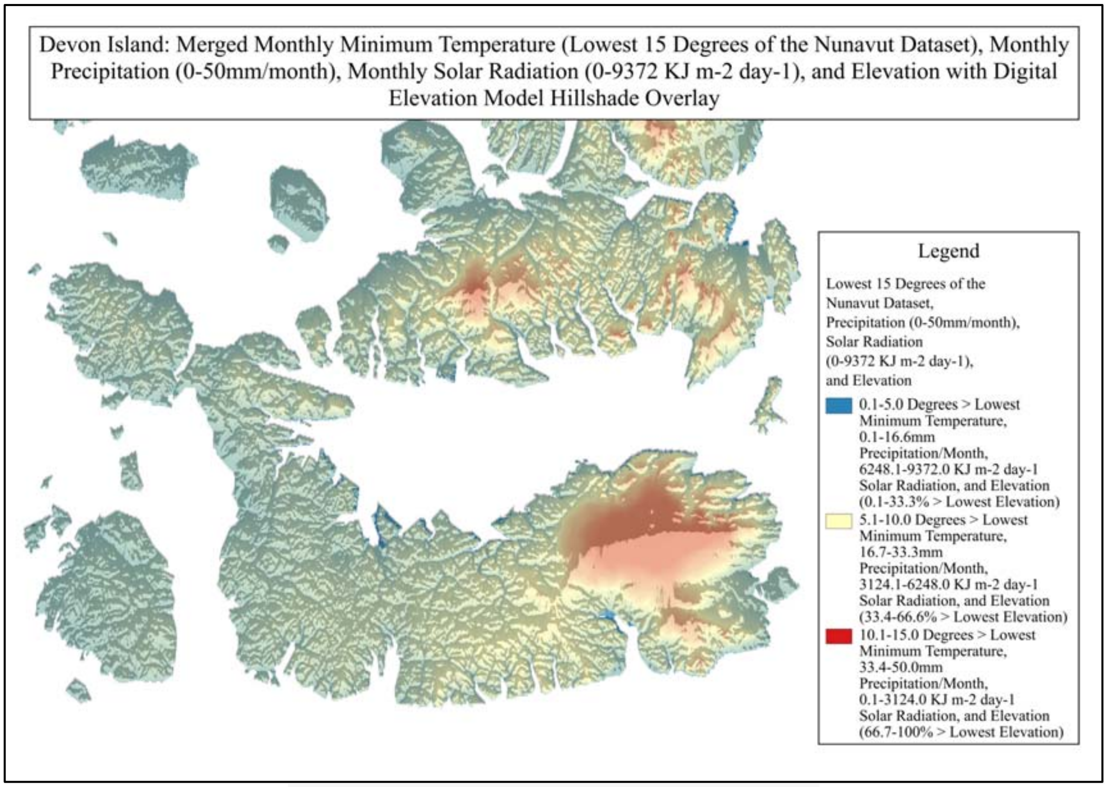

Figure 12. Devon Island Suitability Map

4.2 VEGETATION ANALYSIS

The pixel values in the raster maps that were produced for the suitability analysis were added to the vegetation point data collected from the Global Biodiversity Information Facility. This showed the pixel values, with the same longitudinal and latitudinal coordinates as the corresponding vegetation point data, as a new column in the vegetation point data attribute table. This was then saved as a xlsx. spreadsheet so that the vegetation analysis could be performed.

As mentioned in the Methodology section, the suitability 1 (most suitable) datasets were edited and then compared to the total dataset for each study area. Suitability 1 areas were used for both Ellesmere Island and the Devon Island study areas, however suitability 2 areas were used for Antarctic Peninsula because the Antarctic Peninsula study area did not contain any vegetation occurrences located in the suitability 1 areas. The percentage of genera found in suitability 1 (or suitability 2) areas was subtracted from the percentage of genera found in the total dataset for each study area. This showed a percentage increase or decrease of the occurrences of each genus compared to the overall study area.

For the Antarctic Peninsula, 20 genera of plants had proportionally more occurrences in the suitability 2 areas compared to the overall dataset (Figure 13). For Ellesmere Island 68 genera of plants had proportionally more occurrences in the suitability 1 areas compared to the overall dataset (Figure 14). For Devon Island 42 genera of plants had proportionally more occurrences in the suitability 1 areas compared to the overall dataset (Figure 15). Overall there were 97 different plant genera that were located in suitability 1 areas (located in Devon Island and Ellesmere Island. As well as 109 different plant genera located in the most suitable locations of each study area that also contained vegetation data (Ellesmere Island and Devon Island suitability 1 locations, and the Antarctic Peninsula suitability 2 locations). The total numbers of plant genera listed above have accounted for duplicate genera when comparing the different study areas.

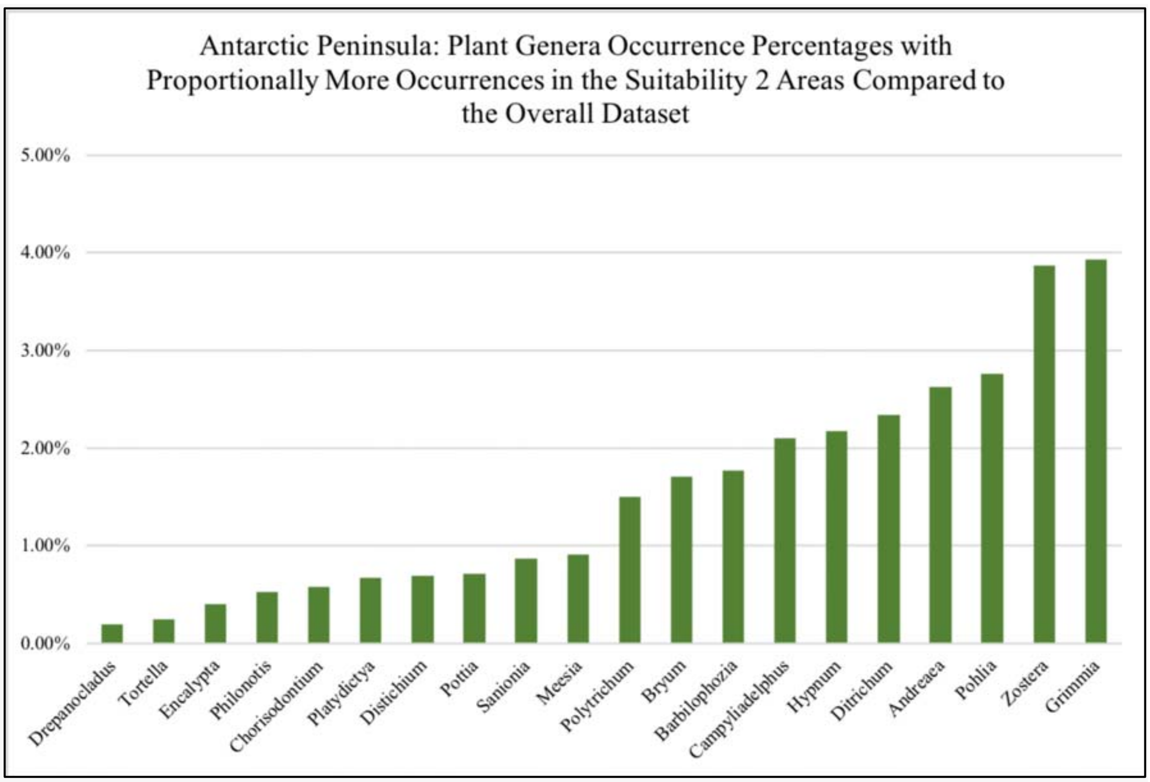

Figure 13. Antarctic Peninsula: Plant Genera Occurrence Percentages with Proportionally More Occurrences on the Suitability 2 Areas Compared to the Overall Dataset

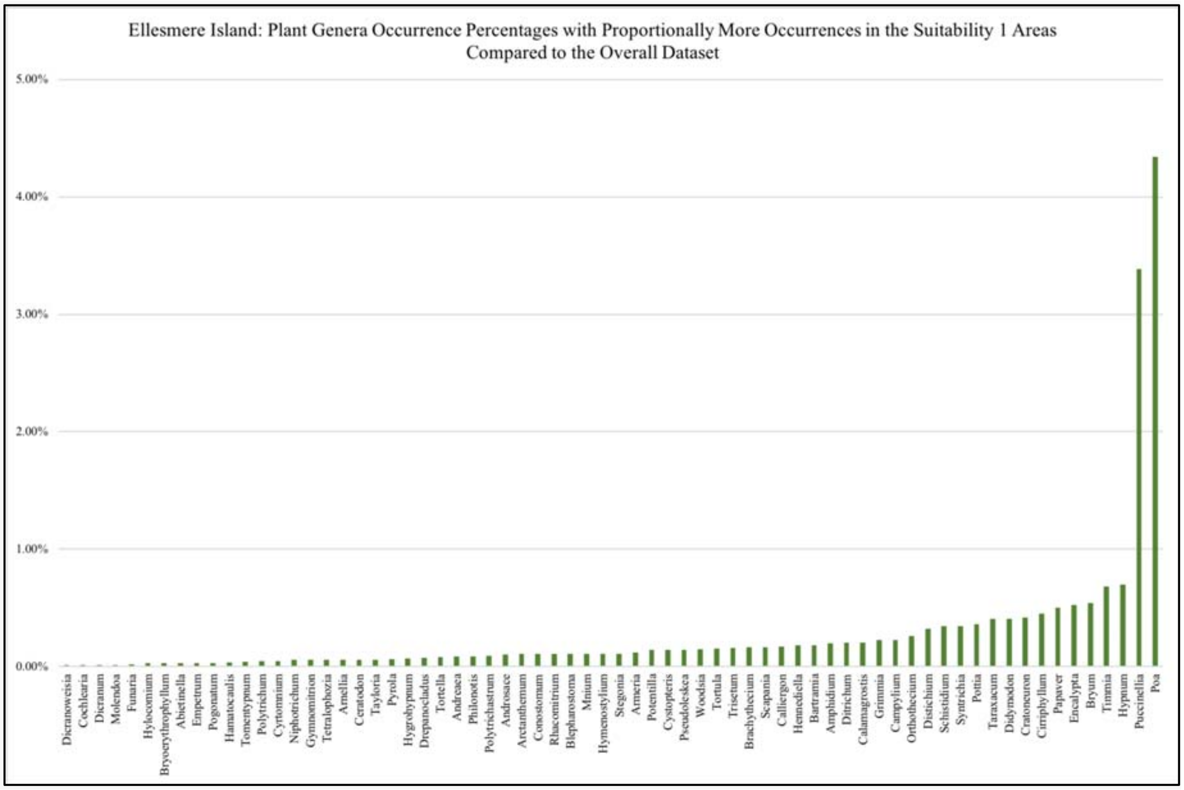

Figure 14. Ellesmere Island: Plant Genera Occurrence Percentages with Proportionally More Occurrences on the Suitability 1 Areas Compared to the Overall Dataset

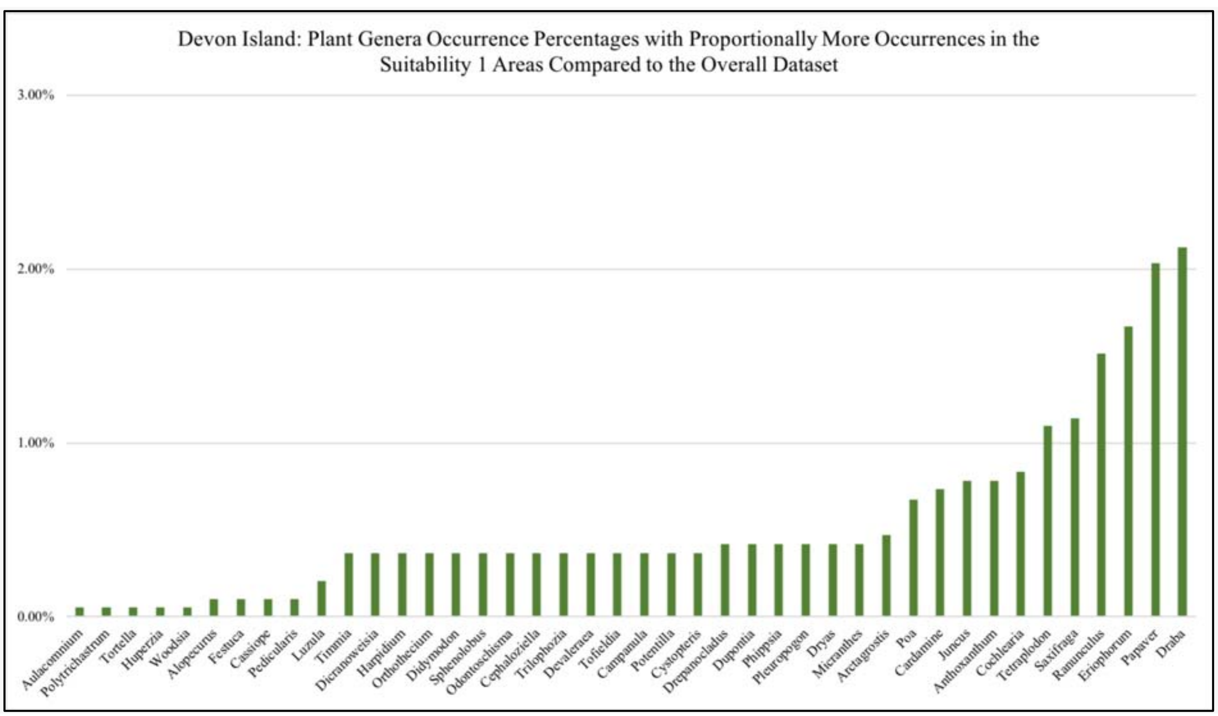

Figure 15. Devon Island: Plant Genera Occurrence Percentages with Proportionally More Occurrences on the Suitability 1 Areas Compared to the Overall Dataset

The vegetation occurrences that had proportionally more occurrences in the suitability 1 (or suitability 2) areas compared to the overall dataset were primarily comprised of tracheophyta and bryophytes. Tracheophyta are a phylum of plants that is comprised of 260,000 species of vascular plants which has xylem which is used to conduct water, dissolved minerals and phloem (Encyclopedia Britannica, 2019). Bryophytes are a phylum of plants that are non-vascular and seedless. Rather than reproducing through seeds, they reproduce through the production of spores and are often perennial plants (Encyclopedia Britannica, 2019).

In the Arctic study areas (Ellesmere Island and Devon Island), the phylum of plants that consistently had the highest proportion of occurrences in the suitability 1 areas compared to the overall dataset were Tracheophyta. For Ellesmere Island, Liliopsida was the class of vegetation which consistently had the highest proportion of occurrences. For Devon Island Magnoliopsida, also known as Dicotyledon, was the class of vegetation which consistently had the highest proportion of occurrences. Liliopsida is a class of monocot plants (flowering plants) that produces seeds that contain one seed leaf (Encyclopedia Britannica, 2019). Dicotyledon is a class of dicot plants (flowering plants) and produce seeds that contain two seed leaves plants (Encyclopedia Britannica, 2019). In the Antarctic Peninsula study area, the phylum of plants that consistently had the highest proportion of occurrences in the suitability 1 areas compared to the overall dataset were Bryophytes. Bryopsida, Andreaeopsida (part of the Bryophyte phylum) and Liliopsida (part of the Tracheophyta phylum) were the class of vegetation which consistently had the highest proportion of occurrences. Bryopsida and Andreaeopsida are non-vascular plants that reproduce through the production of spores, and Liliopsida are monocot plants that produce seeds that contain one seed leaf (Encyclopedia Britannica, 2019).

As mentioned in the methodology section, an additional graph was created that showed plant genera that had proportionally more occurrences in the suitability 1 (or suitability 2) areas and also occurred in multiple study areas (Figure 16). There was a total of 21 genera of plants represented in this graph that occurred in at least two of the study areas. The vegetation represented in this graph was entirely comprised of the plant phyla tracheophyta and bryophytes, with the plant classes Bryopsida and Andreaeopsida (bryophytes), and Liliopsida, Magnoliopsida and Polypodiopsida (tracheophyta). Polypodiopsida is a class of plant (not mentioned previously in the Results section) which is comprised of ferns (non-flowering) that reproduce through the production of spores (Encyclopedia Britannica, 2019).

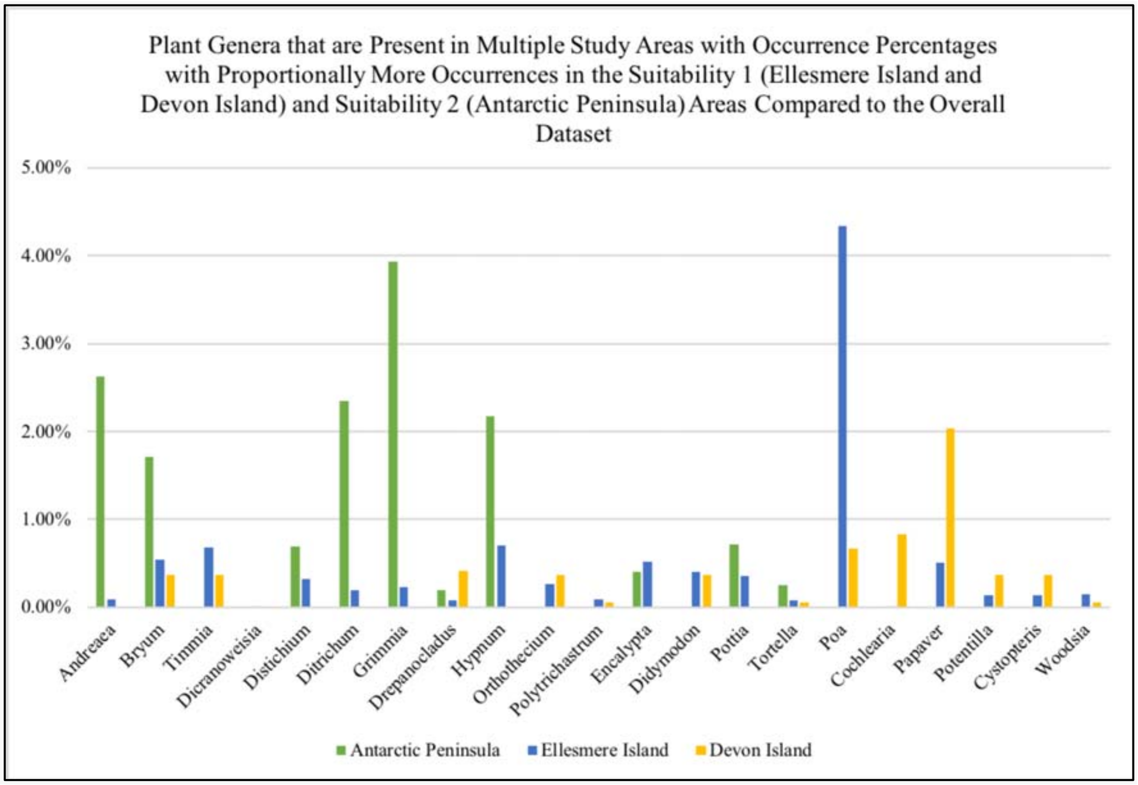

Figure 16. Plant Genera Occurrence Percentages with Proportionally More Occurrences on the Suitability 1 (Ellesmere Island and Devon Island) or Suitability 2 (Antarctic Peninsula) Areas Compared to the Overall Datasets that are also Present in Multiple Study Areas

4.3 REGRESSION ANALYSIS

A regression analysis was performed to determine if there was a negative or positive relationship between the level of suitability and the number of vegetation occurrence points collected by the Global Biodiversity Information Facility. For the Antarctic Peninsula, the line of best fit on the scatterplot showed that as the level of suitability increased (based on the results of the suitability analysis) the number of vegetation occurrence points decreased (Figure 17). It is important to note that the number values associated with the suitability analysis decrease as suitability increases (i.e. the value 0 is associated with high suitability and the value 200 is associated with low suitability). There was a negative relationship between increasing suitability and the number of vegetation occurrence points. This is known because the m or $ß_1$ (slope) value is 1.342, and this value must be interpreted as -1.342 because the number values associated with the suitability analysis decrease as suitability increases. The regression statistics table showed that the multiple r value is 0.232, the r squared value is 0.054, and the standard error is 19.829

(Table 1). This shows that; there is a relationship (albeit relatively low) between the suitability ranking and the number of vegetation occurrence points (multiple r value = 0.232), and very few points are actually falling on the regression line (5%) although the standard error is 19.829, actually the lowest standard error of all the study areas.

For Ellesmere Island, the line of best fit on the scatterplot showed that as the level of suitability increased (based on the results of the suitability analysis) the number of vegetation occurrence points also increased (Figure 18). There was a positive relationship between increasing suitability and the number of vegetation occurrence points. This is known because the m or $ß_1$ (slope) value is -0.130, and this value must be interpreted as 0.130 because the number values associated with the suitability analysis decrease as suitability increases. The regression statistics table showed that the multiple r value is 0.088, the r squared value is 0.008, and the standard error is 33.302 (Table 2). This shows that; there is almost no relationship between the suitability ranking and the number of vegetation occurrence points (multiple r value = 0.088), and very few points are actually falling on the regression line (0.07%) with a relatively high standard error of 33.302.

For Devon Island, the line of best fit on the scatterplot showed that as the level of suitability increased (based on the results of the suitability analysis) the number of vegetation occurrence points also increased (Figure 19). There was a positive relationship between increasing suitability and the number of vegetation occurrence points, although it is the least significant relationship of all the study areas. This is known because the m or $ß_1$ (slope) value is -0.093, and this value must be interpreted as 0.093 because the number values associated with the suitability analysis decrease as suitability increases. The regression statistics table showed that the multiple r value is 0.251, the r squared value is 0.063, and the standard error is 39.346 (Table 3). This shows that there is a relationship (although relatively low, it is the most significant relationship of all the study areas) between suitability ranking and the number of vegetation occurrence points (multiple r value = is 0.251), and very few points are actually falling on the regression line (0.6%) with a relatively high standard error of 39.346, the highest standard error of all the study areas.

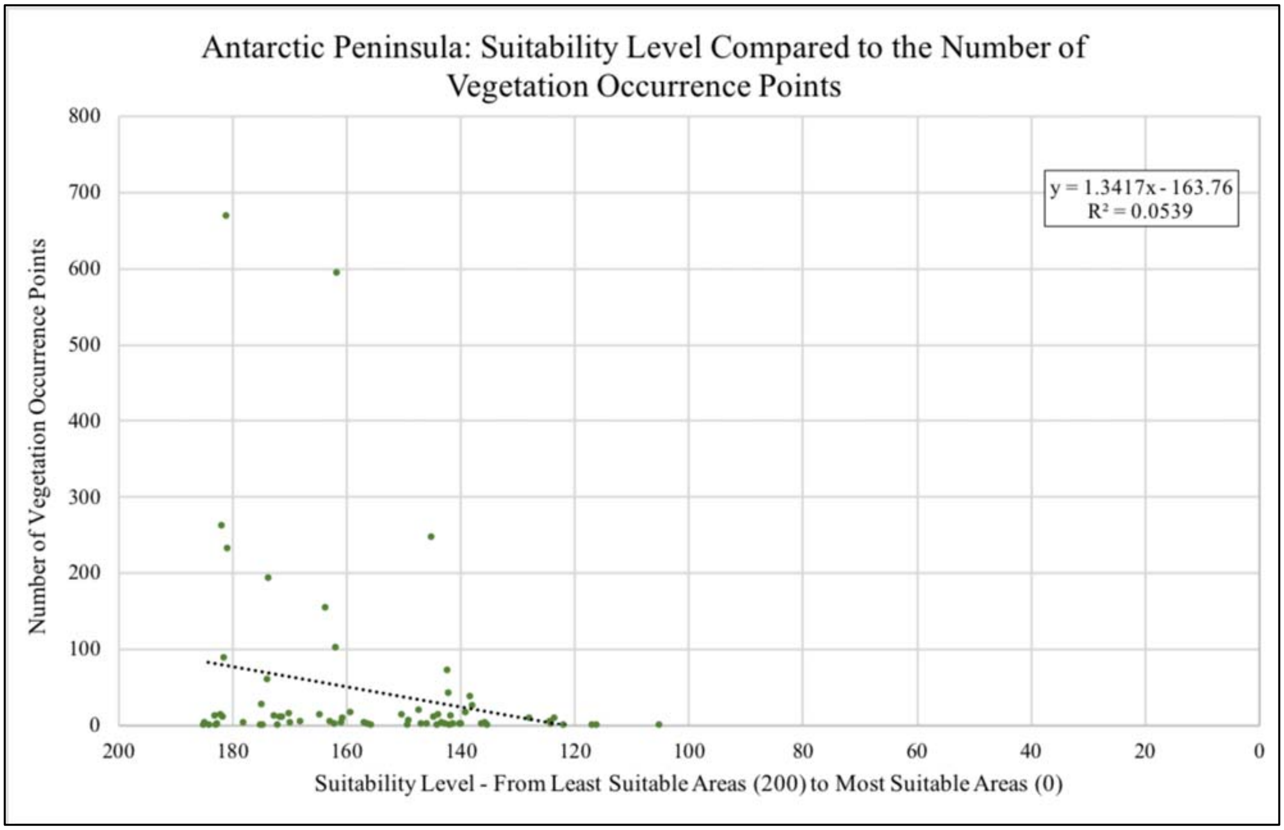

Figure 17. Antarctic Peninsula: Suitability Level Compared to the Number of Vegetation Occurrence Points

Regression Statistics	Column1
Multiple R	0.23222568
R Square	0.05392876
Adjusted R Square	0.04001595
Standard Error	19.8287858
Observations	70

Table 2. Antarctic Peninsula: Suitability Level and Number of Vegetation Occurrence Points Regression Statistics

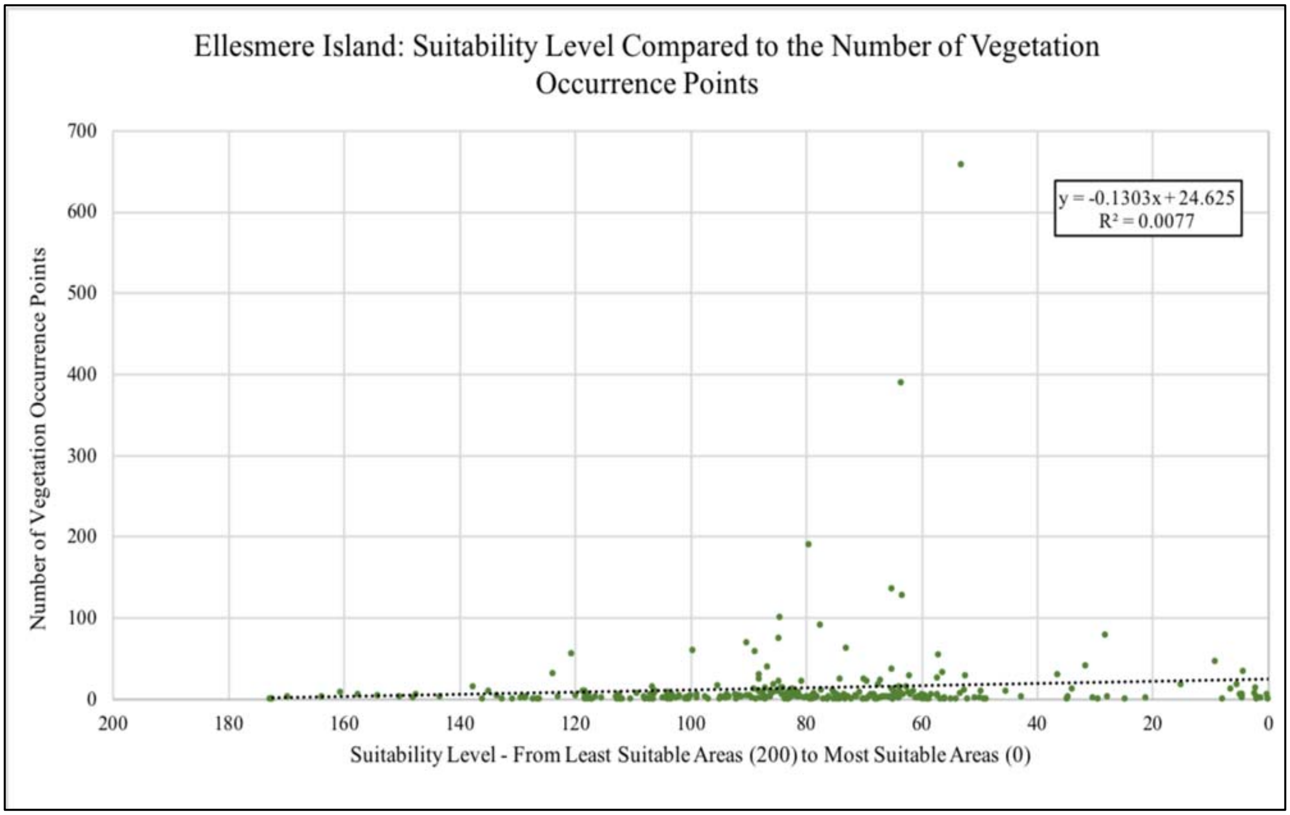

Figure 18. Ellesmere Island: Suitability Level Compared to the Number of Vegetation Occurrence Points

Regression Statistics	**Column1**
Multiple R	0.08768782
R Square	0.00768915
Adjusted R Square	0.0041068
Standard Error	33.3020304
Observations	279

Table 3. Ellesmere Island: Suitability Level and Number of Vegetation Occurrence Points Regression Statistics

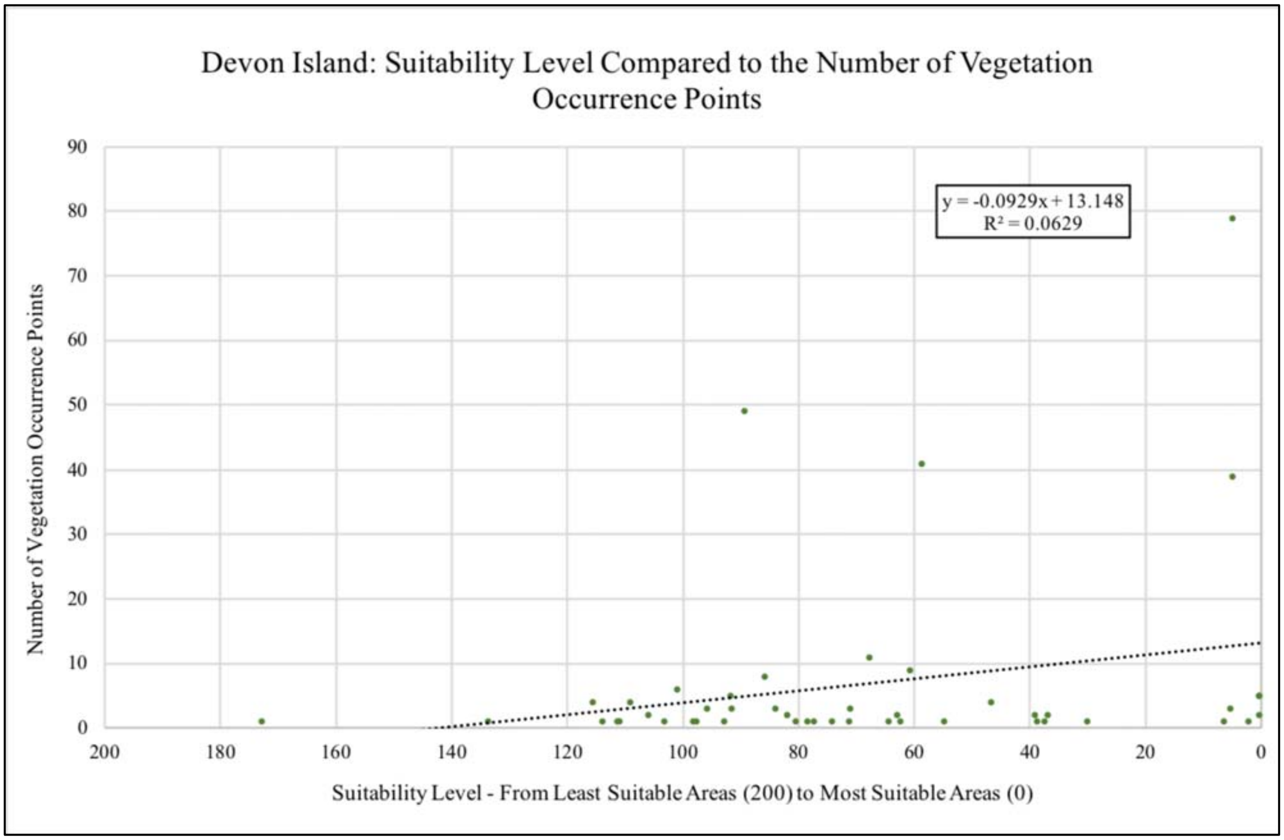

Figure 19. Devon Island: Suitability Level Compared to the Number of Vegetation Occurrence Points

Regression Statistics	Column1
Multiple R	0.2507931
R Square	0.06289718
Adjusted R Square	0.04207267
Standard Error	39.3457314
Observations	47

Table 4. Devon Island: Suitability Level and Number of Vegetation Occurrence Points Regression Statistics

CHAPTER 5
DISCUSSION

As mentioned in the literature review, existing research that has been done in regard to plant growth and reproduction in space discusses the importance of transporting vegetation that; produce large quantities of seeds, take up minimal space, are relatively low maintenance to grow, require minimal energy, and are monocots (Meinen et al. 2018) (Tang et al. 2014). In addition, there is promising research being done by Fujita and others (2016) that ultimately hopes to be able to genetically engineer different species of mosses so that they are better suited for growth on another planet (i.e. Mars). Based on this research, the list of 21 plant genera that had proportionally more occurrences in the suitability 1 (or suitability 2) areas and also occurred in multiple study areas could now be refined to a list of 15 genera of Bryophytes and 1 genus of Tracheophyta. The genera in the phylum Bryophyte that are the most promising candidates include; Andreaea, Bryum, Timmia, Dicranoweisia, Distichium, Ditrichum, Grimmia, Drepanocladus, Hypnum, Orthothecium, Polytrichastrum, Encalypta, Didymodon, Pottia and Tortella. All of these genera are non-vascular and seedless plants which reproduce through the production of spores (which take up minimal space and are produced in large quantities). The genus in the phylum Tracheophyta that is the most promising candidate of the entire study is Poa, also known as Bluegrass. This genus contains more than 500 species of grass that can be found throughout the globe, including the Earths polar regions (Encyclopedia Britannica, 2019). This genus is considered the most promising candidate for a number of reasons including; it is a monocot (flowering plant that produces seeds that contain one seed leaf); it can produce seeds annually and in relatively large quantities; as grass species, the plants and seeds take up relatively minimal space and require little maintenance; this genus had (in proportion to the overall dataset) the highest percentage of occurrences compared to all other genera included in this study and also was located in both the Ellesmere Island and Antarctic Peninsula study areas.

Overall, this study shows that plants that are part of the Bryophyte and Tracheophyta phyla are worthy of further research in regard to possible vegetation candidates that could be brought to Mars. Gaining further insight to how the seeds and spores of the plants mentioned above respond to altered gravity conditions, hypoxic conditions, and extremely low temperatures (such as those found on Mars) will be an important next step to this research. It is recommended that the methods used in this study are repeated in other locations on Earth that have Mars-like environmental qualities in order to determine other possible vegetation candidates that could be brought to Mars. Any vegetation identified if this study were repeated could then be cross referenced with the most promising vegetation candidates identified in this study to determine if there are any genera that are the same. Additionally, repeating this study in other Mars-like areas on Earth could allow the researcher to determine if the Bryophyte and Tracheophyta phyla are consistently the most promising phyla of plants to bring to Mars when looking at all areas on earth that have Mars-like qualities. It is also recommended that when humans are closer to sending manned missions to Mars this study be repeated. This is recommended for a few reasons. First, the collection of vegetation occurrence data is an ongoing process and databases like the Global Biodiversity Information Facility are growing larger (with more vegetation occurrence data being added each day). If this study were to be repeated in 10-20 years, the researcher may be able to gain a more accurate understanding of the different genera (and their population numbers) that live in Mars-like areas on Earth. Second, as technology continues to improve the quality of remotely sensed climate imagery also continues to improve. The pixel size of the high-resolution raster layers that were used for this study were 1km by 1km. Improving the resolution of the raster layers would allow the researcher to create more detailed thematic climate maps which could improve the accuracy of the climate data pixel value as it is associated with each point of vegetation data.

The results of the regression analysis show that in the Arctic study areas (Ellesmere Island and Devon Island) there is a positive relationship between increasing suitability and the number of vegetation occurrence points. Meaning that areas that are more Mars-like in regard to temperature, precipitation levels, solar radiation levels which also are in areas of low elevation, have higher numbers of vegetation occurrences (based on the dataset collected by the Global Biodiversity Information Facility). This can be compared to the Antarctic Peninsula study area where there was negative relationship between increasing suitability and the number of vegetation occurrence points. Meaning that areas that are more Mars-like have lower numbers of vegetation occurrences. This indicates that perhaps the Arctic study areas (Ellesmere Island and Devon Island) are better areas for exploring vegetation that could be brought to Mars for the purpose of terraforming in closed bioregenerative life support systems.

There are a few limitations to this study that are important to acknowledge. First, although the Global Biodiversity Information Facility has an extremely large catalogue of vegetation occurrence data from around the world, it is not possible (with current vegetation occurrence data gathering methods) to actually determine the location and genus of every piece of vegetation in the selected study areas (or any large land area on earth). Second, the vegetation data collected from the Global Biodiversity Information Facility is not robust enough to give a full and accurate understanding of the population numbers and distribution of all of the genera that live in the study areas used for the suitability analysis and vegetation analysis. This may have impacted the results of the regression analysis as certain numbers of vegetation occurrence points were represented as outliers in the scatter plot graphs. Perhaps a more robust vegetation occurrence database would eliminate (or decrease the numbers of) these outliers and be able to provide a more accurate understanding of the relationship between the level of suitability (suitability analysis pixel value) and the associated number of vegetation occurrence points. Third, increasing the resolution of the raster images used for the suitability analysis would have improved the accuracy of both the suitability analysis and the vegetation analysis. Raster image pixel sizes represented a 1km by 1km area, meaning the results of the suitability analysis were accurate to a 1km by 1km area. As the genera of vegetation can vary throughout a 1km by 1km area this may have impacted the accuracy of the vegetation analysis once the data was combined with the results of the suitability analysis. Fourth, an important aspect of this study to acknowledge that can be viewed as a limitation is understanding the ethics of terraforming Mars. Currently NASA has implemented a planetary sustainability initiative and one of the objectives in this initiative is "[to work towards] a multiplanetary society, where the resources of the solar system are available to the people of Earth" (Szocik, 2019). The idea of sending human missions to Mars, and more specifically the idea of colonizing Mars, brings up a number of ethical questions such as; do humans have the right to access resources from other planets at the expense of potential native life forms?; and is it necessary for humans to respect the natural evolution of life forms native to Mars by leaving the planet as untouched as possible to avoid further contamination? (Levchenko et al. 2019). Ethical questions such as these will be important to consider as future unmanned missions to Mars move forward and the possibility of sending humans to Mars becomes more realistic. Nonetheless, the primary purpose of this study was to develop and test a GIS framework that can also be used as a tool by future researchers when attempting to determine which vegetation is most likely to survive in a Martian environment. Ultimately this framework should be used as a first step by future researchers to narrow the list of possible vegetation candidates that could be brought to Mars for the purpose of terraforming in closed bioregenerative life support systems.

CHAPTER 6
CONCLUSION

The goal of this study was to develop a framework that uses spatial environmental data from both Earth and Mars to better understand areas on Earth that share the most environmental similarities to Mars. The primary purpose of this study was to develop and test a GIS framework that can also be used as a tool by future researchers when attempting to determine which vegetation is most likely to survive in a Martian environment.

The literature reviewed to prepare for this study included important research that has been done on the environment on Earth and Mars, terraforming Mars, plant response to environmental conditions found on Mars and the International Space Station, identifying locations on Earth that are environmentally similar to Mars, GIS used as a tool to perform vegetation analysis in polar regions on Earth, suitability analysis using remotely sensed climate images and Digital Elevation Models, and Transporting Vegetation to Mars.

This literature showed that considerations for transporting vegetation to Mars include sourcing vegetation that can utilize the Martian soil and available sunlight as well as sourcing this vegetation from locations on Earth where availability of water is limited solar ultraviolet (UV) radiation is high (Todd, 2006). Based on the literature reviewed, Mars is the best candidate for human missions and terraforming because Mars falls within the habitable zone of the solar system (Jagadeesh et al., 2017), there is a present atmosphere comprised mostly of carbon dioxide (92%) (Haberle et al., 2017), Martian water in the form of stable regolith ice has been discovered at high latitudes of the planet (Wasilewski, 2018), and water is present in the Martian atmosphere in the form of water vapor (Haberle et al., 2017). Terraforming that humans are realistically capable of in the foreseeable future involves the creation of closed bioregenerative life support systems and the utilization of as many in-situ materials as possible (Murukesan et al., 2016). Currently, bioregenerative life support systems are already used on the International Space Station and are able to recover both oxygen and water (Neiderwieser et al., 2018).

The selection of study areas and the development of the methodology for this study was also based on the literature reviewed. Study sites were selected based on work done by Bret Israel for Live Science entitled “7 Most Mars Like Places on Earth” which used data collected from NASA to identify the top seven locations on Earth that have environmental conditions most similar to those found on Mars (Israel, 2012). As well as work done by Preston and Dartnell (2014) who sought to catalogue terrestrial field sites that are analogues to regions found on Venus, Mars, Europa, Enceldus and Titan and summarize the physiochemical environmental conditions in each identified location (Preston and Dartnell, 2014). The methodology for this study was developed based on several academic articles. First, Pertierra and others (2016) who used data collected from the Global Biodiversity Information Facility to explore the potential ranges of two invasive grass species as they spread throughout Antarctica (Pertierra et al,. 2016). Second, Peng and Peng (2014) who performed a suitability analysis using digital elevation model (DEM) data and climactic data to map areas that are most suitable for wetlands based on the water table depth (Peng and Peng, 2014). Third, Piri Sahragard and others (2018) who used soil and topographic data from the Taftan Mountain to perform a suitability analysis to understand the potential distribution of vegetation (Piri Sahragard et al., 2018). Fourth, Uuemaa and others (2018), who were able to perform a suitability analysis that would identify potential areas for wetland restoration or creation (Uuemaa et al., 2018). Fifth, Meinen and others (2018), who discuss some of the important factors for growing plants on the International Space Station (Meinen et al., 2018). Sixth, Nivokiva and others (2015), who looked at the impacts of solar radiation and the environmental conditions found in outer space to see how they impacted seed production in plants (Nivokiva et al., 2015). Seventh, Tang and others (2014), who have evaluated the impacts of removing oxygen from plant environments while seeds are germinating (Tang et al., 2014).

The first step of this study involved map creation which allowed the researcher to perform a suitability analysis that identified areas within the selected study areas (the Antarctic Peninsula, Ellesmere Island and Devon Island) which had the lowest minimum monthly temperature, the lowest levels of monthly precipitation, the highest levels of solar radiation and the lowest levels of elevation. This allowed the researcher to identify specific locations within the selected study areas that would be most appropriate for the vegetation analysis. The second step of this study involved linking the maps used to perform the suitability analysis with the vegetation occurrence data obtained from the Global Biodiversity Information Facility. The third step of this study involved analyzing the vegetation occurrence data that had been linked with the suitability analysis results to identify; which genera of plants occur, proportional to the overall dataset, in the suitability 1 (most suitable) areas; which genera of plants occur in the suitability 1 (most suitable) areas and in multiple study areas; and to use a regression analysis to determine if there was a negative or positive relationship between the suitability analysis pixel value (level of suitability) and the number of vegetation occurrence points collected by the Global Biodiversity Information Facility.

The results of this study showed that the genera in the phylum Bryophyte that are the most promising candidates include; Andreaea, Bryum, Timmia, Dicranoweisia, Distichium, Ditrichum, Grimmia, Drepanocladus, Hypnum, Orthothecium, Polytrichastrum, Encalypta, Didymodon, Pottia and Tortella. In addition, the genus Poa, also known as Bluegrass, which is part of the phylum Tracheophyta is the most promising candidate of the entire study. This is because it is a monocot (flowering plant that produces seeds that contain one seed leaf) which produces seeds annually, the plants and seeds take up relatively minimal space and require little maintenance. Also, this genus had (in proportion to the overall dataset) the highest percentage of occurrences compared to all other genera included in this study, and also was located in both the Ellesmere Island and Antarctic Peninsula study areas.

The results of the regression analysis show that in the Arctic study areas (Ellesmere Island and Devon Island) there is a positive relationship between increasing suitability and the number of vegetation occurrence points and show that in the Antarctic Peninsula study area there is a negative relationship between increasing suitability and the number of vegetation occurrence points. This shows that Arctic study areas (Ellesmere Island and Devon Island) are likely better areas for exploring vegetation that could be brought to Mars for the purpose of terraforming.

Elon Musk has stated that “before we can journey to the stars, we must first go to Mars [and] for any meaningful and long-lasting human presence on Mars, we would likely want to alter the planet and its atmosphere to make it more habitable for human life” (Newstex Global Business Blogs, 2017). The next mission to Mars (NASA’s 2020 Rover) plans to carry out a number of tests and experiments that will allow researchers to gain a better understanding of the planet which will improve the likelihood of humans travelling to and surviving missions to the planet (New Dheli, 2018). The framework developed in this study can be used to better understand vegetation distribution as it relates to climate and elevation and ultimately seeks to narrow the list of possible vegetation candidates that could be brought to Mars for the purpose of terraforming in closed bioregenerative life support systems.

CHAPTER 7
FUTURE WORKS

The intention for this study is that it will contribute to existing research done on; using GIS as a tool to explore climate data as it can be used to perform a suitability analysis as well as vegetation occurrence and abundance; space exploration; terraforming Mars; and gaining an understanding the distribution of vegetation in Mars-like places on Earth. In regard to space exploration, the introduction of vegetation to Mars will be an essential tool that will contribute to oxygen (O_2) production, water (H_2O) recycling, and food production (Wheeler ,2010). The plant genera identified in this study are not suitable candidates for food production, however, they do serve as suitable candidates for both oxygen production and water recycling.

As mentioned in the Discussion section of this study, it is recommended that further research be done on how seeds and spores of the plants mentioned above respond to altered gravity conditions, hypoxic conditions, and extremely low temperatures. Additional recommendations are that the methods used in this study are repeated in other locations on Earth that have Mars-like qualities as well as at a future time when humans are closer to sending manned missions to Mars. As technology and data collection methods continue to improve researchers will likely be able to create more detailed thematic climate maps and have access to vegetation occurrence databases that are more robust.

Additional work that has been inspired by this study includes; developing a methodology based on the one used in this study to understand bacteria distribution in extreme Mars-like places on Earth; and developing a methodology to understand the climactic conditions that occur in areas where vegetation is grown for the purpose of human consumption. As mentioned in the literature review microbial life found at high volcanic elevations are also being studied to explore life forms that live in Mars-like environments (Schmidt et al., 2018). The methodology that was developed for this study could also be used to link climate data and the distribution of microbial life to better understand which genera of microbial life are most likely to be found in Mars-like environments. Although the dataset isn't as robust for the kingdom of bacteria as it is for the kingdom of plantae, the Global Biodiversity Information Facility does contain a dataset with 8,216,269 georeferenced bacteria occurrences[10]. Once connected with the appropriate environmental and climate data, this dataset could be used to determine which genera of bacteria are most likely to survive in a Martian environment.

In addition to understanding the distribution of bacteria in Mars-like places on Earth, the methodology developed in this study could also be used to answer the question; of all the vegetation that is grown for the purpose of human consumption on Earth, which vegetation is grown in areas that share the most environmental similarities to Mars? Developing a framework that could answer this question would provide a significant contribution to research done on terraforming Mars as the vegetation identified would contribute to oxygen (O_2) production, water (H_2O) recycling, and food production. This research would require the acquisition of global georeferenced agriculture data, however identifying the agricultural vegetation that is grown in areas that share the most environmental similarities to Mars could be understood by developing a very similar framework to the one used in this study.

The framework developed for this study has the potential to be used for understanding the abundance and distribution of vegetation and bacteria found in Mars-like places on Earth, including areas that were not selected for this study. In addition, this framework can be adjusted to explore the agricultural vegetation that is grown in areas that share the most environmental similarities to Mars. As mentioned at the beginning of this section this framework as it has been used in this study hopes to contribute to research done on; GIS as a tool to explore climate and perform a suitability analysis; mapping vegetation occurrence and abundance; space exploration; terraforming Mars; and ultimately to help support humans that may someday travel to the red planet.

[10] Follow link to see more: https://www.gbif.org/species/3

APPENDEX A:

Antarctic Peninsula: Plant Phylum, Class, Order, Family and Genus Occurrence Percentages in the Suitability 2 Locations Proportional to the Overall Dataset

Phylum	Class	Order	Family	Genus	Subtracted Percentage
Bryophyta	Andreaeopsida	Andreaeales	Andreaeaceae	Andreaea	2.62%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Bartramia	-0.08%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Conostomum	-0.24%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Philonotis	0.53%
Bryophyta	Bryopsida	Bryales	Bryaceae	Bryum	1.71%
Bryophyta	Bryopsida	Bryales	Bryaceae	Plagiobryum	-0.05%
Bryophyta	Bryopsida	Bryales	Bryaceae	Pohlia	2.76%
Bryophyta	Bryopsida	Bryales	Bryaceae	Ptychostomum	-0.09%
Bryophyta	Bryopsida	Bryales	Meesiaceae	Meesia	0.91%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Anisothecium	-0.24%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Aongstroemia	-0.62%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Chorisodontium	0.58%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Dicranella	-0.14%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Dicranoweisia	-0.94%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Ceratodon	-4.35%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Distichium	0.69%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Ditrichum	2.35%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Philibertiella	-0.19%
Bryophyta	Bryopsida	Dicranales	Drummondiaceae	Hymenoloma	-0.52%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Grimmia	3.93%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Racomitrium	-0.66%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Schistidium	-0.82%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Campyliadelphus	2.10%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Campylium	-0.33%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Drepanocladus	0.20%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Harpidium	-2.23%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Platydictya	0.67%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Sanionia	0.87%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Warnstorfia	-1.47%
Bryophyta	Bryopsida	Hypnales	Brachytheciaceae	Brachythecium	-3.04%
Bryophyta	Bryopsida	Hypnales	Calliergonaceae	Sarmentypnum	-0.14%
Bryophyta	Bryopsida	Hypnales	Hypnaceae	Hypnum	2.17%
Bryophyta	Bryopsida	Hypnales	Plagiotheciaceae	Plagiothecium	-0.05%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichastrum	-0.84%

Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichum	1.50%
Bryophyta	Bryopsida	Pottiales	Encalyptaceae	Encalypta	0.40%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Aloina	-0.19%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Barbula	-0.57%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Bryoerythrophyllum	-0.05%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Didymodon	-1.95%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Hennediella	-1.61%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Hymenostylium	-0.47%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Pottia	0.72%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Pterygoneurum	-0.09%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Sarconeurum	-0.33%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Syntrichia	-1.52%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Tortella	0.25%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Tortula	-0.43%
Bryophyta	Bryopsida			Calliergidium	-0.62%
Chlorophyta	Trebouxiophyceae	Prasiolales	Prasiolaceae	Prasiola	-1.14%
Chlorophyta	Ulvophyceae	Ulotrichales	Gomontiaceae	Monostroma	-0.05%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Anastrophyllaceae	Barbilophozia	1.77%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Antheliaceae	Anthelia	-0.19%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Cephaloziaceae	Cephalozia	-0.24%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Cephaloziellaceae	Cephaloziella	-0.32%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Cephaloziellaceae	Herzogobryum	-0.38%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Lophocoleaceae	Pachyglossa	-0.28%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Lophoziaceae	Lophozia	-0.05%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Lophoziaceae	Lophoziopsis	-0.38%
Marchantiophyta	Marchantiopsida	Marchantiales	Marchantiaceae	Marchantia	-0.14%
Rhodophyta	Bangiophyceae	Bangiales	Bangiaceae	Porphyra	-0.05%
Rhodophyta	Florideophyceae	Ceramiales	Delesseriaceae	Delesseria	-0.14%
Rhodophyta	Florideophyceae	Ceramiales	Delesseriaceae	Myriogramme	-0.14%
Rhodophyta	Florideophyceae	Ceramiales	Delesseriaceae	Neuroglossum	-0.05%
Rhodophyta	Florideophyceae	Ceramiales	Delesseriaceae	Phycodrys	-0.14%
Rhodophyta	Florideophyceae	Ceramiales	Rhodomelaceae	Picconiella	-0.05%
Rhodophyta	Florideophyceae	Ceramiales	Wrangeliaceae	Georgiella	-0.05%
Rhodophyta	Florideophyceae	Gigartinales	Cystocloniaceae	Acanthococcus	-0.09%
Rhodophyta	Florideophyceae	Gigartinales	Gigartinaceae	Gigartina	-0.05%
Rhodophyta	Florideophyceae	Gigartinales	Gigartinaceae	Iridaea	-0.09%
Rhodophyta	Florideophyceae	Gigartinales	Kallymeniaceae	Callophyllis	-0.33%
Rhodophyta	Florideophyceae	Gigartinales	Kallymeniaceae	Kallymenia	-0.14%
Rhodophyta	Florideophyceae	Plocamiales	Plocamiaceae	Plocamium	-0.05%

Tracheophyta	Liliopsida	Alismatales	Zosteraceae	Zostera	3.87%
Tracheophyta	Liliopsida	Poales	Poaceae	Deschampsia	-0.90%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Colobanthus	-0.28%

APPENDEX B:

Ellesmere Island: Plant Phylum, Class, Order, Family and Genus Occurrence Percentages in the Suitability 1 Locations Proportional to the Overall Dataset

Phylum	Class	Order	Family	Genus	Subtracted Percentage
Bryophyta	Andreaeopsida	Andreaeales	Andreaeaceae	Andreaea	0.09%
Bryophyta	Bryopsida	Bryales	Aulacomniaceae	Aulacomnium	-0.14%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Bartramia	0.18%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Conostomum	0.11%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Philonotis	0.09%
Bryophyta	Bryopsida	Bryales	Bryaceae	Bryum	0.54%
Bryophyta	Bryopsida	Bryales	Bryaceae	Leptobryum	-0.10%
Bryophyta	Bryopsida	Bryales	Bryaceae	Mielichhoferia	-0.02%
Bryophyta	Bryopsida	Bryales	Bryaceae	Pohlia	-0.04%
Bryophyta	Bryopsida	Bryales	Bryaceae	Ptychostomum	0.00%
Bryophyta	Bryopsida	Bryales	Catoscopiaceae	Catoscopium	-0.12%
Bryophyta	Bryopsida	Bryales	Meesiaceae	Meesia	-0.07%
Bryophyta	Bryopsida	Bryales	Mniaceae	Cinclidium	-0.24%
Bryophyta	Bryopsida	Bryales	Mniaceae	Cyrtomnium	0.05%
Bryophyta	Bryopsida	Bryales	Mniaceae	Mnium	0.11%
Bryophyta	Bryopsida	Bryales	Mniaceae	Plagiomnium	-0.03%
Bryophyta	Bryopsida	Bryales	Timmiaceae	Timmia	0.68%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Dicranoweisia	0.01%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Dicranum	0.01%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Oncophorus	-0.08%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Ceratodon	0.06%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Distichium	0.32%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Ditrichum	0.20%
Bryophyta	Bryopsida	Dicranales	Ditrichaceae	Saelania	-0.03%
Bryophyta	Bryopsida	Funariales	Funariaceae	Funaria	0.02%
Bryophyta	Bryopsida	Funariales	Splachnaceae	Aplodon	-0.03%
Bryophyta	Bryopsida	Funariales	Splachnaceae	Tayloria	0.06%
Bryophyta	Bryopsida	Funariales	Splachnaceae	Tetraplodon	-0.43%
Bryophyta	Bryopsida	Funariales	Splachnaceae	Voitia	-0.05%

Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Grimmia	0.23%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Niphotrichum	0.06%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Racomitrium	-0.13%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Rhacomitrium	0.11%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Schistidium	0.34%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Calliergon	0.17%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Campylium	0.23%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Cratoneuron	0.42%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Drepanocladus	0.08%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Hamatocaulis	0.04%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Harpidium	-0.03%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Hygrohypnum	0.07%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Loeskypnum	-0.08%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Platydictya	-0.10%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Pseudocalliergon	-0.07%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Sanionia	-0.05%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Scorpidium	-0.13%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Warnstorfia	-0.05%
Bryophyta	Bryopsida	Hypnales	Brachytheciaceae	Brachythecium	0.17%
Bryophyta	Bryopsida	Hypnales	Brachytheciaceae	Cirriphyllum	0.45%
Bryophyta	Bryopsida	Hypnales	Brachytheciaceae	Tomentypnum	0.04%
Bryophyta	Bryopsida	Hypnales	Hylocomiaceae	Hylocomium	0.03%
Bryophyta	Bryopsida	Hypnales	Hypnaceae	Hypnum	0.70%
Bryophyta	Bryopsida	Hypnales	Hypnaceae	Orthothecium	0.26%
Bryophyta	Bryopsida	Hypnales	Leskeaceae	Pseudoleskea	0.14%
Bryophyta	Bryopsida	Hypnales	Plagiotheciaceae	Isopterygiopsis	-0.05%
Bryophyta	Bryopsida	Hypnales	Theliaceae	Myurella	-0.08%
Bryophyta	Bryopsida	Hypnales	Thuidiaceae	Abietinella	0.03%
Bryophyta	Bryopsida	Orthotrichales	Orthotrichaceae	Amphidium	0.20%
Bryophyta	Bryopsida	Orthotrichales	Orthotrichaceae	Orthotrichum	-0.12%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Lyellia	-0.03%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Pogonatum	0.03%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichastrum	0.09%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichum	0.05%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Psilopilum	-0.08%
Bryophyta	Bryopsida	Pottiales	Encalyptaceae	Encalypta	0.52%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Aloina	0.00%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Bryoerythrophyllum	0.03%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Didymodon	0.41%

Bryophyta	Bryopsida	Pottiales	Pottiaceae	Hennediella	0.18%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Hymenostylium	0.11%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Molendoa	0.01%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Pottia	0.36%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Pseudocrossidium	-0.03%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Stegonia	0.11%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Syntrichia	0.34%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Tortella	0.08%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Tortula	0.16%
Bryophyta	Bryopsida	Seligerales	Seligeriaceae	Blindia	-0.02%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Anastrophyllaceae	Tetralophozia	0.06%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Arnelliaceae	Arnellia	0.06%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Blepharostomataceae	Blepharostoma	0.11%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Gymnomitriaceae	Gymnomitrion	0.06%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Scapaniaceae	Scapania	0.17%
Marchantiophyta	Marchantiopsida	Marchantiales	Cleveaceae	Sauteria	-0.03%
Tracheophyta	Equisetopsida	Equisetales	Equisetaceae	Equisetum	-0.78%
Tracheophyta	Liliopsida	Poales	Cyperaceae	Carex	-3.71%
Tracheophyta	Liliopsida	Poales	Cyperaceae	Eriophorum	-0.51%
Tracheophyta	Liliopsida	Poales	Juncaceae	Juncus	-0.28%
Tracheophyta	Liliopsida	Poales	Juncaceae	Luzula	-0.57%
Tracheophyta	Liliopsida	Poales	Poaceae	Alopecurus	-0.08%
Tracheophyta	Liliopsida	Poales	Poaceae	Anthoxanthum	-0.09%
Tracheophyta	Liliopsida	Poales	Poaceae	Arctagrostis	-0.17%
Tracheophyta	Liliopsida	Poales	Poaceae	Calamagrostis	0.20%
Tracheophyta	Liliopsida	Poales	Poaceae	Deschampsia	-0.26%
Tracheophyta	Liliopsida	Poales	Poaceae	Dupontia	-0.42%
Tracheophyta	Liliopsida	Poales	Poaceae	Elymus	-0.05%
Tracheophyta	Liliopsida	Poales	Poaceae	Festuca	-0.77%
Tracheophyta	Liliopsida	Poales	Poaceae	Phippsia	-0.39%
Tracheophyta	Liliopsida	Poales	Poaceae	Pleuropogon	-0.19%
Tracheophyta	Liliopsida	Poales	Poaceae	Poa	4.34%
Tracheophyta	Liliopsida	Poales	Poaceae	Puccinellia	3.39%
Tracheophyta	Liliopsida	Poales	Poaceae	Trisetum	0.16%
Tracheophyta	Lycopodiopsida	Lycopodiales	Lycopodiaceae	Huperzia	-0.03%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Arctanthemum	0.11%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Arnica	0.00%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Erigeron	-0.39%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Taraxacum	0.41%

Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Braya	-0.82%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Cardamine	-0.23%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Cochlearia	0.01%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Draba	-0.30%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Erysimum	-0.24%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Eutrema	-0.27%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Parrya	-0.03%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Physaria	-0.18%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Transberingia	-0.03%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Cerastium	-0.18%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Sabulina	-0.29%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Sagina	-0.03%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Silene	-0.54%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Stellaria	-0.55%
Tracheophyta	Magnoliopsida	Caryophyllales	Plumbaginaceae	Armeria	0.12%
Tracheophyta	Magnoliopsida	Caryophyllales	Polygonaceae	Bistorta	-0.09%
Tracheophyta	Magnoliopsida	Caryophyllales	Polygonaceae	Oxyria	-0.31%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Cassiope	-0.29%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Empetrum	0.03%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Pyrola	0.07%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Vaccinium	-0.04%
Tracheophyta	Magnoliopsida	Ericales	Primulaceae	Androsace	0.10%
Tracheophyta	Magnoliopsida	Lamiales	Orobanchaceae	Pedicularis	-1.16%
Tracheophyta	Magnoliopsida	Lamiales	Plantaginaceae	Hippuris	-0.10%
Tracheophyta	Magnoliopsida	Malpighiales	Salicaceae	Salix	-0.58%
Tracheophyta	Magnoliopsida	Myrtales	Onagraceae	Epilobium	-0.17%
Tracheophyta	Magnoliopsida	Ranunculales	Papaveraceae	Papaver	0.50%
Tracheophyta	Magnoliopsida	Ranunculales	Ranunculaceae	Ranunculus	-0.18%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Crataegus	-0.03%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Dryas	-0.03%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Geum	-0.05%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Potentilla	0.14%
Tracheophyta	Magnoliopsida	Saxifragales	Saxifragaceae	Micranthes	-0.52%
Tracheophyta	Magnoliopsida	Saxifragales	Saxifragaceae	Saxifraga	-0.79%
Tracheophyta	Polypodiopsida	Polypodiales	Cystopteridaceae	Cystopteris	0.14%
Tracheophyta	Polypodiopsida	Polypodiales	Woodsiaceae	Woodsia	0.15%

APPENDEX C:

Devon Island: Plant Phylum, Class, Order, Family and Genus Occurrence Percentages in the Suitability 1 Locations Proportional to the Overall Dataset

Phylum	Class	Order	Family	Genus	Subtracted Percentage
Bryophyta	Bryopsida	Bryales	Aulacomniaceae	Aulacomnium	0.05%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Bartramia	-0.31%
Bryophyta	Bryopsida	Bryales	Bartramiaceae	Philonotis	-0.31%
Bryophyta	Bryopsida	Bryales	Bryaceae	Bryum	-0.63%
Bryophyta	Bryopsida	Bryales	Catoscopiaceae	Catoscopium	-0.31%
Bryophyta	Bryopsida	Bryales	Meesiaceae	Meesia	-0.31%
Bryophyta	Bryopsida	Bryales	Mniaceae	Plagiomnium	-0.31%
Bryophyta	Bryopsida	Bryales	Timmiaceae	Timmia	0.37%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Dicranoweisia	0.37%
Bryophyta	Bryopsida	Dicranales	Dicranaceae	Oncophorus	-0.31%
Bryophyta	Bryopsida	Funariales	Funariaceae	Funaria	-0.26%
Bryophyta	Bryopsida	Funariales	Splachnaceae	Tetraplodon	1.10%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Grimmia	-0.31%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Racomitrium	-0.63%
Bryophyta	Bryopsida	Grimmiales	Grimmiaceae	Schistidium	-0.63%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Calliergon	-0.31%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Drepanocladus	0.42%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Harpidium	0.37%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Hygrohypnum	-0.31%
Bryophyta	Bryopsida	Hypnales	Amblystegiaceae	Sanionia	-0.31%
Bryophyta	Bryopsida	Hypnales	Hylocomiaceae	Hylocomium	-0.31%
Bryophyta	Bryopsida	Hypnales	Hypnaceae	Hypnum	-1.26%
Bryophyta	Bryopsida	Hypnales	Hypnaceae	Orthothecium	0.37%
Bryophyta	Bryopsida	Orthotrichales	Orthotrichaceae	Orthotrichum	-0.63%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichastrum	0.05%
Bryophyta	Bryopsida	Polytrichales	Polytrichaceae	Polytrichum	-0.31%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Bryoerythrophyllu m	-0.31%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Didymodon	0.37%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Syntrichia	-2.15%
Bryophyta	Bryopsida	Pottiales	Pottiaceae	Tortella	0.05%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Anastrophyllaceae	Sphenolobus	0.37%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Cephaloziaceae	Odontoschisma	0.37%

Marchantiophyta	Jungermanniopsida	Jungermanniales	Cephaloziellaceae	Cephaloziella	0.37%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Lophoziaceae	Trilophozia	0.37%
Marchantiophyta	Jungermanniopsida	Jungermanniales	Solenostomataceae	Solenostoma	-0.31%
Rhodophyta	Florideophyceae	Palmariales	Palmariaceae	Devaleraea	0.37%
Tracheophyta	Equisetopsida	Equisetales	Equisetaceae	Equisetum	-0.26%
Tracheophyta	Liliopsida	Alismatales	Tofieldiaceae	Tofieldia	0.37%
Tracheophyta	Liliopsida	Poales	Cyperaceae	Carex	-3.16%
Tracheophyta	Liliopsida	Poales	Cyperaceae	Eriophorum	1.67%
Tracheophyta	Liliopsida	Poales	Juncaceae	Juncus	0.78%
Tracheophyta	Liliopsida	Poales	Juncaceae	Luzula	0.21%
Tracheophyta	Liliopsida	Poales	Poaceae	Alopecurus	0.10%
Tracheophyta	Liliopsida	Poales	Poaceae	Anthoxanthum	0.78%
Tracheophyta	Liliopsida	Poales	Poaceae	Arctagrostis	0.47%
Tracheophyta	Liliopsida	Poales	Poaceae	Deschampsia	-0.31%
Tracheophyta	Liliopsida	Poales	Poaceae	Dupontia	0.42%
Tracheophyta	Liliopsida	Poales	Poaceae	Festuca	0.10%
Tracheophyta	Liliopsida	Poales	Poaceae	Phippsia	0.42%
Tracheophyta	Liliopsida	Poales	Poaceae	Pleuropogon	0.42%
Tracheophyta	Liliopsida	Poales	Poaceae	Poa	0.67%
Tracheophyta	Liliopsida	Poales	Poaceae	Puccinellia	-0.63%
Tracheophyta	Lycopodiopsida	Lycopodiales	Lycopodiaceae	Huperzia	0.05%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Arctanthemum	-0.31%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Erigeron	-0.31%
Tracheophyta	Magnoliopsida	Asterales	Asteraceae	Taraxacum	-0.31%
Tracheophyta	Magnoliopsida	Asterales	Campanulaceae	Campanula	0.37%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Braya	-1.10%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Cardamine	0.73%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Cochlearia	0.83%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Draba	2.12%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Eutrema	-0.31%
Tracheophyta	Magnoliopsida	Brassicales	Brassicaceae	Physaria	-0.26%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Cerastium	-1.21%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Sabulina	-0.26%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Silene	-0.94%
Tracheophyta	Magnoliopsida	Caryophyllales	Caryophyllaceae	Stellaria	-0.26%
Tracheophyta	Magnoliopsida	Caryophyllales	Polygonaceae	Bistorta	-0.58%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Cassiope	0.10%
Tracheophyta	Magnoliopsida	Ericales	Ericaceae	Vaccinium	-1.26%
Tracheophyta	Magnoliopsida	Lamiales	Orobanchaceae	Pedicularis	0.10%

Tracheophyta	Magnoliopsida	Malpighiales	Salicaceae	Salix	-0.26%
Tracheophyta	Magnoliopsida	Ranunculales	Papaveraceae	Papaver	2.03%
Tracheophyta	Magnoliopsida	Ranunculales	Ranunculaceae	Ranunculus	1.51%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Dryas	0.42%
Tracheophyta	Magnoliopsida	Rosales	Rosaceae	Potentilla	0.37%
Tracheophyta	Magnoliopsida	Saxifragales	Saxifragaceae	Micranthes	0.42%
Tracheophyta	Magnoliopsida	Saxifragales	Saxifragaceae	Saxifraga	1.14%
Tracheophyta	Polypodiopsida	Polypodiales	Cystopteridaceae	Cystopteris	0.37%
Tracheophyta	Polypodiopsida	Polypodiales	Woodsiaceae	Woodsia	0.05%

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