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Critical Literature Review
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Green-blue algae in white wonderland – a review of current distributions and possible changes to cyanobacteria distribution caused by anthropogenic climate change in Antarctica.

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Abstract:

Antarctic warming is currently occurring at an unprecedented rate and has been associated with human activities resulting in anthropogenic climate change. Warming of the Antarctic continent has resulted in warmer annual temperatures, changing precipitation patterns and higher abundances of ice-free areas vital to organism survival. Climatic changes impact organisms inhabiting these cold-climate areas and may lead to reduced or extended habitancy in different parts of Antarctica. One organism impacted is cyanobacteria, the most abundant non-marine organism in the Antarctic region (Quesada, Goff & Karentz, 1998). Cyanobacteria is a vital organism in many ecosystems as cyanobacteria fix nitrogen from the atmosphere into soils and photosynthesises CO_2 to O_2, benefiting many organisms. However, in high abundances cyanobacteria can overwhelm an ecosystem and negatively impact cohabiting organisms which is seen in many temperate climate locations. Anthropogenic climate change may impact the future of the endemic cyanobacteria population and other interrelated organisms. Current research has limited knowledge on possible impacts of anthropogenic climate change on the microorganism. Through analysis of factors, which will be affected by climate change (e.g. ice-free regions, temperature, or lake salinity), it is possible to extrapolate potential growth rates of cyanobacteria in the future. Optimal temperature for growth rate, as well as current Antarctic distributions will be used as evidence to assess future environments cyanobacteria may inhabit. Findings that cyanobacteria are thought to come from temperate origins also show current research suggests no reason that Antarctic cyanobacteria species are likely to go extinct and rather that there is potential for geographic species expansion.

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I. Introduction and Importance of cyanobacteria in Antarctica

Cyanobacteria are microorganisms that can exist in all environments where water is present; which may be in a terrestrial, saltwater or freshwater environment. As cyanobacteria are not altitude and temperature confined they can be found in all areas of the Earth, including in mountainous areas, and hot and cold deserts like Antarctica. Contributing to the oxygenation of the atmosphere and fixing of nitrogen in soils, cyanobacteria have many positive implications for the local ecosystems. However, in favourable conditions cyanobacteria blooms can exceed ecosystem allowances. Large populations of cyanobacteria in an environment have implications in many temperate climate regions as they may prevent sunlight entering the water column and impact nutrient resources which can induce stress in benthic organisms resulting in death in severe cases. Cyanobacteria are currently the most abundant non-marine organism in the Antarctic region (Quesada, Goff & Karentz, 1998). Cyanobacteria can thrive in the polar regions as they are extremotolerant/extremophiles and can live in a large range of extreme environments though optimum growth is often found during warmer periods (Jungblut, Lovejoy & Vincent, 2010; Quesada et al., 1998).

Disagreement exists in the literature regarding the likely impacts of climate change on cyanobacteria. As these organisms have been identified in cores dating back 3.5 billion years, their ability to survive in a naturally fluctuating climate is unquestioned (Brocks, Fletcher, Kilburn & Rasmussen, 2008; Potts & Whitton, 2012). However, anthropogenic climate change is impacting the Antarctic region rapidly, with some areas experiencing a warming of 10°C in the last ~30 – 50 years with an additional increase in winter conditions of 0.1°C per year (Convey & Smith, 2005). Yergeau, Newsham, Pearce & Kowalchuk (2007) state that the temperate origins of cyanobacteria will enable adaptation and therefore success in a warmer and wetter climate. Alternately, Jungblut et al. (2010) discusses that potentially endemic cyanobacteria species may be forced into more localized habitats or extinction due to warming climates allowing non-native species to be better suited to the environment. Both situations are potentially detrimental to the environment in Antarctica as changing ecosystem structures at a low trophic level can be potentially problematic. A loss in cyanobacteria will also likely impact oxygen levels in the region as well as available nitrogen.

Some areas in Antarctica have undergone the most dramatic climate warming in the last ~40 years of any region in the world (Convey & Smith, 2005). The 2014 IPCC report states a ~2°C temperature rise on pre-industrial temperatures can be expected globally by 2100, although this is likely to be higher in the Antarctic area due to the polar amplification (Victor et al., 2014). Climate is important as it defines the ecological niche cyanobacteria have evolved into and impacts the organisms' ability to grow and function. The combination of changing UV-B radiation and changing precipitation patterns have impacted ice-free areas and water patterns over much of Antarctica but most notably on the Peninsula area (Convey & Smith, 2005). Antarctic warming has expanded areas of ice-free ground which may enable vegetation and bacteria to diversify and grow in abundance in these areas (Yergeau et al., 2007). Ice-free areas undergo rapid development and habitation from microorganisms, production of ice-free areas resulting from climate change will have important effects on the surrounding environment (Convey & Smith, 2005).

This review aims to identify current distribution of cyanobacteria in Antarctica. Through analysis of the origins of Antarctic cyanobacteria as well as the current ecological niche of present cyanobacteria species a prediction of possible impacts climate change may have on cyanobacteria may be assessed.

II. Cyanobacteria introduction and dispersal in Antarctica and the ecological niche

Although there are endemic Antarctic cyanobacteria, other non-endemic species are also commonly found, including tropical and Arctic species. Analysis of the distribution of non-endemic species show non-endemic cyanobacteria are well adapted for inhabiting and transporting themselves through the Antarctic region (Taton et al., 2006). It was found that currently endemic cyanobacteria are more common in Antarctica than non-endemic species, with 67.9% of cyanobacteria endemic to Antarctica. However, the amount of endemic Antarctic cyanobacteria is being debated by scholars, with many studies noting a high level of similarity with cyanobacteria found in other locations. Taton et al. (2006) found that high levels (67.9%) of cyanobacteria were endemic to Antarctica. Opposingly, Jungblut et al. (2010) state low levels of endemism as several species previously thought of as endemic were >99% genetically similar to species found in the Arctic. Jungblut et al. (2010) also states Antarctic cyanobacteria are more related to Arctic cyanobacteria than to temperate climate cyanobacteria. Genetically similar species to Arctic cyanobacteria are found in the McMurdo Dry Valleys and East Antarctica (Jungblut et al., 2010). Genetic likeness implies that organisms have either adapted from each other or have adapted to be like each other due to environmental conditions, known as convergent evolution. Although both evolution types are possible with wind dispersion, discussions on similar factors have led to theories on possible dispersal methods introducing cyanobacteria to the Antarctic.

Based on Antarctic and Arctic similarities between cyanobacteria species in the McMurdo Dry Valleys and East Antarctica the possibility of wind dispersion was theorised (Jungblut et al., 2010). The wind dispersal theory is aided through another bacteria species using Saharan sand storms to increase their distributional range (Jungblut et al., 2010). Dispersal opportunities will be changed in the future with changing climate as climatic systems change in occurance rates (Turner et al., 2005). Changing wind conditions may increase or decrease dispersion of cyanobacteria and competing microorganisms as the presence of strong wind enables long-range wind dispersion. Dispersion methods along with the resulting changes in latitudinal distribution of cyanobacterial in Antarctic lakes is an evolving area of study which is still developing (Taton et al., 2006).

Further evidence on the dispersion techniques may be taken from the optimum temperature for cyanobacterial growth, 15 - 20°C which suggests a temperate climate (Jungblut et al., 2010). Jungblut et al. (2010) proposed that the original habitat was in a temperate climate and subsequent colonisation of cold climate caused a convergence of the cold-climate species. As the optimum growth temperature is warmer than current conditions an increase in temperature in Antarctica would be expected to increase the growth rate of cyanobacteria (Jungblut et al., 2010). Increasing Antarctic temperatures will impact biodiversity of cyanobacteria and other competing species as rapid growth of one subspecies may outcompete other species in the ecological niche (Jungblut et al., 2010).

Evidence relating to cyanobacteria dispersal can aid in predictions of how cyanobacteria may cope in a future climate. As cyanobacteria species found in Antarctica – drawing on the wind dispersion theory and optimum growth temperature – have previously been successful in a warmer climate, it is possible from this evidence that cyanobacteria may flourish. It is widely accepted that temperature and dispersion ability tend to increase both the density and area of a cyanobacteria bloom (O'neil et al., 2012). These variables will be impacted by changing precipitation and storm patterns in the area as well as on the rate of warming. Anthropogenic warming has been seen at a scale which is more rapidly increasing than other natural warming events. The speed of warming may not allow for the evolution of cyanobacteria to keep up with these timescales.

III. Antarctic cyanobacteria distribution

Cyanobacteria distributions over the Antarctic continent are known to be dependent on many characteristics, including ice cover, presence of liquid water and severity of weather events (Hodgson et al., 2005; Taton et al., 2006; Yergeau et al., 2007). Cyanobacteria are commonly found as benthic communities in lakes across Antarctica (Hodgson et al., 2005; Taton et al., 2006; Yergeau et al., 2007). The distribution of cyanobacteria tends to be in the lower latitudes of the Antarctic region but known populations exist as far South as 87°S Lat. (Lawley, Ripley, Bridge & Convey, 2004). Many scholarly publications focus on cyanobacteria identified in the 60°S – 80°S latitudes (King George and Signy Islands – 60°S, 64°S, 67°S, Shcherbinina Island – 68°S, Larsemann Hills – 69°S, Mars Oasis – 72°S, Coal Nunatak – 72°S, Lake Fryxell in Taylor Valley – 77°S, McMurdo Ice Shelf region – 77°S, Dry Valleys – 77°S, Vestfold Hills – 78°S, Ellsworth Mountains – 78°S and Bratina Island on McMurdo Ice Shelf 78°S) (Comte, Šabacká, Carré-Mlouka, Elster & Komárek, 2007; Hodgson et al., 2005; Jungblut et al., 2005; Nadeau et al., 2001; Pointing et al., 2009; Taton et al., 2006; Yergeau et al., 2007).

Areas of inhabitancy tend to show more correlation with available ice-free land rather than latitude. As some theories state cyanobacteria were dispersed from the tropics the importance of the latitude on cyanobacterial survival is important. Latitude dependency is hard to quantify as temperature and freshwater availability are partially controlled by the latitude itself. In climate change, warming events can be expected to weaken full strength Antarctic storms and increase fresh water availability (Convey & Smith, 2005). It is likely that the regions closer to the Antarctic Coast will therefore increase in cyanobacteria abundance.

IV. Ecological niche in the Antarctic

Discussion on whether cyanobacteria are latitude dependent are based on observations that they only live in ice-free areas or seasonal ice-free areas. Lawley et al. (2004) found eukaryotic organisms like cyanobacteria did not show any decreases in distribution in the southerly latitudes. Taton et al. (2006) also noted a lack of evidence to support latitude dependence, observing abundance over Antarctica was higher than expected based on modelled calculations that estimated abundance from ice free zones. It was also noted cyanobacteria were also found to be distributed over much of the Antarctic continent (Taton et al., 2006).

In contrast, Yergeau et al. (2007) found strong correlations (r=0.6556) between cyanobacteria presence and latitude, which was thought to be due to the more severe and variable climate found in more southerly areas. Ice-core evidence suggests that cyanobacteria have been present in the Larsemann Hills freshwater lakes for 40,000 years, i.e. for a period during which climatic changes have occurred (Hodgson et al., 2005). Climate variation known from analysis of the Vostok core shows a temperature change of 10°C during the last glacial-interglacial period (160,000 years) (Lorius et al., 1988). Climate data from the Peninsula area shows temperature changes of up to 1°C over the past 40 years (Convey & Smith, 2005). Assuming climate conditions varied at similar rates in the McMurdo and Vostok regions, cyanobacteria can survive in conditions colder and warmer than they are currently inhabiting, theoretically allowing them to move further south if the habitat is available. Cyanobacteria having been present in one area for an extended period and the consequential natural climate variation over time is used as evidence to suggest that presence of an ice-free location is more important for cyanobacteria inhabitancies than temperature is (Hodgson et al., 2005; Taton et al., 2006; Yergeau et al., 2007). Cyanobacteria have been identified at 87°S which supports that cyanobacteria can live at any latitude given there are habitable conditions (Lawley et al., 2004). The importance of ice-free areas is reinforced in many papers discussing the Antarctic ecosystem (Hodgson et al., 2005; Taton et al., 2006; Yergeau et al., 2007). Bacterial diversity at sites with dense vegetation was found to be comparable with sites at differing latitudes, which may be due to the micro-climate and selection pressures of this environment (Yergeau et al., 2007). It was, however, found that in sites that contained no substantial vegetation the microorganism diversity decreased at higher latitudes (Yergeau et al., 2007). Due to the relatively warm microclimates in ice-free areas, ecological hotspots tend to occur as lakes may reach temperatures as high as 8°C in summer (Hodgson et al., 2005). Along with temperature, changing salinity in lakes may impact possible occupancy of the area.

Cyanobacteria were commonly found in the most and least saline lakes (Taton et al., 2006). Species identified in saline lakes tended to be halotolerant taxa, terrestrial and freshwater taxa were also identified in saline environments (Taton et al., 2006). Freshwater lakes on the Antarctic Peninsula experienced the highest levels of warming (Convey & Smith, 2005). Convey and Smith (2005) believe that microorganisms are more reliant on freshwater availability than temperature as due to the high specific heat capacity of water a microclimate is found in waterbodies. Other important factors for cyanobacteria survival included factors of water depth such as light intensity, temperature stability and exposure to freezing. Available nutrients from organic matter, rock and mineral leaching and the atmosphere also tend to be important for cyanobacteria growth. Cyanobacteria associated with extreme and diverse biotypes (hot springs, deserts and inside rocks and minerals) found in Antarctica highlight the extreme ability to adapt to variations in salinity, temperature, light and ultraviolet radiation (Taton et al., 2006). As cyanobacteria are extremophiles or extremotolerant organisms, they can remain alive but are unable to grow in frozen conditions. Salinity and light intensity is suggested to be the most controlling variable for cyanobacteria inhabiting an area as they are the most important variables when considering water temperature (Taton et al., 2006). Cyanobacteria that inhabit the polar regions can withstand low temperatures and high radiation through photoprotective pigments, which paired with efficient light capturing, nutrient storage and freeze-thaw tolerance allow cyanobacteria to flourish in the environment (Jungblut et al., 2010).

When considering the evidence of the current distributions and environmental controls on cyanobacteria, there seems to be little indication to suggest cyanobacteria would not be able to adapt to climate change in Antarctica in the short-term. Some of the evidence used to predict future cyanobacteria populations is that light intensity will not be directly impacted by climate change and ice-free areas are likely to increase in a warmer climate. Lakes are likely to become gradually fresher in the short-term due to an increase in ice sheet melting, in the long-term sea water intrusion may impact lake salinities in local areas which will have an impact on cyanobacteria abundance.

V. Comparison between Arctic and Antarctic cyanobacteria

Most papers in the polar cyanobacteria field focus specifically on Antarctic or Arctic cyanobacteria rather than polar cyanobacteria. For understanding potential impacts of climate change on cyanobacteria, research from the Arctic regions seems substantially different. Comte et al. (2007) and Jungblut et al. (2010) reference both the Arctic and Antarctic cyanobacteria based on the cold climate similar in the two poles. Due to the similar conditions in the two poles, genetically similar cyanobacteria species are known to occur between the two poles which are still able to function at -20°C (Comte et al., 2007). Although several of the same species were found in both hemispheres, the environmental conditions tend to be different due to the makeup of the land in these areas which cause differences in the distribution patterns of cyanobacteria (Jungblut et al., 2010). Studies that specifically relate to Antarctica provided more in-depth research on the presence and abundance of Antarctic cyanobacteria. Past identification of cyanobacteria blooms identified in the Finland Ocean and Australian portion of the Indian Ocean may also show similarities between cyanobacteria in the two poles (Sellner, 1997).

VI. Discussion

As cyanobacteria are present in many environments in Antarctica and are microscopic, a comprehensive analysis of the population is lacking. The lack of research on cyanobacteria is highlighted by several researchers and through the dominance of a few authors in this field (Jungblut et al., 2005, 2010; Taton et al., 2006). Further research on Antarctic cyanobacteria is necessary as the full extent of Antarctic cyanobacterial diversity is not known and the possible impacts caused by climate change are also relatively unknown. Further studies on Antarctica cyanobacteria may also identify other potential impacts on cyanobacteria presence, the impact cyanobacteria have on the environment may also become increasingly important. Global and Antarctic cyanobacteria studies are likely to become increasingly important in the future as technology increases and the climate impacts and biotechnological potentials develop in this field (Comte et al., 2007). The importance of Antarctic cyanobacteria studies is also reflected upon by Callejas et al. (2011) who stated that further analysis of multiple cyanobacteria communities may help decipher the possible impacts of climate change on the organisms.

As Antarctic cyanobacteria is a relatively new topic few resources are available due to extreme nature of data collection. Research of cyanobacteria in Antarctica can be improved to aid in temporal abundance knowledge. Future research may be based off temporal studies in a few selected locations which would be beneficial to the knowledge on this topic as over a decadal timescale trends may be shown. The research assessed in this literature review were spatial studies analysing multiple locations where cyanobacteria presence is unknown or where limited knowledge exists. Although these studies aid in knowing the distribution and abundance of cyanobacteria, a comparison method between studies has not yet been established. Some sites had more abundant cyanobacteria than other sites, and percentages of species specific cyanobacteria were stated but there tended to not be a measurement of the area covered by a species at a site. This does not allow for easy interpretation and comparison between different sites and papers. Development of comparison methods could also aid in knowledge of the short-term cyanobacteria growth cycles with extended studies analysing long-term growth.

VII. Conclusions

Although there are no figures on how cyanobacteria populations may adapt with climate change there seems to be little evidence that cyanobacteria populations will decrease. It is commonly known globally that climate change is tending to increase the area and intensity of cyanobacteria blooms (O'neil et al., 2012). Current conditions have caused cyanobacteria blooms in the ocean around Finland which is located at a similar latitude as the Southern oceans (Sellner, 1997). Blooms have also been identified off the southern coast of Australia, bordering the Southern Ocean (Sellner, 1997). This evidence shows that cyanobacteria blooms are possible in the Southern Ocean, and may occur in warmer conditions.

Optimal growth rate and inhabited area evidence tends to suggest populations will not only become more distributed, but populations will also become larger. This may have adverse environmental impacts as cyanobacteria may be more dominating in the environment. Marine cyanobacteria blooms may occur in cold waters when there is no, or little, ice cover and water nutrients are high (Sellner, 1997). Due to the current minimal rock leaching of minerals and little organic matter providing nutrients current blooming potential is low. However, if smaller saline and freshwater lakes became permanently ice-free, a location for cyanobacterial blooming would become available. If nutrient conditions increased through increased mega-fauna excretions, local organic presence or increased rock leaching conditions will become increasingly more favourable. This would have implications for the ecological makeup of these areas as evident from mass blooms that can occur in favourable conditions. Jungblut et al. (2010) predict a decline of habitat suitable to the native ecological niche of Antarctic cyanobacteria, likely causing extinction of some species from some areas which opposes the opinions of other researchers. Although discussion in the literature is present and conclusions are not able to be made on the future distributions of Antarctic cyanobacteria.

Although the future abundance of cyanobacteria in Antarctica is unknown, the history of cyanobacteria – as the oldest living organism – would suggest that cyanobacteria will survive in the Antarctic following global climate change. The extent to which they survive may be an issue for the future in relation to the oxygen production and nutrient fixing cyanobacteria provide, impacting other microorganisms found in the area.

VIII. References

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