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Critical Literature Review
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Viruses Contribute More to Antarctica than the Common Cold: A Review on Viral Importance in Antarctic Lakes

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Abstract:

The role viruses play in mediating the ecology of Antarctic lakes is vastly underrepresented and the effects climate change may have on these roles is widely unknown. At the microbial level viruses are involved in the important roles of limiting host population densities, selecting for host diversity, and contributing dissolved organic carbon to the aquatic environment. These roles are especially important in Antarctic lakes as they are dominated by microorganisms. The ecology of the lake is dependent on viruses as they control microbe population levels and increase nutrient levels into the environment. Climate change may alter Antarctic lake compositions by causing an increase in incidence of blooms, increase in lysogenic viral infections, and an increase in viral decay due to UV-B radiation. These changes will likely have profound impacts on the microbe populations currently residing in Antarctic lakes. Further research needs to be conducted in order to determine if viruses in Antarctic lakes will be able to continue carrying out their important roles in the changing environment.

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Introduction

Viruses have a bad reputation of being horrible disease causing agents associated with ailments such as the common cold and flu. While viruses are capable of causing countless conditions, the role they play in mediating ecology is vastly underrepresented. Viruses can be found in every environment and based on estimations there are roughly 10^31 viral particles on earth (Morris, 2013). Even though viruses lack any metabolism or organelles and are extremely small and simple, they still have the capability of controlling population dynamics. These microscopic entities are not even considered alive by most researchers and need host cell machinery to replicate. At the microbial level viruses are involved in two very important roles in mediating ecology which include limiting host population densities and selecting for host diversity (Slonczewski & Foster, 2013). Viruses also play key roles in the microbial loop by contributing to the dissolved organic carbon which in turn increases bacterial production. These roles are extremely critical in maintaining the balance and diversity of microbial populations in Antarctic lakes.

The vast importance of viruses as mediators of ecology can easily be seen in aquatic environments. Viruses are the most abundant entities in the ocean, one millilitre of water contains up to ten million virus like particles (Slonczewski & Foster, 2013). The abundance of viruses in the ocean has profound effects on bacterial populations in the water. Marine bacteriophages are estimated to lyse (burst) up to twenty percent of bacteria in the ocean daily (Suttle, 1994). Based on their ability to replicate quickly and infect large amounts of bacteria, bacteriophages (viruses that infect bacteria) play vital roles in limiting the densities of harmful blooms. This ability will be extremely important as global ocean temperatures increase resulting in a heightened incidence of harmful cyanobacterial blooms (Paerl & Huisman, 2008). Viruses in all aquatic ecosystems behave in a similar manner in their ability to mediate ecology. This makes marine viral data important in studying viruses in other aquatic systems such as lakes.

Much like marine environments, viruses also play vital roles in mediating ecology in lakes. The significance they have in regulating populations is dependent on the lakes since the composition is widely varied. The lakes of Antarctica in particular are extremely unique and the significance viruses have on mediating the ecology is amplified. Antarctic lakes are not only special because of their geographic isolation from the rest of the world but also because they lack fish, contain few invertebrates, and are mainly composed of bacteria, algae, and protozoa (Laybourn-Parry, 2002). Many Antarctic lakes contain an elevated abundance of virus like particles and high viral to bacterial ratios indicating viruses play a significant role in the dynamics of microbial growth (Mandan, Marshall, & Laybourn-Parry, 2005). Climate change and an increase in temperatures may greatly alter the way viruses interact with other microbes, causing extreme changes in the composition of these lakes. Unfortunately not much is known about how climate change may affect the way viruses mediate ecology in these isolated lakes. This paper aims to examine current literature to produce potential results on how climate change will impact viruses.

The Role Viruses Play in Antarctic Lakes

Antarctic lakes are some the most unique aquatic environments in the world. They are composed mainly of microorganisms and many have extreme conditions such as high salinity levels and minimal sunlight. The role viruses play in mediating ecology of these ecosystems is vastly important in driving host diversity and controlling host populations. When compared to temperate ecosystems much of Antarctica's microbial biodiversity is relatively low, however this is not the case when it comes to viruses in Antarctic lakes (Chown et al., 2015).

Metagenomic surveys, have determined that Antarctic lakes may contain the most diverse viral communities found in any aquatic ecosystem on Earth (Lopez- Bueno et al., 2009). The high diversity of viruses in Antarctic lakes further suggest viruses play important roles in these environments (Cavicchioli & Erdmann, 2015). The roles viruses play in these extreme environments include driving host diversity, contributing to dissolved organic carbon, and controlling host population densities.

Since Antarctic lakes are dominated by microorganisms, microbial diversity is very important, where losing a single species could greatly alter the composition of the lake. Biodiversity plays an important role in allowing communities to better adapt to changes which is vital with regards to potential temperature changes affecting these areas. In these isolated communities many species depend on one another for survival. Viruses in Antarctic lakes are important drivers of microbial diversity. Through selective infection viruses are able to alter microbial community compositions (Anesio & Bellas, 2011). In order to infect an organism many events need to occur. First the virus has to attach to receptors on the cells surface, then the virus must inject its genome, the genetic information must then be replicated using the host cell's machinery, and lastly the genomic information must be packaged into new virions and ultimately exit the cell by bursting it. Microorganisms have developed many strategies in preventing viral infection by halting these important events from occurring. Bacterial diversity in particular is heavily driven by competing in an arms race against bacteriophages, viruses which infect bacteria (Stern & Sorek, 2011). Diversity of bacterial cell membranes commonly occurs to prevent bacteriophages from attaching to the cell, inhibiting infection (Seed, 2015). Viruses drive microorganism diversity by placing selection pressures on the populations, which may be extremely important in Antarctic lakes due to lack of outside selection pressures other than the extreme environment.

Acting as a selection pressure is not the only way viruses have the ability to create microbial biodiversity. Viruses can also contribute to host diversity through transduction. Each time a virus infects a new host it has the potential of accidentally packaging the host cell's DNA into its capsid which in turn can be released and absorbed into a new host's DNA. In marine environments it has been determined that 100 transductions occur per litre of water every day, with each transduction having the potential to increase biodiversity (Jiany & Paul, 1998). Viruses are so important to microbial diversity that marine bacterial communities have even been shown to differ when grown in the presence and absence of viruses (Fuhrman & Schwalbach, 2003). In Antarctic lakes transduction may play a huge role in microbial diversity. Many lakes in Antarctica contain high viral to bacterial rates, allowing for a large portion of the bacteria to become infected. In two freshwater Antarctic lakes (Crooked Lake and Lake Druzhby) a large portion of bacteria were visibly infected by phages, with Crooked Lake showing roughly half of bacteria infected during Autumn (Sawstorm,Anesio,Graneli & Laybourn-Parry, 2007). Ocean bacterial infection rates by bacteriophages show a stark contrast, with roughly 20% of bacteria infected by viruses (Suttle, 1994). With 100 transductions occurring in a litre of marine water daily, it can be assumed that even more transductions may occur in a litre of several Antarctic freshwater lakes due to the much higher infection rates observed. Viruses may even be potential reservoirs of stored host genes that can be transferred back and forth throughout the microbial population (Sawstrom et al, 2008). This can have profound effects in the diversity of the microbes with the possibility of these stored genes providing the "genetic adaptability to change the ecological niche of the host" (Rohwer & Therber, 2009). This further proves the importance of viruses in Antarctic lakes by contributing highly to microbial diversity through a proposed heightened level of transduction rates occurring.

Viruses have special survival mechanisms in order to cope with the extreme environment of Antarctic lakes based on which type of infection it carries out. A virus can undergo two different types of infections, lytic and lysogenic. During a lysogenic infection the virus integrates into its host cells genome and is reproduced as genetic material in the host cells lineage. In a lytic infection the virus uses host cell machinery to make copies and bursts the cell, killing it. It has been proposed that a virus may undergo a lysogenic infection as a survival mechanism to cope in unfavourable conditions (Paul, 2008). In two saline Antarctic lakes there was found to be little to no lysogeny occurring during summer months and high lysogeny rates in winter (Laybourn-Parry, Marshall & Mandan, 2007). Viruses are sensitive to the extreme Antarctic environment just like bacteria, causing lakes in Antarctica to exhibit many changes between the summer and winter months. This includes more viruses in the lysogenic state and a decrease in bacterial production.

Another important role viruses have in mediating Antarctic lake ecology is by contributing to the dissolved organic carbon through host cell lysis. When a virus lyses (bursts) its host cell a release of nutrients is absorbed into the environment. Through models it has been estimated that viral lysis liberates roughly one microgram per litre of dissolved organic carbon per bacterial generation (Proctor, 1991). Even though this amount is very small it is still significant since the total amount of carbon dissolved through viral lysis makes up a large percentage of the rapidly cycling carbon in the ecosystem (Fuhrman & Suttle, 1993). The release of nutrients from viral lysis is vital in Antarctic lakes because many have extremely low nutrient levels and it has been shown that viral lysis is a considerable contributor of dissolved organic carbon in the winter months (Sawstrom et al, 2007). Bacterial growth patterns in Antarctic lakes are influenced by the amount of dissolved organic carbon available (Laybourn-Parry, 2002). It has been found that bacterial production increases when viral lysis occurs (Laybourn-Parry et al, 2007). The bacteria and other microorganisms in Antarctic lakes depend on nutrient cycling to survive these harsh conditions, and surprisingly bacterial production occurs all year, even in the winter months (Laybourn- Parry, Bayliss & Ellis- Evans, 1995). The dissolved organic carbon produced through viral lysis in the winter may play a vital role in allowing bacterial production to occur even in harsh winter months by supplying nutrients that might otherwise be unattainable.

It has also been shown that viruses contribute heavily to controlling host population densities. This is extremely apparent in marine ecosystems where viruses have been estimated to lyse up to forty percent of the standing stock prokaryotes each day (Suttle, 2007). In the oceans viruses have even been attributed to the collapse of algal blooms through viral lysis (Wilson et al, 2002).The role viruses play in controlling host populations is even more important in Antarctic Lakes. Antarctic lakes are unique ecosystems with very few grazers leading to viral infections being responsible for a large portion of bacterial mortality (Sawstrom, Lisle, Anesio, Priscu & Laybourn-Parry, 2008). Two freshwater Antarctic lakes (Crooked Lake and Lake Druzhby) were found to have very high viral induced bacterial mortality, ranging from 38 to 251% (Sawstom et al, 2007). Interestingly freshwater lakes in Antarctica have been found to have the lowest virus to bacteria ratios whereas hyper saline lakes have the highest (Laybourn-Parry, Hofer & Sommaruga, 2001). This suggests that viral induced bacterial mortality may be even higher in hypersaline Antarctic lakes, further showing the importance of bacteriophages to these ecosystems. Bacteriophages are needed in these lakes to control bacterial populations, without bacteriophages the main selective pressure on these microbes would be out competition of other bacteria for vital limited resources in the lakes.

How Climate Change May Impact These Roles

Antarctica has always been viewed as a pristine environment, free from the effects of environmental degradation brought on by human events. This view is unfortunately far from the reality of the Antarctic ecosystem, it too is experiencing effects brought on by human activities, with the focus being anthropogenic climate change. It has been predicted that all ecosystem components will be impacted by climate change, even viruses (Genner et al., 2004). Climate change can affect viruses through changes in viral host interactions, shifts in prokaryotic community compositions, and shifts from lysogenic to lytic reproduction (Danovaro et al., 2011). These changes will greatly alter the way viruses regulate ecology of Antarctic lakes leading to profound changes in the bacterial compositions of the lakes.

Climate change can be very unpredictable, with temperatures around Antarctica continuously varying year to year. The biggest changes have occurred in the Antarctic Peninsula with average annual air temperatures increasing from 1950 to 2000 by an average of 2 degrees Celsius (Quayle, Peck, Peat, Ellis-Evans & Harrigan, 2002). However a more recent review discovered average air temperatures in the area to be decreasing at a statistically significant rate (Turner et al., 2016). This decrease in temperature will most likely not continue indefinitely due to the natural cooling and warming events of the Earth. Temperature changes can have huge impacts on Antarctic ecology and lakes can give a better understanding of what changes may occur on a larger scale. Lakes in the polar regions can act as early detectors of environmental change since all ecological variables are affected by snow and ice cover variation (Quayle et al., 2002).

An increase in temperature has the most profound effects on the ecology of Antarctic lakes. During the 2001/2002 austral summer an extraordinary event occurred in the Taylor Valley in which there was an increase in air temperature by almost +12 degrees Celsius which remained heightened for several weeks (Doran et al., 2008). This drastic increase in temperature had many consequences on the ecology of lakes in the area. The Lakes in the Taylor Valley experienced an increase in nutrient levels due to glacial runoff, leading to algal blooms (Foreman, Wolfe & Priscu, 2004). With potential for an increase in temperatures more glacial runoff events may occur in lakes around Antarctica. An increase in algal blooms will have a huge effect on the way viruses are able to regulate these populations. Some marine environments have shown an increase in viral abundance as temperature increases whereas other marine areas have shown a decrease (Danovaro et al., 2011). Unfortunately there is no data on how viruses in Antarctic lakes may be affected by temperature increases, but if viruses are unable to regulate the uncontrolled growth of algal blooms the lakes environment will be greatly altered.

Climate change may alter which infection a virus will carry out. In winter months more viruses undergo a lysogenic infection in order to deal with the harsh environment (Laybourn-Parry et al., 2007). However as temperatures increase and winter conditions become less harsh, viruses may instead opt to undergo lytic infections. More lytic infections will lead to an increase in bacterial death and an increase in viral particles expelled into the lake environment. The increase in viral particles could help cope with the potential increase in bacterial blooms, but much more research needs to be conducted in order to determine this.

Another threat to Antarctic lake ecology is viral population decay caused by the potential increase in UV-B radiation due to a decrease in ice cover brought on by raised temperatures. Constant daylight and UV-B radiation may increase viral decay rates in polar lakes during the spring and summer months (Sawstrom et al., 2007). In Antarctic lakes viruses greatly outnumber bacteria, so keeping high viral populations is very important in maintaining ecological balance. Viral decline could definitely be a factor in an increase of bacterial production, potentially leading to blooms. In marine ecosystems it has been noted that viral lysis can lead to the collapse of algal blooms (Wilson et al., 2002). With potential increases in UV-B levels it is uncertain if bacteriophages will continue to have the ability to control bacterial populations in Antarctic lakes. In the future there may be Antarctic lakes containing uncontrolled bacterial populations leading to suffocation of other species in these lakes and diversity decline.

Conclusion

Viruses play very important roles in the regulation of bacterial populations in the microbial dominated lakes of Antarctica. Climate change may have profound effects on the way viruses control population equilibrium of these lakes. As temperatures continue to rise there is potential for more glacial runoff to increase nutrient levels in Antarctic lakes, as seen in the 2001/2002 austral summer. The increase in nutrients will lead to more cyanobacterial blooms occurring with the potential of viruses no longer having the ability to control them due to viral decay caused from UV-B radiation. More viruses undergoing lytic infections may be able to cope with the increase in blooms, but this is still undetermined. Antarctic lake compositions may be greatly altered in the future, however more research needs to be done on the effects climate change has on virus's roles in mediating ecology. Thankfully viruses are extremely resilient and can adapt quickly, with the potential to easily control future Antarctic lake composition changes.

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