Microbial responses during the transition to polar night in permanently ice-covered Antarctic lakes

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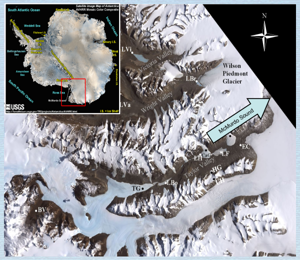
Abstract

A majority of the research on the Antarctic continent occurs during the austral spring and summer (October-January), a period of continuous sunlight, when field support is readily available. Through additional logistical efforts, we were able to collect the first data on the McMurdo Dry Valley (MCM) lakes during the transition from summer to winter (October-April). A combination of bacterial productivity data and 16S ribosomal RNA gene tag sequence libraries allowed us to examine ecosystem responses as photosynthetic input of new carbon stopped. Microbial protein biosynthesis increased in the east lobe of Lake Bonney and in Lake Hoare during March and April ($p<0.05$); there was no change in protein biosynthesis in the west lobe of Lake Bonney or in Lake Fryxell. DNA replication was not affected ($p<0.05$) by the onset of complete darkness, inferring that the bacteria do not rely directly on phytoplankton primary production as their source of organic carbon during this period. An overall decoupling of bacterial protein biosynthesis and DNA replication also occurred during the transition to winter. Protein biosynthesis increased relative to DNA replication as darkness set in, which may signify decreasing rates of cell division. Such a shift in cellular function, in combination with continued bacterial production, indicates that bacterioplankton in the MCM lakes remain active during the polar night, but may direct more energy towards survival than reproduction. Our results indicate that concurrent measurement of protein synthesis and DNA synthesis in dark, sub-ice aquatic systems can provide important information on the physiological state of the microorganisms present.

Site location

MCM lakes in the Taylor Valley in southern Victoria Land, Antarctica. The valley contains four major basins. Moving from east to west, they are: Fryxell (LF on map), Hoare (LH on map), East Lobe Bonney (LBo on map), and West Lobe Bonney (Lbo on map).



Hypotheses

The onset of winter darkness induces a cascade of physiological changes in the microbial communities of McMurdo Dry Valley Lakes:

- **Heterotrophic** bacterial communities are **indirectly affected** by the onset of winter darkness via the **loss of new organic carbon** from primary production.
  - H_A: Heterotrophs **utilize other carbon sources** during the winter; therefore **heterotrophic productivity continues year-round.**
  - H_A: Heterotrophic productivity **decreases during the winter.**
  - H_A: Bacterial **community structures shift** during the winter.

Methods

1. Heterotrophic bacterial productivity was measured between November 2007 and April 2008 using radioactively labeled thymidine and leucine as substrates (20nM, 20hr incubation).
2. Samples were collected in November 2007 and March 2000 and used to generate tag sequence libraries (collaboration with MIRADA LTER) for diversity comparisons.

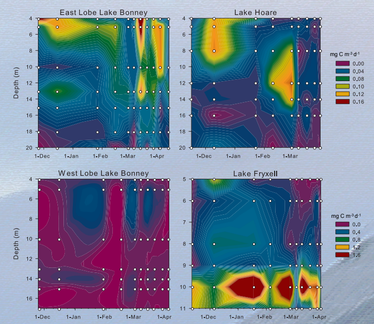


Figure 1
Bacterial Productivity measured by ^{3}H- labeled Thymidine incorporation

Contour plots for the photic zones of the Taylor Valley lakes during the summer-fall transition of 2007-2008. Thymidine incorporation is a proxy for DNA synthesis.

Note the difference in color scales for East Lobe Bonney and Hoare, and West Lobe Bonney and Fryxell.
The white points represent sample points.

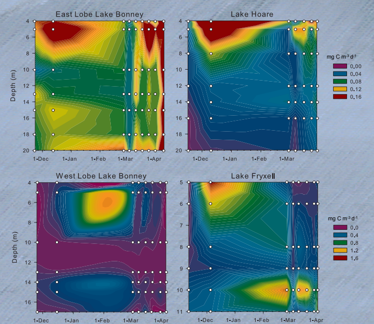


Figure 2
Bacterial Productivity measured by ^{3}H- labeled Leucine incorporation

Contour plots for the photic zones of the Taylor Valley lakes during the summer-fall transition of 2007-2008. Leucine incorporation is a proxy for protein production.

Note the difference in color scales for East Lobe Bonney and Hoare, and West Lobe Bonney and Fryxell.
The white points represent sample points.

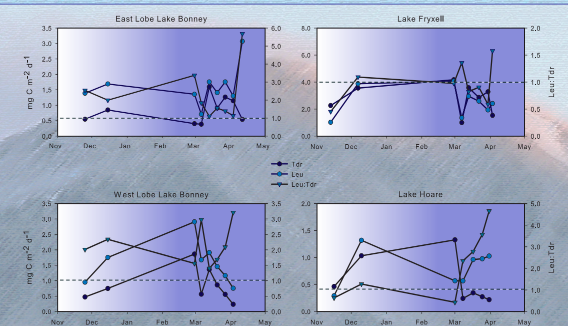


Figure 3 Depth-integrated bacterial productivity Time series plots integrated over the photic zones of all four Taylor Valley lakes, showing rates of thymidine (tdr; black circles) and leucine (leu; blue circles) incorporation and leu:tdr ratio (triangles). The dashed line indicates a 1:1 leu:tdr ratio. Note the different scales.

Leucine incorporation in Lake Bonney at the final April time point was nearly two-fold higher than at any other point during the season. While this cannot be explained by any known error in the sample or data analysis, this rate of incorporation is unprecedented in this system, therefore, we question the validity of this point from a physiological standpoint.

Bacterial productivity remained relatively constant from November through the end of February. During March and April, there was a downward trend in thymidine incorporation, but no change in leucine incorporation except in West Lobe Lake Bonney. After a sharp decrease in both thymidine and leucine incorporation in Lake Fryxell in early March, productivity returned to previous levels for the rest of March and April. The leu:tdr ratio increased at the end of the season, in all lakes.

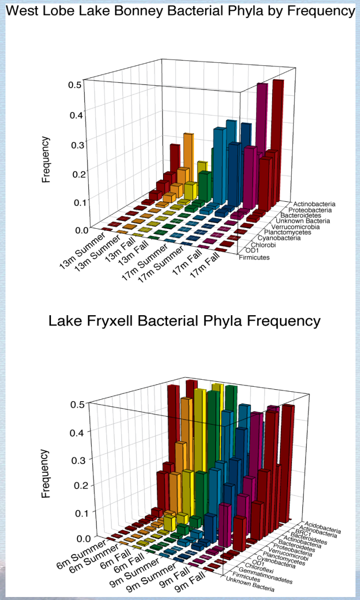


Figure 4 Bacterial Diversity Data from West Lobe Lake Bonney and Lake Fryxell, showing bacterial phylum-level diversity (tag frequency in total library) based on tag sequence libraries. Samples were collected in November (summer) and March (fall) at 13 and 17 meter and 6 and 9 meter depths in the water columns of West Lobe and Fryxell, respectively. Minor phyla (frequencies of $<10^{-4}$) are not shown.

Cyanobacteria decreased by an average 86% at 13m in West Lobe, while Bacteroidetes increased by 75% between November and March sample points. At 17m in West Lobe, Firmicutes and candidate division OD1 (OP11-derived division 1) increased by an average of 92% and 362%, respectively, between November and March.

At 6m in Lake Fryxell, Cyanobacteria and Firmicutes increased by an average of 399% and 666%, respectively. Candidate division OD1 increased by 45%. Bacteroidetes and Planctomycetes decreased by 69% and 61%, respectively, between November and March. At 9m in Lake Fryxell, Acidobacteria and Cyanobacteria increased by an average of 165% and 119%, respectively, while Planctomycetes and Firmicutes decreased by 75% and 73% between November and March.

Conclusions

1. Heterotrophic **bacterial productivity** was between approximately 10^{-3} and 2 mg C m^{-2} d^{-1} in all lakes, throughout the season, but **peaked at variable depths** in the water column. Productivity was highest in Lake Fryxell (Figure 1 and 2).
2. Bacterial **productivity dropped**, and then recovered, in all lakes **during March**, indicating a **possible shift in community structure or physiology** (Figures 1, 2, and 3, and Conclusions 4, 5, and 6).
3. End of season increases in leucine incorporation indicate a possible **shift in cellular function from population growth to survival (Shiah and Ducklow, 1997)**. Leu:Tdr was consistently >1 in all lakes except for Fryxell (Figure 3).
4. Cyanobacteria **decreased** in frequency in West Lobe, but **increased** in Lake Fryxell. Increases could be due to **upward migration of the phototrophic bacteria** in the water column as sunlight decreased (Figure 4).
5. Firmicutes, which include many heterotrophic spore formers **increased** in frequency in both lakes. The ability to form spores may help the organisms to **survive decreased input of organic carbon in the winter** (Figure 4). Sporulation could explain the drop in productivity (Conclusion 2).
6. Candidate division **OD1**, which has no cultivated members, **increased** at 6m in Lake Fryxell depth and 17m in West Lobe (Figure 4). OD1 signatures are commonly found in sulfidic environments, such as Lake Fryxell, and the organisms **may be important in sulfur cycling** (Harris et al., 2004).

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