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Rhea M.M. Esposito
University of Colorado Boulder

S. L. Horn
University of Colorado Boulder

D. M. McKnight
University of Colorado Boulder

M. J. Cox
University of Colorado Boulder

M. C. Grant
University of Colorado Boulder

See next page for additional authors

Authors

Rhea M.M. Esposito, S. L. Horn, D. M. McKnight, M. J. Cox, M. C. Grant, S. A. Spaulding, P. T. Doran, and K. D. Cozzetto

Antarctic climate cooling and response of diatoms in glacial meltwater streams

R. M. M. Esposito,[1] S. L. Horn,[1] D. M. McKnight,[1] M. J. Cox,[1] M. C. Grant,[1] S. A. Spaulding,[1,2] P. T. Doran,[3] and K. D. Cozzetto[1]

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[1] To understand biotic responses to an Antarctic cooling trend, we analyzed diatom samples from glacial meltwater streams in the McMurdo Dry Valleys, the largest ice-free area in Antarctica. Diatoms are abundant in these streams, and 24 of 40 species have only been found in the Antarctic. The percentage of these Antarctic diatom species increased with decreasing annual stream flow and increasing harshness of the stream habitat. The species diversity of assemblages reached a maximum when the Antarctic species accounted for 40–60% of relative diatom abundance. Decreased solar radiation and air-temperatures reduce annual stream flow, raising the dominance of these Antarctic species to levels above 60%. Thus, cooling favors the Antarctic species, and lowers diatom species diversity in this region. **Citation:** Esposito, R. M. M., S. L. Horn, D. M. McKnight, M. J. Cox, M. C. Grant, S. A. Spaulding, P. T. Doran, and K. D. Cozzetto (2006), Antarctic climate cooling and response of diatoms in glacial meltwater streams, *Geophys. Res. Lett.*, *33*, L07406, doi:10.1029/2006GL025903.

1. Introduction

[2] Diatoms are micro-algae that possess inorganic, bipartite cell walls (frustules) and are abundant in freshwater and marine ecosystems. The frustules have distinct ornamentation patterns by which species are recognized (Figure 1). Frustules preserved in sediments are used as indicators of past environmental change because species assemblages reflect environmental conditions, such as water chemistry [*Fallu et al.*, 2002; *Sabbe et al.*, 2003]. Taxonomic studies of diatoms in Arctic lakes and streams have been useful in understanding current and past climate patterns [*Moore*, 1974; *Denys and Beyens*, 1987; *Antoniades and Douglas*, 2002; *Antoniades et al.*, 2004]. Although endemism and biodiversity are prominent issues concerning freshwater diatoms [*Kociolek and Spaulding*, 2000; *Jones*, 1996; *Round et al.*, 1990] and the number of diatom taxa is considered to be underestimated on a global basis [*Mann*, 1999], no analysis of the relation between species endemism and diversity exists. Previous studies of diatom distributions in the Antarctic and sub-Antarctic report relatively low numbers of total species and high incidence of widespread species [*Jones*, 1996; *Van de Vijver and Beyens*, 1999]. These studies conclude that species richness decreases toward the Pole, while numbers of endemic species increase along the same gradient. Recently, greater attention has been given to accurate taxonomy in the study of Antarctic diatoms [*Kociolek and Jones*, 1995; *Spaulding et al.*, 1999; *Van de Vijver and Beyens*, 1999; *Alifinito and Cavacini*, 2000; *Sabbe et al.*, 2003; *Van de Vijver et al.*, 2002, 2004; *Cremer et al.*, 2004], providing a clearer view of the degree of endemism in the region. Furthermore with these new studies, the differences between Arctic and Antarctic species becomes more evident [*Van De Vijver et al.*, 2004].

[1]Institute of Arctic and Alpine Research, University of Colorado, Boulder, Colorado, USA.

[2]Also at U.S. Geological Survey, Denver, Colorado, USA.

[3]Department of Earth and Environmental Sciences, University of Illinois at Chicago, Chicago, Illinois, USA.

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2. Field Area

[3] The McMurdo Dry Valleys are among the coldest and driest deserts on earth [*Fountain et al.*, 1999], and this region has been considered analogous to the Martian environment [*Doran et al.*, 1998]. Dry valley streams are fed by glacial meltwater and differ in water chemistry, length, and total annual stream flow. Stream discharge varies rapidly with changes in air temperature and net solar radiation [*Jaros*, 2003]. A cooling trend is documented in the Dry Valleys between 1986 and 2000 [*Doran et al.*, 2002], continuing at least to January 2005 (MCMLTER, http://www.mcmlter.org/met_home.htm). Cooling has also been widespread on the continent over the last several decades [e.g., *Doran et al.*, 2002; *Kwok and Comiso*, 2002].

[4] Low-flow conditions present a challenging environment for diatoms and other streambed organisms. The cyanobacterial mats which host the diatoms exist in a freeze-dried state for all but 6–10 weeks a year, when streams flow. In addition to daily variation in discharge, phototrophic growth is constrained by days without flow, which occur more frequently during colder, cloudier summers. Only 15 morphotypes of Cyanobacteria and 9 species of Chlorophyta have been found in the streams [*Broady*, 1982; *McKnight et al.*, 1998]. These valleys are also characterized by low diversity of prokaryotes, protists and nematodes, the latter of which is the most complex life form [*Virginia and Wall*, 1999].

3. Methods

3.1. Algal Sample Processing

[5] We sampled diatoms by coring surface algal mats from five streams (Canada Stream, Delta Stream, Bowles Creek, Green Creek and Von Guerard Stream) as part of the McMurdo Long Term Ecological Research project. Five samples were collected from each flowing stream in early January of 1994, 1995, 1998, 2001, and 2003. We did not

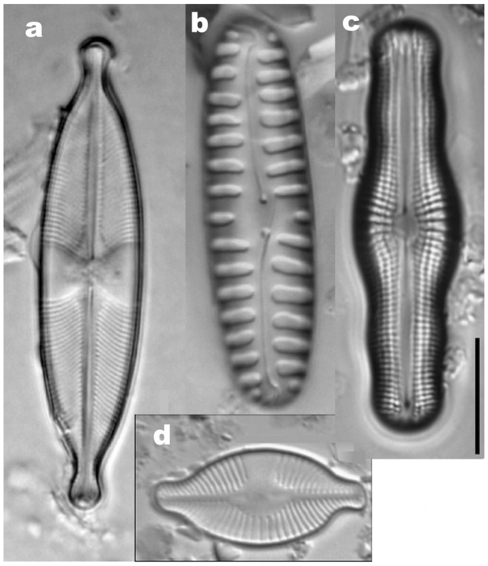

Figure 1. Light micrographs of Dry Valley diatoms. (a) *Stauroneis cf. latistauros*, (b) *Pinnularia borealis*, (c) *Muelleria meridionalis var. #1*, (d) *Psammothidium germainii var. #1*. The scale bar is 10 microns, and applies to all images.

collect samples from streams which were not flowing that summer. We obtained samples from all five years from Canada Stream, which has the most consistent flow. Samples were preserved in formalin solution and refrigerated at 4°C. 50–75% of diatoms were alive at the time of sampling in most samples, which was determined by analyzing samples for the presence of chloroplasts in the frustules. Each sample (~10 mL) was digested using heat and H_2O_2, and rinsed several times with DI. The remaining material was dried onto cover slips and mounted onto permanent glass microscope slides with the mounting medium Naphrax. Relative abundance of diatom species was determined using a light microscope with a 100x oil objective, counting ~250 valves per slide. A complete list of species is in Table S1 in the auxiliary material[1].

3.2. Environmental Data

[6] Stream flow data were collected at gauges on each of the streams (http://www.mcmlter.org/). Air temperature and solar radiation data were collected at 15 minute intervals at the Lake Fryxell Meteorological Station on the ice-free valley floor. We calculated net solar radiation as radiation in minus radiation reflected. Above a threshold temperature, solar radiation causes melt on the glacial surface [*Paige*, 1968; *Chinn*, 1987]. We used −5°C as a threshold in our analyses [*Jaros*, 2003]. We summed these radiation values for time intervals above −5°C to obtain a cumulative annual net solar radiation. Net radiation data for December 1993 were not available, and we used net values determined by linear extrapolation of photosynthetically active radiation (PAR) and net radiation from existing data ($r^2 = 0.90$).

[1]Auxiliary material is available at ftp://ftp.agu.org/apend/gl/2006gl025903.

[7] We calculated harshness rankings for each site in each year using the harshness index developed by *Fritz and Dodds* [2005]. Of their 12 flow-related criteria, we chose three annual and three historical criteria which are well-matched with the Dry Valley habitat. These are: mean annual flow for each year, annual maximum flow for each year, days without flow during the summer period (Dec–Jan), mean annual flow for historical record, mean annual days without flow for historical record, and flood events per year for historical record (maxflow = 0.1 m^3/s). Table S2 in the auxiliary material presents a complete analysis of harshness rankings.

3.3. Mathematical Analysis

[8] We calculated diatom diversity using the Shannon-Wiener (S-W) index:

$$H' = -\sum_{i=1}^{S} P_i \log_{10} p_i$$

where P_i = relative abundance, $p_i = n_i/N$ for each species; S = total number of species, n_i = number of individuals of a species in sample; N = total number of individuals of all species in the sample. Thus the value of H′ (S-W index value) depends on species richness, evenness (the relative proportion of each species) and sample size (N). We also looked at evenness and richness independently. As an index of dominance by Antarctic species (Antarctic Diatom Index), we summed the relative abundances of each Antarctic species in a sample to arrive at a total percentage. We averaged these Antarctic indices for all samples from each year to obtain an overall stream Antarctic diatom index.

4. Results and Discussion

4.1. Species Distribution Trends

[9] Our data demonstrate that diatoms represent an exception to general patterns of low diversity in the Dry Valleys. We found 40 diatom species from 17 genera, 24 of which have only been reported from the Antarctic continent (Figure 2). Of these 24 species, 18 have been found only in South Victoria Land. Twelve of these diatom morphotypes from Dry Valley streams do not fit the descriptions of known taxa, and we consider these morphologies to represent undescribed taxa [*Alger*, 1999; R. M. M. Esposito et al., manuscript in preparation, 2006]. We refer to these taxa not yet known to occur in regions outside of Antarctica as "putative endemic" taxa. Further, we use the phrase "Antarctic species" to refer collectively to the twelve taxa that other investigators have concluded to be Antarctic endemics and the twelve "putative endemic" taxa. For the 112 samples analyzed, Antarctic species accounted for an average 57% of the relative diatom abundance. Most of the Antarctic species are present in the majority of the samples (Figure 2). Applying these criteria to previous studies of diatoms in the Antarctic would lead to comparable levels of dominance by Antarctic species [e.g., *Jones*, 1996; *Sabbe et al.*, 2003].

[10] In addition to geographic isolation, the extreme nature of stream habitats found in the McMurdo Dry Valleys [*Fountain et al.*, 1999] may influence the abundance of

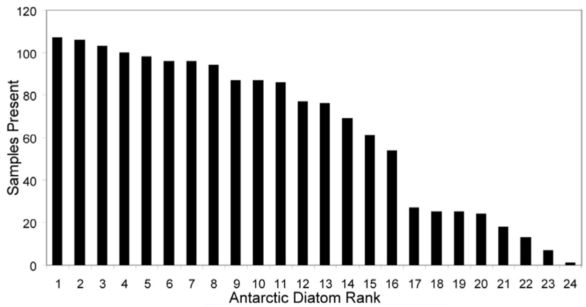

Figure 2. Bar graph of number of times an Antarctic species was seen in the 112 total samples (presence), ranked sequentially from most frequently present to least frequently present. The majority of the Antarctic species are found in over half of the samples. Species names: 1. *Luticola muticopsis var. evoluta*, 2. *Stauroneis cf. latistauros*, 3. *Hantszchia amphioxys sp#1*, 4. *Hantszchia amphioxys sp#2*, 5. *Luticola muticopsis var. reducta*, 6. *Hantszchia amphioxys sp#4*, 7. *Muelleria peraustralis*, 8. *Hantszchia amphioxys sp#3*, 9. *Luticola murrayi var. #1*, 10. *Muelleria meridionalis,* 11. *Diadesmis contenta var. #1*, 12. *Luticola muticopsis fo. capitata*, 13. *Luticola muticopsis fo. #1*, 14. *Nitzschia sp#1*, 15. *Pinnularia cymatopleura*, 16. *Achnanthes taylorensis*, 17. *Luticola sp#1*, 18. *Psammothidium germainii var. #1*, 19. *Nitzschia westii*, 20. *Navicula shackeltoni*, 21. *Muelleria meridionalis var. #1*, 22. *Mayamaea atomus var. #1*, 23. *Luticola cohni var. #1*, 24. *Melosira charcotii*.

Antarctic species. Comparison of the harshness ranking with the Antarctic diatom index (ADI) for each stream and year shows that they have a positive logarithmic relationship (p = 0.01, Figure 3a). A logarithmic relationship is interesting, and can be explained because both harshness and the ADI are relative properties and thus reach an upper threshold. We found no relationship between diversity and harshness.

[11] We also found a strong negative linear relationship between annual stream flow and the ADI in Canada Stream (Figure 3b). For the five years, we found that the regression between annual stream flow and the ADI had an r^2 = 0.87 and was significant (p = 0.03; Figure 3b). Standard errors were small for all years in Canada Stream (Figure 3b). Annual net solar radiation above −5°C was positively linearly related to annual stream flow (r^2 = 0.43, p = 0.05), indicating that variation in solar radiation and temperature drives changes in annual stream flow, and influences the abundance of Antarctic diatoms.

4.2. Relationship Between Diversity and The ADI

[12] We found that the high percentage of Antarctic species (24 of 40) is accompanied by high diversity, measured by a Shannon-Wiener index inter-quartile-range of 1.01–1.14 (Figure 4a). Richness and evenness were also high, with an average of 22 species seen in every sample and an average evenness value of 0.78. The ADI varied from 10% to 90%. High diversity may be associated with variable stream flow on both a yearly and daily basis. The quadratic model fitting diversity to the ADI is highly significant (p < 0.0001) and explains a substantial share of the variation in diversity (r^2 = 0.47). The mathematical

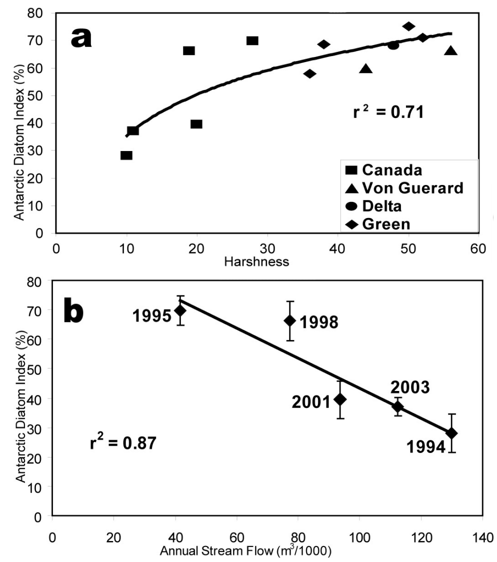

Figure 3. (a) Average percentage of Antarctic diatoms as a function of harshness score. Points are coded according to the legend. The trendline and r^2 value are based on a logarithmic relationship. (b) Average percentage of Antarctic diatoms in Canada Stream as a function of stream flow. Each point represents a yearly value, as indicated. The strong negative relationship is shown with the trendline and r^2 value.

maximum value for the Shannon-Weiner index for 40 species is 1.6. Our maximum observed diversity, SW = 1.3, reaches 81% of this value (Figure 4a). When we examined Canada Stream independently, we also found the quadratic relationship explained a high degree of the variation (r^2 = 0.55, Figure 4b).

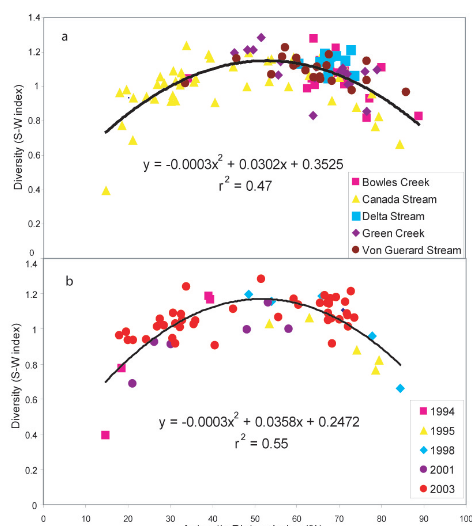

Figure 4. (a) Graph of Shannon-Wiener diversity index as a function of the ADI, measured as the relative abundance of Antarctic diatoms. The equation and curve shown on the graph is significant at the P < 0.0001 level. Points for individual streams (Bowles, Green etc) are coded according to the legend. (b) Graph of Shannon-Weiner diversity index for Canada Stream only. Years are coded according to the legend.

[13] We hypothesize that interactions between widespread diatoms and the Antarctic diatoms are controlling the relationship between diversity and the ADI. At lower levels of the ADI, diversity and Antarctic species dominance could both increase under moderate flow volumes and intermittent periods of desiccation, accounting for a positive relationship (Figure 4). The negative relationship at high levels of the ADI may result from exclusion of widespread species when more frequent desiccation creates a more inhospitable habitat. Increasing harshness [*Fritz and Dodds*, 2005] could cause assemblages to become dominated by Antarctic diatoms that are well adapted to the harsh conditions, with a concomitant decrease in diversity with the loss of widespread species.

5. Conclusions

[14] Our results show that dominance of Antarctic diatoms increases with harshness in glacial meltwater streams in the McMurdo Dry Valleys, one of the most extreme environments on Earth. Given that climate variability impacts the harshness of the stream environment, recent Dry Valley cooling trends [*Torinesi et al.*, 2003; *Doran et al.*, 2002] have the potential to alter the diatom populations. Under cooler, cloudier summer conditions, a higher abundance of Antarctic species would be expected to lower overall diatom diversity. However, this trend may be reversed if warming were to occur, as predicted by *Shindell and Schmidt* [2004].

[15] Taxonomic descriptions and photomicrographs of the diatom species, descriptions of stream sites, and data analyzed are available on the Antarctic Freshwater Diatoms Web site (http://huey.colorado.edu/diatoms/).

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M. J. Cox, K. D. Cozzetto, R. M. M. Esposito, M. C. Grant, S. L. Horn, D. M. McKnight, and S. A. Spaulding, INSTAAR, University of Colorado, Box 450, Boulder, CO 80309, USA. (rhea.esposito@colorado.edu)

P. T. Doran, Department of Earth and Environmental Sciences, University of Illinois at Chicago, MC 186, Chicago, IL 60607-7059, USA.