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FEMS Microbiology Ecology 53 (2005) 61–72

FEMS MICROBIOLOGY Ecology

www.fems-microbiology.org

The structure and stability of the bacterioplankton community in Antarctic freshwater lakes, subject to extremely rapid environmental change

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Received 12 October 2004; received in revised form 10 January 2005; accepted 11 January 2005

First published online 29 January 2005

Abstract

In this study, variation in the bacterioplankton community structure of three Antarctic lakes of different nutrient status, was determined in relation to physical and chemical gradients at depth and at time intervals, across the seasonal transition from winter ice-cover to the summer ice-free period. The three lakes studied were: Moss Lake (low nutrient, with typical nutrient concentrations of 80 $\mu g\,l^{-1}$ nitrate and 10 $\mu g\,l^{-1}$ dissolved reactive phosphate), Sombre Lake (low nutrient, but becoming progressively enriched, with typical nutrient concentrations of 185 $\mu g\,l^{-1}$ nitrate and 7 $\mu g\,l^{-1}$ dissolved reactive phosphate) and Heywood Lake (enriched, with typical nutrient concentrations of 1180 $\mu g\,l^{-1}$ nitrate and 124 $\mu g\,l^{-1}$ dissolved reactive phosphate). Bacterioplankton community structure was determined using a combination of PCR amplification of 16S rRNA gene fragments and denaturing gradient gel electrophoresis (DGGE). Results indicated marked changes in this bacterioplankton community structure, which were particularly associated with the transition period. However, significant changes also occurred during the period of holomixis. Comparison of the results from lakes of different nutrient status suggest that increased levels of nutrient input, and in the timing and duration of ice cover will lead to marked changes in the structure and stability of the bacterioplankton community at existing levels of environmental change.

Keywords: Bacterioplankton; Antarctic; Community structure; DGGE; Seasonal cycle; Environmental change; Climate change

1. Introduction

Antarctic limnological studies to date have generally focussed on the phytoplankton and zooplankton communities [1,2]. On Signy Island, for example, Laybourn-Parry et al. [3] and Butler [4–6] were able to show that significant changes in the protozooplankton community structure could occur over relatively short periods of time. With few exceptions, however, the bacterioplankton community structure in Antarctic systems has not been considered, and has often been regarded as a 'black box' [7]. Relatively few studies have attempted to describe either spatial or temporal patterns in this structure, even though recent investigations have demonstrated that environments differing in important physico-chemical parameters support communities differing in species composition [8]. These communities are sensitive to disturbance and in some cases will change with environmental conditions [9].

A study of the bacterioplankton community is timely, as Quayle et al. [10] report data for Signy Island lakes showing extremely rapid environmental change. Mean lake temperatures in winter have increased by 0.9 °C

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doi:10.1016/j.femsec.2005.01.002

between 1980 and 1995 and nutrient levels at some sites exhibit order of magnitude increases per decade. In addition, photographic estimates suggest that permanent ice cover on these lakes has receded by approximately 45% since 1951, and lake ice records indicate that the open-water period has increased significantly.

The lakes of Signy Island, in the South Orkney Islands (60°43′ S, 45°38′ W), lie at the northern extremity of the maritime Antarctic. The lakes also form part of a latitudinal gradient of environmental conditions (temperature, light and nutrient levels), complexity in their microbiology [11], and have been extensively studied for over 30 years [12]. There are 16 recognized lakes on Signy Island in a range of different catchment types, all of which are freshwater and ice-covered to a depth of 1 m for 8–9 months each year. Lake temperatures range from 0–6 °C and the nutrient content of individual lakes varies considerably, largely as a result of animal activity in accessible lakes nearer to the beaches. By monitoring past records and current trends in these lake systems, it is possible to make predictions about how such systems might change in the future, and in response to current observed trends in climate change.

Although PCR amplification of 16S rRNA gene fragments and denaturing gradient gel electrophoresis (DGGE) [13] has already been used to study bacterioplankton community structure in polar aquatic ecosystems [14–16], seasonal changes in bacterioplankton community structure have only been studied in temperate systems, and the stability of bacterioplankton community structure appears to vary with lake system studied and geographical location. Examples do exist of very stable communities [17–20] but most studies reveal some form of microbial community dynamics [21–29]. Such changes have been attributed to a wide variety of possible mechanisms, including biotic factors: grazing [30], viral lysis [31], biomass of microzooplankton, cryptophytes, chrysophytes and diatoms [32,33], response to episodic bloom events [34], competitive exclusion [35], and also to the physico-chemical factors: water column stability, depth [36] or seasonal change [28]. The application of alternative molecular techniques have also suggested that seasonal patterns of substrate utilization [37], concentrations of available trace metals and dissolved organic matter, chemistry of infiltrating hydrothermal waters, irradiation by high levels of UV [38], changing environmental conditions [39], physico-chemical parameters [40], disturbance [41], presence of lake ice [42] and temperature [43] can all contribute to bacterioplankton community structure. However, the typical ranges of annual bacterioplankton community variability remain to be established for Antarctic freshwater lakes [39]. In this study, the bacterioplankton community structure of three freshwater lakes on Signy Island, selected to represent lakes of different nutrient status, were determined at depth and time intervals over the seasonal transition from winter ice cover to the well-mixed summer ice-free period.

2. Materials and methods

2.1. Study lakes

The physical characteristics of the Signy Island Lakes are given in Table 1. Moss Lake (low nutrient) is situated in Paternoster Valley on the north west corner of Signy Island. The drainage basin of 9 ha is composed of approximately 10% snow and ice, 60% rock, 5% lichen and 1% moss cover. There is no evidence of nutrient input from seals, but up to 1% of the catchment is subject to nutrient input from birds. Much of the nutrient input into Moss Lake is derived from melt water running down from the central ice cap. Sombre Lake (low nutrient but subject to progressive enrichment) is also situated in Paternoster Valley. The drainage basin is composed of approximately 74% snow and ice, 14% rock, 9% lichen cover and 2% moss, with >2% subjected to seal derived and a further 2% bird derived nutrient input. Heywood Lake (high nutrient) is situated in Three Lakes Valley, parallel to, and just to the west of Paternoster Valley. There is evidence of high levels of nutrient input from seal activity over 33% of the catchment area, and up to 1% from bird activity (catchment data from Refs. [44,45]).

2.2. Sampling regime

Samples were taken from above the deepest part of the lake at two-week intervals over a 77 day Signy Island field season (sample date 0–14th November 1999, sample date 1–24th November 1999, sample date 2–14th December 1999, sample date 3–28th December 1999, sample date 4–13th January 2000, sample date 5–24th January 2000 and sample date 6–9th February 2000). Samples of 2 l per depth were taken at the surface and at depth intervals of between 1 and 2 m. During the period of ice cover, sampling equipment was deployed

Table 1
Physical characteristics of the three Signy Island study lakes

	Lake		
	Moss	Sombre	Heywood
Nutrient status	Low	Low (increasing)	High
Length (m)	235	250	427
Width (m)	125	150	137
Area (m^2)	16,680	24,300	41,730
Depth (m)	10.5	11.5	6
Altitude (m)	48	5	4
Distance from sea (m)	800	50	200
Ice cover (months)	9	9	8