THE MICROBIOTA OF ALPINE LAKES AND PONDS AS AN INDICATOR OF CHANGES IN THE HYDROLOGICAL CONVEYOR BELT

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INTRODUCTION

Neither the predicted CO_2^- increase as such nor the "small" globally-assumed temperature increase will regulate aquatic ecosystems in alpine regions but rather the hydrological events, and the availability and supply of nutrients (N,S,P, Fe). The present study illustrates the dynamics and homeostatic potential of aquatic ecosystems typical for alpine locations above the timberline.

Alpine aquatic ecosystems support characteristics of microbial communities which have been naturally selected for the particular conditions existing in high mountain environments. The organisms, constantly challenged by extreme and extremely-variable living conditions, are well adapted. Some of them have to survive for more than half a year in the dark and sometimes under anoxia under a thick snow cover. But, within a few days after snowmelt, they begin to grow and propagate. Some have to scavenge the necessary nutrients for growth from an extremely-dilute aqueous medium and they might experience frequent oligotrophic stress. During the growing season, they are heavily influenced by rapid hydrological changes after storms, during snowmelt, and during periods of dryness. It is through these events that populations get destroyed and nutrients are diluted or replenished. Environmental variations are thus reflected as rapid changes in the community composition, as physiological shifts, or in the form of structural adaptations of certain populations. The microbial populations seem to be well adapted to cope with the kind of environmental fluctuations typical for these extreme environments.

We studied the microbiota of alpine lakes and ponds with the aim of defining their sensitivity toward change in the hydrological cycle. Can these ecosystems adapt rapidly enough to manmade environmental changes, to enlarged nutrient loads, to acidification, and to pollutant emissions?

METHODS

We followed the development and response of phototrophic microorganisms in alpine ponds above the timberline in the Misox valley and in the Tambo Lakes (Southeastern Swiss Alps). Automatic registration of the local meteorological forcing parameters (wind, air and soil temperature, irradiation, and precipitation) were correlated with hydrological and biological response parameters (water temperature, pH conductivity, and oxygen concentration). Alterations in water constituents (NO_3^-, SO_4^{2-}, HPO_4^{2-}, NH_4^+ and several cations) were determined with the aid of modern analytical methods. Changes in the composition of the microbial community (population diversity) were observed microscopically and its physiological behaviour (e.g. cyanotoxin production) was followed employing the protein-phosphate inhibition assay and HPLC.

RESULTS

Overall Biomass Distribution: Oligotrophic ecosystems are comprised of a low biomass content, but they contain a sizeable species diversity mostly consisting of unicellular and filamentous prokaryotes and eukaryotes. Several of the alpine lakes have recently been found to contain microbial mats comprising filamentous cyanobacteria, mostly *Oscillatoria spp.* or *Phormidium spp.* These mats represent locally-high biomass concentration and the mat communities might be responsible for the major portion of energy flow from the atmosphere to the hydrosphere as well as for the nutrient cycling into biomass and within the ecosystem. The mats are probably the driving force for a tightly-coupled microbial loop which regulates the nutrient economy of the entire ecosystem (Laybourn-Parry et al. 1991).

Community Composition: The species must be well adapted to the particular nutrient environment. Much of the observed diversity can thus be attributed to the changing nutrient status, as it has been shown for antarctic inland waters by Heywood (1984). The main genera of cyanobacteria found at the alpine sites include *Coelosphaerium, Merismopedia, Anabaena, Lyngbya, Oscillatoria, Phormidum, Pseudanabaena, Scytonema,* and *Tolypothrix,* in certain cases in association with mass developments of diatoms and the flagellated eukaryotic green algae, *Chlamydomonas botryopara, Chloromonas pumilio, Hefniomonas reticulata, Scenedesmus spp.* and *Haematococcus pluvialis*.

Nutrient Limitation: The organisms live in waters with low nutrient concentrations but they are exposed daily to high irradiation intensities. Photosysnthesis already becomes limiting under these conditions during morning hours, which forces the phototrophic microrganisms into metabolic stress. The consequences are seen to be most severe after a few days of repeatedly high solar irradiance.

Metabolic Stress (toxin production): Although low nutrient concentrations do not normally support blooms of planktonic cyanobacteria, we follow the hypothesis that cynotoxin production is induced as a consequence of nutrient imbalance. In high alpine environments, toxin production might be induced after short periods of excessive growth once the nutrients have become limiting.

Nutrient Replenishment: The high ion concentration present in rain water can change the conductivity of pond water dramatically. Only the very first rain fractions and only rain after a longer dry period contain a high ion content. Initial nutrient concentrations tripled within a very short time span, short enough to be certain that inputs into the pool due to soil leaching could be excluded. Rain constituents thus represent a substantial nutrient input into these alpine ecosystems.

Homeostasis: When nutrients had been increased following a rain event, they were consumed again within the following days. The community composition which collapsed as a consequence of the rain re-established itself within a short period of time.

DISCUSSION

Homeostasis: Microbial communities in alpine lakes and ponds respond rapidly to environmental changes, they normally have a vital regenerating ability after catastrophic events (high homeostatic potential), and some of them show characteristic stress expression behaviour.

Response to Environmental Variability: Although cyanobacterial toxins are known to occur worldwide in natural and manmade aquatic systems, it was not known until recently that cyanobacteria in alpine aquatic ecosystems also produce them. This does not mean that all cyanobacteria present in alpine lakes and ponds produce toxins all the time (Mez et al. 1996). Toxin concentration per cyanobacterial cell as well as toxin production in the course of a day or a few days can vary greatly. We consider toxin production by cyanobacteria as one of the most rapid and most sensitive responses to short term environmental variations. Following this biological signal concurrently with a detailed registration of the development of short term environmental changes will probably teach us more about the rapid responses and adaptability of the biota to environmental variability. The synthesis of these toxins is supposed to be induced or at least enhanced by certain, not yet known, combinations of environmental conditions. A recent study describes a positive correlation between iron concentration in the water and toxin content in the cells (Utkilen and Gjoime 1995). This could lead to an increase in cyanobacterial toxicity in iron-rich alpine ponds.

Ecosystem Dynamics: Since organisms and ecosystems respond to the integrated action of a multitude of environmental factors, an observation once made can never be repeated under exactly the same combination of environmental influences, and repetitions and proper control experiments cannot be made. Microbial ecology can still come to meaningful conclusions from field measurements if patterns and events are observed with the proper time resolution.

Patterns: Nature continuously offers experiments under slightly different conditions. If the variability of natural conditions can be defined with a high degree of time resolution, and if these variabilities can be correlated to biological responses, one might be able to draw conclusions about the environmental regulation of organismic and ecosystem activities.

Events: Strong natural events, mostly hydrological ones, such as dryness, rain, or flooding, are common in mountain environments. They normally disturb an ecosystem's "steady state" behaviour, interrupt organismic interactions, and temporarily change habitat conditions or destroy populations. The recovery phase will teach us about routes and rates of restoration and thus about the homeostatic potential of these high mountain microbial ecosystems.

CONCLUSIONS

Our results contribute to a better understanding of how today's alpine aquatic ecosystems function and respond toward nutrient fluxes, loads, and imbalances, and they further our understanding of the bio-accessibility of nutrients in oligotrophic ecosystems. We have extended the scope of traditional aquatic community ecology by introducing cyanotoxin production as a biomolecular indicator for a particular metabolic stress and as a specific and rapid physiological sensor for environmental changes (Mez et al. 1994).

REFERENCES

Heywood, R. B., 1984. 'Antarctic Inland Waters'. In Law, R.M. (ed). *Antartic Ecology* (pp279-344). London: Academic Press.

Laybourn-Parry, J.E.M.; Marchant, H.J.; and Brown, P.; 1991. 'The Plankton of a Large Oligotrophic Freshwater Antarctic Lake'. In *Journal of Plankton Research,* 13 (pp1,137-1,149).

Mez, K.; Preisig, H.R.; Winkenbach, B.; Hanselman, K.; Bachofen, R.; Nageli, H.; and Hauser, B., 1994. 'Cases of Cyanobacterial Toxicoses on Swiss Alpine Pastures'. In Codd. G.A. Jefferies, T.M. Keevil, C.W., and Potter, E. (eds), *Detection Methods for Cyanobacterial Toxins* (pp142-144). Special Publication No. 149, Royal Society of Chemistry, Cambridge.

Mez, K.; Hanselmann, K.; Bachofen, R.; Naegeli, H.P.; and Preisig, H.R.; 1996. Protei Phosphatase-inhibiting Activity in Cyanobacteria from Alpine Lakes in Switzerland. In *Phycologia* (accepted).

Utkilen, H. and Gjolme, N., 1995. 'Iron-stimulated Toxin Production in Microcystis Aeruginosa'. In *Appl. and Environm. Microbial.*, 61 (pp797-800).