13 *Global Change Impacts on Mountain Waters: Lessons from the Fast to Help Define Monitoring Targets for the Future*

André F. Lotter, Dept. of Palaeoecology, Utrecht University, the Netherlands, and
Roland Psenner, Institute of Zoology and Limnology, University of Innsbruck, Austria

Water, the element of life, has always connected ecosystems and landscape compartments on all spatial and temporal scales. In mountain regions it is not only a resource but also sometimes a threat. Standing and running waters in mountains form unique ecosystems and are, from a scenic point of view, highly valued landscape elements. Moreover, they are part of the hydrological cycle, with atmospheric water being stored äs snow and glasier ice, meltwater feeding lakes and brooks, and major river systems and large streams eventually transporting the water downhill to the sea. Due to their topography, mountain regions are characterized by steep environmental gradients on rather short distances. Under undisturbed conditions these gradients manifest themselves äs distinct, climate-related ecotonal boundaries between different Vegetation types (e.g. montane deciduous forest - subalpine coniferous forest - tree line - alpine meadows - perennial snowfields). Climate change in the past has shifted the elevational position of these ecotonal boundaries repeatedly. However, the ongoing and anticipated global warming (air temperature increase of nearly 2 °C within the past Century in the Alps; see for example Beniston et al., 1997; Lister et al., 1998; Böhm unpubl.) will trigger fast changes in the future that will not only be a threat to human life by, for example, increasing slope instability in former permafrost regions with negative socio-economic effects (e.g. on power supply and production, transport and tourism), but will also change ecosystems drastically, with the effect that for instance the alpine zone will shrink at the expense of the subalpine zone. A very important aspect of these observed and anticipated changes is the different pace at which snow, ice and permafrost retreat, and Vegetation advances. We therefore expect an extended period of hydrological and ecological instability.

In view of the fact that significant anthropogenically induced global change will substantially affect mountain ecosystems, research into terrestrial and aquatic Systems in mountain regions has become increasingly important. Furthermore, aerosols, dust, acid rain, heavy metals and nutrients may pollute even remote, uninhabited areas via atmospheric deposition. For mountain regions such as the Alps, the water towers for the twenty-first Century, this is of major importance with respect to the quality of drinking water. The study of mountain lakes that are not influenced directly by human action such äs industry, agriculture and farming also helps to assess the influence of atmospheric input into these aquatic systems.

Mountain lakes are known to be sensitive indicators of past and present global change, and serve as models to predict future changes. In contrast to lowland lakes, which are often strongly affected by cultural eutrophication, mountain lakes register environmental change more directly (Battarbee et al., 2002). The occurrence and composition of aquatic organisms are strongly related to climate, making mountain lakes particularly sensitive recorders of climate change. The length of ice cover determines the duration of the vegetation period, that is, the primary production in the water column as well as the mixing regime and the amount of oxygen depletion. The climate-dependent weathering rates of catchment soils as well as catchment vegetation have an important influence on water chemistry. Given not only the close interaction between vegetation, hydrology, topography, soil, climate and human activity, but also the link between catchment processes and physical, chemical and biological lake responses, the catchment area of a mountain lake can be considered an important and critical unit for study (Likens and Bormann, 1974).

Earth's history is characterized by constantly changing environmental conditions with stressors occurring at the temporal mega (>10^6 years, e.g. plate tectonics), macro (10^4-10^6 years, e.g. glacial-interglacial cycles) and micro scales (10~^{3}-10^4 years, e.g. fire regimes or short disturbance events such as floods). To understand the behaviour of mountain waters and to assess their natural variability and resilience we need to take into account centennial to millennial timescales that go well beyond the time spans on which monitoring projects commonly operate. It is only with this approach that we can define sensitive physical, chemical and/or biological indicators to be used as early warning signals for global change and as thresholds for management action (Kurtz et al., 2001).

MONITORING OF MOUNTAIN LAKES:THE EXAMPLE OF HAGELSEEWLI

Hagelseewli (46°40'N; 8°02'E) is a small, 18.5 m deep lake located at 2,339 m a.s.l. in a north-facing corrie in the Bernese Alps, Switzerland. In the framework of the MOLAR project (Patrick and Flower, 1999), this high mountain lake has been monitored over a twenty-eight month period with regard to the local meteorology as well as the physical, chemical and biological aspects of its limnology (Goudsmit et al., 2000; Ohlendorf et al., 2000). An automatic weather station recorded climatic parameters at ten-minute intervals on a data logger, and a thermistor chain recorded the water temperature at the same time intervals in 1 m increments in the water column. Samples for water chemistry and biological analyses were generally taken every two weeks during the open water season and once a month during the ice-covered season (Ohlendorf et al., 2000). The results of selected climatic parameters as well as physical, chemical and biological variables are shown in Figure 13.1.

Daily mean air temperatures can fall below 0 °C even in summer, and monthly mean temperatures lie below 0 °C for about six months of the year. This results in Hagelseewli being usually completely ice-covered from November to April and sometimes longer (Goudsmit et al., 2000; Ohlendorf et al., 2000) with ice thickness reaching up to 2.5 m. Open water can co-exist with a thick sheet of ice (> 1 m), overlain with snow, in the centre of the lake for over two months. Due to the very harsh climatic conditions prevailing at higher elevations, the length of the open-water season largely determines the productivity in the water column (Catalan et al., 2002). During the ice-covered period the lake bottom water is depleted in oxygen (see Figure 13.1.d) thus favouring the release of soluble reactive phosphorus (see Figure 13.le) from the sediment. As soon as the ice cover melts the

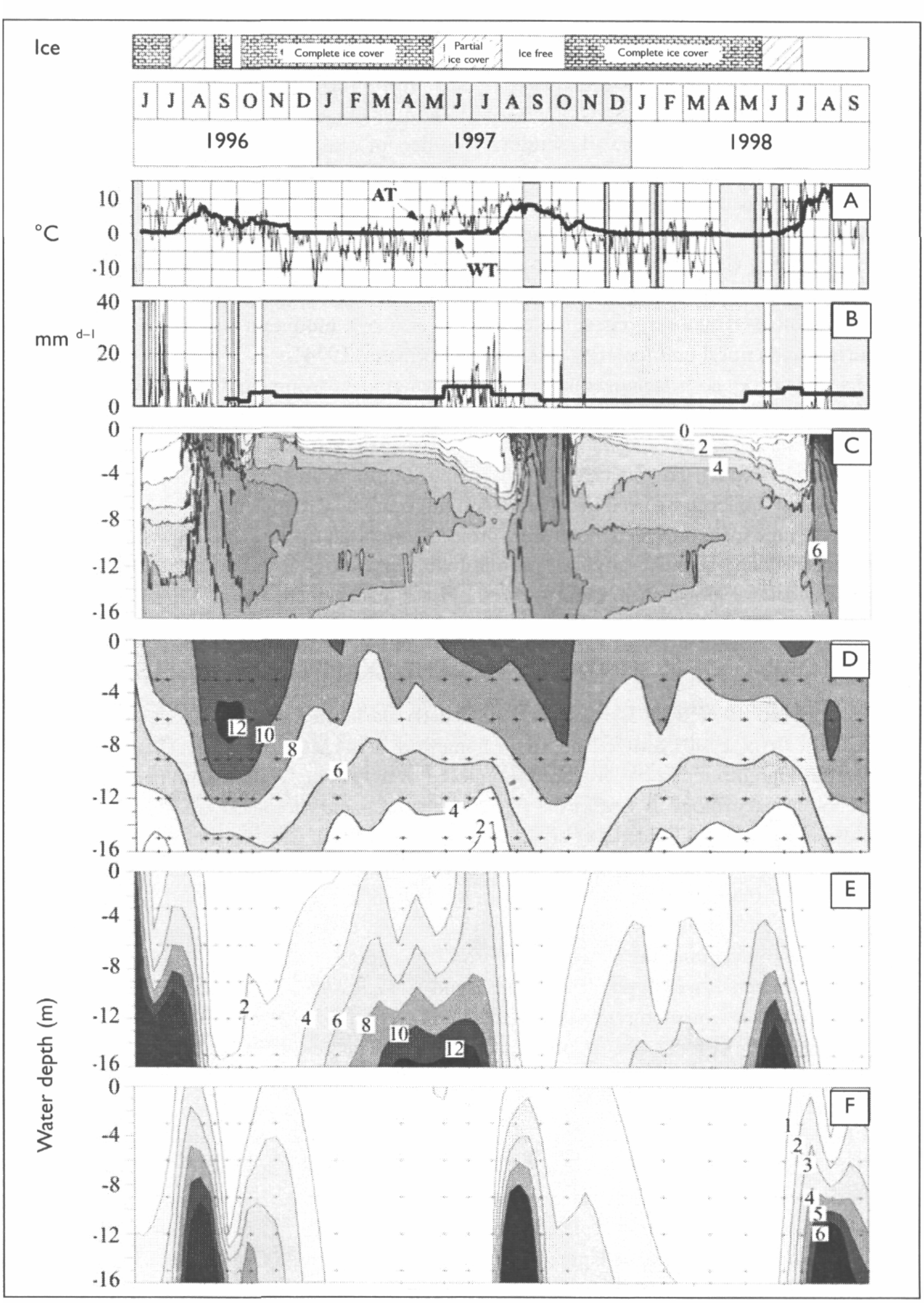

Figure 13.1
Resute *of 28 months (June 1*996-September 1998) *of monitoring of ice cover, climate, physical, chemical and biotic limnological variables in Hagelseewli (2,339 m a.s.l.) in* the Alps

A.Air (AT, thin line) and water temperatures (WT, thick line).
B. Daily precipitation (thin line: automatic rain gauge; thick line: totalizer rain gauge). Grey bands in A and B represent periods where the automatic weather station was not recording due to harsh climatic. conditions.
C. Isoplot of water temperatures (°C) based on thermistor chain data.
D. Isoplot of oxygen concentrations (O$_2$ mg l-^{1}).
E. Isoplot of soluble reactive phosphorus concentrations (ug l^{-1}).
F. Isoplot of chlorophyll a concentrations (ug l^{-1}).

Source: After Ohlendorf et al., 2000.

water column starts mixing (Figures I3.lc and 13.1d) and the available nutrients are taken up by phytoplankton. This is shown by the chlorophyll *a*, concentrations (Figure 13.1f), which peak during the ice-free summer periods.

Figure 13.1b illustrates the problem of measuring precipitation automatically in high-elevation environments. The automatic rain gauge was frozen most of the time and thus not recording precipitation, while the simple totalizing rain gauge provided information about site-specific average precipitation.

To carry out such a monitoring programme a considerable infrastructural effort was necessary (helicopter flights in winter, two-hour hikes in summer). However, despite the continuous automatic sampling of physical parameters, there is always a danger of missing the occurrence of important chemical or biological events happening in the water column, even at closely spaced sampling intervals of two weeks. Moreover, despite the presence of clear climatological and limnological patterns, there is a high inter-annual variability in all data. It is therefore difficult to detect monitoring indicators and to define monitoring targets, even if the data-gathering programme is extended to a longer time period.

LAKE SEDIMENTS AS ENVIRONMENTAL ARCHIVES

Although measurement is difficult, mountain lakes that are characterized by small water volumes and a long ice cover in this way are particularly susceptible to climate change (Livingstone, 1997). Regional or even hemispherical *climate* strongly affects synoptic *weather patterns* (e.g. temperature, precipitation, UV radiation) in mountain regions (see Figure 13.2). Furthermore, climate also strongly influences catchment land cover (e.g. vegetation, glaciers, weathering) and land use (e.g. deforestation, agriculture, pasturing). Mountain lakes show a direct *physical response* to on-site weather conditions (e.g. ice-cover, stratification of the water column), which, together with the catchment land cover, influence the *chemical composition* of the lake water (pH, alkalinity, nutrients, oxygen).

The physical and chemical response of a mountain lake will determine its *biotic response* (i.e. the composition of phyto- and zooplankton as well as the benthos). Together with the erosional input from the catchment, this bioproductivity in the lake will determine the *sediment accumulation* and slowly build up the lake's deposits. These sediments are excellent environmental archives, and sediment cores taken from lakes allow us to unravel the history of the lake and its catchment in a continuous way over millennia. In these sediments a wealth of different biotic and abiotic fossils are preserved. Pollen and spores as well as plant remains allow the reconstruction of catchment vegetation and land use (Lotter et al., 2000), while microscopic charcoal remains give information about fires and their frequency (Wick et al., 2003). Silicified remains of algae such as diatoms or statospores of chrysophytes can be used to elucidate past changes in lake water pH (Psenner and Schmidt, 1992) as shown in Figure 13.3, which demonstrates not only the importance of climate but also a nice fit between diatom-inferred and measured pH values. But nutrients (Hausmann et al., 2002), or the duration of ice cover (Lotter and Bigler, 2000) can also be reconstructed with high accuracy by using biological indicators. Remains of zooplankton and -benthos such as Cladocera and

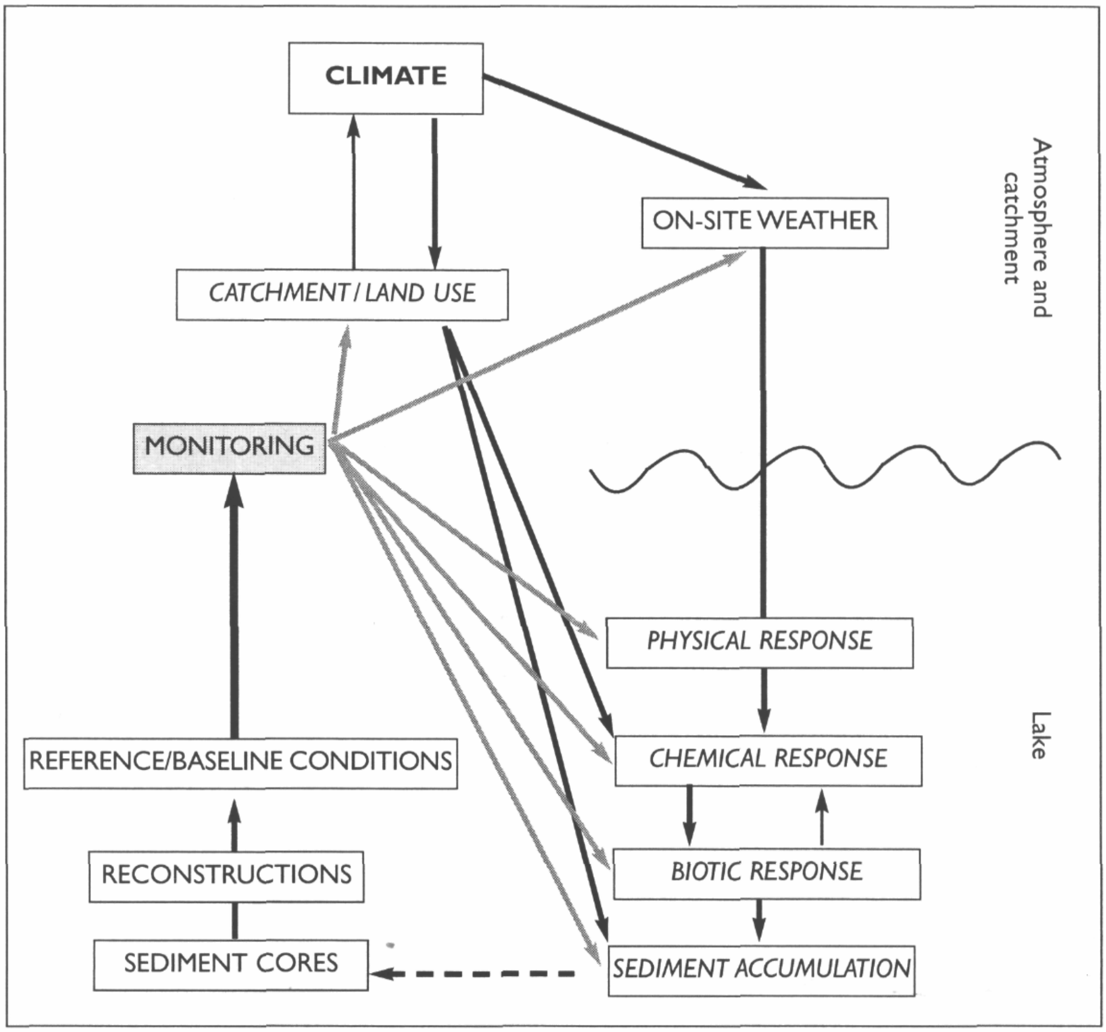

Figure 13.2 *Schematic flowchart of physical, chemical and biotic response in mountain lakes to climate forcing and approach of using sediment-derived information to assess indicators (for details see text)*

chironomid larvae in sediments provide information about past summer temperatures (Heiri and Lotter, 2003; Hofmann, 2003). Biochemical fossils such as pigments of algae or bacteria allow inferences about past nutrient and oxygen conditions in the water column (Lami et al., 2000). As for the abiotic proxies, sedimentology, geochemistry and magnetic properties of the sediments can yield information about natural and anthropogenically induced catchment erosion (Ohlendorf et al., 2003; Koinig et al., 2003; Hirt et al., 2003).

The analysis of biotic remains in dated lake deposits allows a qualitative reconstruction of past environmental condition as well as the study of changes in diversity of aquatic organisms in response to either ecosystem-intrinsic factors or (natural or anthropogenic) external forcing (Lotter, 2001). Given good time-control by physical dating methods (e.g. radiocarbon), the frequencies of disturbances and extreme events such as fires, floods, mudflows, landslides or toxic algal blooms can be assessed (Dapples et al., 2002). Moreover, by using empirical models, so-called transfer functions (for methodological details see Birks, 2003), it is possible to reconstruct in a quantitative way

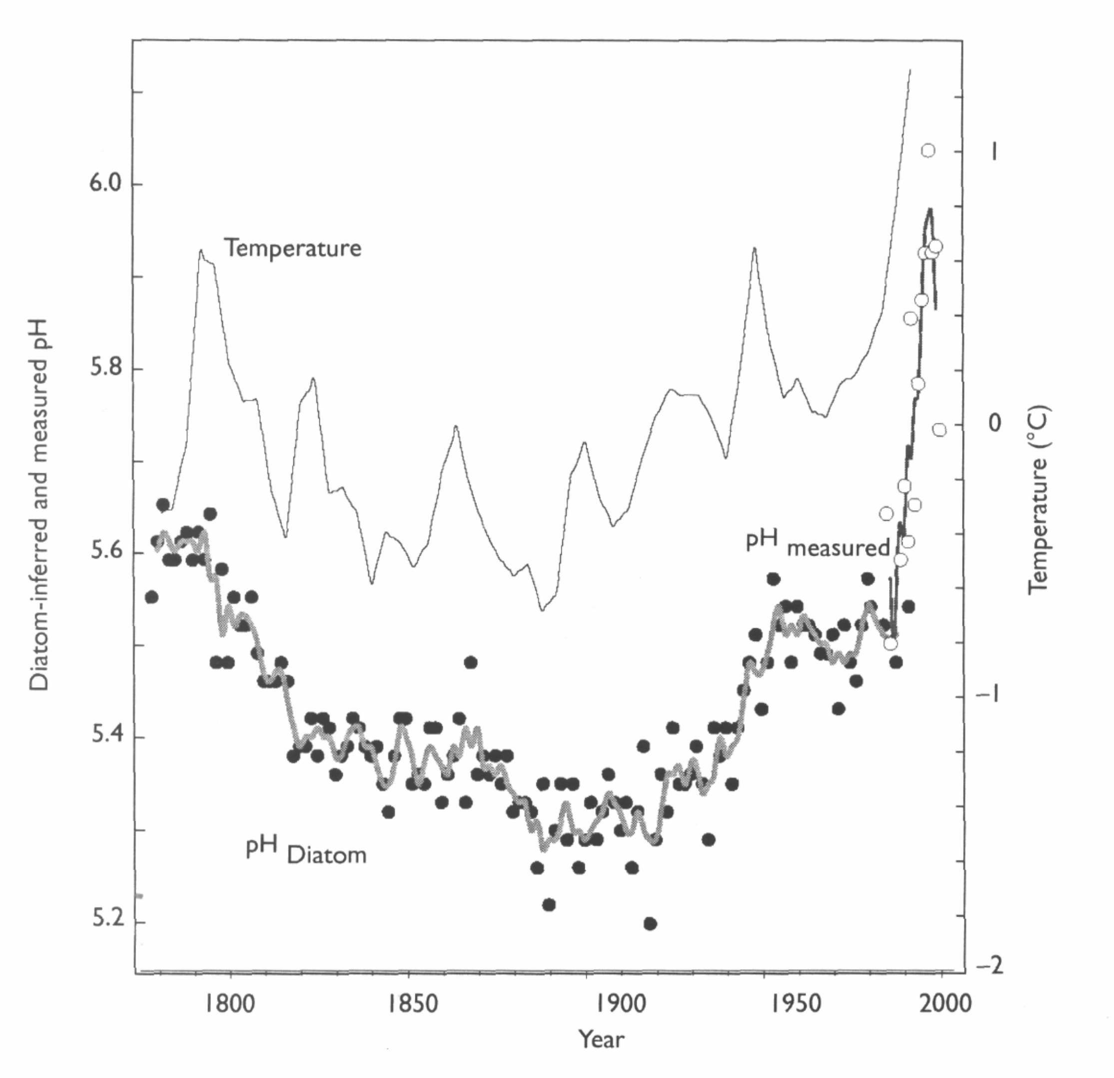

Figure 13.3
Diatom-inferred pH (filled circles) with running average (n=3, thick line) from 1780 to 1991, and measured pH (open circles) with running average (n=3, thin line) from 1985 to 2000 in Schwarzsee ob Sölden, *Tyrol, Austria. Temperature trend at alpine stations (15-year average, thin line).*

important variables that determine the state of the aquatic system, such as pH (Marchetto and Schmidt, 1993), nutrients (Wunsam et ah, 1995) or climate (Lotter et al., 1997; Heiri et al., 2003) over timescales of centennia to millennia.

Such quantitative reconstructions provide valuable information on the long-term behaviour of a lake and its catchment under natural conditions without anthropogenic impact. Furthermore, they allow us to assess the sensitivity of aquatic systems and their resilience after disturbances of different amplitude and length. Such an understanding of the long-term behaviour of complex systems such as mountain lakes is essential to describe baseline conditions of the system (Anderson and Battarbee, 1994), to identify sound monitoring indicators, and eventually to define reference conditions for monitoring and management targets. Moreover, this background knowledge is extremely valuable for modelling the future impacts of global change on mountain waters (Anderson, 1995).

SEEBERGSEE: A SMALL MOUNTAIN LAKE WITH A HISTORY

Seebergsee (46°37'N; 7°28'E) is a small, mesotrophic lake located at the present-day timberline in the Bernese Alps at an elevation of 1,830 m a.s.l. The lake has been stocked with fish since 1902 and has been a nature reserve since 1972. Because of its easy accessibility the catchment of the lake has been used for cattle grazing at various periods. The sediment of the lake is characterized by annual laminations that allow a precise and high-resolution chronology. In a multi-proxy sediment study of this lake (Hausmann et al., 2002) studied the past 2,500 years of the lake's history to define its natural baseline conditions with respect to its phosphorus loading. Here, we shall concentrate on the past 1,000 years, which include the Little Ice Age (LIA), the most pronounced climatic oscillation in historical times in the Alps. The climate change associated with the LIA not only affected terrestrial and aquatic ecosystems but had also a fundamental impact on human society and socio-economic systems in the Alps, leading, among other things, to changes in land use.

The occurrence of high amounts of small planktonic diatoms of the genus Stephanodiscus between the middle of the fourteenth and the late seventeenth century indicate a clear period of strong nutrient enrichment. Older and younger diatom assemblages are dominated by Cyclotella species (Figure 13.4), typical for lakes at this elevation in the Alps with intermediate to low nutrient levels. Since about AD 1345 (Figure 13.3) all biological proxies suggest an increase in pasturing: the beginning of the Stephanodiscus-dominated assemblages coincides with a threefold increase of grazing-indicating pollen types and coprophilous fungal spores (fungi that live on cow dung. The eutrophication of the lake around AD 1345 occurred remarkably fast. The total phosphorus concentration (DI-TP) as estimated by using a diatom transfer function (Lotter et al., 1998) increased in only eight years from about 25 to 140 ug l^{-1}. According to the coprophilous fungal spore data, local pasturing ended around AD 1595. There is a lag of thirty-five years before the grazing indicator pollen and a lag of almost ninety years before the DI-TP reached pre-eutrophication levels. Apparently, the lake needed about a century to recover from its phosphorus load. In contrast, the delayed drop of DI-TP during the second half of the seventeenth century took place very rapidly. Dendroclimatological data from the same region point to a warming in the second half of the seventeenth century, which is likely to have initiated a strong stratification of the water column and the establishment of meromixis in Seebergsee. As a consequence, nutrients from the stratified bottom water were no longer available in the trophogenic zone where planktonic algae live.

Disentangling direct climate effects from indirect effects due to changes in catchment land use is of paramount importance when interpreting palaeolimnological results (Lotter and Birks, 1997). To decide whether the diatom-inferred hypertrophy was induced by climate or by land-use changes, the variance in the diatom assemblage data has been analysed (Hausmann et al., 2002). The statistical results show that grazing indicator pollen and DI-TP concentrations explain ten times more variance than the dendroclimatological data. Nutrient enrichment in Seebergsee thus played an overriding role, while climate played an indirect role by allowing pasturing at higher elevations.

The example of Seebergsee shows that mountain lakes are dynamic systems that can change from one state to another in very short time. Recovery, however, may be delayed substantially due to hysteresis effects and multiple stable states (Scheffer et al., 2001).

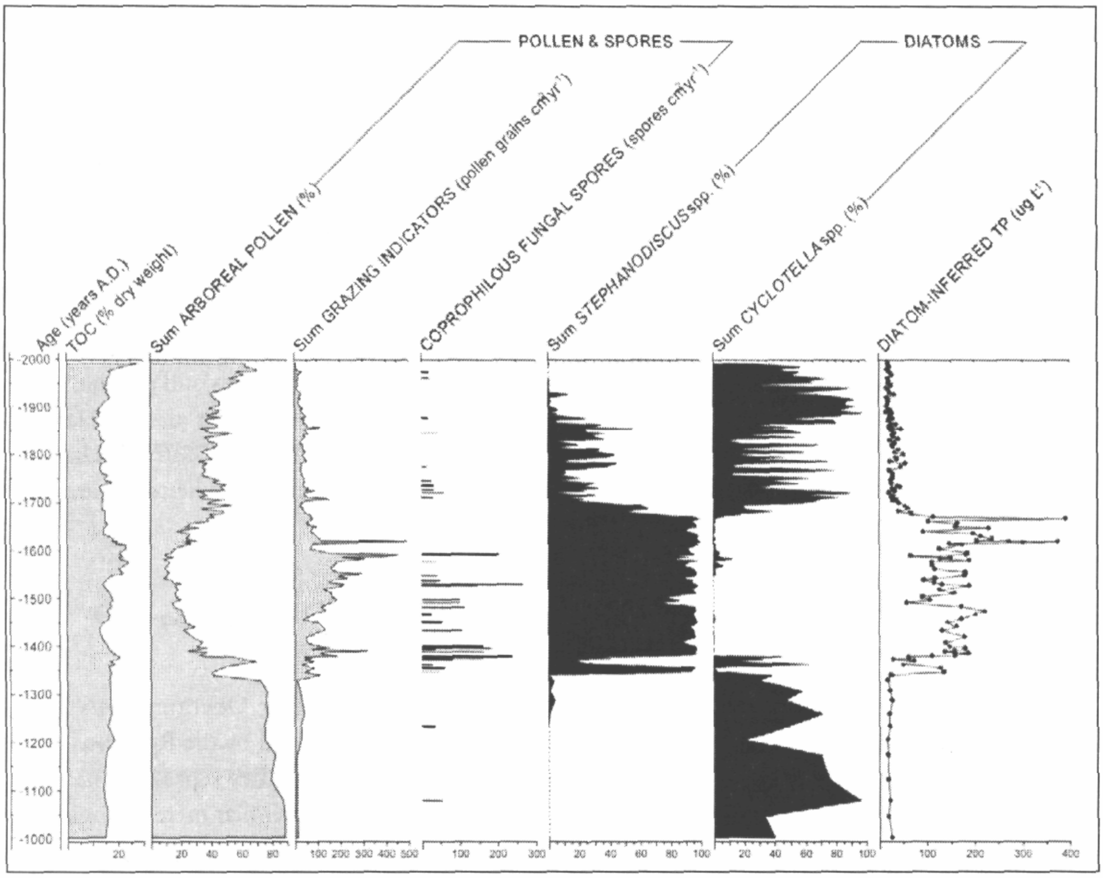

Figure 13.4
Results of sediment, pollen and diatom analyses on annually laminated sediments of the past millennium of Seebergsee (1,830 m a.s.l.)

Source: After Hausmann et al., 2002.

RUNNING WATERS

Regional climate as well as local weather conditions, magnitude and seasonality of rainfall, watershed geology and vegetation are the main factors for the regional hydrology, while temperature gradients, substrate composition, channel geomorphology and chemistry define the local character of running waters. In alpine areas, the stream character is mainly influenced by local water sources and the origin of major tributaries. This has led to the designation of four stream types that can be generally distinguished based on their origin: glacier-fed (kryal), spring-fed (krenal), rainfall or snowmelt dominated (rhithral - the correct name being ombro-chial) and glacial runoff dominated (glacio-rhithral) streams. Depending on the hydrology and geology of the catchment, the proportions of glacial meltwater and groundwater may alter downstream through major tributaries and inflow of groundwater from springs and diffuse sources along its course. These stream types are found worldwide in areas where glaciation, a significant timespan of snow cover and other associated abiotic factors affect the physical and chemical conditions of running waters. The alpine life zone, situated between the timberline and the permanent snowline, compares generally to cold areas located beyond the latitudinal limits of the continuous forest zone. During the last ice age, glaciers covered about 32 per cent of the earth's land surface and glacial rivers were widespread.

Today less than 10 per cent of the land surface remains covered by glaciers. Many glacial rivers have been replaced by snowmelt- and rainfall-dominated rivers. Thus, the relative abundance of glacially influenced rivers has decreased over the past millennia, a transition which has several parallels with the actual phase of climate warming.

Harsh environmental conditions cause alpine streams to differ both in structure (e.g. fewer species, lower densities) and function (e.g. lower growth and production rates, food webs skewed towards different food sources) from headwater streams that are commonly studied. Glacial meltwater has a strong effect on water chemistry and on physical conditions such as turbidity, sediment transport and water temperature. Increased discharge and strong diel fluctuations in surface flow and concentrations of suspended solids in summer create an inhospitable and unstable environment for several months in glacier-fed streams. Increased suspended solid concentrations and organic seston, as well as higher paniculate phosphate and ammonia values are associated with glacial ablation in summer. In high alpine areas, glaciers, springs, snowmelt and/or rainfall influence stream characteristics considerably, with spring-fed streams showing little fluctuation in physico-chemical parameters throughout the year.

ROTMOOSACHE AND KÖNIGSBACH: A GLACIAL AND A SPRING-FED STREAM

The two streams drain parallel valleys in the Austrian Central Alps near Obergurgl (46°50' N; 11°03' E) and are separated by a distance of 4 km. The Rotmoosache is fed by the Rotmoos glacier and the Wasserfall glacier, while the Königsbach is fed by groundwater. They represent the typical kryal and rhithral streams. The streams are northwest exposed and share similar meteorological and geological conditions. In terms of the variation of hydrological, physical and chemical factors, Konigsbach and Rotmoosache show a distinct seasonal pattern (Schütz et al., 2000; Füreder et al., 2000; Füreder, 2004) that can be summarized in five periods: winter, snowmelt, early summer, mid summer and autumn (Figure 13.5).

The two streams are most similar during winter, snowmelt and early summer. In winter the streams have minimal discharge, the stream bed is stable, the water is clear, and mean temperature and daily temperature range stay low. In Rotmoosache the values of dissolved organic carbon, dissolved phosphorus, conductivity and benthic particulate organic matter are high. During snowmelt, discharge increases, and in Königsbach this is the time of maximum discharge. In both streams the channels become unstable, and water temperatures and the content of suspended solids increase, resulting in NO_3 and NH_4 maxima.

Early summer is a period of relative stability in both streams. Discharge is lower than during snowmelt, and on sunny days the mean water temperatures and also the daily temperature ranges increase slightly. During mid-summer, rising air temperatures cause glacial ablation and annual discharge maxima in Rotmoosache, accompanied by high loads of suspended solids and total phosphorus, low conductivity values and a highly unstable channel. In Konigsbach, however, discharge decreases steadily, the stream bed is stable, the water is clear, and water temperatures increase to their highest daily means and high daily ranges. Autumn is again a period of more stable conditions in the glacial stream. Discharge and the load of suspended solids decrease, the channel becomes stable.

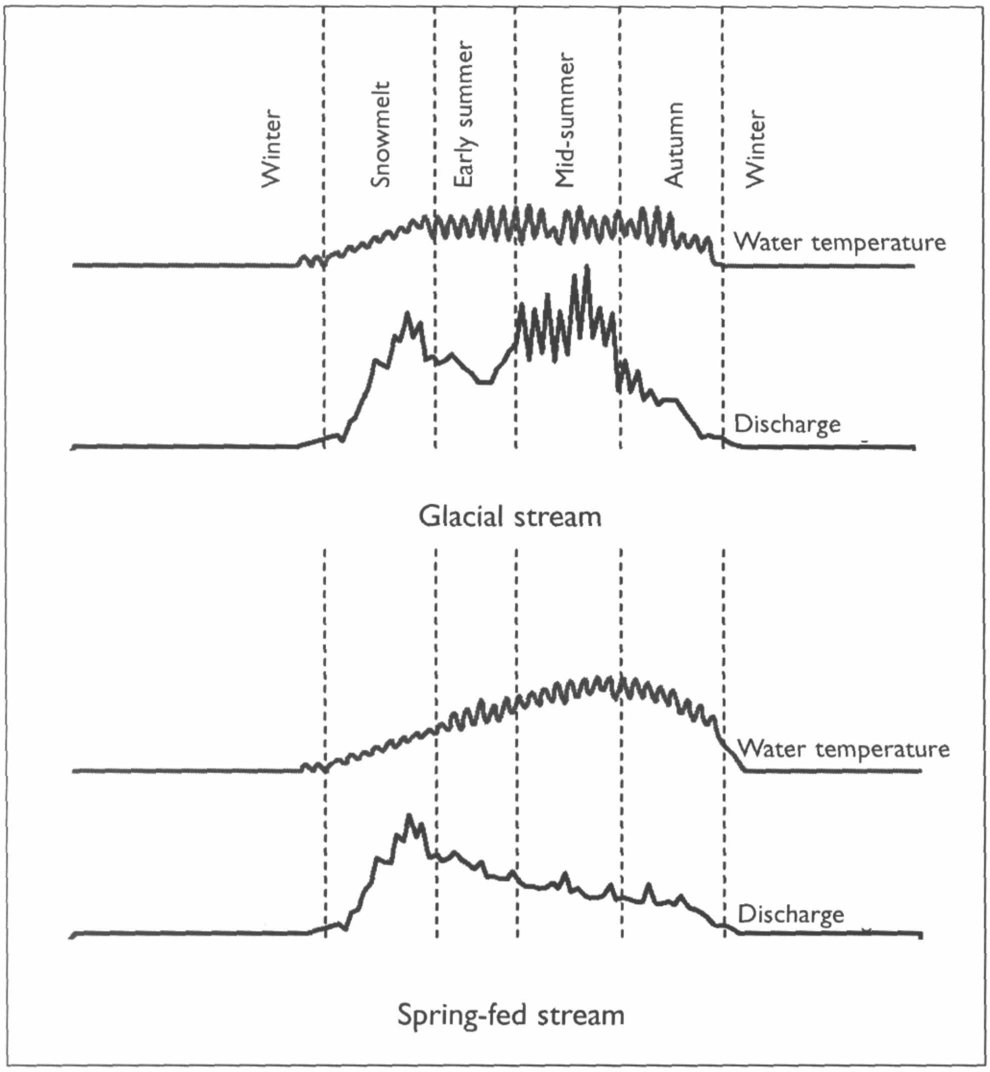

Figure 13.5 *Schematic comparison of a glacial and a spring-fed stream*

Differences between seasons and stream types are based on typical changes in discharge and water temperature.

Source: Modified from Schütz, unpublished.

Mean water temperatures decrease but the daily temperature ranges have their maxima. In the groundwater-fed stream, the fall conditions are not so different from the mid-summer situation.

The aquatic communities reflect the stream-type specific conditions when glacier-fed streams are compared to springfed streams. Reduced densities and/or diversity of certain types of cladocerans (Orthocladiinae), total chironomids and total invertebrates in Rotmoosache point to constraints on the fauna in glacier-fed streams caused by the harsh environmental conditions. Chironomids, as a very successful group of aquatic insects which have developed special adaptations to a variety of inhospitable environments (e.g. to low and even freezing temperatures) generally dominate the alpine stream fauna. With increasing distance to the glacier (i.e. with the influence of groundwater and tributaries from non-glaciated catchments) the environmental harshness declines, and spatial and temporal heterogeneity may cause a complex mosaic of different biotopes and conditions. Within a glacial catchment, key factors responsible for the development of the aquatic communities are time since deglaciation, water temperature, system stability and nutrient or food availability.

CLIMATE CHANGE AND ALPINE RIVER ECOSYSTEMS

It is obvious that glacial retreat and climate warming have a marked influence on the characteristics of alpine streams. With declining glaciation and a decrease in the duration of winter snow cover, both water temperature and stability will increase and physical and chemical conditions will change. The kryal and glacio-rhithral will gradually change into krenal or rhithral stream types. More favourable conditions will prevail on larger stretches of the streams, so the conditions for life in alpine running waters will become more similar. The glacial stream fauna, comprising few but highly specialized species, will be replaced by less specialized ones, especially with regard to temperature and food levels. Specific indicator species or strictly glacial species will gradually disappear.

Alongside these ecosystem considerations, there are perhaps more effects to be expected from climate change. Besides the loss of species adapted to harsh environmental conditions, changing flow dynamics may first bring floods. Together with changes in precipitation patterns they may destabilize alpine vegetation and forests - although, in the long term, the vegetation will reach higher altitudes and 'invade' the former alpine zone. Steady changes in temperature, precipitation and stream hydrology will influence stream biota, but such effects may be minor compared to the impact of extreme events.

CONCLUSIONS

To adequately monitor mountain waters we need to understand how they function. Hydrology and limnology offer a wealth of detailed knowledge about how lakes and streams behave under the influence of different stressors. Since both lakes and streams are defined by climatic, catchment and internal processes, they integrate over changes happening at the scale of landscapes. Moreover, lakes have a 'memory'. However, it is only when we take account of the history of these aquatic systems as archived in lacustrine deposits that we can start defining targets for a sensitive monitoring of mountain waters (Borja et al., 2004). Among the potentially sensitive ecological systems, streams may serve as models to examine the consequences of climate changes; they and their biota can be seen as catchment-scale integrative indicators for a set of hydrological, thermal and biotic variables that might be modified by climate change. A detailed knowledge of ecosystem structure and processes is a prerequisite for understanding and modeling (potential) effects of existing anthropogenic alterations and proposed climate change. Generally a transition from glacial to spring-fed rivers will occur, with significant changes in hydrology, goemorphology and biodiversity. Both types of streams, however, may undergo a period of disturbances caused by floods and the instability of catchments.

ACKNOWLEDGEMENTS

We are especially grateful to Leopold Füreder and Cornelia Schütz for their contributions to alpine stream ecology.

REFERENCES

ANDERSON, N.J. Using the past to predict the future: lake sediments and the modelling of limnological disturbance. *Ecological Modelling,* No. 78, 1995, pp. 149-72.

ANDERSON, N.J.; BATTARBEE, R.W. Aquatic community persistence and variability: a palaeolimnological perspective. In: P.S. Giller, A.G. Hildrew and D. Raffaelli (eds.) *Aquatic Ecology: Scale, Patterns and Processes,* pp. 233-59. London, Blackwell Scientific, 1994.

BATTARBEE, R.W.; THOMPSON, R.; CATALAN, J.; GRYTNES, J.A.; BIRKS, HJ.B. Climate variability and ecosystem dynamics of remote alpine and arctic lakes: the MOLAR project. *Journal of Paleolimnology,* No. 28, 2002, pp. 1-6.

BATTIN, T.J.; WILLE, A.; SATTLER, B.; PSENNER, R. Phylogenetic and functional heterogeneity of sediment biofilms along environmental gradients in a glacial stream. *Applied and Environmental Microbiology,* No. 67, 2001, pp. 799-807.

BENISTON, M.; DIAZ, H.F.; BRADLEY, R.S. Climatic change at high elevation sites: an overview. *Climatic Change,* No. 36, 1997, pp. 233-51.

BIRKS, H.J.B. (2003). Quantitative palaeoenvironmental reconstructions from Holocene biological data. In: A.W. Mackay, R.W. Battarbee, H.J.B. Birks and F. Oldfield (eds.), *Global Change in the Holocene,* pp. 107-23. London, E. Arnold, 2003.

BORJA, A.; VALENCIA, V.; FRANCO, J.; MUXIKA, I.; BALD, J.; BELZUNCE, M.J.; SOLAUN, O. The water framework directive: water alone, or in association with sediment and biota, in determining quality standards? *Marine Pollution Bulletin,* No. 49, 2004, pp. 8-11.

CATALAN, J.; VETURA, M.; BRANCELJ, A.; GRANADOS, I.; THIES, H; NIKUS, U.; KORHOLA, A.; LOTTER, A.F.; BARBIERI, A.; STUCHLIK, E.; LIEN, L.; BITUSIK, P.; BUCHACA, T; CAMARERO, L.; GOUDSMIT, G.H.; KOPACEK, J.; LEMCKE, G.; LIVINGSTONE, D.M.; MULLER, B.; RAUTIO, M.; SISKO, M.; SORVARI, S.; SPORKA, R; STRUNECKY, O.; TORO, M. Seasonal ecosystem variability in remote mountain lakes: implications for detecting climatic signals in sediment records. *Journal of Paleolimnology,* No. 28, 2002, pp. 25-46.

DAPPLES, F.; LOTTER, A.F.; VAN LEEUWEN, J.F.N.; VAN DERKNAAP, W.O.; DIMITRIADIS, S.; OSWALD, D. Paleolimnological evidence for increased landslide activity due to forest clearing and land-use since 3600 cal BP in the western Swiss Alps. *Journal of Paleolimnology,* No. 27, 2002, 239^18.

FÜREDER, F. Alpine Fliefigewa'ssenAuswirkungen des Klimawandels auf natiirliche Okosysteme [Alpine running waters: the impact of climate change on natural ecosystems]. In: *Forum Alpinum 2002: Tlie Nature of the Alps*, pp. 50-5. Austrian Academy of Sciences, 2004.

FÜREDER, L.; SCHÜTZ, C; WALLINGER, M.W.; BURGER, R. Physicochemistry and aquatic insects of a glacier-fed and a spring-fed alpine stream. *Freshwater Biology,* No. 49, 2000, pp. 1673-90.

GOUDSMIT, G.-H.; LEMCKE, G.; LIVINGSTONE, D.M.; LOTTER, A.F.; MÜLLER, B.; STURM, M. Hagelseewli: a fascinating high mountain lake - suitable for palaeoclimate studies? *VerhanAlungcn Internationale Vereinigung fur Limnolofiie,* No. 27, 2000, pp. 1013-22.

HAUSMANN, S.; LOTTER, A.F.; VAN LEEUWEN, J.F.N.; OHLENDORF, C.; LEMCKE, G.; GRÖNLUND, E.; STURM, M. Interactions of climate and land use documented in the varved sediments of Seebergsee in the Swiss Alps. *The Holocene,* No. 12, 2002, pp. 279-89.

HEIRI, O.; LOTTER, A.F. 9000 years of chironomid assemblage dynamics in an Alpine lake: long term faunistic trends, sensitivity of the community to disturbance, and resilience of the ecosystem. *Journal of Paleolimnology,* No. 30, 2003, pp. 273-89.

HEIRI, O.; LOTTER, A.F.; HAUSMANN, S.; KIENAST, F. (2003). A chironomid-based Holocene summer air temperature reconstruction from the Swiss Alps. *The Holocene,* No. 13, 2003, pp. 477-84.

HIRT, A.M.; LANCI, L.; KOINIG, K.A. Mineral magnetic record of Holocene environmental changes in Sagistalsee, Switzerland. *Journal of Paleolimnology,* No. 30, 2003, pp. 321-31.

HOFMANN, W. The long-term succession of high-altitude cladoceran assemblages: a 9000-year record from Sagistalsee (Swiss Alps). *Journal of Paleolimnolojjy,* No. 30, 2003, pp. 291-6.

KOINIG, K.A.; SHOTYK, W; LOTTER, A.F.; OHLENDORF, C.; STURM, M. 9000 years of geochemical evolution of tithogenic major and trace elements in the sediment of an alpine lake: the role of climate, vegetation and land-use history. *Journal of Paleolimnology,* No. 30, 2003, pp. 307-20.

KURTZ, J.C.; JACKSON, L.E.; FISHER, W.S. Strategies for evaluating indicators based on guidelines form the environmental protection agency's office of research and development. *Ecological Indicators,* No. 1, 2001, pp. 49-60.

LAMI, A.; GUILIZZONI, P.; MARCHETTO, A. High resolution analysis of fossil pigments, carbon, nitrogen and sulphur in the sediment of eight European Alpine lakes: the MOLAR project. *Journal of Limnology,* No. 59, 2000, pp. 15-28.

LIKENS, G.E.; BORMANN, F.H. Linkages between terrestrial and aquatic ecosystems. *Bioscienccs,* No. 24, 1974, pp. 447-56.

LISTER, G.S.; LIVINGSTONE, D.M.; AMMANN, B.; ARIZTEGUI, D.; HAEBERLI, W.; LOTTER A.F.; OHLENDORF, C.; PFISTER C.; SCHWANDER J.; SCHWEINGRUBER F.; STAUFFER, B.; STURM, M. Alpine paleoclimatology. In: P. Cebon, U. Dahinden, H.C. Davies, D. Imboden and C.C. Jaeger (eds.), *Views from the Alps: regional perspectives on climate change*, pp. 73-170. Cambridge, Mass., Massachusetts Institute of Technology Press, 1998.

LIVINGSTONE, D.M. Break-up dates of Alpine lakes as proxy data for local and regional mean surface air temperatures. *Climatic Change,* No. 37, 1997, pp. 407-39.

LOTTER A.F. (2001). The effect of eutrophication on diatom diversity: examples from six Swiss lakes. In: R. Jahn, J.P. Kociolek, A. Witkowski and P. Compere (eds.), *Studies on Diatoms,* pp. 417-32. A.RG. Ganther Verlag KG., Ruggell.

LOTTER, A.F.; BIGLER C. Do diatoms in the Swiss Alps reflect the length of ice-cover? *Aquatic Sciences,* No. 62, 2000, pp. 125-11.

LOTTER A.F.; BIRKS, H.J.B. The separation of the influence of nutrients and climate on the varve time-series of Baldeggersee, Switzerland. *Aquatic Sciences,* No. 59, 1997, pp. 362-75.

LOITER, A.F.; BIRKS, H.J.B.; HOFMANN, W.; MARCHETTO, A. Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. I. Climate. *Journal of Paleolimnology,* No. 18, 1997, pp. 395-120.

LOTTER A.F.; BIRKS, H.J.B.; HOFMANN, W.; MARCHETTO, A. Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblages as quantitative indicators for the reconstruction of past environmental conditions in the Alps. II. Nutrients. *Journal of Paleolimnology,* No. 19, 1998, pp. 443-63.

LOTTER, A.F.; HOFMANN, W.; KAMENIK, C.; LAMI, A.; OHLENDORF, C.; STURM, M.; VAN DER KNAAP, W.O.; VAN LEEUWEN, J.F.N. Sedimentological and biostratigraphical analyses of short sediment cores from Hagelseewli (2,339 m a.s.l.) in the Swiss Alps. *Journal of Limnology,* No. 59, 2000, pp. 53-64.

MARCHETTO, A.; SCHMIDT, R A regional calibration data set to infer lakewater pH from sediment diatom assemblages in alpine lakes. *Memorie dell'Istituto Italiano di Idrobiologia,* No. 51, 1993, pp. 115-25.

OHLENDORF, C.; BIGLER C.; GOUDSMIT, G.H.; LEMCKE, G.; LIVINGSTONE, D.M.; LOTTER, A.F.; MULLER, B.; STURM, M. Causes and effects of long periods of ice cover on a remote high Alpine lake. *Journal of Limnology,* No. 59, 2000, pp. 65-80.

OHLENDORF, C.; STURM, M.; HAUSMANN, S. Natural environmental changes and human impact reflected in sediments of a high alpine lake in Switzerland. *Journal of Paleolimnology,* No. 30, 2003, pp. 297-306.

PATRICK, S.; FLOWER R.J. Measuring and modelling the dynamic response of remote mountain lake ecosystems to environmental change: an introduction to the MOLAR project. In: M. Price (ed.), *Global change in the mountains,* pp. 64-5. Carnforth, Parthenon, 1999.

PSENNER, R; SCHMIDT, R Climate-driven pH control of remote alpine lakes and effects of acid deposition. *Nature,* No. 356, 1992, pp. 781-3.

SCHEFFER M.; CARPENTER, S.; FOLEY, J.A.; FOLKE, C.; WALKER B. Catastrophic shifts in ecosystems. *Nature,* No. 413, 2001, pp. 591-6.

SCHÜTZ, C.; WALLINGER, M.; BURGER, R; FÜREDER, L. Effects of snow cover on the benthic fauna in a glacier-fed stream. *Freshwater Biology,* No. 46, 2000, pp. 1691-704.

WICK, L.; VAN LEEUWEN, J.F.N.; VAN DER KNAAP, W.O.; LOTTER A.F. Holocene vegetation development in the catchment of Sagistalsee (1935 m a.s.l.), a small lake in the Swiss Alps. *Journal of Paleolimnology,* No. 30, 2003, pp. 261-72.

WUNSAM, S.; SCHMIDT, R; KLEE, R *Cyclotella-vaia.* (Bacillariophyceae) in lakes of the Alpine region and their relationship to environmental variables. *Aquatic Sciences,* No. 57, 1995, pp. 360-386.