Consiglio Nazionale delle Ricerche

Project of Interest
"NextData"

Research project :

The use of sedimentary proxies in high altitude lakes for inferring the environmental changes during the late Holocene

Coordination: Andre LAMI

Istituto per lo Studio degli Ecosistemi (ISE)

Work Pachage :
WP2.3 ;WP2.6

TITLE OF THE PROPOSED PROJECT:
The use of sedimentary proxies in high altitude lakes for inferring the environmental changes during the late Holocene

Project duration: 2013-2015
Start date: 01 May 2013
End date: 30 September 2015

Scientific coordinator of the proposed project:
LAMI Andrea

CNR Institute coordinating the proposed project:
Istituto per lo Studio degli Ecosistemi (ISE), Verbania

Participating units:

Unit 1:
Istituto per lo Studio degli Ecosistemi (ISE)
Largo Tonolli, 50, 28922 Verbania
Project Coordinator: Dr Andrea Lami
Researcher involved and role:
Dr P. Guilizzoni – pigment analysis
Dr A. Marchetto – diatom analysis
Dr M. Manca – Cladocera analysis

1. GENERAL INFORMATION

Abstract

High altitude lake sediments contain a unique high resolution (decadal) temporal archive of past environmental changes. Lakes are highly sensitive to climate change. They respond rapidly to climate-driven changes in ice cover, water retention times, and thermal conditions by changes in sediment composition, water levels, productivity, and biotic assemblages. They also record atmospheric pollution and catchment inputs.
We intend to collate and re-analyse the sediment record in remote alpine lakes with a multi-proxy approach in order to produce a high resolution reconstruction of the ecological changes in the late Holocene with special focus on the last Millennia.
The activity will focus on high-altitude mountain areas in the Alps. These information will contribute also to the assessment of changes in biodiversity and ecosystems in mountain areas of this strategic region of intervention, through statistical analysis and interpretation of data obtained during the project, and of pre-existing data, which will be made available on the General Portal.

Main goal

The project has four primary objectives

- to reconstruct quantitatively the temporal and spatial changes in trophic state (e.g. primary productivity, phosphorus concentration in lake waters) and in biological communities at a high resolution (decadal) over the last 1000 years so as to obtain baseline data on the natural variability of primary production in several areas of minimal human impact in the Alps. We focus on biological proxy-records because they are closely related to human and climate impacts;
- to contribute to creation of a system of Long Term Data Repositories for lacustrine sequences, environmental data as foreseen in NEXTDATA WP 2.3;
- to evaluate the reconstructed changes from sediment core with the model scenario reconstructed in NEXTDATA WP 2.5;
- to inform policy makers about the impacts of changes in these areas in general ecological and environmental terms.

To achieve these primary objectives we need to (i) derive reliable independent chronologies; and (ii) assemble in a consistent way all the primary data and paleoclimatic reconstructions, (iii) to exchange these results with other interested scientists (e.g. in Switzerland, Austria and France, where there are on-going connections) including the climate modelling community, and (iv) disseminate the results and conclusions in a form useful to both scientists and policy makers.

Expected results

In the last 15 years considerable conceptual and methodological advances have been made in Quaternary geology, paleolimnology, geochronology, and paleoclimatology. As a result it is now possible:

- to obtain cores of soft organic and stiff inorganic lake sediments in deep lakes (>25 m) with high precision and to sample these at a fine temporal resolution (ca. every 25 years);
- to develop detailed and reliable chronologies based on 210Pb, 137Cs and AMS 14C dating of terrestrial macrofossils and to derive statistically robust age-depth models with sample-specific dating errors;
- to reconstruct fluctuations in environmental parameters throughout the Late Holocene from the properties of sediments in lakes;
- to reconstruct environmental parameters (e.g. pH) from assemblages of fossil remains (e.g. diatoms, Cladocera and resting eggs) preserved in lake sediments using modern organism-climate calibration functions, multivariate statistical methods for climate reconstruction, and computer-intensive procedures to derive sample-specific reconstruction errors.
- to establish of databases to be used for assessment of impacts of climate and environmental change, in synergy with the research and monitoring carried out by other NEXTDATA partner. In this way, the community of public and private decision-makers and institutions of territorial management will benefit from a single repository of information, simplifying the job of searching for data and speeding up procedures.
- to identify and to understand those aspects of past climate and environmental change that are of greatest significance for the future of human societies linking with international initiative such as Pages (Past Global Changes; http://www.pages-igbp.org), BioFresh (http://www.freshwaterbiodiversity.eu: an EU-funded international project that aims to build a global information platform for scientists and ecosystem managers).

Role of the different units

Unit 1: CNR – Istituto per lo Studio degli Ecosistemi, Verbania was established in 1938 as Istituto Italiano di Idrobiologia and became part of the of the Consiglio Nazionale delle Ricerche (CNR) in 1978. The Institute's basic and applied research activity is in the field of water and land ecosystems, and is involved in understanding how ecosystems react to the impact of global climate change and anthropogenic pressure. Several international and national projects have been performed related to eutrophication, acidification, climate reconstructions from lakes sediment of many areas of the world (e.g. Italy, North Europe, Himalayas, Svalbard, Antarctica, Africa, Patagonia) and still are the main strategic topics under investigation. A number of

those projects were EU funded and related to mountain lakes (e.g.: MOLAR - MOuntain Lake Research; EMERGE - European Mountain lakes Ecosystems: Regionalisation, diaGnostics & socio-economics Evaluation.; Recover 2010: Predicting Recovery In Acidified Freshwaters By The Year 2010, And Beyond; Euro-limpacs: Integrated Project to Evaluate the Impacts of Global Change on European Freshwater Ecosystems, CNR-Polarnet).

International scientific collaborations with leading international institutions have been carried out in the long tradition of this Institute (e.g. Dept. of Botany, Madison, WI, USA; Dept of Chemistry, Univ. of Melbourne, Australia, ETH-Zürich, Earth Sciences, University of Geneva, Switzerland; CONICET, Argentina; Institute of Limnology, Mondsee and Innsbruck University, Austria, JRC, Ispra; GFZ Potsdam, Germany). CNR-ISE is also National Focal point of the UN-ECE International Co-operative Programme on Assessment and Monitoring Acidification and lakes (ICP-waters).

The CNR-ISE has an extensive range of field equipment for lake sediment coring, sampling and analysis, and for contemporary limnological survey. Laboratory facilities include microfossil preparation rooms, microscope equipped for microphotography and a Digital image Capture System; Elemental Analyser, High Performance Liquid Chromatography UV-VIS spectrophotometers, Ion chromatography and ICP OES.

2. DETAILED PROJECT DESCRIPTION

State of the art and motivations

Ecosystems are exposed to the effects of changing climate with different intesity. Although the impacts of climate change may be difficult to detect since they are often combined with the effects of other activities, such as land use changes, the most recent Global Biodiversity Outlook report (Secretariat of the Convention on Biological Diversity, 2010) identifies climate change as one of the main factors responsible for the current loss of biodiversity. Mountain Ecosystem have been recognized among those more sensitive and endangered by climatic changes.
The exchange of information, approach and methodologies from the present to the past and back to the present so as to build and refine our understanding of global change is one of the achievements of the International Geosphere-Biosphere Programme (1). In these respect, the proposed activity aims to achieve a better understanding of past regional climatic and environmental dynamics through comparison of sedimentary reconstructions and model simulations. We expect to contribute to FOCUS 2 - Regional Climate Dynamics as well as Focus 4 - (Past) Human-Climate-Ecosystem Interactions – PHAROS of the PAGES a core project of the International Geosphere-Biosphere Programme (IGBP).
High altitude lakes commonly have low species richness, strong limiting factors (short growing season, high UV, low food sources), low habitat heterogeneity, small lake size, and geographical isolation that create migration barriers and enhance the "island effect". The likelihood of a shift toward less desired state is then probably higher in high altitude lakes ("sentinel" lakes) than in other lake systems.
Lake sediments are an ecosystem's memory. Their composition of a variety of material originating from manifold sources offers an ideal opportunity to study the past biodiversity trajectory. Biological and non-biological material originating from the lake itself, the surrounding areas, and the atmosphere accumulates in the sediments. The high potential of combining paleolimnology and contemporary ecology in order to study lake biodiversity and functioning has been stressed repeatedly. The temporal dynamics of the lake biodiversity can be reconstructed after extraction and identification of biological remains (e.g. diatoms, chironomids, cladocera, chrysophytes or algal pigment) from sediment records. This approach has been used to assess the response of biodiversity to changing conditions through time. A more widespread approach is the quantification of the magnitude of compositional turn-over and the understanding of their forcing factors (2).
Paleolimnological research has shown that many high mountain lakes have experienced considerable biotic and sedimentary changes in recent decades (3; 4; 5). Despite a simplified food web structure, these ecosystems are often highly dynamic and interpretation of such changes is often problematic, especially when knowledge about their limnology, biology and catchment processes is limited (6). In general, European alpine lakes are relatively well studied from a paleolimnological viewpoint.

Particularly important are studies carried out in Austria (Innsbruck University), Switzerland (ETH, EAWAG) and France (University of Montpellier). In this context, five EU funded projects were carried out from 1988 to 2008. In these projects lakes of the central-western Alps were often selected as key sites to provide a broader, regional, approach to pollution studies (3). Most of these alpine lakes are particularly well-suited to paleolimnological studies because they are numerous, diverse, and experience low anthropogenic impact.

This project is designed primarily to reconstruct, by a combination of qualitative and quantitative paleoecological approaches, changes in lake trophic conditions and climate at a high temporal resolution in the Anthropocene period. Moreover, processes directly or indirectly linked to temperature and precipitation (e.g. storms, floods, avalanches) are some of the most important physical processes changing the European landscape. Such extreme events are having an important impact on the social and economic life of people living in mountainous areas in Europe, with impacts on communications, transport, hydro-electric power, flood frequency, and tourism.

Organic matter constitutes a minor but important fraction of lake sediments. It originates from the complex mixture of lipids, carbohydrates, proteins, and other biochemicals produced by organisms that have lived in the lake and in its catchment. The primary sources of organic matter is from particulate detritus of plant; only a few per cent come from animals. Identification of the different sources of organic matter in the sedimentary record provides important paleolimnological information (7). As the type and abundance of plant life in and around lakes change, the composition and amount of organic matter delivered to the lake sediment changes. Despite the extensive early diagenetic losses of organic matter in general and of some of its important biomarker compounds in particular, bulk identifiers of organic matter, e.g. LOI, C, N, S appear to retain most of the original signal and hence, can be used as proxy records of the original sources. In particular origin of the organic matter can be distinguished on the basis of Carbon to Nitrogen ratio.

Plant pigments that sediment to the ocean and lake floor in senescent or dead phytoplankton cells accumulate as a complex family of “geo porphyrins” in oil and shales. As most carotenoids are specific of single algal taxa, genera or species, it is possible to infer past history of algal assemblages and the past ecology of lake, providing the knowledge of present ecological preference of each taxa (8). Pigments produced by sulphur photosynthetic bacteria give information on the presence and the extent of anoxia in bottom waters, and of changes in the trophic status of the lakes (9) Thus, taking into account a number of biological, physical and chemical factors that influence their deposition and abundance, plant pigments are useful as indices of present and past trophic conditions (10), lake acidification (11), and climate changes (12).

Diatoms have played a major role in the reconstruction of past climate changes, being used as proxy indicators to infer Holocene climate variability in every continent. The majority of recent diatom-based paleoclimatological studies apply quantitative multivariate techniques to reconstruct past environmental variables related to climate,

either directly, such as surface-water temperature and air temperature, or indirectly by reconstructing, for example, salinity, dissolved organic carbon, conductivity, and pH (4).

Cladocerans play an intermediary role in lake ecosystems and food web structure and dynamics, being significant grazers of the lower trophic levels and also an important prey items for secondary consumers such as planktivorous fish. Cladocera remains in sediment cores are useful in indicating past trophic conditions and help to provide insight into the responses of the aquatic ecosystem to external changes in climate and watershed processes (13).

References

1. Bondre, N. R. & Thorsten, K. Editorial: Harnessing the past and the present in the service of the future. *PAGES news* **20,** 7 (2012).
2. Battarbee, R. W., Anderson, J. N., Bennion, H. & Simpson, G. L. Combining limnological and palaeolimnological data to disentangle the effects of nutrient pollution and climate change on lake ecosystems: problems and potential. *Freshwater Biology* **57,** 2091–2106 (2012).
3. Lami, A., Cameron, N. & Korhola, A. *Paleolimnology and ecosystem dynamics at remote European Alpine lakes (Mountain Lakes Reserch programme, MOLAR)*. (Journal of Limnology 59 Suppl., 2000).
4. Battarbee, R. *et al.* in *Tracking Environmental Change Using Lake Sediments* (Smol, J., Birks, H. J., Last, W., Bradley, R. & Alverson, K.) **3,** 155–202 (Springer Netherlands, 2002).
5. Lotter, A. F. *et al.* The sediment record of the past 200 years in a Swiss high-alpine lake: Hagelseewli (2339 ma.s.l.). *Journal of Paleolimnology* **28,** 111–127 (2002).
6. Guilizzoni, P. *et al.* The environmental history of a mountain lake (Lago Paione Superiore, central Alps, Italy) for the last c.100 years: A multidisciplinary, palaeolimnological study RID C-5739-2008. *Journal of Paleolimnology* **15,** 245–264 (1996).
7. Meyers, P. A. & Lallier-Vergès, E. Lacustrine sedimentary organic records of Late Quaternary. *Journal of Paleolimnology* **21,** 345–372. (1999).
8. Leavitt, P. R. A review of factors that regulate carotenoid and chlorophyll deposition and fossil pigment abundance. *Journal of Paleolimnology* **9,** 109–127 (1993).
9. Züllig, H. Pigmente phototropher Bakterien in Seesedimenten und ihre Bedeutung für die seenforshung (mit Ergebnissen aus dem Lago Cadagno, Rotsee und Lobsigensee). *Schweiz. Z. Hydrol.* **47,** 87–126 (1985).
10. Guilizzoni, P., Bonomi, G., Galanti, G. & Ruggiu, D. Relationship between sedimentary pigments and primary production: evidence from core analyses of twelve Italian lakes. *Hydrobiologia* **103,** 103–106 (1983).
11. Guilizzoni, P., Lami, A. & Marchetto, A. Plant pigment ratios from lake sediments as indicators of recent acidification in alpine lakes. *Limnology and Oceanography* **37,** 1565–1569 (1992).
12. Reuss, N., Leavitt, P. R., Hall, R. I., Bigler, C. & Hammarlund, D. Development and application of sedimentary pigments for assessing effects of climatic and environmental changes on subarctic lakes in northern Sweden. *Journal of Paleolimnology* **43,** 149–169 (2010).
13. Korhola, A. & Rautio, M. in *Tracking Environmental Change Using Lake Sediments* (Smol, J., Birks, H. J. & Last, W.) **4,** 5–41 (Springer Netherlands, 2002).

Detailed description of the project, including the work plan, deliverables and milestones (explicitly indicating the activities of the different years)

Work plan

First year:

The activity will be mainly focused on data collation of the several study site exiting in the Alpine mountains to check the consistency of these data to better document the natural variability at decadal and centennial periods. At the same time, we will explore to possibility for a co-operation (e.g. exchange of information, data and eventually joint activity) with other research group based in French, Austria and Switzerland. For this purpose, archives and scientific literature will be thoroughly reviewed to identify all suitable high altitude sites where cores have been retrieved. Subsequently, they will be used to extract all the necessary metadata for the characterization of the sites, particularly those linked to the analyses and processing undertaken. This preliminary activity will be realized in accordance with the guide line of the Web-GIS dedicated to the archive of sediment cores developed under the NEXTDATA WP 2.3. This preliminary WP activity will generate the metadata necessary for the characterization of the site, which will then be included in the updatable Web-GIS, thus constituting the basic archive of sediment cores.

Among the paleolimnological proxies we will focus on:

Loss-on-ignition (LOI) to estimate the organic content of lake sediments. The relative amount of organic material is a function of autochthonous and allochthonous organic production and clastic input.

Magnetic susceptibility of lake sediments largely reflects the concentrations of magnetic minerals and has been used to also infer variations in glacier activity. Moreover, magnetic susceptibility commonly shows parallel variations from core to core within the same lake or even in cores from different lakes in the same catchment, it can provide a basis for core-correlation.

Diatoms are extremely abundant in freshwaters and are usually well preserved in lake sediments. They can be identified to species level and have well-defined optima and tolerances for lake-water pH and nutrients. Diatom assemblages have been shown to be sensitive quantitative sensors of past changes in water quality and climate. However, in order to apply climate-reconstruction techniques confidently, it is important to know what features of climate are being reconstructed. Key questions are (a) which physical aspects of climate (e.g. temperature, radiation) are diatoms responding to and (b) which season dominates the climatic response? We will address these questions.

Spectrophotometric and chromatographic analyses of fossil algal and bacterial pigments (e.g. chlorophylls and their derivatives, carotenoids, etc.) can provide information about trophic conditions, productivity, redox conditions, past periods of meromixis, and varying autochthonous and allochthonous contribution, all of which may be limnological responses to changing climate in low and high-altitude lakes. Analysis of fossil pigments will be made as a means of assessing limnological

responses to changing climate rather than as a basis for reconstructing past temperatures.

Milestone:

Description	*Delivery date[1]*
Identification of the site on mountain areas where lacustrine sediment cores are available, data consistence and the identification of the knowledge gap to be filled in the second year	*8*
Population of the GIS based archives developed within the Sub-project 2: Long-term system of digital data on climate and environment of NEXTDATA project	*12*

1Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date

Deliverable:

Description	*Type*	*Delivery date[1]*
A report on proxies analysed in lacustrine sediment cores covering the last 1000 yr on alpine lakes to describe the natural variability at fine time scale	*Report*	*12*
Final report for the activity of the 1st year	*Report*	*12*

[1]Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date

Second year:

Based on the results from the previous year, the activity will focus on the site selection and coring of one or two lakes in order to provide data for a detailed reconstruction of changes in trophic state biodiversity and ecosystems in mountain areas in strategic regions and to compare these reconstruction with the output generated by the modelling activity of NEXTDATA.

The identification of the site is particularly critical because sediments accumulate in lakes with different pattern. For example, lakes located downstream from glaciers reflect variations in glacier activity in the form of variations in grain size, sediment thickness, sediment accumulation rate, and organic/minerogenic content. In the lake selection process, care will be taken to avoid lakes subject to massive sediment displacement (turbidites, slumps), erosion by currents, physical mixing, and direct human activity. A chain of lakes at different altitudes with well-defined moraine features is ideal because the presence and strength of the glacial meltwater signal in the sediments at various distances downstream from the glacial terminus can be used as an indicator of past glacial extent.

After sampling, the cores obtained from the lakes will be longitudinally cut, photographed, and described visually in terms of colour, structure, and lithology. The cores will be analysed for magnetic susceptibility, dry matter, water, and organic contents. These data will help to assess the occurrence of any sedimentary disturbances. Carbon and nitrogen will be also be measured. Lake sediments originate from three main sources - lake, surrounding catchment, and atmosphere. Constancy through time of the relative contribution from these sources is important for reliable

paleoenvironmental and paleoclimatic reconstructions. Such constancy can be tested by studying sediment physical properties. Changes in lithology and grain-size composition may provide evidence of changes of input sources associated, for example, with extreme weather events. To reconstruct the biological responses to changes along the core we will analyse fossil of diatoms as well as sedimentary pigments and Cladocera.

Milestone:

Description	*Delivery date[1]*
Site selection, using consistent criteria, of the appropriate pro-glacial and non-glacial lakes for coring, lithostratigraphic and biostratigraphic analyses, and for radiometric dating;	*18*
Time series of dry weight, water, and organic content, pigments, diatoms, magnetic susceptibility from new lacustrine sediment cores.	*24*

1Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date

Deliverable:

Description	*Type*	*Delivery date[1]*
Uploading of geo and biostratigraphic data for the new sites in NEXTDATA archive	*Data set*	*20*
Dissemination of results with the participation to scientific conference and workshop;	*Publication*	*24*
Final report for the activity of the 2nd year	*Report*	*24*

[1]Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date

Third year:

The analysis on the new sites will be completed and the data used to develop a detailed reconstruction of changes over the time span covered by the cores at the selected new sites. These reconstructions, as well as the information form the archive, are expected to produce a detailed reconstruction in terms of space and time of the changes occurred in the last Millennia and make possible to validate climate models derived from the NEXTDATA modeller community in the WP 2.5

In this year we expect also to complete the creation of a Long Term Data Repositories for lacustrine sediment cores based on the architecture structure develop by the NETXDATA project within the Work package 2.6 and contribute to the creation of a the establishment of a national "Network of Excellence" for the measurement, storage, analysis and interpretation of sedimentary data, in order to make them available to the scientific community, and stakeholders.

The statistical analysis and interpretation of data obtained during the project, and of pre-existing data, which will be made available on the General Portal will contribute to the assessment of changes in biodiversity and ecosystems in mountain areas in strategic region such as Alps.

Milestone:

Description	*Delivery date[1]*
Completion of sedimentary and biostratigraphy analyses of the new sites	*30*
Reconstructed late Holocene climate change and anthropogenic impacts at the selected sites based on sediments from lakes (organic matter content, diatoms, Cladocera and plant pigments;	*30*

1Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date

Deliverable:

Description	*Type*	*Delivery date[1]*
Uploading of geo and biostratigraphic data for the new sites in NEXTDATA archive	*Data set*	*35*
Dissemination of results with the participation to scientific conference and workshop;	*Publication*	*35*
Final report for the activity of the 3rd year	*Report*	*36*

[1]Month in which the deliverable will be available. Month 1 marking the start of the project, and all delivery dates being relative to this start date