Conference Volume	5th Symposium for Research in Protected Areas 10 to 12 June 2013, Mittersill	pages 59 - 64

Monitoring of French altitude lakes in multi-stressors situations: focus on 5 lakes in Haute-Savoie

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Abstract

Lakes are valued for their role in the water cycle and services including supply of drinking water, fishing, recreation, and tourism. The major types of stressors that potentially combine to affect lakes biodiversity, functioning and services include eutrophication, acidification, toxic materials, climate change and species introduction. At present days, most of European lakes have suffered from perturbations, including high altitude lakes although long considered as pristine sanctuaries.

The response dynamic of lakes facing changing conditions and anthropogenic stressor is a crucial issue for protected areas managers aiming at maintaining or restoring these ecosystems.

In the multi-stressors situation, it is critical to better understand and predict the response of the lake biodiversity and functioning in face of changing environment and climate, and to monitor it. In the French Alps and in Corsica, ecosystems managers and scientists from physical, biological and social sciences joined into a network called "Sentinel Lakes" aiming at enhancing the share of information and data about the future of lake biodiversity and functioning in the context of the global change.

Since 2009 this network brings together researchers from different institutes, French National Parks, National Natural Reserves, Water Agency, French National Fishery Federation and ONEMA (French Water and Aquatic System Board). Protected areas currently implements protocols to monitor the physical and biological parameters of altitude lakes that aims to be standardized. Some of the lakes have been studied since 15 years, such as five lakes in the National Natural Reserve of Haute-Savoie. The first results show that the five studied lakes are characterized by contrasted structure and composition of phytoplanktonic communities. These differences reveal contrasted functioning of the lakes' food webs.

Keywords

High altitude lakes, monitoring, sentinel lakes network, plankton, lake food web, ecological diagnosis.

Introduction: Why a 'Sentinel lakes' network ?

High altitude lakes are important for their biodiversity and the ecosystem services they provide. They also have great cultural and socio-economic value, being the place for numerous human activities, such as tourism and outdoor activities, fishing or hydroelectricity production.

At elevations between 1800 and 2800 m, in some cases ice-covered for 8 months of the year, they constitute unique ecosystems in Europe. As they are distant from large urban areas and rather difficult to reach, high altitude lakes are usually considered as natural land preserved from the impacts of human activities. However, recent international studies have challenged this view, showing that they have been subjected to severe human stresses, on both local and global scales, sometimes for ages.

There is particularly a growing concern about the impact of global changes on the ecological state and future trajectories of these lakes. Indeed, some European altitude lakes have been shown to be contaminated by atmospheric inputs of nutrients (nitrogen fertilizer and phosphorus) or pollutants, such as metals (Lead, Mercury - ARNAUD et al. 2004; THÉVENON et al. 2011) or persistent organic pollutants (PAH or pesticide residues, DDE), carried over long distances (BATTARBEE 2005). They were also repeatedly shown as affected by fish stocking and fishing and warming linked climate change (EMERGE project, 2000, EU FP5).

Lake managers face a dilemma since they are required to preserve the lakes' 'natural' state while maintaining traditional human activities linked to these areas. Each of these activities is likely to trigger, in the short or longer term, substantial changes in the ecological state of these mountain lakes (SCHINDLER 2001; KNAPP 2001), especially since their peculiar properties (small size, extreme climate conditions, remoteness, small number of species) make them highly sensitive to any biological or chemical disturbances in the environment.

Recently, rangers and scientists surveying mountain lakes in the French Alps and in Corsica have observed recent changes in their status, such as an increase in the algal production and the appearance of cyanobacteria (CAZAUBON 2006**)**, reduced water quality, hypoxic conditions at lake bottom (GIGUET-COVEX et al. 2012)**,** introduction and loss of species. But there is still a lack of knowledge about the reasons for these changes, the impact of the multistressors on lakes and about the means to protect or restore them. Currently, managers face up three main issues:

- What are the consequences of local human activities?
- What is the impact of global changes on the behavior and state of conservation of these ecosystems?
- How do these environments evolve? How to diagnose and correct for possible dysfunction?

In this context, ecosystems managers plus scientists from physical, biological and social sciences have joined a network called "Sentinel lakes". Its aim is to enhance research and information and data sharing on high altitude lake biodiversity and functions in a context of global change. It is coordinated by Asters (the manager of the nature reserves of Haute-Savoie) and includes researchers from universities, from the National Centre for Scientific Research and INRA (National Institute for Agricultural Research) as well as managers and stakeholders from French National Parks, National Nature Reserves, Water Agency, French National Fishery Federation and ONEMA (French Water and Aquatic System Board) from the French Alps and Corsica (BIRCK et al. 2013, accepted in Ecomount).

The objective of this article is to present the experience of the monitoring of the Haute-Savoie lakes, carried out within the framework of the French network "Sentinel lakes", which investigates how mountain lakes respond to local or global stressors.

Methods

Study sites and Framework

Initiated by the Scientific Committee of the Nature Reserves of Haute-Savoie, Asters (the manager of the nine nature reserves located in Haute-Savoie, France) has implemented a monitoring on 5 mountain lakes (table.1) that started 15 years ago. Chemical, physical and biological parameters are measured each year by the rangers to assess the evolution of the ecosystem. INRA of Thonon carries out the analyses.

Table 1: Morphological and physic-chemical characteristics of the 5 studied lakes

Lakes	Brévent	Cornu	Pormenaz	Grand Jovet	Anterne
Nature Reserve	Aiguilles Rouges	Aiguilles Rouges	Passy	Contamines-Montjoie	Sixt-Passy
Geolocation	45°92'N ;6°82'W	45°95'N;6°84'W	45°96'N ;6°79'W	45°75'N ;6°73'W	45°99'N ;6°79W
Altitude (m)	2159	2276	1945	2173	2063
Depth max (m)	20.4	22.0	9.4	8,5	12.5
Volume m3	230 000	550 000	168 000	330 000	760 000
Surface ha	2.9	5.3	1.3	5.5	11.5
Depth (average) (m)	7.9	10.4	12.8	4.4	6.6
Stocking with alevins	Stopped in 2011	Yes	Yes	Stopped in 2011	Yes
Chlorophyll *a* (µg/L)	2.30	1.42	1.09	1.45	0.66
Secchi depth	5.5	10.5	8.5	3.3	8.5
Chemical analyses on integrated sample (0-5m)					
PO4 (mgP/L)	0.003	0.004	0.001	0.004	0.002
NO3 (mgN/L)	<0.005	0.02	0.01	0.12	0.01
NH4 (mgN/L)	0.001	0.003	0.007	0.006	0.015
N total (mgN/L)	0.15	0.11	0.19	0.13	0.13
COT (mgC/L)	2.49	0.95	1.73	0.59	0.94

Sampling and analyses

The monitoring is designed to allow an easy sampling and field measurements for the rangers.
For each lake, sampling is carried out once a year, in September, at a reference sampling station located above the deepest part of the lake.

Various physical, chemical and biological parameters are followed:

- Water transparency is estimated from Secchi disk measurement.
- Vertical profiles are obtained along the water column using a multiparameter device for measurements of water temperature, pH, conductivity, dissolved oxygen concentration and conductivity.
- Sampling for metazooplankton counting is performed using a 60-µm-mesh zooplankton net from a vertical haul from near-bottom to the surface.

- From an integrated sample (5L obtained for the stratum 0-5m), a first sub-sample (500mL) is preserved for microphytoplankton counts, a second subsample (50 ml) is used to quantify the abundance of picophytoplankton (i.e. picocyanobacteria and small autotrophic eukaryotes) by and a third sub-sample (1L at least) is used to collect Chlorophyll-a on Whatman GF/C filters.
- Chemical analyses are performed both from the integrated sample (0-5m) and from a water sample taken at deepest depth of the water column. The total organic carbon (TOC) and nutrient concentration (N total, NH_4^+, NO_3^-, SiO_2, P total, PO_4^{3-}) are measured according to the standard french protocols AFNOR (details available at http://www.thonon.inra.chimie.net/page/public/analyses.asp).

Figure 1: Sampling in lake Anterne by the ranger of the natural reserve (ASTERS).

Results

Not all the results are detailed in this article but we rather focused on the main characteristics of the lakes:

Chemical parameters

As described previously by WINIARSKY (2000) these lakes are considered oligotrophic (in terms of availability of dissolved nutrients and transparency of water) however one lake of these (Lake Brévent) is characterized by higher concentrations of total organic carbon and total nitrogen and lower water transparency which confirm a potential enrichment of this system that could lead to disturbances in food web functioning.

Biological parameters

As generally expected for high altitude lakes, the chlorophyll-a concentration are low. In our case, the highest concentrations, measured in Lake Brévent, does not exceed 2.3 µg/L, while the lowest value (0.66 µg/L in 2012) is estimated in Lake Anterne. However, phytoplanktonic biomass while moderate, is not extremely low in comparison to biomasses recorded in large deep lakes (i.e. Lake Brévent exhibited phytoplanktonic biomasses that varied from 400 000 µm3/mL to ~3 500 000 µm3/mL)

It's worth mentioning that the phytoplanktonic composition of these 5 lakes is contrasted. Indeed the dominant taxa in lakes Anterne & Jovet (the most oligotrophic systems) are mainly diatoms (with especially centric diatoms as *Cyclotella* spp in Lake Anterne and pennate diatoms as *Staurosira* (which is generally considered as a benthic species) or *Amphora* in Lake Jovet). The importance of diatoms is consistent with rather high concentrations in silica in these 2 lakes exhibited the lowest phytoplanktonic biomasses (Figure 2). In contrast, in Lake Cornu, Dinophyceae and Chrysophycées dominate the phytoplanktonic biomass with especially *Peridinium and Gynmnodinium, while* Chlorophyceae dominate in Lake Pormenaz (with especially small chlorophyceae as *Oocystis* and *Chlorella* spp.) and Lake Brévent is characterized by the dominance of Zygophyceae (particularly *Spondilosium* (small size plankton <10µm)) and the lowest value for Shanon diversity index.

Discussion

Methological aspects

This monitoring protocol differs widely from protocols requiring intensive monitoring, as it is the case for some environmental observatories (SOERE GLACPE; http://www.allenvi.fr/?page_id=775), but it is considered sufficient to observe the status and trends of these small mountain lakes. Protocols are likely to evolve over the years, particularly with the implementation of the project "sentinel Lakes". For instance, a recent ecological diagnosis performed on Lake Brévent confirmed, based on a benthic indicator (Indice Biologique Lacustre, VERNEAUX et al. 2004), the existence of perturbation in the ecological status of this lake (BELLE 2012).

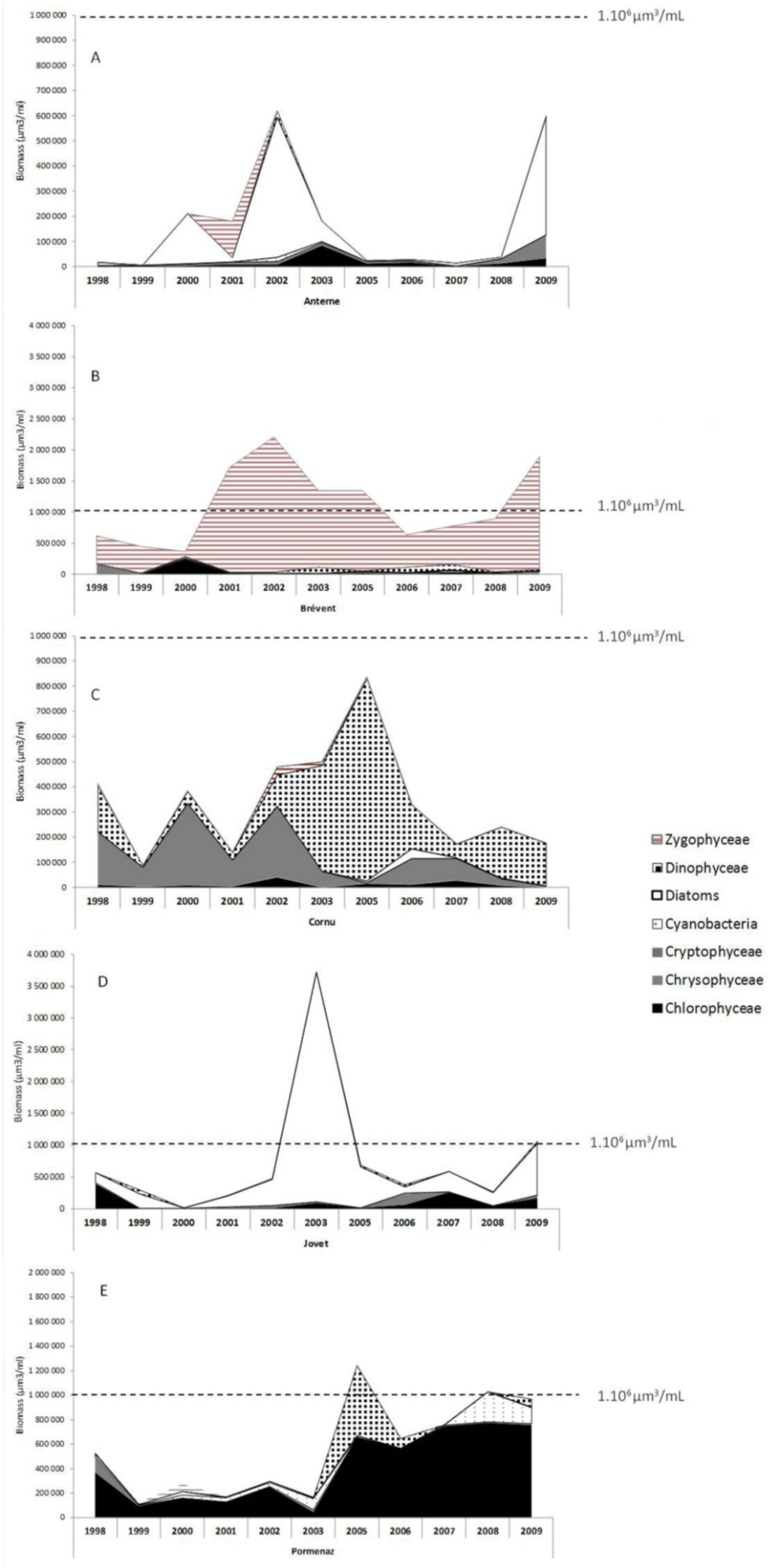

Figure 2: Temporal dynamics of phytoplanktonic biomass (expressed as µm3/mL) in the five lakes over a 10 years period.

Apart from the relevance of the physical-chemical-biological parameters, the robustness of the protocol depends on the availability of rangers (time devoted to research in proportion to police and management work in Natural Reserve), access to the site, partnerships with research laboratories for analysis.

It's necessary to distinguish in first hand the establishment of monitoring "routine" where managers are independent at least for the sampling and in the other hand a full monitoring on specific sites where managers supports the scientists in logistical knowledge of the field.

Knowledge on food web structure is essential for lake characterization.

Biodiversity has been identified as one of the key factors determining lake resilience. Consequently, a crucial issue for lake management is to unravel the controlling factors of biodiversity. High altitude and latitude lakes are supposed to have low biodiversity and resilience**.** Indeed, high altitude and latitude lakes commonly have low species richness, mainly due to a short growing season, high UV radiation, low nutrient levels, limited food resources, low temperature, low habitat heterogeneity, small lake size, and geographical isolation that create migration barriers and enhance the "island effect". As a consequence, in such lakes, the functional redundancy is theoretically initially low and therefore any loss of species caused by changing conditions (local and global changes) should induce a shift toward less desired state which is probably higher in these "sentinel" lakes than in initially more diverse systems.

However, it seems rather clear from our data that all high altitudes lakes cannot be considered similar in terms of biological diversity and structure of biological communities. Indeed the five studied lakes are characterized by contrasted structure and composition of phytoplanktonic communities. These differences reveal contrasted functioning of the lakes' food webs; as a consequence, we can expect that the effect of forcing factors may lead to different types of responses according to the considered lake.

The major types of stressors that potentially combine to adversely affect lake biodiversity, functioning, and services include eutrophication, acidification, toxic pollution, climate change, and species introduction (among which fish, which are able to impact the structure and functioning of lake food webs via top-down effects). Even high altitude lakes long considered as pristine sanctuaries can be deeply impacted.

In the multi-stressors situation, this is a critical issue to get a better understanding and prediction of the response of the lake biodiversity and functioning to changing environment and climate.

In prospect…

The creation of a mountain lake observatory at the scale of the French Alps will be a priority to provide an evaluation and decision support tool to the management of protected areas. It will require a standardized monitoring of the lakes from the northern Alps to Corsica to have a set of data (physicochemical, biological…) which are consistent on the whole territory before extending them to other mountain ranges. Once validated and analyzed by scientists, the data will constitute a key component for sharing information between different stakeholders in the framework of this network.

The network will also allow the synergy between research and managers on identified studied sites.
The goal is both to detect modifications in the ecological state of lakes (modifications which could be linked to changes in "lake-uses" (tourism, fishing etc)) and progress on the understanding of specific ecological process in order to, *in fine*, apply the adapted remediation.

Conclusion

There is evidence that, in spite of their remote position, high-altitude Alpine lakes have undergone modifications triggered by human pressure. Multidisciplinary research can help to understand how the ecosystem responds to these multi-stressors conditions. Monitoring of a large number of mountain lakes and sharing the results within the network will also enable better protection and management of these habitats.

In the future, there is a need to better characterize the causes of changes observed in these lakes, through further investigation and coordination of specific research project.

Other scientists and/or protected areas managers working on or interested in the subject are kindly invited to contact us.

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