

# CLANIMAE - Results

## Climatic and Anthropogenic Impacts on African Ecosystems

DURATION OF THE PROJECT  
01/01/2007 - 31/07/2011

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### KEYWORDS

Biodiversity, climate change, East Africa, ecosystem services, hydrology, natural resources, paleoecology, soil erosion, sustainable water-resource development, vegetation dynamics, water quality

### CONTEXT

The magnitude and geographic reach of human impact on Earth's biosphere has increased rapidly over the last century, in particular in East Africa where rates of population growth and the intensification of agriculture are among the highest in the world, and where developing economies strongly depend on water and other goods and services provided by natural ecosystems. Economic development with conservation of biodiversity and ecosystem functioning requires spatially and temporally explicit knowledge of the timing and relative magnitude of (pre-)historical and modern human impact on terrestrial and aquatic ecosystems to 1) evaluate the current health of these ecosystems and their resilience to anthropogenic disturbance, 2) model the range of their possible responses to future climatic, demographic and economic change, and from these 3) develop locally optimal strategies for land and water-resource management.

3) evaluate the resilience of African ecosystems, and the prospects for restoration of disturbed ecosystems if human pressure were to be reduced.

### MAJOR RESULTS AND CONCLUSIONS OF THE RESEARCH

CLANIMAE activities were grouped in 5 work packages dealing with 1) the calibration and validation of paleoenvironmental indicators; 2) reconstruction of past climate variability; 3) reconstruction of (pre-)historical changes in terrestrial ecosystems; 4) reconstruction of (pre-)historical changes in water quality; and 5) data integration and causal attribution of past environmental change. Part of these activities were developed through comparative study of diverse crater lake ecosystems in western Uganda. We completed seven field campaigns, during which we surveyed a total of 66 lakes. For all lakes we collected data on basin morphometry, land use, water-column transparency and frequency of mixing, water chemistry, nutrients, aquatic biota (algae, zooplankton, zoobenthos) and aquatic productivity; and collected intact surface-sediment samples for calibration of diverse paleoecological proxies in relation to modern-day environmental gradients and the intensity of human activity within lakes' catchments. Analysis of the water-quality and environmental data revealed significant negative exponential relationships between transparency (measured as Secchi depth, SD) and total phosphorus concentration, and between transparency and algal biomass (measured as the concentration of chlorophyll a).

This relationship allows rough estimation of the productivity of Uganda crater lakes using simple measurements of Secchi disk depth. There was no significant correlation between transparency and dissolved inorganic nitrogen. Our data indicate that the water column of most fresh Uganda crater lakes mixes completely at least occasionally, but only those less than about 30 m deep mix completely at least once per year. Meteorological conditions allowing the complete mixing of deeper lakes (cold air temperature coinciding with windy conditions) are relatively rare, on the order of once in several decades for some of the deepest lakes.

### OBJECTIVES

CLANIMAE aimed to produce guidelines for sustainable management of land and water resources in tropical East Africa, partly through comparative study of pristine and disturbed ecosystems in the modern landscape, and partly by reconstructing the long-term historical perspective to climate-environment-human interactions affecting those ecosystems today. This **'the past is the key to the present (and future)'** approach was developed by coupling data of past vegetation and water-quality changes preserved in dated lake-sediment records to information on decadal to century-scale climate variability across the gradient from humid western Uganda to semi-arid eastern Kenya. With this methodology, CLANIMAE achieved to

- 1) separate the influences of past natural climate variability and past human activity on East African ecosystems, and determine the timing and relative magnitude of pre-20<sup>th</sup> century ecosystem disturbances by indigenous people compared to colonial-era and recent landscape alteration;
- 2) determine the severity of water-quality losses due to siltation and excess nutrient input directly caused by deforestation and agriculture, compared to temporal variability in water quality associated with natural long-term ecosystem dynamics; and



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We then selected 30 principal study lakes to determine the influence of water-column depth and frequency of mixing on a lake's vulnerability to water quality loss when subjected to human exploitation of the surrounding landscape. We classified these lakes according to their aquatic productivity using the Trophic Lake index  $TLi = Chl\ a/SD$ . Among the 30 study lakes, 7 are oligotrophic (low productivity,  $TLi < 0.02$ ), 9 are mesotrophic (moderate productivity,  $0.02 < TLi < 0.12$ ), 11 are eutrophic (high productivity,  $0.12 < TLi < 0.6$ ) and 3 are hypertrophic (very high productivity,  $TLi \geq 0.6$ ). Uganda crater lakes not or little impacted by human activity tend to be oligotrophic when  $>90$  m deep, and mesotrophic when  $<90$  m deep. Lakes with significant human impact can be oligotrophic (depth  $>90$  m), mesotrophic (depth range 35-90 m) or eutrophic/hypertrophic (depth  $<35$  m). Thus, significant land use within a crater basin is likely to raise the productivity of shallow and moderately deep lakes, while very deep lakes remain relatively unaffected. The large volume of their rarely mixed lower water column allows more or less permanent nutrient storage, because the low frequency of deep mixing hampers nutrient recycling to the lake surface where production takes place.

CLANIMAE developed the first inference model to reconstruct past changes in the aquatic productivity of African lakes based on assemblages of fossil diatom algae preserved in lake sediments. Simultaneous investigation of the silicon-isotope composition of fossil diatoms as a possible geochemical tracer for past aquatic productivity resulted in improved understanding of the important silica cycle in African lakes. We also studied environmental controls on the distribution of aquatic plants in Ugandan crater lakes, similarly to explore their value as environmental indicators. This analysis revealed eight major ecological communities, each with particular indicator species and with distinct habitat requirements for local water depth, distance from shore, transparency (or its inverse, turbidity), temperature, dissolved ion content and dissolved oxygen. Use of fossil remains of aquatic plants to infer past changes in lake hydrology and water quality is compromised by poor preservation of several species, which introduces bias in paleo-environmental interpretation. This can be partly resolved by using well-preserved species as proxy indicator for particular aquatic plant communities. Parallel studies on the distribution of Cladocera (water fleas) and Ostracoda (mussel shrimps) in 62 Uganda crater lakes demonstrated their potential as biological indicators for water quality and ecosystem health in East African lakes. By playing an important role in the aquatic food web, both groups contribute to the ecological integrity of these lake ecosystems. The distribution of Cladocera among lakes was influenced mainly by nutrient availability (total phosphorus concentration), aquatic plant diversity, pH and the fraction of the lake basin under agriculture.

An important part of the work programme focused on reconstructing past vegetation dynamics based on analysis of fossil pollen in well-dated lake-sediment records. We also calibrated the magnitude of terrestrial ecosystem response to climate change as recorded in pollen data, by comparing the vegetation history of a pristinely natural and an anthropogenically disturbed landscape.

We found that even a few decades of mildly wetter weather (5-10% more rainfall), such as during the late 19<sup>th</sup> century and in the 1960s-1970s, caused significant migration of the grassland-woodland ecotone. This finding is important because this ecotone reflects the difference in ecological carrying capacity required for pastoralism vs. (irrigated) crop agriculture.

Some important African food staples such as banana can be traced in time using phytoliths, glass bodies present in plant tissue. Partly through a BeISPO-funded visiting postdoctoral fellowship, CLANIMAE validated fossil phytoliths as indicator of past banana cultivation by calibrating the relation between phytolith abundance in the sediments of 25 Ugandan lakes and the surrounding cover of banana plantations. This test classified land-cover in 6 types of natural vegetation, 16 types of cultivated crops, and 4 types of fallow agricultural land. We used the same sediment samples and land-cover data to calibrate the ecological indicator value of African non-pollen palynomorph microfossils recovered in fossil pollen preparations, also along a landscape gradient ranging from pristinely natural to severely impacted by human activity.

CLANIMAE produced new vegetation reconstructions for the Queen Elisabeth NP, Bunyaruguru and Kasenda areas of western Uganda, and for the eastern Lake Victoria and Mt. Kilimanjaro areas of southern Kenya. These and published records indicate that significant human impact on the East African landscape (deforestation, crop cultivation) dates back to (at least) ~1000 AD in sub-humid western Uganda, and to ~1700 AD in central Kenya. Semi-arid environments reveal tentative signatures of land use by pastoralists dating back up to 600 years, but the more intense vegetation and soil disturbance typical of crop cultivation, and the resulting water-quality loss, appears mostly limited to the last 70-80 years. Fossil-diatom data from Lake Chibwera showed no evidence of recently increasing productivity or water-quality loss, consistent with the undisturbed condition of savanna vegetation in Queen Elisabeth National Park. In contrast, data from the heavily impacted Lake Katinda (and Kanyamukali) indicate that anthropogenic water-quality loss started ~700 years ago. Earlier evidence for increased productivity can also be explained by temporary, climate-driven episodes of low lake level.

### CONTRIBUTION OF THE PROJECT TO A SUSTAINABLE DEVELOPMENT POLICY

Referring to stated priorities of the 'Science for a Sustainable Development' (SSD) programme, CLANIMAE addressed important research questions with critical relevance to the environmental policy on 1) sustainable economic development, 2) natural resource management, 3) biodiversity conservation, 4) adaptation of vulnerable communities to global change, and 5) a more humane globalization.



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Project results particularly relevant to policy development on water and land resources in tropical Africa are:

- 1) The productivity of Uganda crater lakes can be monitored using simple, repeated measurements of water-column transparency with a Secchi disk.
- 2) The vulnerability of Uganda crater lakes to eutrophication and water-quality loss for a given intensity of land use is strongly related to lake depth and the associated frequency of water-column mixing. Lakes < 35 m deep are highly vulnerable, lakes > 90 m deep are relatively resistant to water-quality loss. In their pristine condition, shallow Uganda lakes are usually mesotrophic (with slightly elevated productivity), not oligotrophic (unproductive).
- 3) Clear-water crater lakes (now almost without exception >90 m deep) are a most valuable source of drinking-quality water, and should be managed for ecotourism and modest recreation only. More productive lakes of shallow or intermediate depth (35-90 m) already subject to intensive land use can be managed for fisheries development and agricultural water extraction, the latter within limits determined by lake volume and water renewal rate. In both shallow and intermediate-depth lakes, runaway algal production leading to noxious blooms and frequent fish kills can be avoided by creating buffer strips of vegetation preventing soil run-off from reaching the lake. Fish farming should be limited to productive shallow lakes, where added nutrients and food are continually recycled into the water column.
- 4) Variation in species of aquatic plants, diatom, zooplankton and zoobenthos along gradients of natural habitat and intensity of human impact confirm their applicability as biological water-quality indicators in African lakes.
- 5) Evidence for major natural vegetation response to modest historical rainfall variability shows that strategies for sustainable economic development must take into account large temporal variability in ecosystems, which affects their carrying capacity and realized service to society.
- 6) In semi-arid regions (e.g., the central Kenya Rift Valley), hydrological sensitivity of lakes to naturally large water-balance fluctuations requires creation of a water-resource buffer against intermittent severe drought. Studies of sedimentation help set appropriate limits to water extraction by identifying the lake-level threshold below which a clear-water, healthy ecosystem state switches to a turbid state with poor water quality.
- 7) The crater lakes of Uganda carry value well beyond their own economic significance as analogs of ecosystem functioning in the large lakes Victoria and Tanganyika, in their historical, present-day and possible future state.

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