WOTRO

Netherlands Foundation
For the Advancement of
Tropical Research

2003 *Please consult instructions and subsidy guide* **File number:**

Status:	**Individual research project - New Project**			
1. **Applicant(s):** name and affiliation (not necessary to fill in address details again)	Marten Scheffer, Aquatic Ecology and Water Quality Management group, Wageningen University			
2. **Project title:** (including country of research in parentheses)	**Climate induced shifts in South American Lake Ecosystems Threats and Novel Restoration Perspectives**			
3. **Project outline:** (in case of subsidising the project, this description will be used in WOTRO yearbook and other WOTRO publications)	Shallow lakes are an important natural resource in many densely populated areas in South America. Temperate shallow lakes are among the best understood ecosystems in terms of stability and community dynamics. In particular, it has been shown that such lakes tend to be in either of two alternative stable states: a clear state dominated by submerged plants and high in biodiversity, and a turbid state dominated by phytoplankton which is much lower in biodiversity and has various water-quality problems that greatly reduce human utility. Preliminary work suggests that shallow lakes may be very sensitive to climatic change. However, our ability to predict effects of expected climate change is limited severely by a lack of appropriate data on lower latitude lakes. In the proposed project we will sample 100 lakes along a latitudinal gradient from Brazil to Argentina and analyze sediment cores and time series of satellite images to address the hypotheses that I) average climatic conditions affect the critical nutrient level at which shallow lakes fall into a turbid state, and II) extreme meteorological conditions can induce shifts between alternative stable states. The anticipated results will be of great fundamental value as they would provide the first test of the hypothesized response of multiple stable ecosystems to climate change. Furthermore, they will provide water quality managers in South America as well as Europe with a tool for predicting potential effects of climate change. A practical implication is that predicted El Niño or La Niña events may be used as a 'window of opportunity' to shift lakes to a clear state with relatively little effort.			
4. **Composition of the research group:** - in the Netherlands: (in case of PhD-research, please indicate promotor)	Names and titles	Specialisations/universities	Financed by	Hours per week on project
	Prof.dr. Marten Scheffer (promotor)	**Aquatic Ecology/ Wageningen University NL**	**WU**	**4**
	Prof. Dr. André. F. Lotter	Palaeolimnology Utrecht University NL	UU	1
	AIO	**Aquatic Ecology**	**ALW**	**36**
- in the country where the project is carried out: - in other countries:	**Dr. Nestor Mazzeo**	**Aquatic Ecology/ University of Montevideo, Uruguay**	**UM**	**4**
5. **Previous** file number:	- W 01.53.2002.061			
6.	Proposed starting date:			

2003

Duration of the project:	Four years	January 2004

7.

Detailed description of the project including at least the following aspects:

a. scientific significance/ innovative aspects

b. hypothesis/research question

c. research methodology

d. history of the project

e. co-operation with other national and international universities/research groups

(**max. 3500 words**, using **Arial 10 pt font**, **add word count**; **i**nsertion of additional pages is allowed)

Freshwater of good quality is an increasingly limiting resource in many areas of the world. The basic mechanisms behind eutrophication with resulting toxic algal blooms and other forms of pollution have been well studied. However, the potential impact of climatic variation on water quality and aquatic biodiversity is still largely unknown. In this study we will address this aspect focussing on shallow lakes (depth < 4m) which are the dominant lake type in most flat areas of the world including The Netherlands and large parts of the South American Continent.

Intensive work over the past decade has made shallow lakes among the best understood ecosystems in terms of stability and community dynamics (Jeppesen et al. 1999; Scheffer 1998; Moss 1988). A remarkable property is that such lakes tend to be in either of two contrasting states: a clear state dominated by submerged aquatic vegetation, or a turbid state dominated by phytoplankton (Fig. 1). Lakes may shift abruptly from one state to the other, and intermediate stages are rare. Compared to the clear state, the turbid state is much lower in biodiversity of birds, fish and invertebrates and also has various water-quality problems that greatly reduce human utility. In particular, blooms of cyanobacteria in turbid lakes are notorious for causing deterioration of smell and taste as well as potentially serious toxicity of the water.

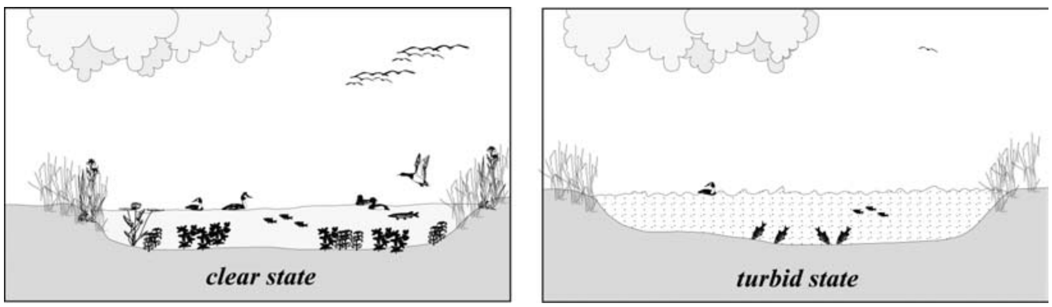


Fig. 1 Schematic representation of differences between two alternative stable states of shallow lakes

Eutrophication has driven many lakes that were originally clear to the turbid state, and efforts to restore these lakes to a clear state have long been unsuccessful. Even when the nutrient content of lakes was reduced to a level at which they were originally clear, most lakes remained in the turbid state. It appeared that this could be explained from the fact that both the clear and the turbid state have stabilizing mechanisms. Therefore, once a lake is in one state it tends to remain there. The interaction between submerged plants and turbidity is the main mechanism explaining this remarkable property (Fig. 2).

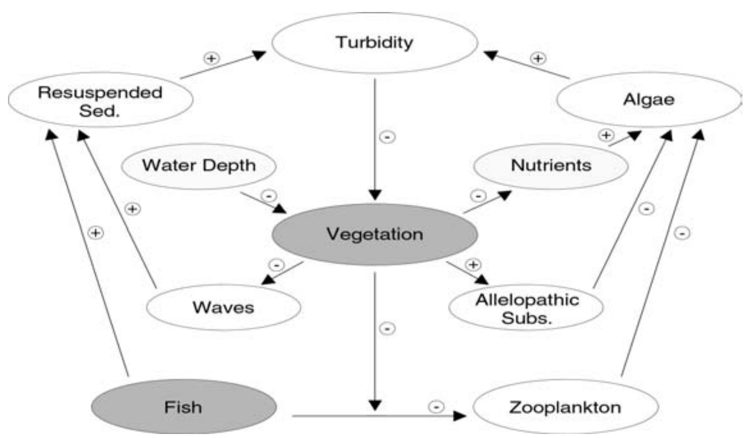


Fig. 2 Lack of light in turbid water suppresses growth of submerged vegetation, however vegetation itself can reduce turbidity through a suite of mechanisms: Aquatic plants reduce nutrient availability for planktonic algae, excrete allelopathic substances that limit algal growth, reduce wave resuspension of sediments, and provide a refuge against fish predation for zooplankton which graze on the algae. Thus, once submerged plants are present they improve their own growing conditions.

The stability of the clear and the turbid state depend to a large extent on the ***nutrient content*** as can be illustrated by a simple graphical model (Fig. 3).

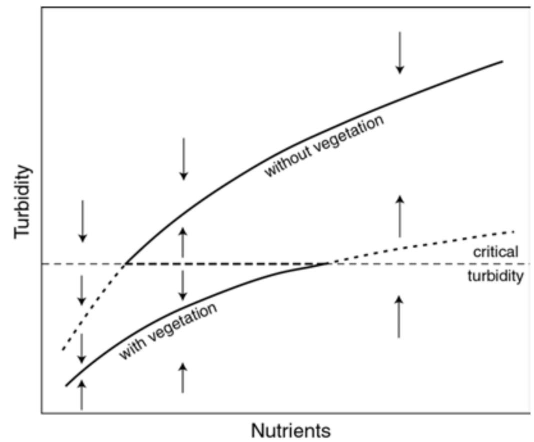


Fig. 3. A graphical model of the effects of nutrients on the state of a shallow lakes based on three assumptions:1) Turbidity increases with increasing nutrient levels. 2)Vegetation reduces turbidity. 3) Vegetation disappears entirely when a critical turbidity is exceeded. In view of the first two assumptions, equilibrium turbidity can be drawn as two different functions of the nutrient level: one for a macrophyte dominated, and one for an unvegetated situation. Above a critical turbidity, macrophytes will be absent, in which case the upper equilibrium line is the relevant one, below this turbidity the lower equilibrium curve applies. Over a range of intermediate nutrient levels two alternative equilibria exist: one with macrophytes, and a more turbid one without vegetation. At lower nutrient levels, only the macrophyte dominated equilibrium exists, whereas at the highest nutrient levels, there is only a vegetationless equilibrium (Scheffer et al. 1993).

The course of the eutrophication process can be derived from this picture. Gradual enrichment starting from low nutrient levels will cause the system to proceed along the lower equilibrium curve until the critical turbidity is reached at which vegetation disappears. A jump to a more turbid equilibrium at the upper part of the curve occurs. In order to restore the macrophyte dominated state by means of nutrient management, the nutrient level must be lowered to a value where algal growth is limited enough by nutrients alone to reach the critical turbidity for macrophytes again. This likely explains why many shallow lakes remained turbid after nutrient reduction (Jeppesen et al. 1999; Meijer et al. 1999).

Note that at the extremes of the range of nutrient levels over which alternative stable states exist, either of the equilibrium lines approaches the critical turbidity that represents the breakpoint of the system. This corresponds to a decrease of '*resilience'* (Holling 1973). Near the edges, a small perturbation is enough to bring the system over the critical line and to cause a switch to the other equilibrium state.

Although it was originally thought that there is a fixed critical nutrient level at which shallow lakes become turbid, it is becoming increasingly clear that various factors affect this critical nutrient level. ***Water level*** in the lake is definitely an important variable, as can already be seen from the graphical model. Since vegetation can resist a higher turbidity if the lake is shallower, the horizontal breakpoint-line in the diagram will occur at a higher critical turbidity in shallower lakes. Thus, in lakes that are close to the breakpoint already, changes in water level can bring about a switch from one state to the other. This view is confirmed by observations of lakes which have shifted between clear and turbid states in response to water level change (Blindow et al. 1993; Wallsten and Forsgren 1989; Sanger 1994). Also, recent work suggests that ***lake surface area*** may affect the critical nutrient level for a collapse into the turbid state. For instance, work on 200 floodplain lakes along the lower Rhine suggests that smaller lakes are significantly more likely to be clear at a given nutrient level (Van Der Geest unpublished results).

An important unresolved question is what would be the potential impact of a ***warmer climate*** on the chances that shallow lakes fall in a turbid state. Although we have little information on this there are good reasons to expect a large climatic impact on these ecosystems. We know, for instance, that warmer conditions have a large effect on the so-called 'trophic cascade' from fish to phytoplankton. In temperate conditions most fish reproduce only once a year, leaving a period in spring in which there are few small (juvenile) fish, allowing large zooplankton to become abundant and filter the water clear of phytoplankton (Sommer et al. 1986). By contrast, top-down control of zooplankton by fish is very strong all year round in warmer lakes at low latitudes due to the fact that fish are abundant and reproduce continuously in such (sub)tropical lakes (Dumont 1994). This will tend to promote the turbid state in warmer lakes. On the other hand, numerous field studies in temperate lakes suggest positive effects of warming on aquatic vegetation performance (Grace and Tilly 1976; Best and Dassen 1987; Nelson 1997; Scheffer et al. 1992; Rooney and Kalff 2000) which would push the other way.

In systems with alternative stable states even brief ***climatic extremes*** may induce a shift to another state in which the system subsequently remains for a long time (Scheffer et al. 2001). Indeed, there are indications that shallow lakes may be affected by climatic extremes in this way (Scheffer 1998). For instance, heavy storms have induced a shift to a permanent turbid state by destroying vegetation (McKinnon and Mitchell 1994; Schelske and Brezonik 1992). An example is Lake Apopka in Florida which has been pushed to a turbid state by a hurricane in 1947 and never recovered to the clear state since then. However, perhaps the most important potential impact of climatic extremes is can be through their effect on water level fluctuations to which these lakes are very sensitive as mentioned before. Low water levels enhance light conditions for submerged plants, and also lead to increased fish mortality which may lead to a switch to the clear state (Scheffer 1998).

Hypothesis/ research questions

The proposed project aims to study the effect of lake size, average temperature and climatic extremes on the risk of shallow lakes to become turbid. Unlike Europe, the South American continent offers an excellent opportunity to study sets of comparable shallow lakes along a large latitudinal climatic gradient. In addition, much of the continent is exposed to pronounced (often El Niño related) climatic fluctuations. This makes it a perfect place to study not only the effects of gradual change in climate (through comparison along the latitudinal gradient) but also of extreme climatic events which are predicted to become more pronounced and frequent with global warming.

Specifically we will focus on three central hypotheses:

I) The critical nutrient level for maintaining a clear lake changes with average temperature.
II) Episodes of low precipitation leading to low water levels can push lakes to the clear state.
III) Smaller lakes have higher chances of shifting to the vegetation dominated state

Scientific significance and innovative aspects

The anticipated results will be of great fundamental value as they would provide the first test of the hypothesized response of multiple stable ecosystems to climate change (Scheffer et al. 2001). Perhaps more importantly, if we understand the effect of climatic variation on ecosystem stability, it would allow the use of extreme climatic conditions as a 'window of opportunity' to shift lakes to a clear state with relatively little effort (e.g. through fish-stock manipulation). This would be an entirely novel restoration perspective analogous to the recent idea using rainy El Niño events to trigger forest regeneration in semi-arid areas (Holmgren and Scheffer 2001) which is now being tested in large scale field experiments in Chile and Peru (http://www.biouls.cl/enso/).

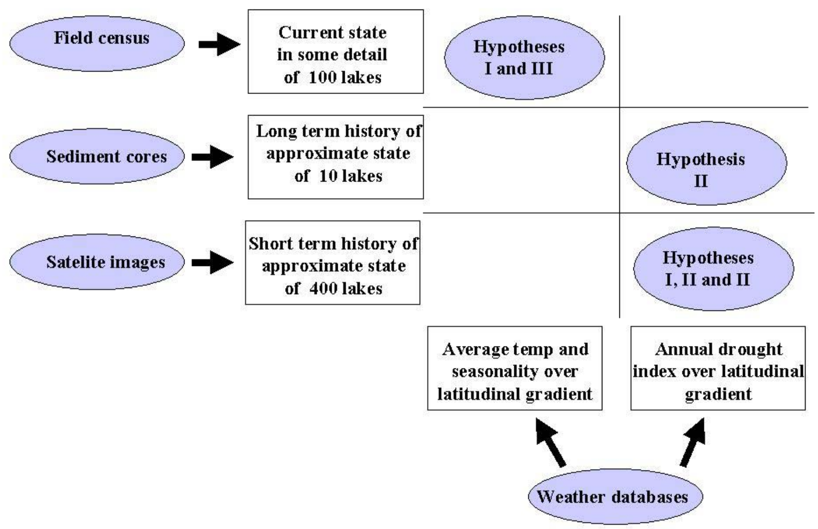
Research methodology

In order to address our research hypotheses, we will collect information on the current state and history of lakes along a latitudinal gradient in western South America and the climatic conditions along four lines:

1. A one-time mid-summer **census** of the state and basic properties of a selected set of about 100 lakes, complemented by existing sets of data from shallow lakes in the region.
2. Sediment **cores** of a representative subset of 10 of the censused lakes.
3. Time series of **satellite** images of the censused and other lakes.
4. Data on the latitudinal gradient of **climate** and history of climatic extremes from existing databases

Here we describe briefly how the information will be gathered and used to address the our three working hypotheses. The flow of information is summarized in the schedule at the end of this section.

	The **census** (1) will focus on depth, vegetation cover, turbidity, chlorophyll-*a*, nutrient concentrations and top sediment characteristics. Most measurements will be done with in situ equipment, but water, plankton and sediment samples will also be collected for later analysis. The data will be used to address the hypothesis that climatic conditions as they differ over the latitudinal gradient affect the critical nutrient level at which lakes fall into a turbid state. We will estimate the available nutrient pool in the lakes, and its distribution over water-column, macrophytes, and top-sediment (Jeppesen et al. 1991; Van der Molen and Boers 1994). Multiple logistic regression will be used to link the probability of the clear water state and macrophyte dominance and cyanobacterial blooms to variables such as lake depth, lake size, nutrients (total P-pool and other indicators) and climate (mean summer temperature, seasonal temperature amplitude and other indicators). To check whether critical nutrient levels for maintaining the clear-water state differ from those in Europe, we will use existing data on numerous Dutch lakes which are available at the Wageningen group, and data from other European lakes. The sediment **cores** (2) that we collect will be used to extract basic information on long term (centuries) dynamics of selected lakes. We will collect the top 2 meters from the center of the lakes using a Livingstone core with piston system. In order to keep this work package feasible within the current project we will focus the analysis on dating the cores (^{210}Pb and ^{137}Cs) and using simple chemical indicators for macrophyte dominance and other aspects of lake state. Although, this does not have the resolution of a full palaeolimnological approach, it will likely produce good hints on major changes in the lakes. For instance, work on Lake Apopka (Florida USA) which switched from clear to turbid half a century ago has demonstrated that the C/N ratio adequately indicates whether the lake was clear and vegetated or turbid and phytoplankton dominated (Schelske 1999). The relationship between top-sediment characteristics and the other measured variables in the censused lakes will be used to tune and develop simple transfer functions that relate sediment core characteristics to ecosystem state. We will especially look for correlations to known climatic extremes such as droughts in the resulting data set, but also use it to obtain a rough image of the natural succession and possible antropogenic influences. Although we expect to obtain important information from this superficial approach we will seek additional funding to do a thorough analysis of the cores. **Satellite** images (3) from Landsat Thematic Mapper (or a comparable system) of the 100 lakes at the time of sampling will be collected. The census data of the 100 lakes-set will be used to tailor existing algorithms that predict turbidity and vegetation dominance from reflection at different wave-lengths (Dekker et al 2001). Subsequently these algorithms will be used to check on a large set of lakes (approximately 400) whether ecosystem states fall into distinct contrasting clusters which is a way to check the alternative stable state hypothesis (Carpenter 2001; Scheffer et al. 2001). Furthermore, recent history (past 15 years) of lake state change across the latitudinal gradient will be reconstructed from sets of satellite images. This analysis will show how frequent state shifts occur, and how they are related to lake size, average climatic conditions and climatic extremes such as droughts The **climate** data will be obtained from existing data bases. As indicated our focus will be on seasonality and average values of temperature and on precipitation anomalies on the locations along our latitudinal gradient.



History and co-operation among research groups

The project will be coordinated by Nestor Mazzeo (Uruguay) and Marten Scheffer (NL). In order to cover the broad latitudinal and methodological spectrum needed to address our research questions properly, it is essential that several key researchers have agreed to collaborate in the proposed project. Here we briefly describe the research network and its history.

The Uruguayan group headed by Nestor Mazzeo has over the past years created a boost to the research on stability of lake ecosystems and their foodwebs in South America. PhD courses in Montevideo by renown specialists such as Brian Moss, Colin Reynolds, Marten Scheffer and Erik Jeppesen have helped tuning in to state-of-the-art aquatic systems ecology. Importantly, the 1999 course by Scheffer which was visited by students from Uruguay, Argentina and Brazil has lead to intensive ongoing exchange of students and ideas, and to cooperation on several themes. The Uruguayan group has also a history of cooperation with Xavier Lazzaro who is a specialist on Brazilian lakes. The inclusion of these key-researchers in our current team ensures that we can cover the latitudinal gradient in a proper way, select lakes efficiently and have good access to existing data that can be of use. In the Netherlands the expertise of Marten Scheffer of lake ecology and stability will be complemented by that of Jan Clevers who is a remote sensing specialist in the same department, and by André Lotter and Henry Hooghiemstra for coaching of the Palaeolimnological work.

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