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Eutrophication and restoration of shallow lakes – the concept of stable equilibria revisited

Martin T. Dokulil & Katrin Teubner
Institute of Limnology, Austrian Academy of Sciences, Mondseestrasse 9, A-5310 Mondsee, Austria
E-mail: martin.dokulil@oeaw.ac.at

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Abstract

Shallow polymictic lakes are very abundant in many regions of the world, they are more numerous than deep lakes and are of great importance especially in densely populated areas even when small. Their ecology differs from stratified lakes in many ways. During the eutrophication process, lakes may change from a clear water, macrophyte dominated state to an algal dominated state, a process known as the concept of 'alternative stable equilibria'. The usefulness of this concept as a descriptor for the eutrophication process and as the basis for rehabilitation of lakes is tested on long-term data from two contrasting case study sites using a novel multivariate bubble-plot technique. In one case the concept proved to be useful and successful while it could not be applied to a large shallow turbid lake. The equilibrium concept is then generalised using further examples. Shallow lakes which are either macrophyte dominated or light limited because of high inorganic background turbidity have ratios of total phosphorus (TP) to algal Chlorophyll-*a* at or below 3:1. Deep oligotrophic or algal dominated lakes in contrast exhibit ratios between 3:1 and 1:1. Alternative stable equilibria of macrophyte or algal domination can occur within the same water-body at various locations, at different times of the year or during trophic development.

Introduction

Shallow lakes are more numerous worldwide than deep lakes and provide humankind with many services such as nutrition, water for drinking, irrigation and dilution of pollutants, transportation, recreation and aesthetic enjoyment (Padisák & Reynolds, 2003). These services are impaired by exploitation, most commonly by nutrient enhancement leading to eutrophication. Restoration, rehabilitation and management are therefore needed to ensure sustainable development.

In contrast to deep lakes, many shallow lakes can quite abruptly switch between different stable states representing alternative equilibria, a hypothesis developed and established over the past 20 years and summarised in Scheffer (1998). Lakes can switch from a clear-water macrophyte dominated state to a new turbid state dominated by phytoplankton. This bistable situation has been intensively investigated (e.g. Blindow et al., 1993; Scheffer et al., 1993) while situations of stable states within phytoplankton assemblages or more than two equilibria have attracted much less attention (Scheffer, 1998).

This paper tries to explore how generally applicable this concept is as a tool for restoration of eutrophied shallow lakes. The argument is mainly developed from results originating from two case study sites, Alte Donau (Old Danube) and Neusiedler See. Generalisation is attempted using published data from a number of other lakes.

The sites

Both sites are situated in the Pannonian European Ecoregion, they are shallow, wind exposed and with similar nutrient levels. Morphometric and hydrological features of the two sites are summarised in Table 1. Alte Donau is an urban seepage lake of moderate size and has a relatively short retention time. The lake has been densely covered by submerged macrophytes and stone wort in the past (Löffler, 1988). As an endorheic