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Phytoplankton community dynamics of two adjacent Dutch lakes in response to seasons and eutrophication control unravelled by non-supervised artificial neural networks

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ABSTRACT

Long-term time-series of the eutrophic Dutch lakes Veluwemeer and Wolderwijd were subject to ordination and clustering by means of non-supervised artificial neural networks (ANN). A combination of bottom-up and top-down eutrophication control measures has been implemented in both lakes since 1979. Dividing time-series data from 1976 to 1993 into three distinctive management periods has facilitated a comparative analysis of the two lakes regarding both the seasonal and long-term dynamics in response to eutrophication control. Results of the study have demonstrated that non-supervised ANN are an alternative technique: (1) to elucidate causal relationships of complex ecological processes, and (2) to reveal long-term behaviours of ecosystems in response to different management approaches. It has been shown that external nutrient control combined with food web manipulation have turned both lakes from nitrogen to phosphorus limitation, and from blue-green algae to diatom and green algae dominance.

1. Introduction

Both lakes Veluwemeer and Wolderwijd are situated in the central part of The Netherlands in-between reclaimed polders and the mainland. Being adjacent both lakes share similar geographical and climate conditions with mean depths of 1.6 m and 1.8 m and surface areas of 3400 ha and 2500 ha respectively (Table 1). Increased nutrient loadings during the 1960s and 70s caused eutrophication and frequent blue-green algal blooms. In 1979 a sewage treatment plant up streams to Lake Veluwemeer and winter flushing of the lake with phosphorus poor water was put into operation. As Lake Wolderwijd receives out flowing water from Lake Veluwemeer, its eutrophication status gradually improved as well since the early 1980s as a result of eutrophication control in Lake Veluwemeer. The fact that these two lakes have been studied simultaneously for almost 30 years under similar climate and environmental conditions but under different management makes them unique study sites for multivariate time-series analysis by ordination and clustering. Ecological time-series data of lakes have previously been ordinated and clustered by conventional multivariate statistics (e.g. Varis et al., 1989; Varis, 1991; Van Tongeren et al., 1992) but failed to cope with the multiple non-linear nature of the data. By contrast data ordination and clustering by non-supervised ANN (Kohonen, 1989, 1995) proves to be applicable to highly complex and non-

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Table 1 – Comparison of attributes of the Lakes Veluwemeer and Wolderwijd

Attributes	Lake Veluwemeer	Lake Wolderwijd
Latitude	52° 23'	52° 20'
Longitude(–0.2 m below sea level)	5° 40'	5° 35'
Area (km^2)	32.4	26.7
Maximum depth (m)	7.8	5.7
Mean depth (m)	1.58	1.81
Precipitation (mm)	800	800
Geological components	Sandy deposits	Sandy deposits

linear data including limnological time-series (e.g. Chon et al., 1996; Recknagel et al., 2006a,b).

In the framework of the present study non-supervised ANN were applied to the ordination, clustering and mapping of relationships between physical, chemical and biological time-series data of the two adjacent lakes. Three distinctive periods of data from 1976 to 1978, 1983 to 1985 and 1991 to 1993 reflecting pre- and postmanagement conditions at different stages were processed by non-supervised ANN. The aim of the study was to test non-supervised ANN as alternative technique for determining improvements in water quality and changed dominance of phytoplankton 2 populations in both lakes in response to the consecutive implementation of external phosphorus control and food web manipulation.

2. Study sites, materials and methods

2.1. *Lake Veluwemeer*

Lake Veluwemeer was created in 1957 and is adjacent to Lake Wolderwijd (Fig. 1). Both lakes have similar geographical and hydrological conditions (Table 1). Originally Veluwemeer was a clear water lake with abundant macrophytes. From 1965 onwards the lake became increasingly turbid as a result of rising phosphorus loadings. As a result frequent blooms by *Planktothrix agardhii* occurred in the mid-1970s. Phosphorus control by a sewage treatment plant and lake flushing in winter was implemented in 1979. Polder water with low concentrations of algae and phosphorus but high concentrations of calcium and nitrate was used for flushing. From 1985 onwards, summer flushing was also implemented. Commercial fishing was introduced to Lake Veluwemeer in the early 1990s, peaking in 1994 (Portielje and Rijsdijk, 2003).

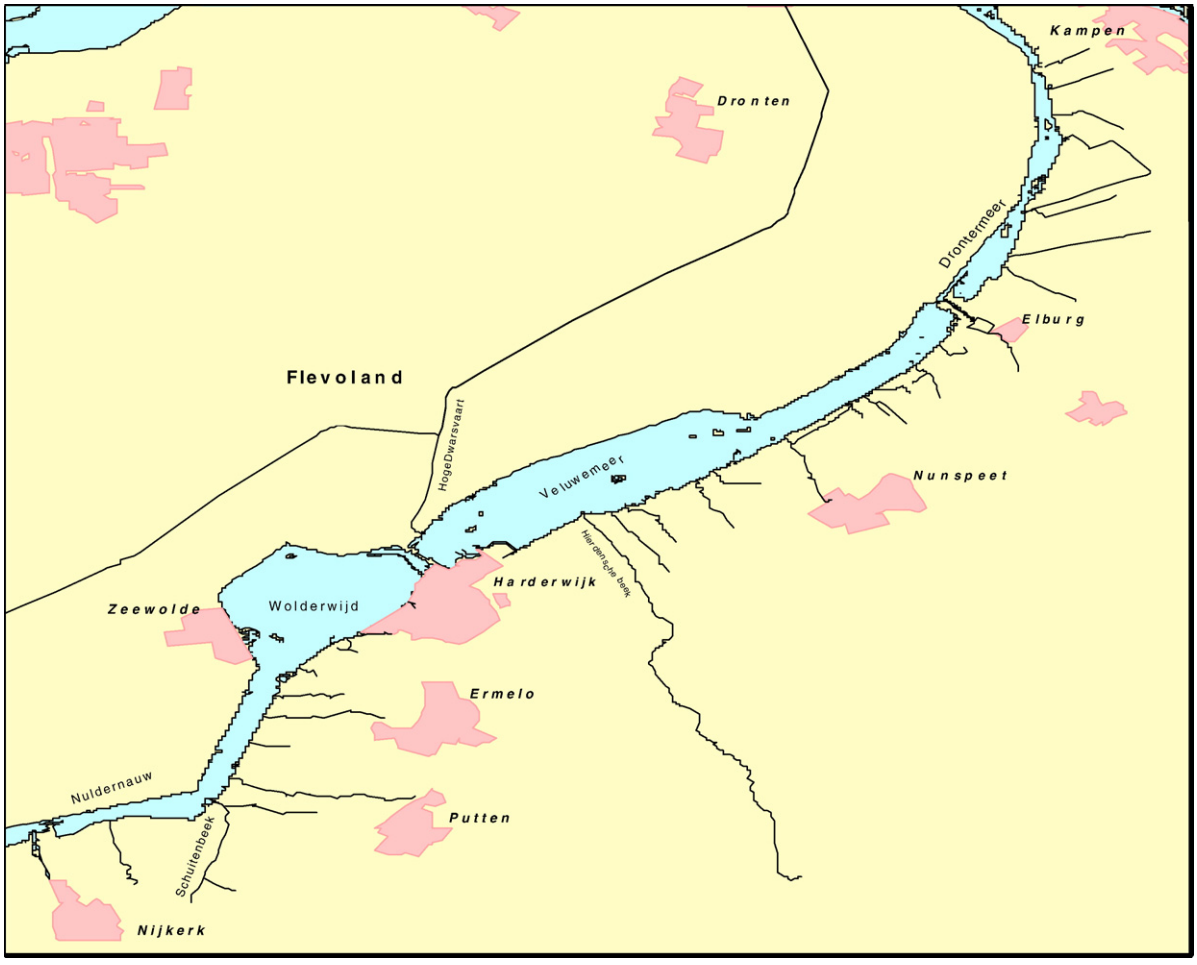

Fig. 1 – Locations of Lakes Veluwemeer and Wolderwijd in central Netherlands.