ASSESSMENT OF ECOLOGICAL INTEGRITY FROM ENVIRONMENTAL VARIABLES IN AN IMPACTED OLIGOTROPHIC, ALPINE LAKE: WHOLE LAKE APPROACH USING 3D-SPATIAL HETEROGENEITY

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Abstract. The ecological integrity of a lake as a whole can only be assessed through an adequate sampling strategy. Spatial heterogeneity of phytoplankton as well as vertical and horizontal variability of physical and chemical variables were estimated from 57 stations at four seasons differing in their hydrological regime. Resolution of grid positions, located by GPS, was 250 m near the impact site, 500 m for the southern part of the lake, and 1000 m in the northern part. Data are analysed by conventional gridding methods as well as in three dimensions with a novel GIS-technique. Horizontal large scale differences in several variables are associated with hydrological situations. Local variability in the southern bay was due to input of industrial tailings at times. Spatial variation of phytoplankton biomass estimated as chlorophyll-a and relevant associated environmental variables were analysed using a graphical multimetric approach. With this technique, the directly impacted area can be evaluated relative to the remaining part of the lake. The lake is then compared with two reference lakes, one within the same catchement, the other in a different water-shed. An index of ecological integrity was developed describing multimetric intra- and interspecific lake variability. The final index was used to describe the status of lake water quality relative to a 'undisturbed' reference lake. Results showed that Traunsee is ecologically intact although its chemistry differs substantially from an 'external' reference.

Keywords: aquatic health, index of ecological integrity, metric scores, multimetric approach, phytoplankton, reference condition, spatial 3D-heterogeneity

1. Introduction

Bio-assessment of water quality and criteria to detect impairments are becoming increasingly important in monitoring fresh-waters world-wide. Historically, monitoring programs have measured individual pollutants in the water column and sediments. Today, environmental concerns have lead to holistic approaches such as ecological integrity or ecosystem health (Karr, 1991; Rapport, 1992). The monitoring and protection of ecological integrity and the health of waterbodies becomes imperative for countries such as the U.S.A. or the European Union (US-EPA, 1998; EU-Council, 2000).

To implement criteria for the assessment of ecological integrity, formally standardized techniques are needed. The complexity of biological systems and the varied

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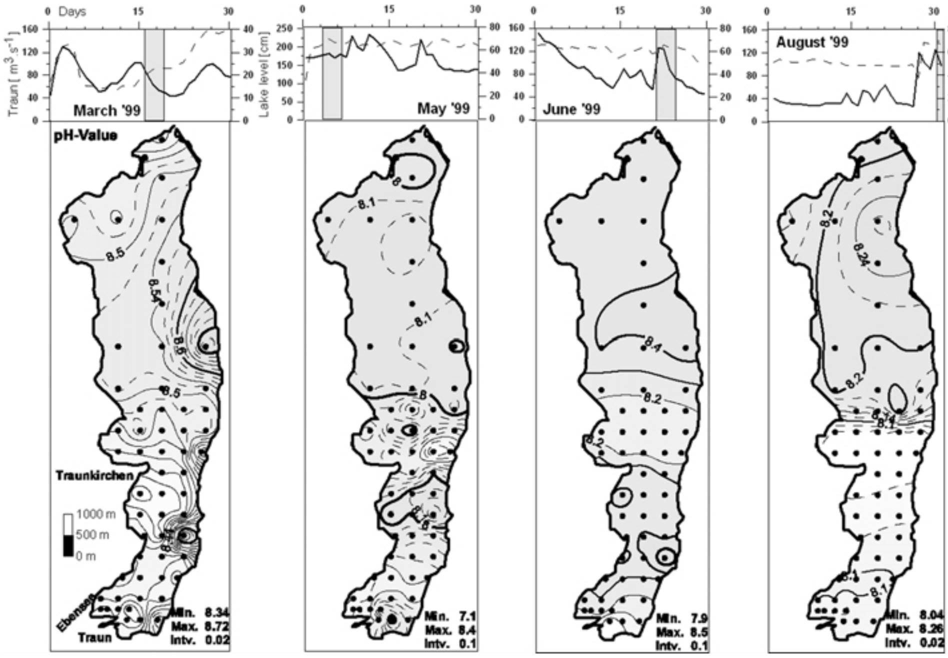

Figure 4. Contour plots of average pH-values of the top 20 m and the 4 investigation periods. Minimum, Maximum and intervals are indicated in each panel together with sampling points, major locations and distance. Panels on top of each graph show water discharge of the River Traun in m^3 s^{-1} (solid line) and lake level in cm (dashed line) for all days of the respective month. Sampling periods are hatched.

3. Results

3.1. Spatial heterogeneity

From our large data-set, only those results are extracted and shown here which are relevant for assessing ecological integrity. Since industrial effluents impacting the lake are alkaline, contain large amounts of suspended solids and high concentrations of chloride, these variables have been selected for display and discussion.

Vertical differences of pH are minimal and orthograde, corresponding to the oligotrophic character of the lake. Horizontal distribution of average pH-values in the top 20 m and the four investigation periods is summarised in Figure 4. The hydrological situation of the respective month is shown on top of each contour map. The period prior to sampling in March was characterised by a moderate increase in river discharge and lake level from low values. Correspondingly, variation of pH was narrow throughout the lake ranging from 8.34 to 8.72 with lower values in the south and central part of the lake and somewhat higher values at localised stations along the eastern shore. Two months later, in early May, at much higher and constant discharge from the river Traun, much grater horizontal variation of pH

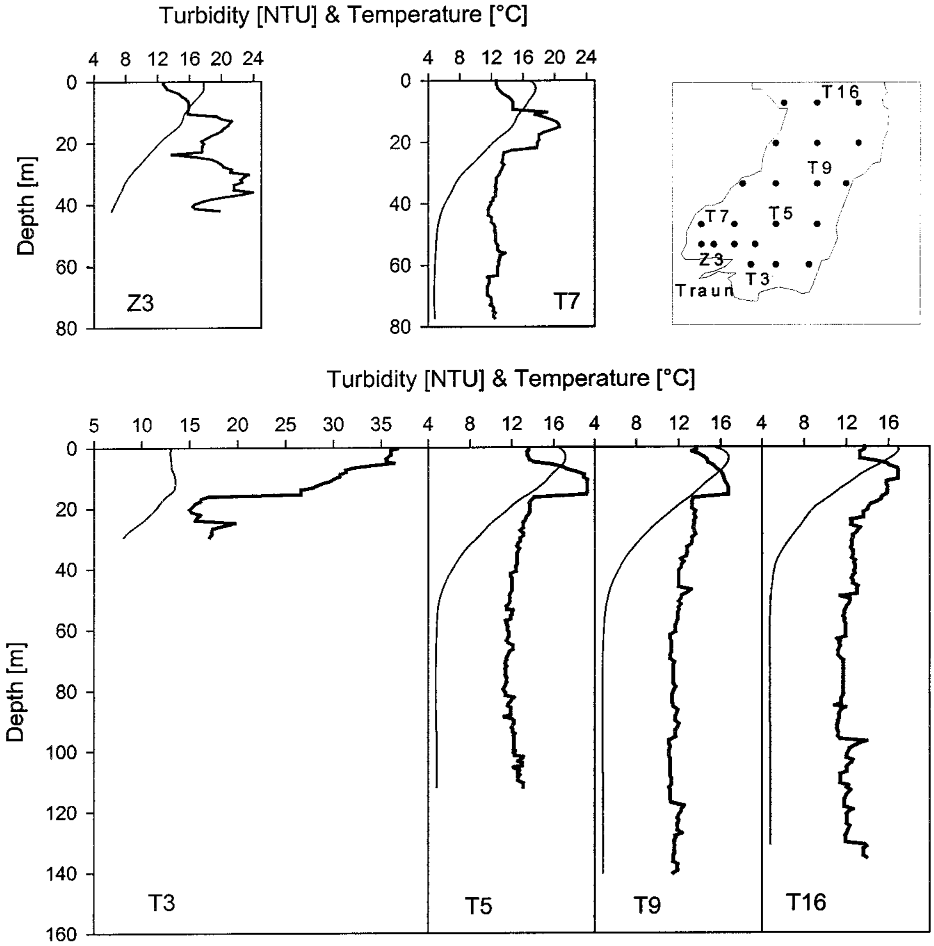

Figure 5. Examples of turbidity and temperature profiles along a transect (T3 – T16) from the mouth of the River Traun into the lake in north-east direction taken from the August cruise (lower panel). Upper panels show profiles from station Z3 as an example of turbidity input by industrial tailings and from sampling point T7, a location 250 m further north and 1000 m west of T5. For explanation refer to the text. — = turbidity as NTU; — = temperature in °C.

to the situation in August except that most of the turbid plume remained near the lake surface, because of the similarity of temperatures in the river and in the lake.

Conductivity and chloride concentration are essential features of the lake because of the chemical nature of the industrial input in the bay of Ebensee. The horizontal distribution of these two variables is exemplified in the left and centre panel of Figure 7 for the August cruise. Specific conductivity ranges from 420 to 660 μS cm^{-1}. While values are close to 460 μS also applied to most of the lake, a pronounced gradient was observed near the impacted area reaching values as high as 660 μS at the input (see the blow-up of conductivity at EB in Figure 7).

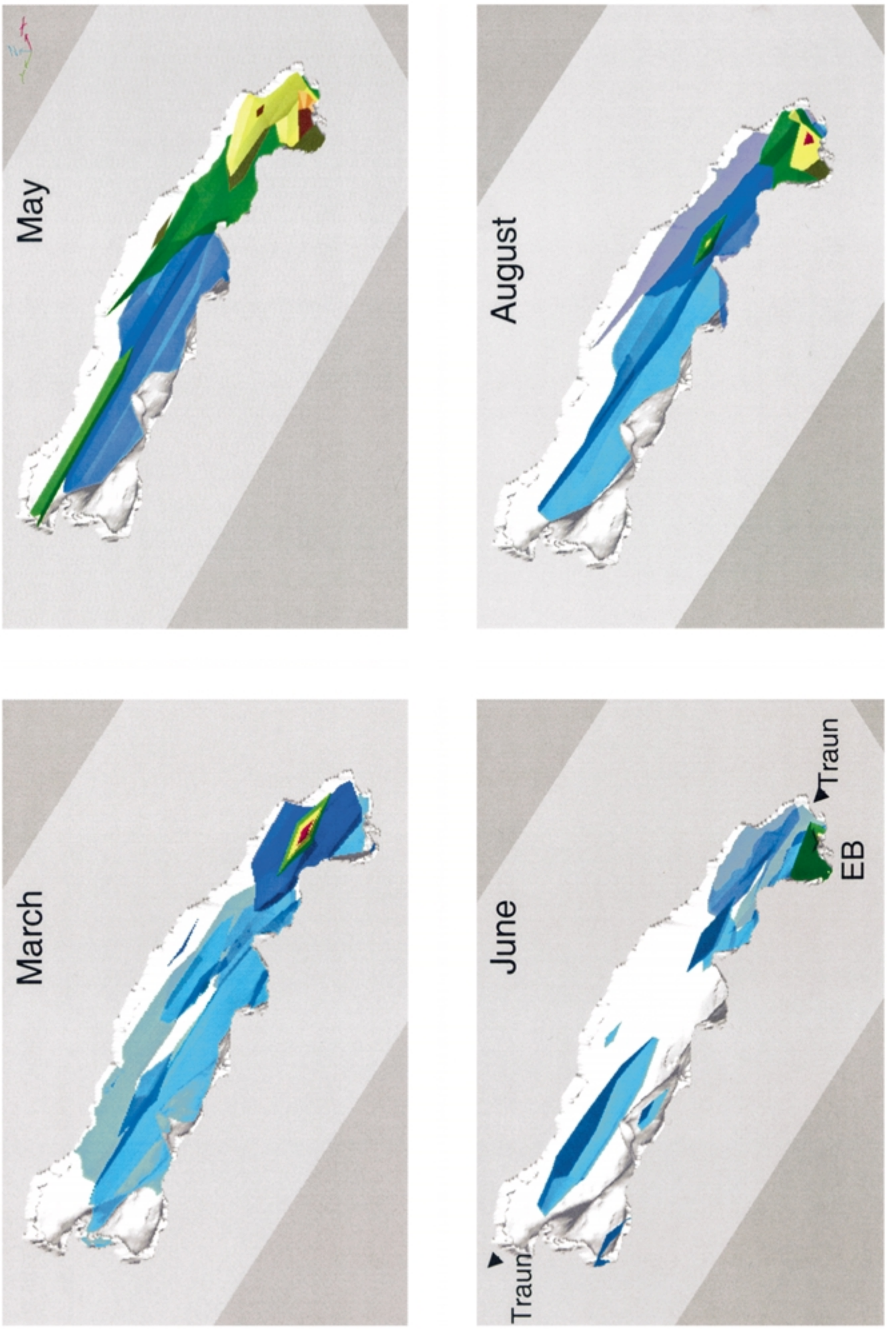

Figure 6. Three-dimensional (3D) Voxel-plots of turbidity (NTU) for the four investigation periods. Nephelometric units increase from cyan through blue, dark blue, green, greenish, brown, yellow to red. EB = Bay of Ebensee. In- and outflow of the River Traun are marked.

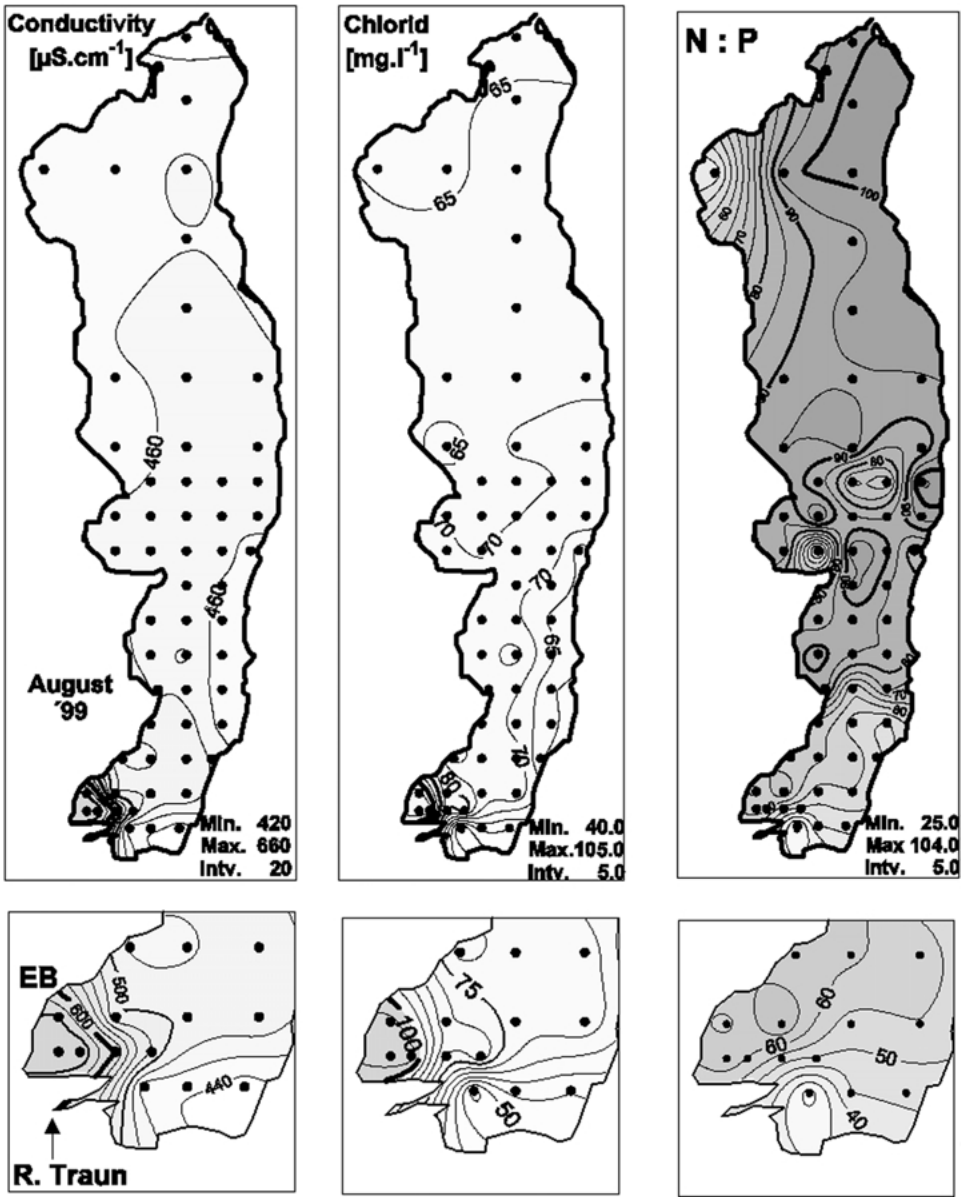

Figure 7. Selected contour plots of average 0–20 m specific conductivity in μS cm^{-1} at 25 °C, chloride concentration in mg l^{-1} and N:P ratios per weight for the August cruise. The detailed situation in the Ebensee bay (EB) is shown in the blow-ups underneath.

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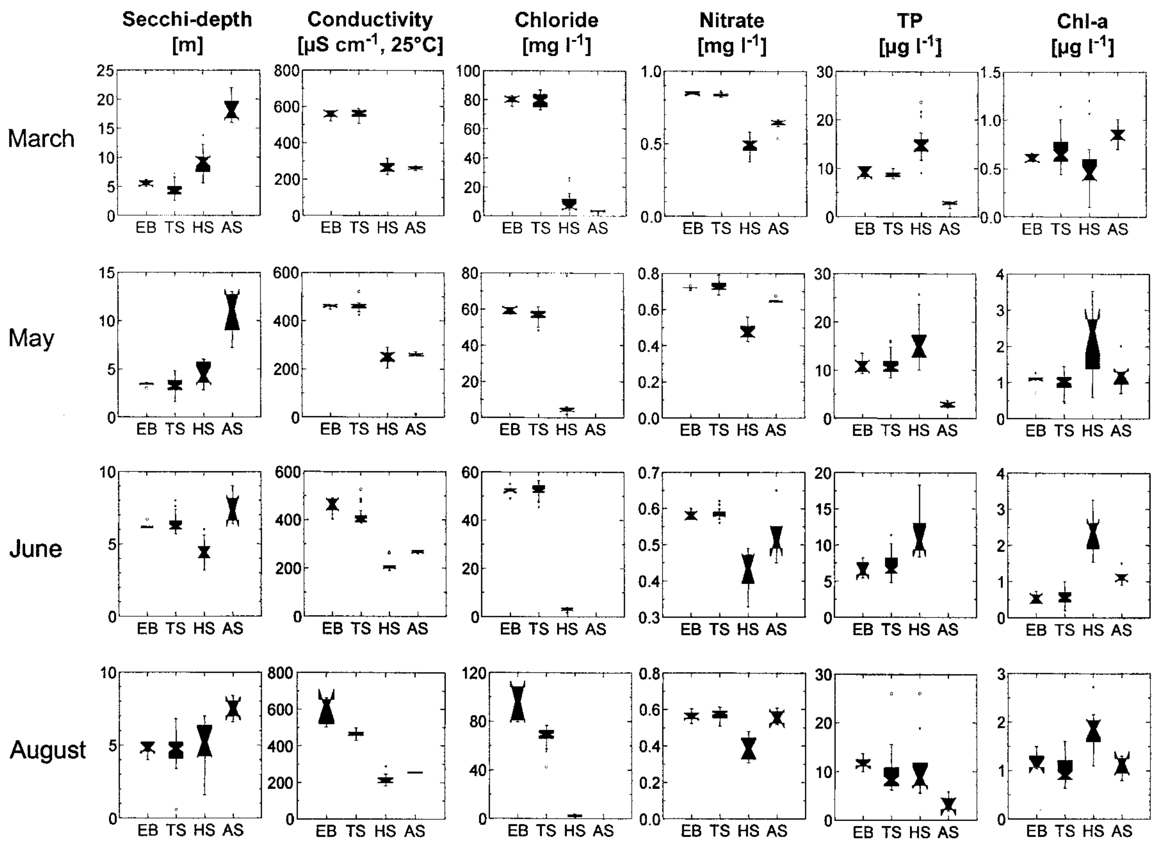

Figure 8. Notched box-whisker plots of selected variables from all four investigations on Traunsee 1999. Stations in the bay of Ebensee (EB, n = 6) are compared to all other locations in Traunsee (TS) and contrasted to measurements from the two reference sites, Hallstätter See (HS) and Attersee (AS). Box-plots are statistically different if notches (equal to 95% c.l.) do not overlap.

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