# DISTRIBUTION PATTERN OF BENTHIC INVERTEBRATE COMMUNITIES IN TRAUNSEE (AUSTRIA) IN RELATION TO INDUSTRIAL TAILINGS AND TROPHY

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**Abstract.** Traunsee, an oligotrophic Alpine lake, has suffered from inputs of industrial tailings (soda- and salt-mining industries) for several decades. The effects of the industrial sludges on the spatial distribution of the littoral and profundal invertebrate fauna was investigated along three transects at five dates. In the littoral zone, no negative impacts were found. A distinct gradient in faunal composition and diversity was, however, observed along a profundal transect relative to the distance from the waste emission. Near the industrial input, the enhanced pH, the substrate instability, and the poor sediment quality for substrate- and deposit-feeders were the main factors that lower or prohibit colonization of the industrial sludges. Along a transitional zone between the waste emission and the deepest basin, recolonization was delayed, but did occur as soon as layers of a few mm natural sediment seal the sludge. Mobile, epibenthic organisms are the first to settle these areas, whereas recolonization by tube-building oligochaetes and chironomids requires thicker sealings of the industrial sludges. Differences in the abundance of benthic invertebrates at different profundal sites were not only related to the waste emission, but also to the influence of the main tributary, the River Traun. The enhanced availability of allochthonous organic matter was probably responsible for high densities of tubificids near the inlet in the South of Traunsee. Moreover, a higher proportion of tolerant oligochaete and ostracod species in the lower profundal outside the influence of the industrial tailings was interpreted as reflecting the increased trophy of Traunsee in the 1970s, which forced sensitive species to shift to the upper profundal when the oxygen climate deteriorated.

**Keywords:** Alpine lake, benthic invertebrates, distribution pattern, industrial tailings, trophy

## 1. Introduction

Traunsee, an oligotrophic Alpine lake in Austria, has been affected by soda-producing and salt-mining industries since the 1920s. The release of up to 720 tons of liquid and 387 tons of solid tailings per day in the Bay of Ebensee increased chloride concentrations up to 160 $\mu$g L$^{-1}$ (Jagsch *et al.*, 2002); it also resulted in the deposition of highly alkaline (up to a pH of 12.5) sludges. The industrial deposits accumulated in the Bay of Ebensee, forming a 47-m-high cone composed mainly of calcite (60–80%), aragonite, vaterite, gypsum and brucite (Schneider *et al.*, 1986). Probably triggered by flood events of the River Traun (Schmidt, 1989), turbidity currents expanded from the Bay of Ebensee towards the central part of Traunsee (Müller and Sturm, 1984). Sedimentological and echosounding records in 1981 by Schneider *et al.* (1986) revealed that industrial turbidites had reached the deepest basin, about 6 km away from the emission site. The revisitation campagne during 1999 by Müller *et al.* (2002) has, however, shown that in the central basin sequences of former turbidites were covered by natural sediments of various thickness. The revisitation indicated that the area of industrial sludges in the Bay of Ebensee has expanded compared with 1981, and that two tongues of industrial sediments protrude from the Bay of Ebensee towards the deepest basin. These industrial turbidites were thickest between 3 and 5 km away from the emission site. This finding supported the observations of Pechlaner (1986) and later of Jagsch and Schwarz (1997) that a favoured corridor for industrial effluents into the deepest basin exists in the southwest of the lake. The northernmost border of superficial industrial sediments in 1999 according to Müller (2002, Figure 1) was situated at the 185 m isobath.

Neresheimer and Ruttner (1926) were the first to observe a negative impact of the alkaline deposits on the benthic communities in the profundal of Traunsee. Danecker (1970) reported a negative correlation between enhanced pH values and the invertebrate assemblages. Quantitative studies by Pechlaner (1986) confirmed this relationship. Löffler (1983) studied the fossil ostracod assemblages and found them to be comparable with other large and deep lakes of the area. These assemblages were, however, absent in the areas covered by industrial sludges. Saxl and Zapf (1991) discussed Pechlaner's (1986) results and, with respect to pH and oligochaete distribution, distinguished four strata within the profundal zone of Traunsee:

- Stratum 1: Here, the industrial sludges formed the surface of the lake bottom (Bay of Ebensee). pH reached values = 8.45 (maximum 12.5).
- Stratum 2: In this 'transitional' zone, turbidites were covered by natural sediments of various thickness. The pH values in the pore water of the uppermost natural sediments did not exceed 8.45, whereas in deeper layers, which were covered by natural sediments, pH sometimes was higher (up to 9.75). Oligochaetes were absent in several samples within stratum 2.
- Stratum 3: This area covered the south-eastern part of Traunsee, which was not affected by industrial sludges but influenced by the River Traun. pH resembled the values found in the northern profundal of Traunsee. Oligochaete densities were significantly higher than in the other strata.
- Stratum 4: No turbidites have reached this stratum in the northern profundal of Traunsee. The natural sediments in this zone were characterized by pH values below 8.6. Oligochaete densities were comparable to deep oligo- to mesotrophic lakes.

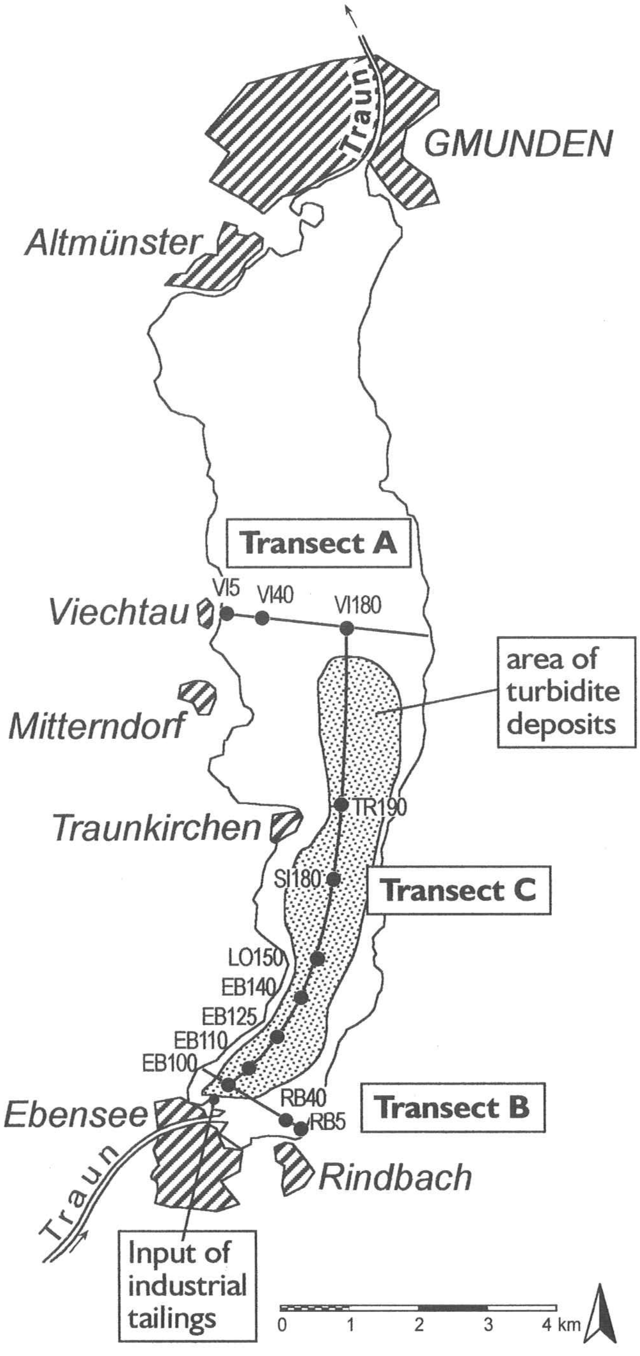


*Figure 1.* Study area and sampling sites in Traunsee. The shaded area represents the profundal zone, which according to the 1999 survey is covered by industrial turbidite deposits (cf. Müller *et al.*, 2002).

TABLE I

Sampling schedule of Traunsee (cf. Figure 1) with site codes (referring to the sampling depth (in m)) and the numbers of replicates

| Transect | Site | 26-11-97 | 11-03-98 | 20-/27-04-98 | 17-08-98 | 29/30-10-98 |
|---|---|---|---|---|---|---|
| A | VI5 | 12 | | 6 | 6 | 6 |
| A | VI40 | 12 | | 6 | 6 | 6 |
| A | VI180 | 12 | 6 | 6 | 6 | 6 |
| B | EB100 | 12 | | 6 | 6 | 6 |
| B | RB40 | 12 | | 6 | 6 | 6 |
| B | RB5 | 12 | | 6 | 6 | 6 |
| C | TR190 | | 6 | 6 | | |
| C | SI180 | | 6 | | | |
| C | LO150 | | | 6 | | 6 |
| C | EB140 | | | | | 3 |
| C | EB125 | | | | | 6 |
| C | EB110 | | | | | 6 |

Only a few faunistic studies on the littoral benthos exist from the time before the lake became impacted by the industrial tailings (Claus, 1877; Imhof, 1885; Cori, 1898; Brehm and Zederbauer, 1906; Keissler, 1907; Pesta, 1923/24). In the mid-20th century, Gusenleitner (1953) investigated the invertebrate fauna at different habitats of the littoral zone, but did not discuss potential industrial impacts. Hamann (1954) studied the zoobenthos both from the littoral and the profundal and provided faunistic data on molluscs and microcrustaceans. Some faunistic data on selected taxonomic groups can also be found in Franz (1954, 1970, 1974) and Bauernfeind (1990).

This article persues two objectives: (1) The quantitative description of the spatial and temporal distribution of benthic invertebrates in Traunsee compared with former and concurrent (this issue) studies, (2) the assessment of the ecological integrity of the benthic communities affected by the industrial tailings.

## 2. Material and Methods

### 2.1. Study Sites and Field Sampling

Sampling was carried out at five dates along three transects in various water depths (Table I, Figure 1):

- Transect A, in the north of Traunsee, represented a more remote reference site, with three sampling stations in the littoral (VI5), in the upper (VI40) and the lower profundal (VI180, stratum 4 *sensu* Saxl and Zapf, 1991).
- Transect B, in the south of the lake, was located near the effluents of the soda industry and consisted of three sampling stations in the littoral (RB5), in the upper (RB40, stratum 3 *sensu* Saxl and Zapf, 1991) and the lower profundal (EB100, stratum 1 *sensu* Saxl and Zapf, 1991).
- Transect C, in the profundal, spanning from north to the south between the sites VI180 and EB100 (sampling stations TR190, SI180, LO150, EB140, EB125, EB110, stratum 2 *sensu* Saxl and Zapf, 1991).

A multiple sampler (Danielopol and Niederreiter, 1990) with three cores (diameter of each core: 6 cm, area: 28.3 $cm^2$) was used. The uppermost 8 cm of sediment were taken and preserved in 4% formaldehyde.

Some additional sites distributed irregularly in the littoral were sampled semi-quantitatively. The results of these additional sites are not presented in detail, but species which were found only at these sites are included in the species list (Appendix).

### 2.2. Sample preparation

The samples were sieved in the laboratory with a 100 $\mu$m mesh and split into two fractions (0.1–1 mm and >1 mm). In most cases, all individuals were sorted out from both fractions. In cases of very high densities (especially of microcrustaceans or oligochaetes), the fine fraction was divided further into subsamples using a rotary sample divider by Fritsch ('laborette 27'). All sorted benthic organisms were determined to the lowest taxonomic level possible, except the Hydrozoa, Turbellaria, Nematoda, Sphaeriidae and Hydracarina.

The following literature was used for determination: Mollusca: Glöer and Meier-Brook (1998), Oligochaeta: Sperber (1948), Brinkhurst and Jamieson (1971), Anomopoda: Flössner (1972), Copepoda: Einsle (1993), Janetzky *et al.* (1996), Ephemeroptera: Bauernfeind (1994, 1995), Trichoptera: Waringer and Graf (1997), Chironomidae: Moller-Pillot (1984a, b), Cranston (1982), Wiederholm (1983), Schmid (1993), Janecek (1998).

### 2.3. Colonization and survival experiments

To evaluate the influence of the industrial deposits on the zoobenthic assemblages, a colonization and survival experiment was started in spring 1998. Profundal sediment from 80 m water depth was transferred from the Bay of Ebensee to the profundal (80 m) near Viechtau, and *vice versa*. For this experiment, a new sampling device was designed at the Institute of Limnology, Dept. Mondsee, of the Austrian Academy of Sciences. It consisted of six pots (⌀ = 15.5 cm, h = 13 cm) which were mounted on a platform and could be automatically opened and closed by removable plates *in situ* on the lake bottom. Ten sampling devices, each with six pots of sediment, were placed at each exposure site and fixed to buoys at the water surface. It was intended to expose the devices for 10 weeks and sample selected pots at intervals of two weeks. Unfortunately, at the very beginning of the experiment, several sets of the sampling device were destroyed by vandalism. Hence, only preliminary results regarding colonization of benthic invertebrates were obtained, which are not presented in the results but are referred to in the discussion.

### 2.4. Statistical analyses

Abundances of benthic invertebrates are given as arithmetic means. The 95% confidence limits were calculated from log-transformed values (Elliott, 1977). For selected benthic groups a multiple comparison (intra-site and intra-date) of mean abundances (ANOVA, after log-transformation of the data) was performed with the statistical package SYSTAT® . The significance of the difference between sample pairs was tested with Scheffè's *post hoc* test (Sachs, 1992). The Shannon-Wiener diversity index was calculated with the program 'Species Diversity and Richness' (PISCES Conservation Ltd). Confidence limits of diversity were estimated by means of the Jackknife method (Smith and Van Belle, 1984) in MS Excel® 97.

## 3. Results

### 3.1. Species richness and composition

139 taxa of benthic invertebrates were found in the sediments of Traunsee; 87 were identified on species level (Appendix). In terms of species richness, the benthic communities were dominated by chironomid larvae (53 taxa) and Oligochaeta (19 taxa). Molluscs and insects other than chironomids were represented by fewer taxa. The meiofauna comprised mainly microcrustaceans (12 Cyclopoida, 8 Harpacticoida, 6 Ostracoda, 4 Anomopoda).

Most taxa were found at the littoral sites (Table II). 49 taxa were restricted to the littoral, 23 taxa to the upper profundal. At site RB40, several taxa such as the Orthocladiinae *Parametriocnemus stylatus* or *Orthocladius rivicola* were probably dislocated from the inlets Rindbach or Traun. No species inhabited only the lower profundal (100–190 m). Some taxa such as *Spirosperma* sp. or *Paracladopelma* sp. were, however, concentrated at deeper sites.

In October, species richness distinctly decreased at the profundal sampling sites along transect C from north to south. No benthic invertebrates at all were found at site EB100. Also on the other dates, with one exception, no living benthic organisms occurred at site EB100 (Table II). Dead microcrustaceans and insects, possibly dislocated from the littoral zone, were occasionally found.

TABLE II

Mean total density (ind. $m^{-2}$) with lower (L.C.) and upper (U.C.) confidence limits, number of taxa, Shannon-Wiener diversity index (H', calculated from the mean densities at each site) and proportion of six major groups of benthic invertebrates (Nem = Nematoda, Sph = Sphaeriidae, Oli = Oligochaeta, Cop = Copepoda, Ostr = Ostracoda, Chi = Chironomidae) at the sampling sites of Traunsee

| Sites/dates | Mean | L.C. | U.C. | Taxa | H' | Nem | Sph | Oli | Cop | Ostr | Chi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 26-11-1997 | | | | | | | | | | | |
| VI5 | 42,559 | 38,163 | 47,463 | 68 | 3.06 | 9% | 7% | 6% | 20% | 9% | 40% |
| VI40 | 6,160 | 4,752 | 7,985 | 27 | 2.21 | 39% | 5% | 23% | 6% | 14% | 10% |
| VI180 | 7,191 | 5,160 | 10,022 | 15 | 1.63 | 2% | 0% | 22% | 5% | 71% | 0% |
| EB100 | 0 | – | – | 0 | – | – | – | – | – | – | – |
| RB40 | 229,684 | 165,845 | 318,097 | 37 | 1.95 | 3% | <1% | 94% | 2% | <1% | 1% |
| RB5 | 103,274 | 73,517 | 145,075 | 41 | 1.34 | 68% | 2% | 3% | 3% | <1% | 22% |
| 18-03-1998 | | | | | | | | | | | |
| VI180 | 7,368 | 4,187 | 12,966 | 13 | 2.11 | 6% | 0% | 66% | 2% | 22% | 5% |
| TR190 | 3,596 | 2,181 | 5,928 | 13 | 1.20 | 34% | 0% | 2% | 33% | 21% | 10% |
| SI180 | 1,709 | 769 | 3,800 | 7 | 2.04 | 66% | 0% | 7% | 24% | 0% | 3% |
| 20/27-04-1998 | | | | | | | | | | | |
| VI5 | 43,384 | 32,002 | 58,815 | 36 | 2.59 | 17% | 4% | 4% | 22% | 7% | 23% |
| VI40 | 3,832 | 2,126 | 6,904 | 10 | 1.57 | 49% | 0% | 32% | 6% | 8% | 0% |
| VI180 | 4,421 | 2,829 | 6,909 | 14 | 1.93 | 11% | 0% | 65% | 5% | 15% | 4% |
| TR190 | 1,886 | 1,381 | 2,577 | 7 | 1.12 | 0% | 0% | 84% | 0% | 0% | 16% |
| LO150 | 42,323 | 33,589 | 53,330 | 18 | 1.04 | 1% | <1% | 85% | 12% | <1% | 1% |
| EB100 | 0 | – | – | 0 | – | – | – | – | – | – | – |
| RB40 | 245,924 | 179,788 | 336,388 | 37 | 1.69 | 1% | 2% | 91% | 4% | 0% | 1% |
| RB5 | 59,241 | 39,164 | 89,610 | 43 | 2.11 | 45% | 2% | 7% | 9% | 1% | 25% |
| 17-08-1998 | | | | | | | | | | | |
| VI5 | 54,466 | 41,269 | 71,884 | 36 | 2.41 | 14% | 2% | 6% | 4% | 5% | 64% |
| VI40 | 3,065 | 1,481 | 6,346 | 6 | 2.31 | 8% | 0% | 52% | 25% | 2% | 6% |
| VI180 | 12,025 | 5,394 | 26,808 | 12 | 1.21 | 68% | 0% | 25% | 5% | 2% | 0% |
| EB100 | 59 | 44 | 79 | 1 | 0.00 | 0% | 0% | 0% | 100% | 0% | 0% |
| RB40 | 320,904 | 234,438 | 439,259 | 22 | 0.61 | 1% | <1% | 98% | <1% | <1% | 1% |
| RB5 | 27,764 | 24,109 | 31,973 | 32 | 2.48 | 12% | 4% | 15% | 3% | 2% | 61% |

TABLE II
*(continued)*

| Sites/dates | Mean | L.C. | U.C. | Taxa | H' | Nem | Sph | Oli | Cop | Ostr | Chi |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29/30-10-1998 | | | | | | | | | | | |
| VI5 | 25,052 | 21,177 | 29,637 | 31 | 2.26 | 2% | 5% | 9% | 5% | 20% | 56% |
| VI40 | 5,600 | 3,763 | 8,334 | 21 | 2.38 | 35% | 0% | 20% | 3% | 16% | 24% |
| VI180 | 6,661 | 4,994 | 8,885 | 17 | 2.13 | 34% | 0% | 20% | 4% | 18% | 21% |
| LO150 | 4,539 | 2,517 | 8,184 | 10 | 1.06 | 1% | 0% | 1% | 94% | 0% | 4% |
| EB140 | 1,061 | 773 | 1,457 | 4 | 1.15 | 0% | 0% | 11% | 89% | 0% | 0% |
| EB125 | 2,417 | 2,144 | 2,724 | 5 | 1.13 | 0% | 0% | 0% | 98% | 2% | 0% |
| EB110 | 5,010 | 2,978 | 8,430 | 4 | 0.75 | 0% | 0% | 0% | 100% | 0% | 0% |
| EB100 | 0 | – | – | 0 | – | – | – | – | – | – | – |
| RB40 | 156,738 | 103,880 | 236,492 | 25 | 1.49 | 4% | 3% | 90% | 1% | 0% | 1% |
| RB5 | 66,550 | 48,336 | 91,628 | 24 | 1.94 | 37% | 4% | 11% | 6% | 3% | 39% |

## 3.2. Abundances

### 3.2.1. *Littoral (5 m)*

The mean total density in the littoral region (VI5, RB5) was 52,786 ind. $m^{-2}$. In April, no significant differences ($p > 0.05$) were found between the littoral in the south (RB5) *versus* north of the lake (VI5). In November 1997 and October 1998, RB5 had significantly higher abundances ($p < 0.01$) than VI5, whereas in August significantly lower abundances were found in the south (Table II).

In terms of the major taxonomic groups, several differences between the two littoral sites emerged. In November 1997 and October 1998, nematodes were significantly more abundant in the southern littoral (RB5) than in the north (VI5). At the latter date, oligochaetes and chironomids also had higher densities in the south. Chironomids, however, reached higher abundances at VI5 in August 1998. Both in November and in April 1998, copepods and ostracods were more abundant at VI5 than at RB5. In April, no significant differences were found for either of these groups (Figure 2).

The most dominant taxa in the littoral were nematodes (34% over all dates and both littoral sites), *Procladius* sp. (15.9%), *Tanytarsus* sp. (11%), *Biapertura affinis* (4.7%), *Paracyclops fimbriatus* (4.6%), *Potamothrix hammoniensis* (3.8%), *Micropsectra* cf. *contracta* (3.6%), *Cypria ophthalmica* (2.9%) and *Pisidium (Casertiana)* sp. (2.3%).

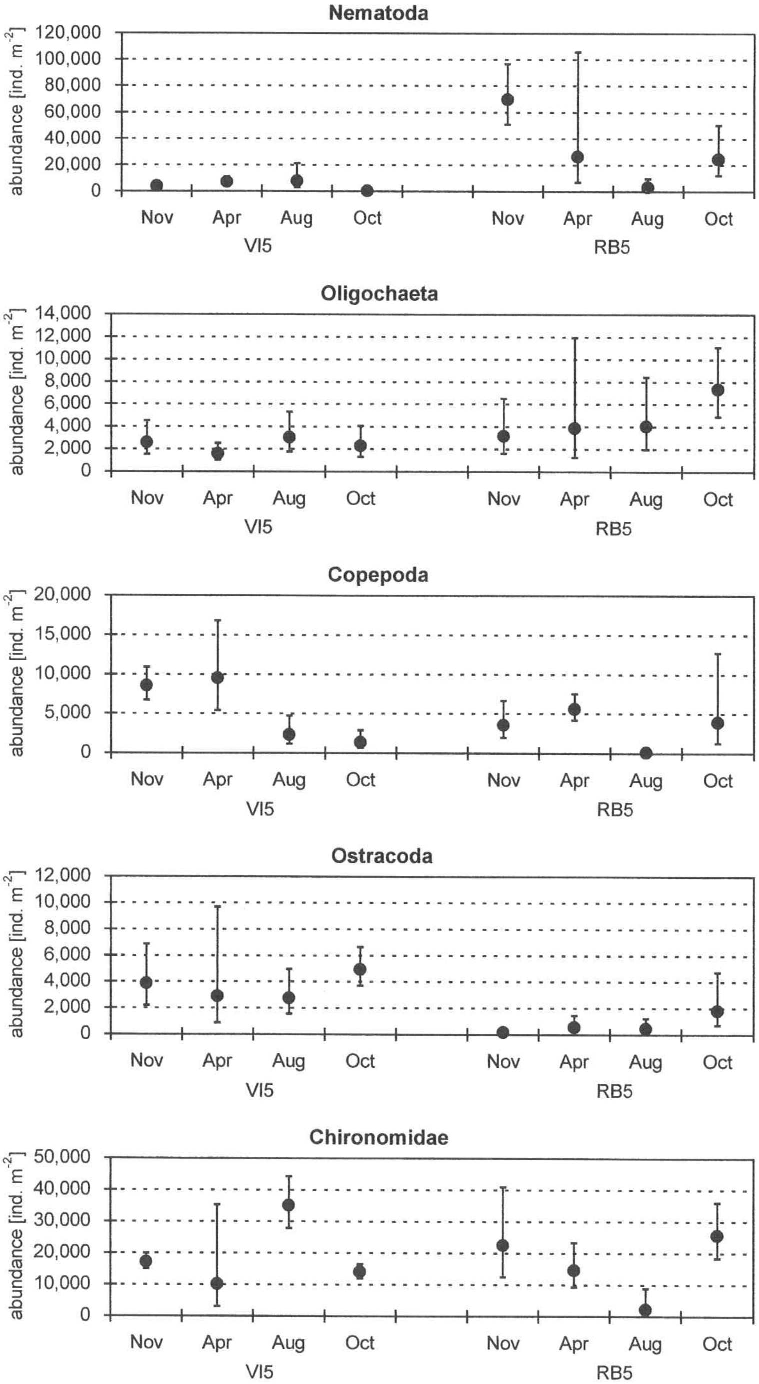


*Figure 2.* Densities (mean ind. $m^{-2}$ with the 95% confidence limits) of five major benthic groups at the sampling sites VI5 and RB5 in the littoral of Traunsee.

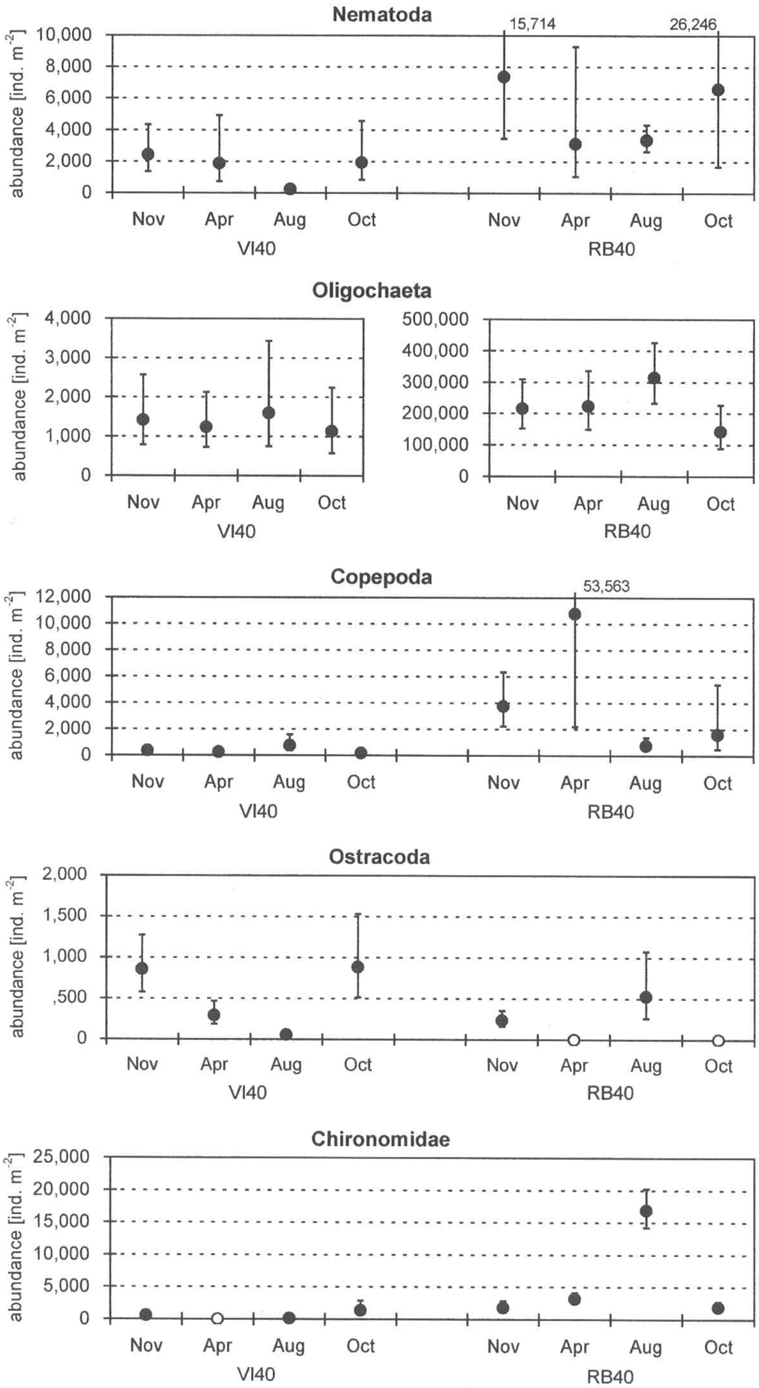


*Figure 3.* Densities (mean ind. $m^{-2}$ with the 95% confidence limits) of five major benthic groups at the sampling sites VI40 und RB40 in the upper profundal of Traunsee.

### 3.2.2. *Upper profundal (40 m)*

The highest densities of benthic invertebrates were found in the upper profundal in the south of Traunsee. The mean abundance at RB40 was 238,313 ind. $m^{-2}$ (Table II). At all sampling dates, the abundances were significantly higher at this site than at station VI40 in the north. The differences can be attributed primarily to the oligochaetes, which dominated at RB40 with 90 to 98% relative proportion of total density (Table II). Moreover, at several dates chironomids (in November, April and August) and nematodes (in August) also had significantly higher abundances in the southern upper profundal than in the north. Ostracods, present in the upper profundal in very low densities (max. 855 ind. $m^{-2}$), were significantly more abundant at VI40 at all dates except for August, when values were higher in the south (Figure 3).

Taxa with at least 2% relative proportion of total density at site VI40 (based on the mean of all dates) were nematodes (34.8%), *Spirosperma* sp. (18.2%), *Candona candida* (5.5%), *Micropsectra* sp. (5.1%), *Potamothrix bedoti* (4.1%), *Cytherissa lacustris* (3.2%), *Limnodrilus hoffmeisteri* (2.5%), *Megacyclops gigas* (2.4%), *Eucyclops serrulatus* (2.1%) and *Tanytarsus* sp. (2.1%). At RB40, *Tubifex tubifex* was the most abundant species (e.g. > 280,000 ind. $m^{-2}$ in August, relative abundance: 59.5%), followed by *P. hammoniensis* (14.8%), *L. hoffmeisteri* (7.5%), *Psammoryctides barbatus* (3.5%) and nematodes (2.1%).

### 3.2.3. *Lower profundal (100–190 m)*

Overlapping confidence limits at the profundal *reference sites* of transect A (VI40 and VI180) indicate no significant differences in total individual density between upper and lower profundal (Table II). The mean abundance here (VI40 + VI180, all sampling dates) was 6,258 ind. $m^{-2}$.

Ostracods dominated the benthic assemblage at VI180 in November 1997, oligochaetes in March and April 1998. Towards autumn, nematodes had higher abundances, peaking at ca. 8000 ind. $m^{-2}$. No significant differences in abundance between nematodes, oligochaetes, ostracods and chironomids were observed in October 1998 (Figure 4).

Dominant to subdominant taxa in the lower profundal of transect A were nematodes (30.4%), *L. hoffmeisteri* (14.4%), *P. hammoniensis* (12.4%), *C. candida* (12.4%), *C. ophthalmica* (10.0%), *P. bedoti* (5.0%), *Micropsectra* sp. (3.0%) and *T. tubifex* (2.9%).

In the *transitional zone* along transect C (= stratum 2 *sensu* Saxl and Zapf, 1991), between the Bay of Ebensee near the waste emission and the remote site VI180, total densities as well as densities of the major taxonomic groups varied strongly. Some values ranged within the same order of magnitude as at the reference site VI180 (Table II). Significantly higher densities than anywhere else in the lower profundal were found at site LO150 in April, when oligochaetes peaked at more than 36,000 ind. $m^{-2}$. At the same water depth, however, nearly no oligochaetes were found six months later in October. Generally, the sites near

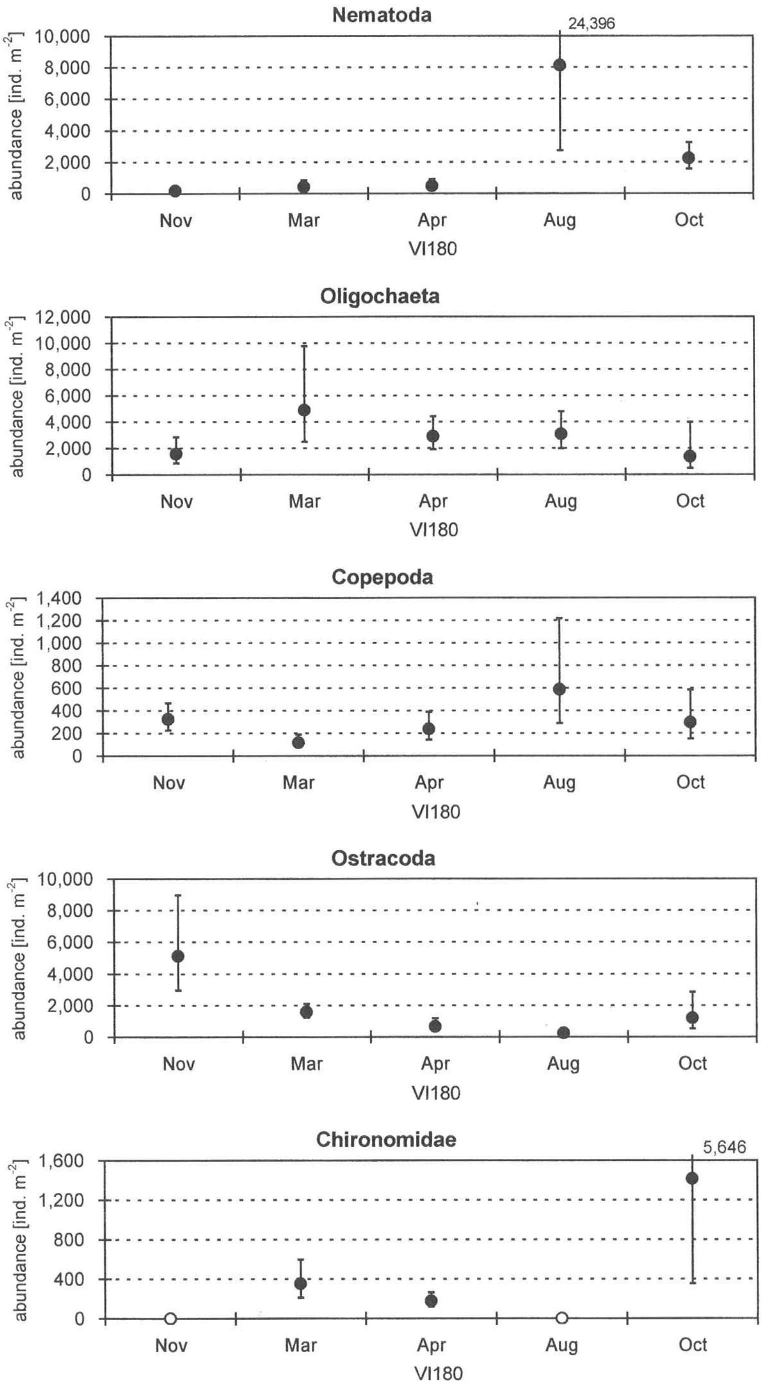


*Figure 4.* Densities (mean ind. $m^{-2}$ with the 95% confidence limits) of five major benthic groups at the reference sampling site VI180 in the lower profundal of Traunsee.

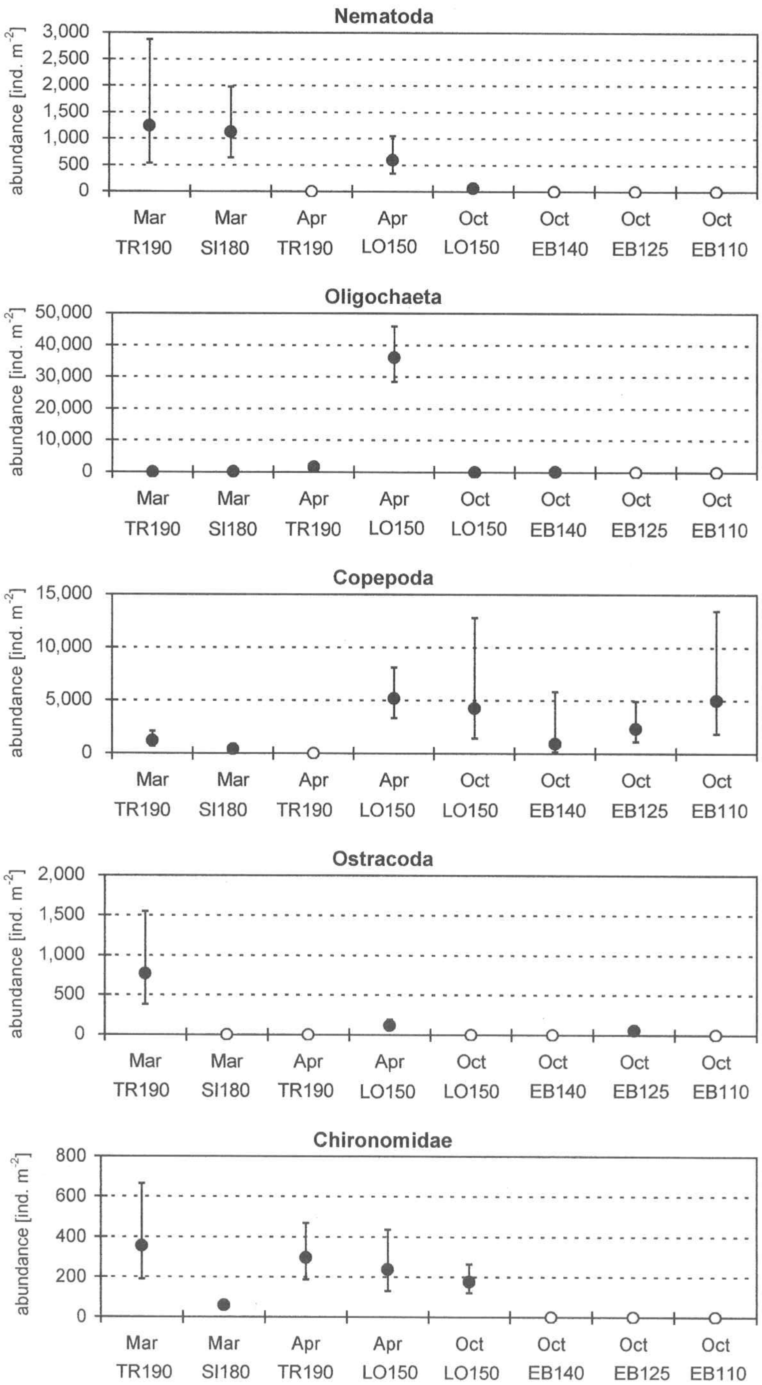


*Figure 5.* Densities (mean ind. $m^{-2}$ with the 95% confidence limits) of five major benthic groups at the samplings sites in the transitional zone in the lower profundal of Traunsee.

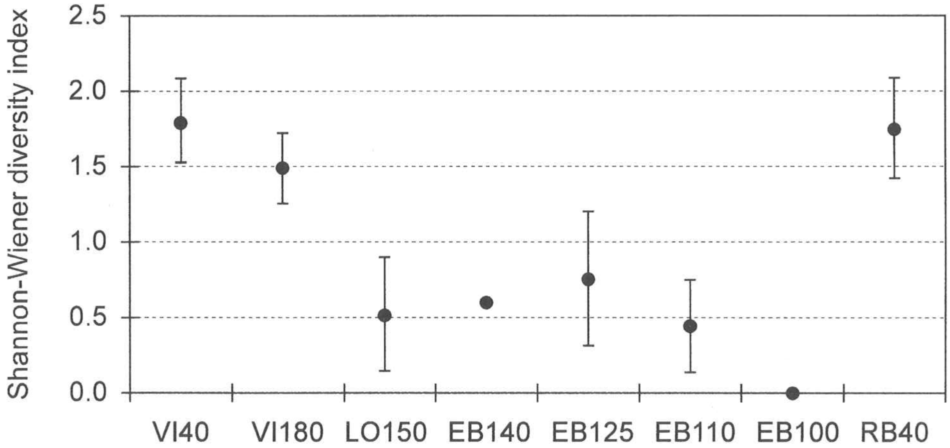


*Figure 6.* Shannon-Wiener diversity index (H', mean ±95% confidence limits, calculated for each site as mean of the diversities of the six replicates) in the profundal of Traunsee in October 1998. Confidence limits were not calculated for site EB140, where only 3 replicates were taken.

transect A (TR190 and SI180) resembled the situation found at VI180, whereas significant differences were observed at sampling stations closer to the industrial inputs. Between EB110 and EB140, only single specimens of oligochaetes and ostracods were found, whereas copepods such as *P. fimbriatus*, *E. serrulatus* and *E. macrurus* clearly dominated the assemblage, with relative abundances between 89 and 100% (Table II, Figure 5).

Upon the *industrial sludges* at site EB100, nearest to the waste emission, no benthic invertebrates at all were found. Only in August 1998, a single specimen of *M. gigas* was caught with the corer.

### 3.3. DIVERSITY

The Shannon-Wiener diversity index was highest in the littoral, with values of up to 3.06. At the profundal sites VI40 and VI180, diversity varied beteween 1.21 and 2.38 (Table II). Confidence limits of diversity were calculated from the October profundal sites on the basis of the diversities of the single samples (Figure 6). No significant difference was found between the profundal sites VI40, VI180 and RB40, although the profundal sites situated in the south of transect C had significantly lower diversities than the reference sites along transect A.

## 4. Discussion

### 4.1. Littoral

Differences in sampling and sieving techniques, as well as in the habitats sampled, make it difficult to compare the littoral fauna of Traunsee with other lakes. The species composition of littoral soft bottom sediments in Traunsee, however, is comparable to other oligotrophic lakes such as Attersee (Haempel, 1926), Lake Constance (Frenzel, 1979, 1982, 1983a, b), Lake Konnevesi (Särkkä, 1983), or Thingvallavatn (Lindegaard, 1992). Considering only studies in which a 100 or 150 $\mu$m mesh was used, abundances are within the range found in the littoral of other oligotrophic lakes. Soft bottom sediment densities were 2300 to 46 500 ind. $m^{-2}$ in the littoral of Polish lakes (Kolodziejczyk, 1976), about 18 000 to 20 000 ind. $m^{-2}$ in Thingvallavatn (Lindegaard, 1992), and 54 000 ind. $m^{-2}$ in Marion Lake (Kajak and Kajak, 1975).

The comparison of the two littoral sites VI5 and RB5 revealed significant differences in terms of abundance. Species composition, however, was similar. The different abundances cannot be definitively attributed to either abiotic or anthropogenic impacts. As suggested by Wolfram *et al.* (2002), who studied the epiphytic community on *Potamogeton perfoliatus* L. in Traunsee, the differences between the littoral sites might reflect the natural variability within highly structured habitats.

### 4.2. Upper profundal

*Spirosperma* sp., which dominated the macrozoobenthos in the upper profundal at site VI40, most probably belongs to either *velutinus* or *ferox*. The first species indicates oligotrophic conditions, the latter mesotrophic conditions (Lang, 1990). *Spirosperma* sp. is known from several other oligotrophic lakes such as Attersee (Dolezal, 1980), Bodensee (Probst, 1987), Lake Geneva and Lake Neuchatel (Lang, 1984). Gusenleitner (1953) reported *S. ferox* from the littoral of Traunsee. He also found *Limnodrilus variegatus* (Müller) here, another species indicative of oligotrophic waters; it inhabited stony substrates. As both species are known to settle greater water depths (e.g. Särkkä, 1978; Dolezal, 1980), they most likely formerly inhabited also the profundal zone of Traunsee.

The upper profundal ostracod assemblage of Traunsee is also comparable with the taxocene of other Alpine lakes (Löffler, 1972). Löffler (1983) assumed that all specimens he observed in the subfossil samples should at present occur in the profundal of Traunsee. This was not the case only for *Cyclocypris* and *Leucocythere mirabilis* Kaufmann. *Cyclocypris ovum* (Jurine) and *C. laevis* (Müller) were, however, present in the littoral sampled by Gusenleitner (1953) and Hamann (1954). Both species are eurytopic (Meisch, 2000) and known from many other Alpine lakes (Graf, 1938). A more intensive survey at other sites and/or water depths would probably have proved their existance also in Traunsee. *L. mirabilis* is a very rare species. In Austria, recent populations are only known from Mondsee

(Danielopol *et al.*, 1985; 1988) and from subfossil records from Attersee (Löffler, 1983) and Bodensee (Schwalb *et al.*, 2000).

Chironomids and harpacticoids in the upper profundal were only present in low densities, which hampers a comparison of the species composition of Traunsee with other lakes. The presence of chironomid taxa such as *Macropelopia*, *Heterotrissocladius*, *Paracladopelma*, *Micropsectra* (cf. *contracta*), and *Tanytarsus* as well as of the canthocamptids *Paracamptus schmeili* and *Bryocamptus echinatus* does indicate oligotrophic conditions (Sæther, 1979; Gerstmeier, 1989; Fittkau and Colling, 1992; Särkkä, 1996).

At site RB40, in the south of Traunsee, the species composition and abundance differed significantly from VI40. Generally, species indicative of higher trophic levels and tolerant against organic pollution, such as *Tubifex tubifex*, *Procladius* sp., *Prodiamesa olivacea*, *Chironomus anthracinus* and *Cypria ophthalmica,* dominated in the south, whereas sensitive taxa were lacking or were abundant in only very low densities. The high densities of benthic organisms, especially of Oligochaeta, at RB40 are most probably due to an enhanced organic influx from the River Traun and the brook Rindbach in the south of Traunsee; this no doubt increases the food availability for profundal invertebrates. This finding in Traunsee corresponds with those by Pechlaner and Sossau (1982), with observations from Lake Constance (Zahner, 1964; Probst, 1987), or with data from high alpine lakes (Wagner, 1975).

### 4.3. Lower profundal at reference site VI180

The lower profundal at site VI180, which is situated outside the influence of industrial deposit turbidites, was similar to the upper profundal at VI40 in terms of total abundance. Species composition of oligochaetes and ostracods, however, differed significantly. *Spirosperma* sp. was absent, whereas species indicative of meso- to eutrophic conditions such as *P. hammoniensis*, *L. hoffmeisteri* and *T. tubifex* (Lang, 1990) predominated the oligochaete assemblage.

The ostracod assemblage at this site was reduced to *Cypria ophthalmica* and *Candona candida*. *Limnocythere sanctipatricii*, which was abundant in 40 m water depth (and observed during the experiments in 80 m), was lacking in the lower profundal (180 m). *Cytherissa lacustris* occurred in the lower profundal in a few specimens only. The cytheroids *L. mirabilis*, *L. sanctipatricii* and *C. lacustris*, in contrast to the euryecious species *C. ophthalmica* and *C. candida* (Meisch, 2000), are known to be highly sensitive to environmental stress. The obvious differences in the vertical distribution of the profundal ostracods of Traunsee resembles that of nearby Mondsee. During eutrophication of this lake, the cytheroids disappeared earlier than *C. ophthalmica* and *C. neglecta* (Danielopol *et al.*, 1993).

The absence, or very low density, of oligotrophic species among oligochaetes and ostracods in the lower profundal might be due to the increased trophy of Traunsee in the 1970s, which during 1971 to 1974 was coupled with increased hypolimnetic chloride concentrations (Jagsch *et al.*, 2002). The change from oligoto mesotrophic conditions during the 1970s was also indicated by the diatom succession (Schmidt, 1989). Oxygen concentrations were at minimum 3.5 mg $L^{-1}$ in December 1978 (Pechlaner and Sossau, 1982; Sossau, 1982). Anoxic conditions were never measured in the profundal of Traunsee during the last 20 yr (Jagsch *et al.*, 2002). Sensitive species, however, might have shifted to the upper profundal when the oxygen climate temporarily deteriorated. Why have these species not recolonized the lower profundal when the lake became oligotrophic again? A delay in the recovery of oligochaete communities after reversel of eutrophication has been reported by Lang (1991) and by Lang and Reymond (1992, 1993) from deep Swiss lakes. This may also be valid for Traunsee in light of the relatively short 15-year time span of re-oligotrophication.

In contrast to oligochaetes and ostracods, other taxonomic groups such as copepods and chironomids showed no differences in species composition between upper and lower profundal (VI40 vs VI180). The taxonomic composition of the chironomids in the lower profundal at VI180 indicates oligotrophic conditions, comparable to VI40. The contradiction in trophic indication at Traunsee supports Wiederholm's (1980) hypothesis that oligochaetes react more slowly than chironomids to change in eutrophication. Similar differences in trophic indication from oligochaetes and chironomids were observed e.g. in Thingvallavatn by Lindegaard (1992) as well in Swiss lakes by Lang and Lods-Crozet (1997) and Lang (1998).

### 4.4. Lower profundal along transect C

The sampling stations in the 'transitional zone' along transect C deviated from reference site VI180 in terms of species composition and relative abundances of major taxonomic groups. The most striking difference to VI180 was found at site LO150. In April, the oligochaete abundance at this station resembled the high values found at site RB40, whereas they were very low in October. Since sediments can change over short distances in the deltaic area, slight divergences in the localization of the sampling site might account for the difference in abundance between the two dates.

The deviations from site VI180 in taxonomic composition, abundance and diversity were least in the north of the transitional zone (TR190) and most obvious near the waste emission site in the Bay of Ebensee (EB110). No distinct zonation, but a gradual change in community structure was found along transect C. Generally, nematode, oligochaete, ostracod and chironomid density significantly decreased from north to south along transect C. Most representatives of these four groups dwell within or in close contact to the sediment. The only benthic group that was found regularly and in high densities in the south of Traunsee was cyclopoid copepods. These mobile epibenthic invertebrates can avoid close contact with the sediment. These results confirm the findings of Löffler (1983) and Pechlaner (1986), who found a reduced ostracod and oligochaete density in areas temporarily affected by industrial turbidites. Hence, the deviations can be attributed to the emission of industrial tailings in the south of Traunsee as well as in the transition zone up to site TR190 (see Müller *et al.*, 2002).

Industrial tailings might affect the benthic communities in various ways:

(1) One reason, already stressed by Danecker (1970), Löffler (1983) and Pechlaner (1986), is the enhanced pH in the sediment pore water. The pH values up to 12.5, which were measured near the emission site, were considered as hostile for the profundal fauna. Little is known about pH tolerances of the species at Traunsee. Pechlaner (1986) found oligochaetes which were abundant even in sediments with pore waters of pH 9.75.
(2) Chloride concentrations in Traunsee are significantly higher than in nearby reference lakes (Jagsch *et al.*, 2002). Griebler *et al.* (2002), however, found no significant differences between the concentrations measured in the pelagial and in the pore water of the natural sediments and industrial sludges. Moreover, the magnitudes (maximum 160 $\mu g\ L^{-1}$) are distinctly lower than those known from the literature (Bayly, 1972) to affect macrozoobenthos.
(3) The alkaline pore waters could help mobilize otherwise fixed or adsorbed heavy metals (Schneider *et al.*, 1986). Müller *et al.* (2002) suggested that the increased heavy metal concentrations in the sediment surfaces of Traunsee reflected the anthropogenic background rather being attributable to heavy metal mobilization onto the sediment surface. No accumulation of heavy metals was observed in the pelagic food web, but in *Dreissena* (Meisriemler, 1990; Wanzenböck *et al.*, 2002).
(4) Griebler *et al.* (2002) observed for the industrial sludges a 10-fold lower bacterial abundance and biomass as well as significant deviations in the C/N ratio compared with unaffected sediments. Since bacteria form an essential food resource for substrate- and deposit-feeders (Brinkhurst *et al.*, 1972), this resource is considerably lower near the waste emissions than at the remote sites.
(5) The water content of the industrial sludges at the emission site is high, which favours their mobility. McLachlan (1969, 1976) noted that some chironomid species preferred certain substrate textures and actively searched for more suitable sediment conditions. Moss and Timms (1989) suggested substrate stability as an important factor for benthic invertebrate colonization in the Norfolk Broads. Substrate stability was also found to be crucial for amphipods recolonizing marine sediments affected by mine tailings (Burd, 2002). The high water content and the instability of the sediment near the waste emission site of Traunsee might hamper the building of tubes and, thus, inhibit colonization by tube-dwelling oligochaetes and chironomids.
(6) Recolonization of areas formerly devastated by industrial turbidites in the deepest basin of Traunsee depends on the time span between the various turbidite events, and on the thickness of natural sediments which overlie the industrial sludges. Schmidt (1989) dated the industrial turbidite events in Traunsee using varve counting of the laminated sections which intercalate the turbidites. Ac-

cordingly, the turbidites indicated a correlation with floods of the River Traun in 1966, 1974/1975, 1978, 1981/1982, and 1985, with a discharge > ca. 400 $m^3 s^{-1}$. Between 1985 and 1998 (no data were available for 1999–2001), five flood events (1991, 1992, 1995, 1996, and 1997) reached discharge values > 400 $m^3 s^{-1}$ (Hydrographisches Jahrbuch, 1989–2001). Assuming that these flood events also triggered turbidites of industrial sludges, recolonization times along the transect between EB110 and TR190 ranged from a few months to six years. The preliminary results of the colonization experiments revealed that a few months might be sufficient for recolonization. Beside time, the sealing of the industrial sludges by natural sediments was important for recolonization. For the northern profundal of Traunsee, which is not affected by industrial tailings, Schneider *et al.* (1986) obtained an average annual sedimentation rate of about 4 to 5 mm $yr^{-1}$. This value is comparable to that of the central basin obtained by Schmidt (1989) from varve formations. The colonization experiments carried out at 80 m water depth showed that even thin layers of a few mm natural sediment were quickly recolonized first by mobile epibenthic species, such as *M. gigas*. Tube-building invertebrates, such as oligochaetes and chironomids, might, however, need a thicker sediment cover (cf. McLachlan and Cantrell, 1976) sealing the industrial sediments.

## 5. Conclusions

The main impacts on the benthic invertebrate communities in Traunsee considered here were: (1) industrial tailings, (2) discharge of the main tributary, the River Traun, (3) trophic history.

(1) The lower profundal of Traunsee in the Bay of Ebensee was significantly affected by the industrial tailings. The industrial sludges close to the waste emissions were not colonized by benthic invertebrates. In the vicinity of the waste emissions, the enhanced pH, the unstable substrate, which hampers tube building, and the poor quality of the sediment for substrate- and deposit-feeders were considered as the main reasons which lower or hinder colonization of the industrial sludges. In the following transition zone, up to 6 km north, the integrity of the benthic assemblages varied. In contrast to the remote site VI180, where oligochaetes, nematodes, ostracods and chironomids dominated, epibenthic cyclopoid copepods prevailed along this transect (C). The proportions between endo- and epibenthic invertebrates appeared to be a useful tool to indicate the varying impact of industrial tailings. With respect to the resilience of benthic invertebrates, layers of a few mm natural sediment appeared to be sufficient to enable mobile, epibenthic organisms to settle in areas formerly devastated by industrial sludges. Recolonization by tube-building oligochaetes and chironomids, however, requires thicker covering layers. Both the sealing of

former industrial turbidites and sufficient time for recolonization (possibly in the range between 3 months to 6 years) may explain the present less impacted conditions near the more remote site VI180.

(2) In the south of Traunsee, the River Traun significantly influences the benthic community. The enhanced availability of allochthonous organic matter is probably responsible for the high densities of the zoobenthos (especially tubificids), which reached abundances up to 321 000 ind. $m^{-2}$.

(3) The increased trophy of Traunsee in the 1970s most probably altered the species composition in the lower profundal as compared to the upper profundal. At site VI180, a higher proportion of tolerant oligochaete and ostracod species was found at the expense of species indicative of oligotrophic conditions. In contrast, the chironomid species composition indicated oligotrophic conditions, both in the upper and the lower profundal. A temporal delay in the recovery of oligochaete communities might explain the contradiction in trophic indication between oligochaetes and chironomids.

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## Appendix

Species list of sediment-dwelling invertebrates in Traunsee, 1997–1998. Taxa found in the littoral (L = VI5 and RB5), the upper profundal ($UP_{VI}$ = VI40, $UP_{RB}$ = RB40), and the lower profundal (remote site VI180 = $LP_{rem}$, transitional zone TR190-SI180 = $LP_{tr\_1}$, transitional zone LO150-EB110 = $LP_{tr\_2}$, industrial sludge at site EB100 = $LP_{is}$; cf. Figure 1) are marked. The number of samples at each habitat is indicated.

| | L | $UP_{VI}$ | $UP_{RB}$ | $LP_{rem}$ | $LP_{tr\_1}$ | $LP_{tr\_2}$ | $LP_{is}$ |
|---|---|---|---|---|---|---|---|
| No. of samples | 60 | 30 | 30 | 36 | 18 | 27 | 30 |
| Hydrozoa | + | | | | | | |
| Turbellaria | | + | + | | | | |
| Nematoda | + | + | + | + | + | + | |
| Bivalvia | | | | | | | |
| Sphaeriidae | | | | | | | |
| *Pisidium* sp. | + | + | | | | | |
| *Pisidium* (*Casertiana*) sp. | + | | + | | | + | |
| Dreissenidae | | | | | | | |
| *Dreissena polymorpha* (Pallas) | + | | | | | | |
| Gastropoda | | | | | | | |
| Viviparidae | | | | | | | |
| *Viviparus* sp. | + | + | | | | | |
| Bithyniidae | | | | | | | |
| *Bithynia tentaculata* (Linnaeus) | + | + | | + | | | |
| Valvatidae | | | | | | | |
| *Valvata pulchella* Studer | + | + | | | | | |
| *Valvata piscinalis* (Müller) | + | | | | | | |
| *Valvata piscinalis alpestris* Küster | + | | | | | | |
| Hydrobiidae | | | | | | | |
| *Bythinella bavarica* Clessin | | + | | | | | |
| *Potamopyrgus antipodarum* (Gray) | + | | | | | | |
| Physidae | | | | | | | |
| *Physa fontinalis* Linnaeus | + | | | | | | |
| Hirudinea | | | | | | | |
| Glossiphoniidae | | | | | | | |
| *Glossiphonia complanata* (Linnaeus) | + | | | | | | |
| Oligochaeta | | | | | | | |
| Naididae | | | | | | | |
| *Amphichaeta leydigii* Tauber | + | | | | | | |
| *Chaetogaster cristallinus* Vejdovsky | + | | | | | | |
| *Nais elinguis* Müller | + | | | | | | |
| *Stylaria lacustris* (Linnaeus) | + | | | | | | |
| *Uncinais uncinata* (Orsted) | + | | | | | | |
| *Vejdovskyella comata* (Bretscher) | | + | + | | + | | |

| No. of samples | L 60 | $UP_{VI}$ 30 | $UP_{RB}$ 30 | $LP_{rem}$ 36 | $LP_{tr\_1}$ 18 | $LP_{tr\_2}$ 27 | $LP_{is}$ 30 |
|---|---|---|---|---|---|---|---|
| Oligochaeta (continued) | | | | | | | |
| Tubificidae | | | | | | | |
| *Aulodrilus pluriseta* Piguet | + | + | | + | | | |
| *Limnodrilus* sp. | + | | + | + | | + | |
| *Limnodrilus claparedeanus* Ratzel | + | | + | | | | |
| *Limnodrilus hoffmeisteri* Claparede | + | + | + | + | | + | |
| *Limnodrilus profundicola* Verrill | + | | + | + | | | |
| *Potamothrix bedoti* Piguet | + | + | + | + | | | |
| *Potamothrix hammoniensis* Michaelsen | + | + | + | + | + | + | |
| *Potamothrix vejdovskyi* (Habre) | + | + | | | | | |
| *Psammoryctides barbatus* (Grube) | + | | + | | | | |
| *Spirosperma* sp. | | + | | | | | |
| *Tubifex ignotus* Stolc | + | + | + | + | | + | |
| *Tubifex tubifex* Müller | + | | + | + | + | + | |
| Lumbriculidae | | | | | | | |
| *Stylodrilus* sp. | + | | + | | | | |
| Hydracarina | + | + | + | | | | |
| Anomopoda | | | | | | | |
| Chydoridae | | | | | | | |
| *Biapertura affinis* (Leydig) | + | + | | | | | |
| *Eurycercus lamellatus* (Müller) | + | | | | | | |
| *Leydigia quadrangularis* (Leydig) | + | | | | | | |
| Iliocryptidae | | | | | | | |
| *Iliocryptus sordidus* (Liévin) | | | + | | | | |
| Copepoda Cyclopoida | | | | | | | |
| Cyclopidae | | | | | | | |
| *Paracyclops fimbriatus* Fischer | + | + | + | + | + | + | |
| *Eucyclops macrurus* Sars | + | + | + | + | | + | |
| *Eucyclops serrulatus* (Fischer) | + | + | + | + | | + | |
| *Eucyclops speratus* (Lilljeborg) | | | + | | | | |
| *Eucyclops* sp. | + | | + | + | + | + | |
| *Megacyclops gigas* (Claus) | + | + | + | + | + | + | + |
| *Macrocyclops albidus* (Jurine) | + | | | | | | |
| *Macrocyclops distinctus* (Richard) | + | | | | | | |
| *Diacyclops languidus* (Sars) | | + | | | | | |
| *Diacyclops* sp. | | | | + | | | |
| *Mesocyclops leuckarti* (Claus) | + | | | | + | | |
| *Cyclops abyssorum* Sars | + | + | + | + | | + | |
| Copepoda Harpacticoida | | | | | | | |
| Canthocamptidae | | | | | | | |
| *Paracamptus schmeili* (Mrázek) | + | + | | + | + | | |
| *Canthocamptus staphylinus* (Jurine) | + | | + | | + | + | |
| *Attheyella crassa* (Sars) | + | | | | | | |
| *Attheyella wierzejski* (Mrázek) | | + | | | | | |
| *Bryocamptus echinatus* (Mrázek) | | + | | | | + | |
| *Bryocamptus zschokkei* (Schmeil) | + | | | | | | |
| *Echinocamptus pilosus* (Van Douwe) | + | | | | | | |
| *Mesochra* sp. | | | | + | | | |

| | L | $UP_{VI}$ | $UP_{RB}$ | $LP_{rem}$ | $LP_{tr\_1}$ | $LP_{tr\_2}$ | $LP_{is}$ |
|---|---|---|---|---|---|---|---|
| No. of samples | 60 | 30 | 30 | 36 | 18 | 27 | 30 |
| Ostracoda | | | | | | | |
| Candonidae | | | | | | | |
| *Candona neglecta* Sars | + | + | | | | | |
| *Candona candida* (Müller) | + | + | | + | + | + | |
| *Cypria ophthalmica* (Jurine) | + | + | + | + | + | + | |
| Limnocytheridae | | | | | | | |
| *Limnocythere inopinata* (Baird) | + | + | | + | | | |
| *Limnocythere sanctipatrici* (Brady and Robertson) | + | + | | | | | |
| Cytherideidae | | | | | | | |
| *Cytherissa lacustris* (Sars) | + | + | + | | | | |
| Amphipoda | | | | | | | |
| Gammaridae | | | | | | | |
| *Gammarus roeseli* Gervais | + | | | | | | |
| *Gammarus lacustris* Sars | + | | | | | | |
| Isopoda | | | | | | | |
| Asellidae | | | | | | | |
| *Asellus aquaticus* (Linnaeus) | + | | | | | | |
| Ephemeroptera | | | | | | | |
| Baetidae | | | | | | | |
| *Centroptilum luteolum* (Müller) | + | | | | | | |
| Ephemeridae | | | | | | | |
| *Ephemera danica* Müller | + | | | | | | |
| Caenidae | | | | | | | |
| *Caenis horaria* (Linnaeus) | + | | | | | | |
| Heteroptera | | | | | | | |
| Corixidae | | | | | | | |
| *Micronecta* sp. | + | | | | | | |
| Trichoptera | | | | | | | |
| Sericostomatidae | | | | | | | |
| *Sericostoma flavicorne/personatum* | + | | | | | | |
| Leptoceridae | | | | | | | |
| *Athripsodes albifrons* (Linnaeus) | + | | | | | | |
| *Athripsodes albifrons/bilineatus* | + | | | | | | |
| *Athripsodes aterrimus* (Stephens) | + | | | | | | |
| *Athripsodes cinereus* (Curtis) | + | | | | | | |
| *Mystacides azurea* (Linnaeus) | + | | | | | | |
| *Mystacides nigra/longicornis* | + | | | | | | |
| Limnephilidae | | | | | | | |
| *Limnephilus lunatus* Curtis | + | | | | | | |
| Polycentropodidae | | | | | | | |
| *Polycentropus flavomaculatus* (Pictet) | + | | | | | | |
| Megaloptera | | | | | | | |
| Sialidae | | | | | | | |
| *Sialis fuliginosa* Pictet | + | | | | | | |
| *Sialis lutaria* (Linnaeus) | + | + | | | | | |

| No. of samples | L<br>60 | $UP_{VI}$<br>30 | $UP_{RB}$<br>30 | $LP_{rem}$<br>36 | $LP_{tr\_1}$<br>18 | $LP_{tr\_2}$<br>27 | $LP_{is}$<br>30 |
|---|---|---|---|---|---|---|---|
| Coleoptera | | | | | | | |
| Dytiscidae | | | | | | | |
| Hydroporinae indet. | | | + | | | | |
| Diptera | | | | | | | |
| Chironomidae | | | | | | | |
| *Apsectrotanypus trifascipennis* (Zetterstedt) | | | + | | | | |
| *Macropelopia* sp. | + | + | + | | + | + | |
| *Procladius* sp. | + | + | + | | | + | |
| *Ablabesmyia* sp. | + | | | | | | |
| *Thienemannimyia* sp. | + | | | | | | |
| *Zavrelimyia* sp. | + | | | | | | |
| *Protanypus forcipatus* (Egger) | + | | | | | | |
| *Monodiamesa* sp. | | | + | | | | |
| *Prodiamesa olivacea* (Meigen) | + | | + | | | | |
| *Cricotopus/Orthocladius/ Paratrichocladius* sp. | + | | + | | | | |
| *Eukiefferiella claripennis* (Lundbeck) | | | + | | | | |
| *Eukiefferiella* sp. | | | + | | | | |
| *Heterotrissocladius marcidus* (Walker) | + | | | | | | |
| *Heterotrissocladius* sp. | + | + | | | | | |
| *Orthocladius rubicundus* (Meigen) | + | | | | | | |
| *Orthocladius rivicola* Kieffer | | | + | | | | |
| *Orthocladius* gr. *rivicola* | | | + | | | | |
| *Paracladius conversus* (Walker) | + | | | | | | |
| *Parakiefferiella triquetra* (Pankratova) | + | + | | + | | | |
| *Parametriocnemus stylatus* (Kieffer) | | | + | | | | |
| *Psectrocladius psilopterus* (Kieffer) | + | | | | | | |
| *Rheosmittia spinicornis* (Brundin) | | | + | | | | |
| *Smittia* gr. *aquatilis* | + | | | | | | |
| *Chironomus anthracinus* Zetterstedt | + | | + | | | | |
| *Chironomus* sp. | | | + | | | | |
| *Cryptochironomus* sp. | + | | | | | | |
| *Cryptotendipes holsatus* Lenz | + | | | | | | |
| *Demicryptochironomus* sp. | + | | | | | | |
| *Endochironomus albipennis* (Meigen) | + | | | | | | |
| *Harnischia* sp. | + | | | | | | |
| *Microtendipes* gr. *chloris* | + | | + | | | | |
| *Parachironomus* gr. *vitiosus* | + | | | | | | |
| *Paracladopelma* sp. | | + | + | + | + | + | |
| *Paralauterborniella nigrohalteralis* (Malloch) | + | | | | | | |
| *Paratendipes albimanus* (Meigen) | + | | + | | + | | |
| *Phaenopsectra* sp. | + | | | | | | |
| *Polypedilum albicorne* (Meigen) | | | + | | | | |
| *Polypedilum laetum* (Meigen) | | | + | | | | |
| *Polypedilum* cf. *nubeculosum* (Meigen) | + | | | | | | |

| | L | $UP_{VI}$ | $UP_{RB}$ | $LP_{rem}$ | $LP_{tr\_1}$ | $LP_{tr\_2}$ | $LP_{is}$ |
|---|---|---|---|---|---|---|---|
| No. of samples | 60 | 30 | 30 | 36 | 18 | 27 | 30 |
| Diptera (continued) | | | | | | | |
| Chironomidae | | | | | | | |
| *Polypedilum* gr. *scalaenum* | + | | + | | | | |
| *Polypedilum* sp. | + | | + | | | | |
| *Stictochironomus* sp. | | + | | | | | |
| *Cladotanytarsus* sp. | + | | | | | | |
| *Micropsectra atrofasciata* (Kieffer) | | | + | | | | |
| *Micropsectra contracta* Reiss | + | | | | | | |
| *Micropsectra* cf. *contracta* Reiss | + | + | + | + | | + | |
| *Micropsectra* sp. | + | + | + | + | + | | |
| *Paratanytarsus* sp. | + | | | | | | |
| *Rheotanytarsus* sp | + | | | | | | |
| *Stempellina bausei* (Kieffer) | | | | + | | | |
| *Tanytarsus* sp. | + | + | + | + | + | | |
| *Tanytarsus* cf. *brundini* Lindeberg | + | | | | | | |
| *Tanytarsus gregarius/inaequalis* | + | | | | | | |
| Ceratopogonidae | + | + | + | | | | |
| Empididae | + | | | | | | |

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