Ciliates- Lake Constance data documentation

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Authors: Ursula Gaedke, Alice Boit

Lake name: Lake Constance

Contact person: Professor Dr. Ursula Gaedke (gaedke@uni-potsdam.de), Institute of Biochemistry and Biology, University of Potsdam, Maulbeerallee 2, 14469 Potsdam

If not available, try Dr. Dietmar Straile (Dietmar.straile@uni-konstanz.de), Limnological Institute, University of Constance (Konstanz)

Sampling site

Lake Constance (LC) is a temperate, large (476 km^2), deep (mean depth = 101 m, max. depth 252 m), and warm-monomictic lake north of the European Alps of glacial origin. It has weak pelagic-benthic coupling, and little allochthonous input into the pelagic zone (Bäuerle and Gaedke 1998). The focal measuring site is in the north-western fjord-like arm of the lake (mean depth ca. 100 m, max. depth 146 m). From 1987-1998 sampling was done weekly during the growing season and approximately bi-weekly during the winter months (Müller (1989), Müller et al. (1991) and Weisse et al. (1990).

Organisms

Ciliates are unicellular organisms ranging in size from 10µm to 160µm in length (longest linear dimension, LLD) in LC which are characterized by the presence of hair-like organelles. Many of the planktonic ciliates in L. Constance are predominantly algivorous but picoplankton filter-feeders and carnivorous forms occur as well (Gaedke & Wickham 2004). Due to their large population size and high weight-specific growth and grazing rates, their significance as algal consumers and secondary producers may exceed that of the other herbivores during the spring bloom and amount to about half when averaged over the season (Gaedke & Straile 1994, Gaedke *et al.* 2002, Lischke *et al.* 2016). Many ciliate species exhibit large phenotypic plasticity and intraspecific variation of traits. They are therefore interesting candidates for investigating long-term trends in trait distributions and also for ecological modelling.

In Lake Constance, ciliates play a major role during spring, are suppressed around the clear-water phase and regain importance thereafter (see ref. above, Tirok & Gaedke (2006) and Boit & Gaedke 2014). They are important herbivores but also upgrade the food quality of larger grazers such as crustaceans (Hartwich, Straile, Gaedke & Wacker (2012)). During the spring bloom they may co-occur at high biomass levels with their algal prey without exhibiting pronounced predator prey cycles likely due to biomass-trait feedbacks (Tirok & Gaedke 2007, 2010). Ciliates responded much less to the reoligotrophication occurring during the measuring period than crustaceans (Gaedke & Wickham and lit. cited therein) and the seasonal fluctuations of the different morphotypes were rather synchronized (Vasseur & Gaedke (2007).

Datasets overview

We provide five datasets (for details, see the point “Datasets description” below):

1. Dataset 1 provides the ciliates’ biovolume and biomass in units of carbon for the years 1987-1998 resolved by 47 counting categories at different depths.
2. Dataset 2 is derived from Dataset 1, and aggregates the data into 25 morphotypes.
3. Dataset 3 is derived from Dataset 2, and integrates the data across the uppermost 0-20m depth (corresponding approximately to the euphotic zone/epilimnion).
4. Dataset 4 is derived from Dataset 3 by summing up the biovolume and biomass of all ciliates (cf. Fig. 1 as a reference).
5. Dataset 5 is a lookup table on ciliate taxonomy and traits which links the counting categories to the morphotypes and their specific traits.

Datasets 2-4 are provided for convenience, i.e., database users who seek quick access to the aggregated data. Measurements stopped in 1998, but started again from 2006 onwards. If you need data from the most recent years you have to contact Dietmar Straile or Ursula Gaedke personally as data preparation was not yet finalized when uploading the data from 1987-1998.

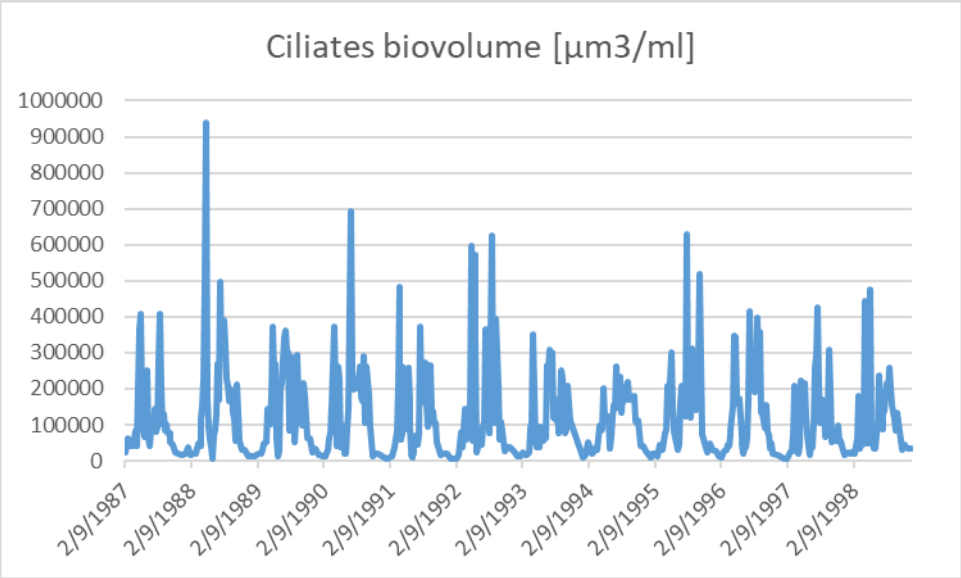

Fig. 1: Total, depth-integrated ciliate biovolume in µm^3/ml as provided by Dataset 4.

Sampling methods

The abundance of all ciliates was assessed using advanced microscopy techniques. For routine counting, ciliates were fixed with Lugol’s solution (Müller 1989). Ciliate sampling, counting and sizing were described in detail by Müller (1989), Müller et al. (1991) and Weisse et al. (1990).
Ciliate cellvolume was established by measuring cell dimensions several times during the measuring period but not for every sampling date, and converted to units of carbon assuming a carbon to fresh-weight ratio of 15.4% (Weisse & Müller 1998) assuming 40% shrinkage due to fixation. Ciliate biovolume was obtained by multiplying the cell volume with the cell abundance.

Ciliate taxonomy

Counting categories: During counting the ciliates, morphologically different categories were distinguished based on the longest linear dimension, shape and taxonomy of the ciliates. This high resolution was used to assess the ciliates' biovolume as accurately as possible and e.g. account also for intraspecific size differences. However, it implies that the same population may be spread across two morphological categories. Thus, **for further analysis using a population approach, these categories need to be combined** as done e.g. in publications on Lake Constance ciliates. For details see Müller (1989), Müller et al. (1991) and Weisse et al. (1990).

Morphotypes: Ciliates were grouped into 24 morphotypes following Müller (1989), Müller *et al.* (1991), Weisse & Müller (1998). These morphotypes represent either individual species or higher taxonomic units which could be identified by light microscopy. Unidentified ciliates were additionally included and labelled as morphotype 25. During counting, they were allocated to different counting categories by size and shape, and different cell volumes were allocated to them to enable an accurate estimate of their biovolume. The relative share of unidentified ciliates generally amounted to 0–5 % of total ciliate biomass.

Ciliate traits

Functional groups

All identified ciliates were allocated into one of five functional groups (1,…,5) according to their prey and predator spectrum depending on body size, shape and feeding mode according to Lang (1997). For further details on the functional composition of the ciliates, see Tirok & Gaedke (2007). For a description of the trophic links in the food web, see Boit *et al.* (2014).
Note: If the morphotype is 25 („Unspecified"), then the functional group is -1 in the lookup table associated with the datasets. A short description of the functional groups follows here:

Functional group 1: Picoplankton filter-feeders (prey size: 0.2 - 2 µm)
This functional group consists exclusively of small filter-feeders which feed on pelagic bacteria and autotrophic picoplankton (APP). The involved taxa belong to the families *Peritrichida* and *Oligotrichida* with a longest linear dimension (LLD) of < 20-100 µm.

Functional group 2: Pico-/nanoplankton filter-feeders (prey size: 0.2 - 10 µm)

This functional group comprises medium-sized filter-feeders of LLD > 20-100 µm. These ciliates feed on pelagic and substrate-bound bacteria (substrate = detritus particles, algal colonies, etc.), APP, small and well-edible algae as well as heterotrophic nanoflagellates (HNF). These ciliates belong to the families of *Oligotrichida* and *Scuticociliatida*.

Functional group 3: Nanoplankton raptorial-feeders (prey size: 2 - 10 µm)

This functional group consists of raptorial feeders of LLD < 20-35 µm which belong to the families of *Prostomatida* and *Haptorida*. These ciliates feed on smaller and larger algae and possibly, also HNF.

Functional group 4: Nanoplankton filter-feeders (prey size: 2 - 10 µm)

This functional group comprises medium-sized filter-feeders of LLD 20-100 µm from the family *Oligotrichida*. They feed on the same prey as the raptorial nanoplankton feeders (c.f. functional group 3) but their predators partly differ due to their larger size.

Functional group 5: Nano-/microplankton raptorial-feeders (prey size: 2 - 100 µm)

This functional group consists of large raptorial feeders which feed on larger algae, on small and larger (< 50 µm) ciliates and on HNF. The LLD of this group ranges from 20- >100 µm and the species belong to the families *Suctorida*, *Haptorida*, *Prostomatida* and *Heterotrichida*.

Feeding type

The seven feeding types refer to the size class of the organisms which the ciliates feed upon (pico-, nano- or microplanktonic) and whether the ciliates are primarily interception or filter feeders (Gaedke and Wickham 2004 and literature therein). Feeding types in the lookup table associated with the datasets are numbers which translate to the following types:

1 Nanointerception feeders
2 Microinterception feeders
3 Nano- & micro-interception feeders
4 Pico- & nanointerception feeders
5 Nano-filterer
6 Pico- & nano-filterer
7 Picofilterer

Cell volume

Ciliates were subdivided into 5 size classes according to their longest linear dimension (LLD): <20, 20 to <35, 35 to <50, 50 to <100 and >100 µm (Müller *et al.* 1991). The numbering of the counting categories follows this classifications: Morphotypes with LLD < 20 µm have the numbers 1x, 20-<35 µm numbers with 2x etc. Here, we report the LLDof the cell and the average cell volume [μm^3]. The LLD was measured under the light microscope and the cell volume was derived from the LLD and approximate geometric cell form (rod-shaped, spherical etc.) before fixation. The cell volume was used to calculate the biovolume and biomass from cell counts (abundance).

Seasonal co-occurrence

Seasonal co-occurrence is categorized in nine clusters (1,…,9). In order to group the 24 ciliate morphotypes into a smaller number of unique clusters, whose members were found approximately at the same time, disjoint (non-hierarchical) cluster analysis was used (Gaedke & Wickham 2004). Ideally, members of a cluster share almost all their variance with other members of the cluster, while at the same time having very little variance in common with members of other clusters. The correlation matrix was used in order to standardize variance across morphotypes. Unidentified

ciliates were omitted from the cluster analysis, as they were likely to be a disparate group, without any consistent temporal patterns.

The cluster analysis suggested 9 groups of ciliates which were relatively coherent, with no less than 31% total variance shared between a morphotype and its group, and no more than 18% shared between a morphotype and the next closest cluster. The size of the clusters ranged from 5 morphotypes (Cluster 2, Table 1 in Gaedke & Wickham 2004) to 1 (Cluster 8, *Tintinnids*). Because the clustering was based on a common biomass pattern over time, the clusters were often taxonomically heterogeneous.

Depth-integration and unit conversion

Biomass in units of carbon is given here in [mgC/m^2]. This implies the biomass is depth-integrated over the water column of the uppermost 0-20m (roughly the euphotic zone) and projected onto a unit of surface area (that is, per m^2). Other authors prefer a volumetric unit such as [µgC/m^3]. The conversion factor from mgC/m^2 to µgC/m^3 is 1000 x 1/20 = 50 because each cubic meter within the 20m-deep water column is thought to contain 1/20 of the depth-integrated biomass per square meter.

Datasets description

We provide five datasets on ciliates in Lake Constance. Data types in the datasets are listed below in parentheses "(…)", and units in brackets "[…]".

Dataset 1:

Filename: "Dataset_1_LakeConstance_Ciliates_DepthResolved"

This dataset (n = 18499) contains the approximately weekly (Apr-Nov) to bi-weekly (Dec-Mar) depth-resolved biovolume [μm^3/ml] and biomass [mgC/m^2] of 47 counting categories associated with 25 ciliate morphotypes from 1987-1998. In 1991 from April to mid-June, measurements were more frequent and ciliate data is available 2 to 3 times per week (Weisse & Müller 1998).

Column headers

A. Date
B. Depth [m]
C. Counting category (integer from 10….510)
D. Morphotype number (integer from 1…25)
E. Biovolume [μm^3/ml]
F. Biomass [mgC/m^2]

Note: Biovolume is given for certain depth intervals (i.e. averaged across 0-8 m and 8-20 m; sampling was done with a 2m long "tube" across these depth intervals, and counting was done either for 0-4, 4-8, 8-12,12-16 and 16-20 m separately during early years, or for mixed samples 0-8 and 8-20 m in later years) or for samples which were taken at distinct depths (i. e. 50 and 140m). Biomass was integrated either over 0-8 m depth or over 8-20 m, i.e. weighted by factor 8 and 12, respectively. A „-1" was inserted in the biomass column for measurements in distinct depths i.e. 50m or 140m (= there are no depth-integrated values available at these depths). That is, the biomass values in mg C/m^2 integrated over the first 0-20m (which roughly represent the euphotic zone) are obtained when adding up the biomass values provided for 8m and 20m depth (see Datasets 3 & 4).

Dataset 2:

Filename: "Dataset_2_LakeConstance_Ciliates_Morphotypes_DepthResolved"

This dataset (n = 13427) is based on Dataset 1. It comprises the approximately weekly (Apr-Nov) to bi-weekly (Dec-Mar) biovolume and biomass of 25 ciliate morphotypes at different depths from 1987-1998.

Column headers

A. Date
B. Morphotype number (integer from 1…25)
C. Depth [m]
D. Biovolume [μm^3/ml]
E. Biomass [mgC/m^2]

Biomass is integrated either over 0-8 m depth or over 8-20 m as in Dataset 1.

Dataset 3:

Filename: "Dataset_3_LakeConstance_Ciliates_Morphotypes_DepthIntegrated"

This dataset (n = 7033) is based on Dataset 2. It comprises the approximately weekly (Apr-Nov) to bi-weekly (Dec-Mar) biovolume and biomass of 25 ciliate morphotypes integrated (=summed) across 0-20m depth from 1987-1998. That is, the biovolume value in $\mu m^3/ml$ integrated over the first 0-20m depth (which roughly represent the euphotic zone) are obtained when adding up the biovolume values provided for 0-8m and 8-20m depth in dataset 2 weighted by factor 0.4 and 0.6, respectively. The biomass values in mg C/m^2 integrated over the first 0-20m are obtained when adding up the biomass values provided for 0-8m and 8-20m depth in dataset 2.

Column headers

F. Date
G. Morphotype number (integer from 1…25)
H. Biovolume [$\mu m^3/ml$]
I. Biomass [mgC/m^2]

Dataset 4:

Filename: "Dataset_4_LakeConstance_Ciliates_All_DepthIntegrated"

This dataset (n = 490) is based on Dataset 3. It comprises approximately weekly (Apr-Nov) to bi-weekly (Dec-Mar) data on total ciliate biovolume and biomass integrated across 0-20m depth from 1987-1998.

Column headers

A. Date
B. Biovolume [$\mu m^3/ml$]
C. Biomass [mgC/m^2]

Dataset 5:

Filename: "Dataset_5_Lake_Constance_Ciliates_LookupTable"

This dataset (n = 56) provides the lookup table for ciliate counting categories, morphotype numbers, and morphotype-specific traits. An entry "Unspecified" in the column "Name" means that no species could be identified. For such species, the entry for genera and taxa are "n.a." (not available) and the morphotype is set to 25 (Unspecified). If trait values could not be determined, the entries in the columns F-J are set to -1, e.g. for the unspecified morphotype 25. For more detailed explanations of the categories and traits, please see the text above.

Column headers

A. Name (text)
B. Genera (text)
C. Taxa (text)
D. Counting category (integer from 10,…502; not all numbers are assigned, for explanation see above)
E. Morphotype number (integer from 1,…25; 25 means not specifiable)
F. Functional group (integer 1,…5)

G. Feeding type (integer 1,….7)
H. Seasonal co-occurrence (integer 1,….9)
I. LLD [µm]
G. Cell volume [μm^3]

References

General references on Lake Constance

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