Phytoplankton Lake Constance data documentation

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Lake name: Lake Constance

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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 with weak pelagic-benthic coupling, and little allochthonous input into the pelagic zone (Bäuerle and Gaedke 1998). Plankton biomass and the factors regulating growth exhibit strong seasonality (Sommer *et al*. 1986, Geller 1991, Gaedke 1992, Boit & Gaedke 2014). Lake Constance underwent a re-oligotrophication process from rather eutrophic to mesotrophic conditions with a decline of total phosphorus concentrations during winter mixing (the most limiting nutrient for phytoplankton growth) from more than 87 µg total phosphorus (TP) L^{-1} in 1979 to 17 µg TP L^{-1} in 1998, resulting in a pronounced phosphorus depletion in the epilimnion during summer. From the mid-'90s onwards, soluble reactive phosphorus concentrations dropped below 1-2 µg L^{-1} right after the onset of the phytoplankton bloom and phytoplankton Carbon-to-phosphorus (C:P) ratios steadily increased until late summer to very high values (Hochstädter 2000). Despite the fairly high maximum TP concentrations during winter mixing, no pronounced cyanobacteria blooms occurred during the eutrophic period which might be attributed to the great depth of the lake.

The LC dataset comprises long-term, high-frequency time series up to 20 years of abiotic conditions (e.g. secchi depth, euphotic depth, temperature, vertical mixing intensity, nutrient, DOM and POM concentrations), phyto- and zooplankton species biomasses, primary and bacterial production measurements, chlorophyll concentrations, and the energy and nutrient flows within the food web (Gaedke *et al*. 1998, Gaedke *et al.* 2002, de Castro & Gaedke 2008, Gaedke & Straile 1994, Boit & Gaedke 2014). The annually repeated, successional cycle in LC is largely driven by autogenic processes during the growing season from March until October/November (Sommer et al. 1986, Sommer 1986, Peeters 2007, Tirok & Gaedke 2007).

Sampling methods

Plankton samples were taken weekly during the growing season (2-3 times per week in 1981 and twice a week in 1987, second half of 1983 is lacking) and less regularly (approximately every two weeks) in winter at a central sampling site (max. depth 147 m) in the northwestern arm of the lake, Überlinger

See. We provide here the data from different depths of the lake, predominantly from the upper 20m which roughly correspond to the epilimnion and the euphotic zone as well as fewer data from the deepest sampling point at 140m. In the upper 0-20 m plankton (except crustaceans) was sampled with a 2 m long tube sampler and the resulting 10 samples were combined to 2-5 samples which were then counted separately. Phytoplankton abundances were obtained by microscopic counting with the Utermöhl technique (Gaedke & Schweizer 1993, Sommer et al. 1993, Bäuerle and Gaedke 1998, Gaedke 1992). Cell volumes were estimated by measuring the length and width of individual cells several times throughout 1979-1998. Results were compared with those obtained by R. Kümmerlin sampling at the central part of the lake. Biovolume was calculated by the product of cell density per ml and average cell volume in μm^3.

The smallest cells that were reliably counted were about 3-4 µm in length with a cell volume of ca. 20 μm^3. We used a 50 ml sedimentation chamber for 24 hours which may imply that very small cells (i.e. < 3-4 µm) did not settle fully quantitatively. Hence, very small cells are likely underestimated (cf. Gaedke 1992). Given different microscopes, smallest cell counts are not consistent throughout the study period but the effort to count them was larger from 1988 onwards. For Autotrophic Picoplankton (APP, i.e. autotrophs <=2 µm), a separate dataset exists. APP was counted using epifluorescence microscopy.

Phytoplankton datasets

We provide four datasets 1-4 with approximately weekly measurements comprising the long-term phytoplankton data for each sampling date (1979-1999) at two different levels of taxonomic aggregation. Dataset 1 provides the biovolume of up to 264 species in high taxonomic resolution, resolved by different depth layers (n = 31711). Derived from this dataset, we provide two additional datasets: Dataset 2 contains the biovolume for each sampling date integrated across the upper 0-20m depth at the same high taxonomic resolution (n = 23340), and Dataset 3 provides this information at an aggregated, intermediate taxonomic resolution (n = 14253). The intermediate resolution comprises 36 of the most important phytoplankton morphotypes in LC. Dataset 4 provides total phytoplankton biovolume summed up across all 36 morphotypes as a reference for database users (Fig.1).

The 4 datasets are accompanied by 2 lookup tables: 1. for the high taxonomic resolution which applies to both the depth-integrated and depth-resolved dataset, and 2. for the intermediate taxonomic resolution (which is available as a depth-integrated dataset only). The lookup tables contain the species name, species number or morphotype number together with morphological and behavioural traits as well as taxonomic and morphological categorizations.

The classification schemes used to establish phytoplankton taxonomic groups and traits are explained in the Appendix to this document.

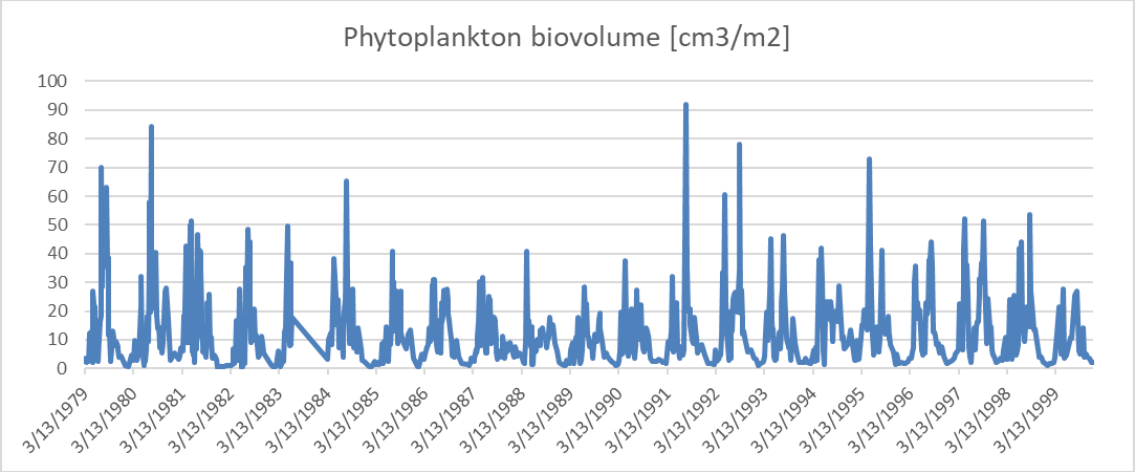

Fig. 1: Total phytoplankton biovolume in cm^3/m^2 as provided by Dataset 4.

Dataset 1: Depth-resolved, high taxonomic resolution

Filename: "Dataset_1_Lake_Constance_Phytoplankton_High_Resolution_Depth_Resolved"
This dataset is the depth-resolved information underlying datasets 2 and 3. It provides the maximum taxonomic resolution that is available for Lake Constance containing the biovolume of each of more than 200 species in units of $\mu m^3/ml$ resolved across different depth layers at each sampling date from 1983-1999. That is, for the years 1979-1982 only depth integrated values are available (see dataset 2). Please see the Appendix under point "Depth resolution" for details about the depth-resolved information.

Column headers

A. Date

B. Depth [m]

C. Species number: ranges from 1 - 245

D. Genus name

E. Species name

F. Biovolume [$\mu m^3/ml$]

Dataset 2: Depth-integrated high taxonomic resolution

Filename: "Dataset_2_Lake_Constance_Phytoplankton_High_Resolution_Depth_Integrated"
This dataset provides the maximum taxonomic resolution that is available for Lake Constance containing the biovolume of each of more than 200 species in units of cm^3/m^2 integrated across the upper 0-20 m depth at each sampling date from 1979-1999 (n=21122). The taxonomic resolution is not consistent across the 20 years because sampling techniques and the taxonomical expertise and /or intentions regarding taxonomical resolution of the taxonomist in charge varied over the course of the years. Thus, the higher taxonomic resolution in later years (i.e. during the reoligotrophication of the lake) is not necessarily due to changes in trophic state, but at least partly due to improved microscopic techniques and taxonomical skills. **Therefore, this dataset cannot be used e.g. for evaluating long-term trends in species biodiversity**. The phytoplankton data provided here comprise all eukaryotic autotrophs, mixotrophs, and larger heterotrophs (represented mostly by *Ochromonas*

sp. and *Gymnodinium helveticum*, for heterotrophic pico- and nanoflagellates see separate data set) (for details see below).

Column headers

A. Date

B. Species number: ranges from 1 - 245, but not all numbers are assigned.

C. Genus name

D. Species name

E. Biovolume [cm^3/m^2]

Lookup table 1 for the high taxonomic resolution

Filename: "Lookup_table_1_Phytoplankton_Lake_Constance_High_Resolution"

The high taxonomic resolution is accompanied by a lookup table containing species-specific information. The lookup table applies to both the depth-integrated and the depth-resolved dataset in high taxonomic resolution.

Column headers

A. Species number
B. Morphotype number
C. Genus name
D. Species name
E. Cell volume [μm^3]
F. Higher taxa
G. Genus level
H. Edibility
I. Mixotrophy
J. Competitive strategy

Dataset 3: Depth-integrated, intermediate taxonomic resolution

Filename:"Dataset_3_Lake_Constance_Phytoplankton_Intermediate_Resolution_Depth_Integrated".

This dataset provides an intermediate level of taxonomic aggregation comprising the biovolume of 36 morphotypes (see Appendix under point "Morphotype numbers" for details) from 1979-1999. We report here the depth-integrated values phytoplankton biovolume in cm^3/m^2 for 0-20m (approx. the euphotic zone) of the most important morphotypes of phytoplankton. Each of these morphotypes contributes at least 5% to the biovolume of total phytoplankton at an individual sampling date during 1979-1982, i.e. the information about rare species and the depth resolution got lost for the years 1979-1982. In total, these 36 morphotypes comprise about 92% of total phytoplankton biomass. The biovolume is aggregated across the upper 0-20 m depth in this dataset. We used this dataset for most of our more recent publications (e.g. Gaedke & Klauschies 2017, Weithoff & Gaedke 2017, Weithoff *et al.* 2015, Rocha *et al.* 2012, Rocha *et al.* 2011) and strongly recommend using this dataset for long-term studies because it largely compensates for the differences in taxonomical resolution.

The 36 morphotype numbers range between 1…138 and are derived (aggregated) from species numbers of the higher taxonomic resolution given in dataset 1. The association between species numbers and morphotype numbers is made by the lookup table for the high taxonomic resolution (see under Lookup table 1).

To achieve maximum comparability between years, the raw dataset was pre-processed taking the following steps:

1. Phytoplankton cells with a species number X.3 (reduced chloroplasts) are omitted. This data is still available on request.
2. Heterotrophic phytoplankton cells (i.e. no or hardly any chloroplast visible) are omitted. They carry the species numbers 45, 46, 93 and 233 and have a trait value of 1 in the column mixotrophy.
3. Cells smaller than 20 μm^3 are omitted because very small cells might have not settled completely during 24 hours in the sedimentation chamber and their counts with the early microscopes are less reliable.

Column headers

A. Date
B. Morphotype number: ranges from 1…138 with 36 unique entries.
C. Biovolume [cm^3/m^2]

Dataset 4: Depth-integrated, total phytoplankton biovolume

Filename:"Dataset_4_Lake_Constance_All_Phytoplankton_Depth_Integrated".

This dataset sums up the biovolume given in Dataset 3 per date and over all morphotypes.

Column headers

A. Date
B. Biovolume [cm^3/m^2]

Lookup table 2 for the intermediate taxonomic resolution

Filename: "Lookup_table_2_Phytoplankton_Lake_Constance_Intermediate_Resolution"

The intermediate taxonomic resolution is accompanied by lookup table 2 containing species-specific traits. The lookup table links species names to 36 morphotype numbers. It provides the cell volumes per morphotype and five other eco-physiological traits (edibility, longest linear dimension, silica use, motility, and mixotrophy, see the Appendix for details).

Column headers

A. Morphotype number
B. Species name
C. Cell volume (μm^3)
D. LLD = longest linear dimension (μm)
E. Silica use
F. Motility
G. Edibility
H. Degree of mixotrophy

Appendix: Phytoplankton traits and taxonomic classification

Counting individual cells and colonies

Different researchers were involved in counting individual phytoplankton cells and colonies. They were Ulrich Sommer (1979-1982), Gisela Richter (1983), Carola Braunwarth (1984-1987), Anette Schweizer (1988-90), Joachim Fürst (1991-93), and Hanna Binder (1994-1999).

Depth resolution

In the depth-resolved file with high taxonomic resolution, an entry in the column "Depth [m]" refers to different water layers in different time periods due to a changing sampling scheme:

How to read this explanation: The entry "10" in the column "Depth" in the years 1983-1985 refers to the water layer between 0-10m (and so on).

1983-1985
10: water layer between 0-10m
20: water layer between 10-20m

1986
5: water layer between 0-5m
10: water layer between 5-10m
20: water layer between 10-20m
140: measured at 140m depth

1987
5: water layer between 0-5m
10: water layer between 5-10m
15: water layer between 10-15m
20: water layer between 15-20m

1988 onwards
8: water layer between 0-8m
20: water layer between 8-20m

For the depth-integrated dataset, the biovolume per layer was weighted to yield the integrated biovolume per square meter in the euphotic zone between 0-20m of depth, e.g. if the biovolume in the layer between 0-8m depth is denoted *A* and the one in the layer between 8-20m depth is denoted *B*, then the depth integrated biovolume per square meter in the euphotic zone is (8x*A* + 12x*B*). Thus, to achieve an average biovolume per cubic meter across 0-20m, the depth-integrated value per square meter has to be divided by factor 20. If an entry for a specific species in a certain water layer is missing, e.g. species no. 1 has no entry for depth=20m at a sampling date in 1983, this means that the measured biovolume was zero at this date. It does NOT mean that the species was not sampled at this date.

Unit conversion

For conversion of the biovolume from the units of the depth-integrated data sets (in cm^3/m^2)
into the units of the depth-resolved dataset ($\mu m^3/ml$), you have to divide the biovolume value by factor 20 and multiply by factor 10^6.

Morphotype number

This classification is the most recent since October 2004 and serves as the basis for the 36 morphotypes in the intermediate taxonomic resolution. Morphotype number range from 1…138 with 36 unique entries. In the dataset with high taxonomic resolution, the morphotype number „-1“ was assigned to very rare species or to those which were encountered very unfrequently, or to those which are subject to discussion for other reasons. Species which were discovered during the later years (1994 onwards) and which did not match with previously established morphotypes were assigned to morphotype number “0”. The biovolume of morphotype -1 and 0 amounts on average to 8.5% of the total phytoplankton biovolume (i.e. 92% of the total biovolume is covered by the 36 morphotypes listed in the dataset with the intermediate taxonomic resolution). In the dataset with intermediate resolution, the morphotypes 0 and -1 are omitted because the species information is not given here.
To promote the functional analysis of the long-term data set all species were classified according to various criteria which are listed below.

Classification into higher taxa

1 = Cyanophyta

2 = Cryptophyta

3 = Crysophyta

4 = Haplophyta

5 = Order Centrales

6 = Order Pennales

7 = Order Dinophyta

8 = Chlamydomonales

9 = Volvocales

10 = Chlorellales

12 = Ulotrichales

13 = Conjugatophyceae

8-13 = Chlorophyta

Classification at the genus level

1 = Anabaena

2 = Microcystis

3 = Cryptomonas

4 = Rhodomonas

5 = Dinobryon

6 = Chrysochromulina

7 = Stephanodiscus hantzschii/spp

8 = Stephanodiscus neoastrea

9 = Stephanodiscus binderanus

10 = Melosira

11 = Asterionella

12 = Fragilaria

13 = Diatoma

14 = Ceratium

15 = Peridinium

16 = Pandorina

17 = Chlamydomonas

18 = Staurastrum

19 = Mougeotia

20 = Ulothrix

22 = Scenedesmus

23 = Chlorella

24 = Cyclotella

25 = Mallomonas

26 = Pediastrum

27 = Synedra

Note: not all species were classified.

Trait: Silica use

0 = no; 1 = yes

Trait: Motility

0 = immotile; 1 = motile

Trait: Edibility

Edibility is considered from the perspective of grazers, in particular cladocerans (*Daphnia*, cf. Knisely & Geller 1986)

1- well edible, small individual cells, mostly phytoflagellates

2- less edible, large individual cells, or colonies

3- less edible, strains/filaments, cyanobacteria or green algae

4- less edible, large and/or spiky cells of diatoms, colonies or strains

5- fairly well edible, small cells including some diatoms, small coccales

Trait: Extent of mixotrophy

0- Purely autotrophic

0.1 Potentially mixotrophic, i. e. there is some indication that a mixotrophic (osmotrophic) supplementation of the autotrophic growth may occur but detailed measurements are lacking or the degree of mixotrophy was low.

0.5 Evidently mixotrophic. For these or closely related species measurements on bacterivory such as clearance rates or ingestion rates are available in the literature.

1 (Almost) purely heterotrophic species. *Ochromonas* is allocated to this group although specific measurements (Diploma thesis Rita Büskens 1998, supervisor Karl-Otto Rothhaupt) showed that at least one strain in Lake Constance is mixotrophic. In 1991-93 *Ochromonas* is used interchangeable with a group called microheterotrophs, i. e. seemingly non-chlorophyll containing species were aggregated into the category called *Ochromonas*. Addressing *Ochromonas* as heterotrophic originates from the fact that no chlorophyll was detectable with the microscopes available at that time.

Trait: Competitive strategy

0- non classified species

1- C- strategists (competitors)

2- R- strategists (ruderals => disturbance-tolerant)

3- S- strategists (stress-tolerant)

The C-, R-, S-strategy classification was done by Guntram Weithoff (weithoff@uni-potsdam.de) and based on Reynolds (1997).

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