SCOPE NEWSLETTER

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Nutrient sources

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A review of studies of nutrient fluxes to the Danube basin shows the considerable level of uncertainties concerning discharges and retention mechanisms. Households (with more than two thirds via sewage works) are considered to make up <30% of phosphorus discharges to the Danube. Diffuse particulate phosphate discharges and subsurface flows are systematically underestimated – the authors suggest a correction factor of x2.

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Daphnia control of filamentous algae

Enclosure experiments in an artificially nutrient enriched lake showed that Daphnia were able to strongly reduce densities of filamentous blue-green algae. Ammonia addition showed that this was not because Daphnia modified the N:P availability ratio and that other mechanisms are more important .

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An 11 year study of 23 Danish lakes show clear biological community response to reductions in lake phosphorus levels, but not necessarily to external P loadings because of internal cycling. Eutrophic lakes showed less response. Biomanipulation of fish populations significantly increased response.

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EU Research

Questioning nutrient "thresholds"

The first of a series of workshops, organised by the European Commission Research Directorate General to address the question of "thresholds of environmental sustainability" (what is meant, how can they be defined, and as importantly used) taking as a starting point the case of nutrients, took place on November 6th 2001. The workshop brought together scientific experts on nutrients from across Europe. The report from this workshop is summarised here. The second workshop took place on 18th-19th June 2002.

The series of workshops aims to provide a definition of such "thresholds" as associated with ecological carrying capacities, and tools for translating these into environmental monitoring indicators and for coupling them with policy decisions reflecting costs and short- and long-term ecological impacts.

Public acceptability

The workshop accepted the "general public" definition of a threshold as a "***level beyond which undesirable effects tend to occur***". This means that a threshold is necessarily dependent on both specific characteristics of a given site or ecosystem and of a given time, but also on what are considered as "undesirable effects", which is a socio-economic consideration.

The workshop concentrated on nutrient enrichment of the marine environment as a case study, looking for operational definitions of the short- and long-term effects of marine nutrient enrichment, whether "thresholds" could be defined in this respect and how they could be used to support public policy making.

For the case of nutrients, the "threshold" was considered to be defined by six factors:

- the level (flux or loading) of nutrients considered to be compatible with acceptable ecosystem functioning
- the carrying capacity of the ecosystem: resilience, tolerance of nutrient inputs
- potential negative effects on the ecosystem
- dependence on the specific context: place (local ecosystem) and time
- concept of "critical" when applied to thresholds, leading to the need to fix "ecological quality objectives"
- the possibility of recovery of the ecosystem and/or the **costs of restoration**

The "threshold" can thus be defined variously as "a level causing unwanted negative impacts", a level "exceeding carrying capacity or system tolerance", a level leading to "restoration efforts which are difficult or prohibitively costly", a level giving "a high probability of unwanted impacts".

In particular, given nutrient loadings may or may not give undesirable impacts as a function of the **other factors and usages** impacting a water body.

Which nutrients to consider ?

The workshop decided to address the case of marine nutrient enrichment. Nitrogen is generally the key nutrient linked to negative effects in marine environments (for example, related to *Phyaeocystis* algal development in the Southern Blight of the North Sea – Christiane Lancelot) but the workshop decided that "nutrient thresholds" should consider **the sum of organic and inorganic nitrogen, phosphorus, carbon and silicon**.

Several case studies showed the deterioration of coastal ecosystems, in particular with algal blooms, related to increased nutrient loadings, including the Adriatic, the Baltic, the North Sea, Mediterranean, and the coast of Norway. Sources of nutrients cited include: agricultural run-off, atmospheric deposition and inadequately treated human sewage. However, all the speakers emphasised the difficulties in defining "nutrient thresholds" given both the **lack of long-term data** to support recommendations, and the need to define specific thresholds for different local circumstances. Even within given marine water bodies, **reaction to nutrients varies considerably between local areas** (eg. "*It seems impossible to define one unique nutrient threshold in the Mediterranean according to the different effects of human nutrient inputs and to the non-steady state of these inputs*" – J. Béthoux and D. Ruiz-Pino). N. Navarro and C. Duarte provided evidence of the major differences between different marine waters in Europe, contending that "*the unit of analysis should be the European Coastal Biogeochemical Provinces which are still to be defined*".

The speakers emphasised that "*it is very difficult to predict the occurrence of harmful algal blooms from* *resource supply*" (Helmut Hillebrand). This is partly because of the influence of many other factors, for example residence time: "*the fate of nutrients can be quite different depending on their residence time in a different environment*" (Serrena Fonda Umani comparing the North Adriatic and the Gulf of Trieste). For the Mediterranean, Marta Estrada and Jordi Camp also emphasised that nitrogen/phosphorus ratios vary widely and "*consideration of anthropogenic effects on physical properties in the environment must be integrated with that of chemical and biological factors*".

Complexity

Christian Béchemin summarised these difficulties by underlining that "the definition of threshold (concentration, ratio, balance) is also connected to the biodiversity, to the special adaptation capacity of species … requires to take into account the diversity, multiplicity of nutrients and their balance, as well as the diversity and multiplicity of organisms … and finally the diversity of end-users".

The debate is rendered even more complex because in some cases **the unwanted effects of nutrient enrichment may exist irrespectively of and prior to human inputs**. J. Béthoux and D. Ruiz-Pino indicated that anoxia (oxygen deprivation) existed in the Black Sea was present before the increase of human activities, because of natural land weathering in the watershed, and that periodic anoxia in the Mediterranean also occurs naturally because of water circulation mechanisms.

The workshop concluded that nutrient thresholds are needed as a tool for communications between scientists, decision makers and the public, but that flexibility is necessary in their use because ecological processes are not reflected by the allocation of "pass/fail" status in response to numerical threshold values. Further **the definition of thresholds depends directly on the definition of ecological quality objectives** (or what is an "unwanted" effect) and this will vary between different stakeholders. Finally, thresholds must **take into account socio-economic factors** and a cost-benefit analysis.

"Thresholds of environmental sustainability – the case of nutrients" First Workshop Report. EU Commission, DG Research – Environment and Sustainable Development Programme, Policy Aspects, Unit I.1 – Research in Enclosed Seas series 11 – EUR 20170 – 2002.

Netherlands

Regional nutrient and ecological targets

The authors attempt to define nutrient standard values for different types of surface water occurring in the Netherlands, by assessing the nutrient level which would be necessary in order to achieve – by nutrient reduction alone – a switch in water quality conditions considered as appropriate ecological objectives for each water type.

This approach is comparable to that of the **EU Water Framework Directive 60/2000**, which requires surface waters to all be restored to "good quality status" by 2015 (save certain exceptions), this being defined for nutrients as enabling near-natural plant and animal communities to develop. The approach is also comparable to the US Environmental Protection Agency (EPA) currently ongoing definition of "ecoregional nutrient criteria" (see SCOPE Newsletter n° 44).

The authors consider 9 **different water types**: small streams, artificial ditches/drainage dykes, lakes, heathland lakes, moorland lakes, IJsselmeer, Vokerak, North Sea coastal waters and the Rhine (as it flows into the Netherlands).

Nutrient standards are suggested for some or all of: P (total phosphorus) and N (total nitrogen, nitrate nitrogen and/or ammonia nitrogen) concentrations in water (summer average) or loadings (inputs/hectare/year).

Nitrogen limitation in coastal waters

In the North Sea coastal waters, there are no clear indications that phosphorus limitation has ever occurred (that is, phosphorus levels do not appear to be the factor influencing algal growth), and **summer algal blooms appear to be nitrogen driven**. Considerable reductions of phosphorus loadings have already been achieved (through sewage treatment), but not significant reductions of nitrogen loads, yet a *further* 60-70% reduction of phosphorus loads would be necessary to achieve phosphorus limitation of the spring algal bloom, according to the authors' estimates. It is difficult to see how this could be practically achieved. **Nitrogen reduction thus appears to be the solution to reduce summer algal blooms and avoid toxic algae development**.

For lakes, the Netherlands currently has "Maximum Tolerable Concentration" standards of 0.15 mgP/l and 2.2 mgN/l (summer averages, total P and N), corresponding to a "desired ecological quality" criterion of limited algal development (chlorophyll concentrations < 100 mg/l).

Other factors

The authors note that in some lakes this desired chlorophyll concentration target is achieved at total phosphorus levels higher than 0.15 mgP/l. **In these lakes, algal growth is not limited by phosphorus, but by another factor, such as nitrogen concentrations or light**.

The authors attempt to assess nutrient (N and P) concentrations which would be low enough to ensure switching of the relevant ecosystem types from a eutrophied to a near-natural conditions. These critical values "*were found to be very low to sometimes extremely low*" so that "*nutrient reduction must be extreme*" to enable ecosystem recovery. This suggests that in many cases **such extreme nutrient reductions will be very difficult to achieve in practice and it may be appropriate to instead try to achieve ecosystem restoration by other actions**.

These target concentrations are **up to ten times lower** than those derived from an analysis of the biological communities present in different types of surface waters in the Netherlands (data from several waterboards) – see SCOPE Newsletter n° 30. This previous study suggested quality levels for "specific environmental quality" (50% of sites achieving highest or nearly highest water quality) of for example 0.24 mgP/l (upper reaches) to 1 mgP:l (lower reaches) for hill streams, 0.15 – 0.36 mgP/l for lowland streams.

"Nutrient standards for nutrients in surface water types" (Watertypegerichte normstelling voor nutrienten in oppervlaktewater). In Dutch with summary in English. RIVM report 703715005/ 2002 for the Netherlands Environment Ministry. Z. van Liere, D. Jonkers.

Phosphorus and nitrogen targets suggested by the authors are as follows:
(summer average water concentrations)

*	small streams	0.02 mgP/l 0.28 mgNO3-N/l 0.02 mgNH4-N/l
*	ditches	0.23 - 2.3 mgP/l 1.3 – 3.3 mgN/l (plus loading limits)
*	lakes	0.05 mgP/l 1 mgN/l
*	IJsselmeer, Volkerak	0.05 – 0.06 mgP/l
*	heathland, moorland lakes	5 – 10 kgN/ha/year (atmospheric)
*	coastal waters	0.6 mgDIN-N/l
*	Rhine	0.08 mgP/l

(limit set to protect IJsselmeer downstream)
1.8 mgN/l
(limit set to protect coastal waters downstream)

Danube basin

More work needed on nutrient fluxes

This paper presents the current state of the art as regards nutrient sources to the Danube basin, pathways and sinks, and transport to the Black Sea, including results of emissions estimates and the Danube Water Quality Model approach and comparisons with measured water monitoring data. Considerable knowledge gaps and margins of error are identified, and the paper concludes that considerable further work is required to achieve reliable estimates of nutrient sources and pathways.

The paper reports results from the EU study "Nutrient Balances for Danube Countries" (EU/AR102A/91, 1997) and the GEF/UNDP River Danube Pollution Reduction Programme. The Danube is nearly 2,900 km long with a catchment of 817,000 km2, including areas of 13 countries.

Total nutrient emissions to the catchment were estimated at 750 – 1,050 ktN/year and 90-130 ktP/year for 1996/1997. Of these totals, 21% of nitrogen inputs were estimated to come from households, of which just under 2/3 via sewage works. For phosphorus inputs, 29% were estimated to come from households, of which just over 2/3 via sewage works. Small amounts of phosphorus from agriculture and industry also go into sewage works, so that sewage works input in total is 33% of total estimated phosphorus inputs.

Underestimation of diffuse sources

If detergent phosphates make up around 30% of sewage phosphate levels, these figures mean that at present they would 30%x29% = 8,7% of catchment phosphorus – assuming no retention in sewage works. After implementation of EU legislation (P-removal in sewage works), they would contribute at most 30%x9% (part not going through sewage works) <3%. Both these figures are likely to be significantly lower because of the indicated underestimation of diffuse phosphorus inputs (up to 50%).

As well as inaccuracies and incoherence between different countries' data and estimates of diffuse inputs, the authors emphasise that total nitrogen inputs are inaccurate because of a lack of data on organic nitrogen. **For total phosphorus, two systematic errors were identified: an underestimation because of low sampling frequency (so that large flows during high rainfall events, due to erosion, are not taken into account), and an underestimation because of the use of surface samples only**. Total phosphorus concentrations measured in the river were found to be not representative of input estimates. The authors used a combined correction factor of 2 to adjust for these underestimations. They estimate that the use of surface samples only, for example, will inevitably cause **an uncertainty in total phosphorus concentrations of up to 50%.**

Furthermore, instream phosphorus concentrations are significantly affected by retention mechanisms, with a drop of around 25% occurring with sedimentation of phosphorus in the Iron Gates dam backwaters, for example.

The paper concludes with the **need for considerable further work to better understand nutrient inputs and pathways in the Danube**, in particular regarding agriculture, catchment retention, estimation of real river loads and impacts on the Black Sea. These issues are being addressed by the EU "daNUbs" project launched in February 2001.

"Nutrient fluxes from the Danube Basin to the Black Sea" Wat. Sci. Tech. vol. 46, n°8, pages 9-17. Article can be purchased at: http://www.iwaponline.com/wst/04608/wst046080009.htm

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Hungary
Underestimates of diffuse lake phosphorus inputs

Diffuse sources (land and agricultural run-off …) made up 60-70% of phosphorus loadings to Lake Balaton, Hungary, by the mid-1990's (Jolankai, 1997), mainly carried to the lake by tributary rivers and streams (see "Response of Lake Balaton to sewage nutrient removal" in this Newsletter). Of these, the largest tributary, the Zala river, drains nearly half of the Lake's watershed area (total 5776 km^2) and has a mean flow of 7 m^3/second.

Phosphorus loads have been monitored in the Zala river and in smaller tributaries 2-4 times/month since 1975, at the point of entry into the lake, and diffuse lake P inputs derived from them. This article assesses the inaccuracy in such load estimates, by using different statistical re-analysis of the available water quality and daily flow data for 5 lake tributaries:

- **unbiased ratio estimate**, where flow weighted mean concentrations based on discrete observations are multiplied by mean flows
- **cluster method**, where observed ranges of flows are grouped into clusters for which average loads are calculated
- **load-flow relationship**, where loads estimated using attentive seasonal regression analysis, differentiating between different seasons' typical loading patterns using 8-15 years' data.

The results of these different load prediction methods were then compared with loads estimated by the routinely used calculation method, where measured P concentration for each sample is multiplied by sample flow (biased routine method).

Importance of flood flows and load underestimates

This analysis suggested that **nearly 25% of runoff flow and 30-50% of phosphorus loads were associated with extreme flood flow events**. This confirmed previous work by for example Bodo and Unny. This explains why the routine calculation methods tend to provide inaccurate river P load estimates. The error, for twice-monthly monitored small inflows lies in the range 15-80%, and varies according to the specific features of the river's watershed.

The biased routine method is assessed as giving a 5-20% underestimation of total phosphorus loads to Lake Balaton, and a 50-150% underestimate of loads to the Lake's Eastern bay areas.

In some cases, the loads recalculated using the historic seasonal regression analysis exceeded those given by the routine calculation method by factors of 2 or 3.

"Improving uncertain nutrient load estimates for Lake Balaton". Water Science and Technology, vol. 43, n°7, pages 279-286, 2001.
http://www.iwaponline.com/wst/04307/wst043070279.htm

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Czech Republic

Challenges of agricultural nutrient run-off

The Zelivka reservoir provides the largest drinking water supply for Prague, as well as supplying the Central Bohemia and Jihlava regions. The reservoir contains up to nearly 257 million m^3 with a retention time of 1-2 years. This study looked at an 85 km^2 subcatchment of the Zelkiva watershed, the Sedlicky Brook catchment, which drains into the reservoir near the reservoir dam. The area comprises mixed arable and temporary grass fields, and is a high risk area for soil erosion. Around one quarter of the area is covered by forest.

The water quality of the Sedlicky brook is mainly affected by **diffuse nutrient pollution resulting from intensive agriculture and soil erosion**. By 2000, diffuse nutrients were reaching the limits for drinking water quality.

The **annual average soil loss** was estimated as 1.8 – 4.1 tonnes/hectare and the annual average export of nitrogen from arable land as 2.5 gN/m^2 and phosphorus as 0.01 gP/m^2.

Agricultural nutrient export

Long term trends for nitrogen (nitrate) and phosphorus loads being carried by the Sedlicky Brook into the reservoir were available from 1976 through to 2000. These indicated, considerable annual variations, but **a trend of increases of both nitrate concentration (reaching 50 mgN-NO_3/l by 2000) and phosphorus (reaching 0.15 mgP-Total/l).**

In response to this situation, a **catchment Clean Water Programme** was defined, involving local municipalities, the private water company operating the drinking water supply using the reservoir, and farmers. Prevention principles and best management practices were funded by the water company. Long term nutrient monitoring enabled maps defining particularly vulnerable zones to be established. Action can thus include targeted farmers to payments to appropriately manage specified areas to reduce nutrient export and soil erosion, in particular changes of land use and creation of "buffer zones" of permanent vegetation.

The total cost of the Clean Water Programme in the Zelivka reservoir catchment is estimated at 24-31 million € Euros/year.

"Integrated watershed approach in controlling point and non-point source pollution within Zelivka drinking water reservoir". Wat. Sci. Tech. Vol. 45 n°9, pages 293-300. Summary at:
http://www.iwaponline.com/wst/04509/wst045090293.htm

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Mexico

Tropical lake nutrient resilience

Lake Zirahuen has a surface area of nearly 10 km^2 and lies in a catchment of 260 km^2 in the Central Mexico highlands around 19'N, 101'W, at an altitude of just over 2000m. The mean lake depth is 22M and the water residence time is long.

The lake faces considerable anthropogenic nutrient inputs, both from agriculture (60% of the catchment area) and from direct sewage input from around 24,000 inhabitants.

The lake's water temperature varied from 19 – 22.5°C in the summer near the surface (stratification), falling to 16-17°C in winter (lake mixing) and was constant at 16.5°C near the bottom (1998). For the last 10 years, approximately, the bottom waters have regularly become anoxic at the beginning of the summer stratification period.

The significant external nutrient loadings to the lake and the potential for internal nutrient loadings due to sediment anoxia, contrast with the excellent condition of the lake, which shows highly transparent waters (whose blue makes the lake an important tourist attraction) and low algal biomass. Phosphorus loadings to the lake have been calculated at 0.25 gP/m^2 in 1987 rising to 0.34 gP/m^2 in 1996, but chlorophyll levels (highest surface concentrations 4 µg/l chl_a) confirm the lack of response to nutrient loadings.

This paper presents algal growth experiments in lake water samples (bioassays) to which nutrients were added, carried out to test whether the low algal response in the lake was due to toxic inhibition of algal growth (one hypothesis suggested that copper pollution could be responsible for this). Bioassays were carried out using water from 5 sampling sites (4 in the lake, one in the La Palma stream, the lake's only inflow), each at four different dates (July, September, December, February). For each sample, four replicates were carried out for each of four treatments: control (no nutrient addition), addition of nitrogen (1000 µgN/l), addition of phosphorus (50 µgP/l), both nitrogen and phosphorus. The samples were filtered (0.45µm membrane) then placed in illuminated, test tubes, with a 40:60 proportion of air, at around 24°C, and shaken every 24 hours.

No response to nutrient loadings from La Palma waters.

In the lake water samples, the controls (no nutrient addition) consistently showed no algal growth potential (AGP), whereas in some seasons (particularly summer) the samples from the inflowing streams showed significant potential. In all tests with lake water, neither the addition of only phosphorus nor the addition of nitrogen only stimulated algal growth (compared to the control test), and stimulation resulted only from the combined addition of phosphorus and nitrogen.

The authors note that the absence of algal growth in the lake water (without nutrient additions) is **consistent with the observed absence of eutrophication symptoms in the lake**, whereas the algal growth potential in the inflowing stream water is consistent with the incoming nutrient loadings – and thus "*the Lake Zirahuen enigma continues*".

The good algal growth found for nutrient addition in the stream waters eliminates the hypothesis of copper inhibition from upstream industrial spills as the explanation of the low in-lake algal growth. **The authors conclude that the lake is co-limited for phosphorus and nitrogen**, and that algal response to nutrient inputs may be prevented by: **(a) significant subsurface flushing of the inflowing nutrients** (stream inflow waters were warmer, so lighter, than the lake bottom water in winter, but colder so denser in summer); and **(b) internal control mechanisms** preventing the mobilisation of nutrients into the food chain.

"Assessing trophic state of an endorheic tropical lake: the algal growth potential and limiting nutrients", Arch. Hydrobiol. 153 – 2, pages 323-338, Jan. 2002

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Winsconsin Lakes

Large daphnia and water clarity in eutrophic lakes

13 eutrophic, summer-stratified lakes in South Winsconsin (USA) were selected for study on the basis of recorded occurrence of summer algal blooms, *Daphnia* grazing, and dominance by either *Daphnia galaeta mendotae* or *D. pulicaria*.

The lakes' areas varied from 78 – 3,985 hectares and their maximum depth from 8.5 – 25.3 m. In 6 of the lakes, *Daphnia* populations were dominated by *D. galaeta mendotae* (average size 1.0 mm, 5.9 µg dry weight), and in 6 by *D. pulicaria* (average 1.3 mm, 17.6 µg). In one lake, the dominant population of *Daphnia* changed from spring to autumn.

The population densities of *Daphnia* in the *D. galaeta mendotae* and *D. pulicaria* dominated lakes were similar (16 and 15 individuals/litre average respectively). However, the **larger average size of *D. pulicaria* resulted in a higher *Daphnia* biomass/litre** in the lakes dominated by this species (192 compared to 104 µg dry weight/litre) and a significantly higher "mean filtration potential" – a measure of the capacity to graze algae (411 vs. 99 ml/l/day in May, 225 vs. 85 ml/l/day in June).

Clear water despite high nutrient levels

Total phosphorus concentrations were higher in the *D. pulicaria* dominated lakes (66 vs. 25 µgP/l average May-July). Chlorophyll levels in both classes of lakes were similar in early spring and were found to then be related essentially to the *Daphnia* filtration rate. As a consequence, **the clear water phase in *D. pulicaria* lakes tended to start earlier, last longer and achieve better levels of water transparency** (greater Secchi disk depth) in May and June.

This study concords with the authors' previous work (Kasprzak & Lathrop, 1997), which used a series of bag experiments and indicated that *D. pulicaria* was a more effective grazer of algae than *D. galaeta mendotae* and that the difference is because of the greater body size and so filtration potential.

The authors also assessed the risks of blue-green algal blooms related to *Daphnia* grazing, because these algae can be inedible to *Daphnia*. Blooms of *Aphanizomenon*, a local problem blue-green, were related to interactions between nutrients, growth of other edible and inedible algae, and grazing. The study results suggest that sufficient abundance of large *Daphnia* may delay blue-green *Aphanizomenon* blooms: in the studied lakes *Aphanizomenon* did not develop in the *D. pulicaria* lakes where grazing potential was higher than 250 ml/l, with the opposite occurring in than *D. galaeta mendotae* lakes.

The authors conclude that high densities of large-sized *Daphnia* are a desirable goal in eutrophication management as natural lake populations can attain grazing levels high enough to increase summer water clarity. This confirms similar conclusions reached for lakes in Hungary (Grigorsky *et al.*, Hungary, 1998, reported in SCOPE Newsletter n° 39).

"Influence of different sized Daphnia species on chlorophyll concentration and summer phytoplankton community structure in eutrophic Winsconsin lakes", Journal of Plankton Research, vol. 21, n°11, pages 2161-2174 (1999).

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Ohio, USA

Importance of Daphnia in controlling algae

Six water column enclosures (1.4m diameter, 2.5m depth, from the lake surface to the sediments) were installed in spring (early June – end of August) in Crystal Lake, a small hypereutrophic man-made lake 5km west of Akron, Ohio, USA.

After an initial treatment to eliminate zooplankton and fish (CO_2 as dry ice), except in the "control" column, **two different types of native zooplankton population dominated in the columns** :

- the small cladoceran *Bosmina longisrostris* in three columns (including the control)

- *Daphnia galeata mendotae* in the other three columns

The development of these two types of zooplankton population was fortuitous: other larger *Daphnia* species were in fact artificially introduced into certain columns but did not survive, and populations of these two native species instead appeared. A few fish (bullheads *Ictaluras melas*) were present in the control column (which had not been CO_2 cleared at the start) but none in the other five columns.

The *Daphnia* dominated columns showed average densities of nearly 100 *D.* individuals per litre, compared to near zero in the lake and the *Bosmina* dominated columns. The *B.* densities were on average 450 ind./l in the *Daphnia* dominated columns, around 2,000 in the *B.* columns (2.460 in the control) and around 1.000 in the lake.

Daphnia grazing effectiveness in controlling blue-greens

The *Daphnia* dominated columns showed algal counts five times lower than the *B.* columns, and three times lower chlorophyll levels. The main difference in algal biomass is due to a decrease in the relative abundance of the large, extensively sheathed, blue-green alga *Microcystis.* Edible green algae, primarily *Scendedesmus* (the most abundant green algae family in the lake) made up a relatively higher proportion of algal biomass in the *Daphnia* columns. The green colony alga *Coelastrum* developed only in the *D.* columns, to around 12% of algal biomass (this alga is probably inedible for *Daphnia*).

As a consequence water transparency was better in the *Daphnia* columns, whereas anoxic conditions appeared on occasions in the *B.* columns.

Are blue-greens edible for Daphnia ?

The authors note that other publications suggest that *Daphnia* cannot digest blue-green algae, although they may be grazed and pass through the *Daphnia* and no longer be viable after this passage. The apparent *Daphnia* control of blue-greens in this experiment may be related to differing levels of toxicity of for different strains of these algae, or for algae of different ages.

It may also be indirect results of *Daphnia* grazing which is in fact controlling blue-greens. Mechanisms for this could include the reduction of nutrient levels resulting from sedimentation of *Daphnia* faeces (accelerated in this case as the *Daphnia* tended to congregate at the column base just above the lake floor sediments during the day), increased water transparency (green algae are more efficient than blue-greens in good light conditions) or lower pH (*Daphnia* grazing lowers total algal biomass, and thus primary production, and so pH).

"Direct and indirect effects of zooplankton grazing on phytoplankton in a hypereutrophic lake". Oikos 42, pages 291-302, Copenhagen, 1984.
http://www.blackwellmunksgaard.dk/tidsskrifter.nsf/tidsskrifter/Oikos/aimandscope?OpenDocument

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Norfolk Broads, England

Fish, plants, zooplankton and control of algal growth

Five lakes of the shallow Norfolk Broads lake system in Eastern England were studied for three years, from 1993-1995, over the growing season from April to September. Monitoring included sampling of zooplankton across the range of different macrophyte cover densities present in the lakes (from plant covered areas to open water), composition of lakeside vegetation, point-abundance sampling (by electrofishing) of small fish populations, and radio-tracking of piscivorous fish.

The surface area of the five lakes varied from 1.9 to 14.3 hectares and the mean depth from 0.9 – 1.7m. The average proportion of water covered by macrophytes varied from 0 – 91%.

In most of the Broads studied, the key zooplankton grazers *Daphnia sp.* Showed an early summer peak of abundance, followed by a rapid decline. Various pieces of evidence suggests that this population reduction is the result of predation by (small) planktivorous fish, and not simply a response to food limitation: previous studies showing correspondence to timing of development of populations of small fish, ability of even small populations of small fish to cause zooplankton population collapse and failure of *Daphnia* populations to develop in the Spring where significant populations of small fish over-winter.

Further, the relatively high concentrations of nutrients and of algae (chlorophyll) in the Broads suggest that food levels are rarely, if ever, limiting for zooplankton.

Role of macrophytes

Previous work (Stansfield *et al.*, 1997) showed that the **decline in *Daphnia* populations, even in the presence of dense small fish populations, tended to be delayed in the presence of macrophytes**. This is thought to be because the macrophytes (plant vegetation) provides zones in which the zooplankton can shelter from fish predation (refuges), as is confirmed by observations of *Daphnia* behaviour, including grouping near the edges of macrophyte cover. Small fish tend not to enter macrophyte zones because of the high risk of attack by piscivorous fish (such as Northern pike *Esox lucius*) which can hide in such zones, and even when small fish, particularly roach (*Rutilus rutilus*) do enter macrophyte cover zones they may not feed on *Daphnia* because of the difficulty of capturing prey in structured environments.

Several studies have shown **diel horizontal migration of *Daphnia***, that is moving out from macrohyte cover to open water at night (to graze algae) and returning to cover during the day. However, planktivorous fish are apparently capable of feeding in darkness (Townsend and Risebrow, 1982) so that a reduced predation pressure would still exist.

The presence of macrophytes tends to result in a zooplankton community shift from *Daphnia* dominance to smaller species such as *Simocephalus*, *Ceriodaphnia* and *Sida* species. Crucially, the latter three species appear to take over the principal grazing role from *Daphnia.*

The beneficial effect of refuges may also be enhanced by the presence of non-grazing copepods or macro-invertebrates in the vegetation, which provide an alternative food source for small fish, reducing predation on grazing zooplankton.

Conditions for zooplankton populations

Experimental work by Shriver *et al.*, 1995, in shallow lakes in Denmark, suggested that **macrophyte coverage of at least 20% of lake surface area and small fish density <2 fish/m^2 were necessary for zooplankton grazer population stability**. The figures suggested by this Norfolk Broads study suggest that the zooplankton community was here more fragile, requiring a minimum 40% macrophyte cover and small fish density < 1 /m^2. The type of fish predator appears to be a key factor.

Control of algal development

Stansfield *et al.,* 1997, illustrated that broads with cladoceran (grazing zooplankton) population densities > 30 individuals/litre achieved low algal development (chlorophyll$_a$ concentrations < 25 µg/l). Previous studies have suggested that **a filtration rate (zooplankton grazing) of 300-400 ml/l/day would be adequate to prevent algal blooms and ensure clear water**. This rate was effectively ensured by *Daphnia* in the early spring and then later by *Simocephalus* and *Ceriodaphnia* in this case.

Other studies have also shown that natural zooplankton grazer population densities can prevent algal development, for example Grigorsky *et al.*, Hungary, 1998, reported in SCOPE Newsletter n° 39.

Jepesen *et al.*, 1998, showed that it was **plausible that refuge-using zooplankton could effectively control algal growth at least until mid-summer**. However, an increase in fish densities (> 1 ind./m^2) will not necessarily lead to algal blooms, which may be limited by other factors such as nutrient competition with macrophytes.

The authors conclude that zooplankton grazing is susceptible to control algal development in these eutrophic shallow lakes. However, even a low fish density (0.2 fish/m^2) can eliminate all grazing zooplankton by mid-summer unless macrophytes are present. A cover of at least 30-40% may provide an effective refuge against fish for a range of grazing zooplankton, until a critical fish density is exceeded.

"The practical importance of the interactions between fish, zooplankton and macrophytes in shallow lake restoration" Hydrobiologia 395/396 (1999) pages 199-210.

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Canadian lakes

Daphnia control of filamentous algae

Stoichiometric theory suggests that when significant populations of "phosphorus rich" zooplankton such as *Daphnia* develop (*Daphnia* biomass N:P ratio is lower than that of phytoplankton), then this should increase the ratio of available N:P in water and decrease the abundance of nitrogen-fixing blue green algae.

This paper reports on experiments carried out in the artificially nutrient enriched Lake L227 (North-West Ontario, Canada), where **development of filamentous blue-green algal populations (cyanobacteria) was examined in enclosures with/without *Daphnia*** populations, and with high/low soluble nitrogen:phosphorus ratios. The authors argued that, if *Daphnia* can affect blue-green algae by changes in N:P availability, then the effects of *Daphnia* on blue green algae would be expected to be greater in enclosures receiving low N:P loading.

The initial phytoplankton communities in the enclosures were dominated by the filamentous blue-green *Aphanizomenon sp.*, with *D. pulicaria* being the main *Daphnia* species. Twelve 1m x 1.1m x 1.9m depth polythene enclosures were suspended in the lake on floating frames, including sediment in the bottom of each enclosure. The 1.9m depth was slightly greater than the mixing depth of the lake at the time of the experiment (June-July, duration 6 weeks).

***D. pulicaria* were collected from a nearby lake (L110) and added at an average density of 480µg/l** in the with-*Daphnia* enclosures. Soluble phosphorus was added to all the enclosures at 23 mgP/m^2/week, equivalent to the lake's phosphorus loading regime. For the high N:P ratio enclosures only, soluble nitrogen was added (as ammonia) to generate an N:P loading ratio of 33:1.

Daphnia survived well in all the enclosures to which they were added, dominating the zooplankton populations (>85% of biomass) and maintaining **densities comparable to those found in the lake surface waters** (average 300 µg/l). *Daphnia* were nearly never found in the enclosures to which they had not been added.

Impact of *Daphnia* on algae

***Daphnia* presence had a strong negative influence on algal biomass, with mean phytoplankton biomass an order of magnitude lower in with-*Daphnia* than without-*Daphnia* enclosures**. Furthermore, filamentous cyanobacteria made up 75% of algal biomass in without-*Daphnia* enclosures by the end of the experiment, compared to just 20% in with-*Daphnia* enclosures. *Daphnia* had a much stronger influence on algal biomass and community structure than did nitrogen addition.

In the with-*Daphnia* enclosures, total phosphorus decreased considerably because of greater sedimentation of particulate phosphorus. In contrast, total nitrogen did not change relative to without-*Daphnia* enclosures because losses of suspended particulate N were balanced by increasing dissolved nitrogen. This resulted in higher dissolved N:P ratios in with-*Daphnia* enclosures than in without-*Daphnia* enclosures (both for the with and without added nitrogen cases).

Because of the near-absence of a cyanobacterial response to ammonium addition, the authors conclude that ***Daphnia* did not control filamentous cyanobacteria through changes in N:P ratios**. They suggest that *Daphnia* control of cyanobacteria may have been achieved by grazing, or by damage to the algae in attempted grazing even if they were in fact inedible (average filament length > 300 µm). Alternatively, other nutrient changes related to the presence of *Daphnia* such as **decreased Dissolved Inorganic Carbon (DIC) concentrations** may have affected cyanobacteria and prevented their response to the changes in N:P ratios. DIC limitation may have occurred artificially in the enclosures as a result of reduced wind speeds at the enclosure surfaces (reduced aeration), due to the sheltering effect of the enclosure support structures above the water level.

The authors indicate that **the role of DIC in affecting cyanobacterial dominance remains poorly understood** and merits further study.

"The effects of Daphnia on nutrient stoichiometry and filamentous cyanobacteria: a mesocom experiment in a eutrophic lake", Freshwater Biology n°47, pages 1217-1233, 2002.

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Varying lake reactions to reduced phosphorus

Over 11 years (1989-1999), regular sampling of water total phosphorus concentrations, algal density (chlorophyll$_{-a}$), algal (phytoplankton), zooplankton and fish communities were analysed throughout the spring-summer period (May-September) in 18 Danish lakes showing significant in-lake phosphorus reductions, plus 5 reference lakes where in-lake phosphorus was fairly stable.

In four of the 18 P-reduction lakes, biomanipulation measures were taken, reducing cyprinid fish populations considerably (70% reduction in fish biomass in 1992-1994), thus limiting predation on zooplankton.

The P-reduced lakes had mean depths of 1 – 3.5m and areas of 0.9 – 4.9 km^2, with in-lake total phosphorus concentrations of 26 – 885 µgP/l (average 206 µgP/l for the 14 non bio-manipulated lakes, 132 µgP/l for the four biomanipulated lakes). The five reference lakes were considerably smaller (0.4 – 1.0 km^2 with low in-lake total phosphorus concentrations (20 – 59 µgP/l, average 31 µgP/l.

The summer chlorophyll levels in the 18 P-reduction lakes declined significantly over the 11 year period, whereas no ch anges were recorded in the 5 reference lakes. In the P-reduction lakes, the proportion of non-heterocystous cyanobacteria (blue-greens) declined considerable, with heterocystous cyanobacteria and in some cases dinophytes and cryptophytes increasing. The effects were stronger in the biomanipulated lakes. No significant changes were noted for chrysophytes and diatoms.

In the P-reduced lakes, despite no significant changes in total zooplankton biomass, there were significant increases in the contribution of *Daphnia* to cladoceran communities, and an increase in the mean body mass of *Daphnia*. Because of the decrease in phytoplankton biomass, the zooplankton/phytoplankton biomass ratio increased and so the grazing pressure on phytoplankton increased. Again, these different effects were more marked in the biomanipulated lakes.

In the P-reduced lakes, the biomass of zooplanktivorous fish declined, while the percentage of piscivorous fish increased markedly. The improvements in the lake water quality is therefore both an effect of enhanced “top-down control” (piscivorous fish eating zooplanktivorous fish and thereby releasing the predation pressure on zooplankton, which may then exert a high grazing pressure on the phytoplankton) and “bottom-up” control (less nutrients means less phytoplankton). In biomanipulated lakes, the role of top-down control was larger.

Internal phosphorus cycling

These different biological responses to reduced in-lake phosphorus concentrations were particularly noticeable in the lakes with P concentrations of 1.2 mgP/l or lower, with only minor changes occurring at concentrations in the 1.2 – 4.0 mgP/l range.

The authors also note that the **biological changes are recorded in response to in-lake phosphorus concentrations, but not necessarily to external phosphorus loading reductions, because of internal loadings**.

“Response of phytoplankton, zooplankton, and fish to re-oligotrophication: an 11 year study of 23 Danish lakes”, Aquatic Ecosystem Health and Management 5(1), pages 31-43, 2002.
http://www.aehms.org/5_1_jeppesen.html

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SCOPE NEWSLETTER

The SCOPE Newsletter

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