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Special Study on Sediment Discharge and Its Consequences (SedSS)

Technical Report Number 7

NITROGEN DYNAMICS IN NORTHERN LAKE TANGANYIKA

by
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Pollution Control and Other Measures to Protect Biodiversity in Lake Tanganyika (RAF/92/G32)
Lutte contre la pollution et autres mesures visant à protéger la biodiversité du Lac Tanganyika (RAF/92/G32)

Le Projet sur la diversité biologique du lac Tanganyika a été formulé pour aider les quatre Etats riverains (Burundi, Congo, Tanzanie et Zambie) à élaborer un système efficace et durable pour gérer et conserver la diversité biologique du lac Tanganyika dans un avenir prévisible. Il est financé par le GEF (Fonds pour l'environnement mondial) par le biais du Programme des Nations Unies pour le développement (PNUD)"	The Lake Tanganyika Biodiversity Project has been formulated to help the four riparian states (Burundi, Congo, Tanzania and Zambia) produce an effective and sustainable system for managing and conserving the biodiversity of Lake Tanganyika into the foreseeable future. It is funded by the Global Environmental Facility through the United Nations Development Programme.

Burundi: Institut National pour Environnement et Conservation de la Nature
D R Congo: Ministrie Environnement et Conservation de la Nature
Tanzania: Vice President's Office, Division of Environment
Zambia: Environmental Council of Zambia

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1 INTRODUCTION

1.1 GENERAL

The central African Lake Tanganyika is World's longest freshwater lake. It is 677 km in length, with an average width of 50 km and a total area of 32,900 km_. It is also the World's second deepest lake, with a maximum depth of 1433 meters. It receives waters from a watershed draining Western Rwanda and Burundi, Eastern Congo-Zaire, whole Tanzania and Northern Zambia. The outlet of Tanganyika Lake is the Lukaga River, an affluent of River Zaire.

The Northern part of the lake receives the large Rusizi river which flows from lake Kivu and represent the largest water contributor of the lake with an average discharge of 182 m_/s, and several smaller rivers draining Burundi’s capital Bujumbura like Mutimbuzi (3 m_/s) and Ntahangwa (2.5 m_/s) Rivers (see Figure 1). These inflowing water masses are probably important nutrient sources for the lake, either in their dissolved or particulate form. Indeed suspended sediments probably play a major role in the nutrient cycling of the lake. They are major contributors to the nutrient load as they carry particulate organic matter that can be mineralised. Indirectly, by increasing the turbidity, they can also influence microbial processes of the nutrient cycle, either positively (nitrification for example) or negatively (photosynthesis). Finally, as they are also submitted to sedimentation processes, they can also constitute a sink for attached microorganisms and adsorbed nutrients. There’s only little recent information about the dissolved and sediment-linked nutrient input and cycling in Lake Tanganyika.

1.2 HYDRODYNAMICS AND NUTRIENT REGIME

Earlier work made by Coulter and Spigel (1991) showed that the main hydrological characteristic of the lake is that its water column is highly stratified during the rainy season, which last from September to March. During the dry season however, due to strong southerly winds, an upwelling region develops in the Southern part of the lake while the northern water masses stay stratified. This dynamic will have dramatic implications on the nutrient regime in Lake Tanganyika. Indeed, during the rainy season in the South and all over the year in the North, water masses of different depths do not mix together. A consequence of this is that bottom waters of the lake are completely anoxic below a depth of 200 m (Hecky *et al.*, 1991).

Nutrients (inorganic N, P and Si) in aquatic ecosystems are very important as they control the primary production in aquatic systems together with light and temperature. In most tropical lakes like the Tanganyika, because of the highly transparent waters, the continuously high temperatures and the absence of solar radiation variability, nutrients are expected to be very low in the euphotic zone. The absence of strong vertical mixing is one factor more that induces low nutrient concentrations. In these lakes, the most limiting nutrient for primary production is nitrogen (Talling, 1966; Moss, 1969).

Figure 1 Northern Lake Tanganyika and it’s affluents.

Figure 2 shows a typical vertical profile of dissolved inorganic nitrogen in the North Basin of Lake Tanganyika (Hecky *et al.*, 1991). This profile can be used to have a qualitative idea of the important N-fluxes within the water column.

In the euphotic zone of surface waters, both ammonium and nitrate are depleted by phytoplankton uptake. Ammonium stays low until 150 m, thus even in dark conditions. This is due to the nitrification process which oxidises ammonium to nitrate in the presence of oxygen and at reduced light intensities. At 30m, when light intensity decrease, nitrate starts to increase because it is not taken up anymore by phototrophic organisms and it is produced by nitrification. Nitrate increases until 75 m and then starts to decrease when approaching the depth where oxygen is depleted. Indeed, when there is no oxygen available, there is no nitrification anymore and nitrate is denitrified to N_2 until complete depletion. When nitrate starts to decrease, we also see an increase of the ammonium. At this depth, there is no sufficient oxygen anymore to sustain nitrification and ammonium is not consumed anymore. It accumulates through mineralisation of organic nitrogen.

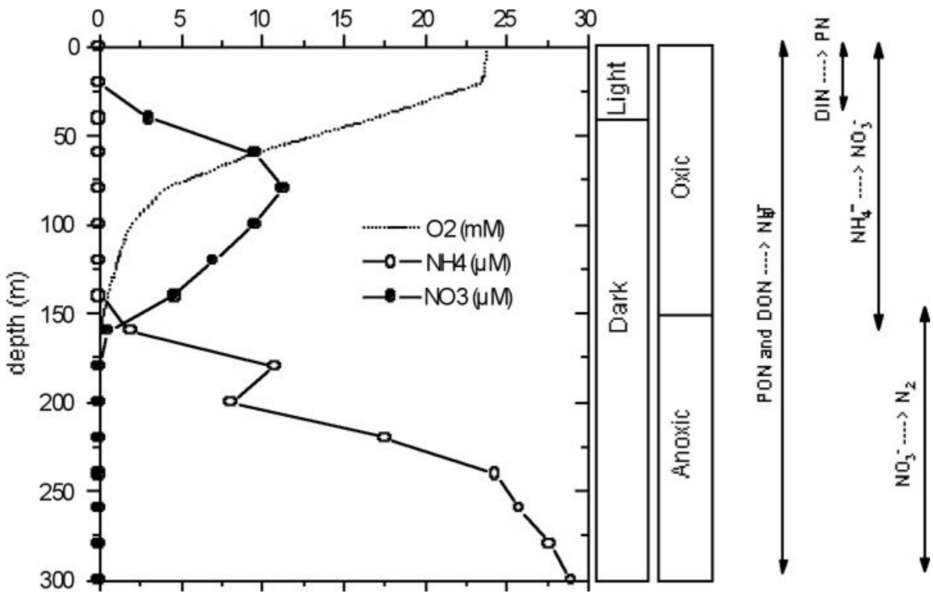

Figure 2: Typical vertical profile of dissolved inorganic nitrogen and oxygen measured in the northern basin of lake Tanganyika. From Hecky *et a.l* (1991). PON, particulate organic nitrogen; DON, dissolved organic nitrogen; DIN, dissolved inorganic nitrogen.

2 *OBJECTIVE*

The general objectives of our work are:

To determine the seasonal influence of the rivers as nutrient sources for the northern part of the lake, with a focus on nitrogen species.

To contribute to the determination of internal N fluxes in the water column of this zone by measuring the seasonal variation of N uptake rates by phytoplankton.

3 *METHODS*

3.1 SAMPLING

Sampling campaigns were conducted from end August 1998 to August 1999.
Samples were taken at a northern station of Lake Tanganyika (1 km from lakeshore, 29°19 E - 3°22 S) and at the outlet of the 3 major rivers arriving in the Northern part of the lake: Grande Rusizi (station at 1 km from the lakeshore), Mutimbuzi (station at 1.5 km from the lakeshore) and Ntahangwa (station at 3 km from the lakeshore). River samples were taken with a bucket from a bridge in the middle of the stream and lake samples from a Zodiac. Water samples for nutrient analysis were immediately brought back to the laboratory for analysis.

3.2 PHYSICOCHEMICAL PARAMETERS

Temperature (T), pH, conductivity, and oxygen concentration (O2) were measured on lake and river samples directly after collection with a specific probe.
Annual discharge data for the 3 rivers were collected either in literature or by IGEBU.

3.3 DISSOLVED INORGANIC NITROGEN (DIN) DETERMINATION

For lake samples, DIN are measured directly on the collected samples and for river samples, because of the high turbidity, they are measured on GF/F (Whatman) filtered water. Ammonium, nitrate and nitrite determinations are performed immediately after sampling by colorimetric methods. Ammonium concentrations are measured with the indophenol blue complexion colorimetric method according to Koroleff (1969). Nitrate is first reduced to nitrite on a cadmium-copper column according to Gardner *et al* (1976) and nitrite is analysed with the sulphanilamide colorimetric method according to Bendschneider and Robinson (1952). The used spectrophotometer is a Perkin Elmer lambda 2 with cells with an optical path of 5 cm.

3.4 DETERMINATION OF SUSPENDED MATTER

Suspended matter concentration is measured immediately after collection by filtering a known sample volume on combusted (8h at 450°C) pre-weighted GF/F membranes.

3.5 NITROGEN UPTAKE EXPERIMENTS

Uptake of nitrogen by phytoplankton is measured with the ^{15}N-tracer technique (Dugdale and Goering, 1967). Transparent plastic incubation bottles of 750 ml volume are filled with water samples and spiked with labelled nutrients, $^{15}NO_3^-$ (99.5 %) or $^{15}NH_4^+$ (99.8 %). The exact concentration of nutrients is measured immediately after the spike. Samples are incubated *in* situ in a floating incubator at natural light for about 6 hours. At the end of incubation final nutrient concentrations are measured as a control and the particulate matter from each incubation bottle is filtered through a combusted GF/F membrane for ^{15}N abundance measurements. The ^{15}N abundance for each incubation bottle is measured with an emission spectrometer Jasco NIA 1 (Kumazawa, 1969). Incubations and concentration determinations are performed in

Bujumbura by UoB. ^{15}N determinations will be performed at the VUB. This was done on the lake sample for the cruise of October.

The uptake rates are calculated according to Dugdale and Wilkerson (1986) and Collos (1987) from the following equations:

$$Adi = \frac{Co \times An + (Ci - Co) \times As}{Ci}$$

$$U = \frac{(Apf - An)}{(Adi - Apf) \times \Delta t}$$

With:
Co: the initial concentration of NH_4^+ or NO_3^- before tracer addition (measured)
Ci: the concentration of NH_4^+ or NO_3^- after tracer addition (measured)
An: natural abundance of ^{15}N = 0.365 %
As: abundance of ^{15}N in the NH_4^+ or NO_3^- tracer = 99.5 or 99.8 %
Adi: abundance of ^{15}N in the NH_4^+ or NO_3^- of the sample after tracer addition (calculated)
Δt : incubation time
Apf: abundance of ^{15}N in PON at the end of the incubation (measured)
U: specific NH_4^+ or NO_3^- uptake rate

4 RESULTS AND DISCUSSION

4.1 RIVER DISCHARGE

Maximum, minimum and annual river discharge for the Mutimbuzi, Ntahangwa and Rusizi rivers are given in table 1.

m_/s	Mutimbuzi	Ntahangwa	Rusizi
Minima	6.7	1.9	148.4
Maxima	3.2	14.4	221.9
Yearly Average	3	2.5	182.4

Table 1. Minima, maxima and yearly average of the discharge of rivers Mutimbuzi, Ntahangwa and Rusizi.

4.2 TEMPERATURE, PH AND CONDUCTIVITY

Temperatures are from 22 to 28°C in the rivers and slightly higher in the surface waters of the lake (27 to 29°C). Peak temperatures are generally observed during the rainy season, between September to April. During the dry season, southerly winds induce evaporative cooling of the surface waters and temperatures are slightly lower (Coulter and Spigel, 1991).
All samples have an alkaline pH, especially the water from the lake and the Rusizi River. Conductivity is around 10 times higher in the Rusizi and in the lake than in the waters of the Mutimbuzi and Ntahangwa.

The high conductivity and pH of the Rusizi and the lake Tanganyika are related to the alteration of basaltic rocks in the watershed of South Kivu and to the volcanism of the region.

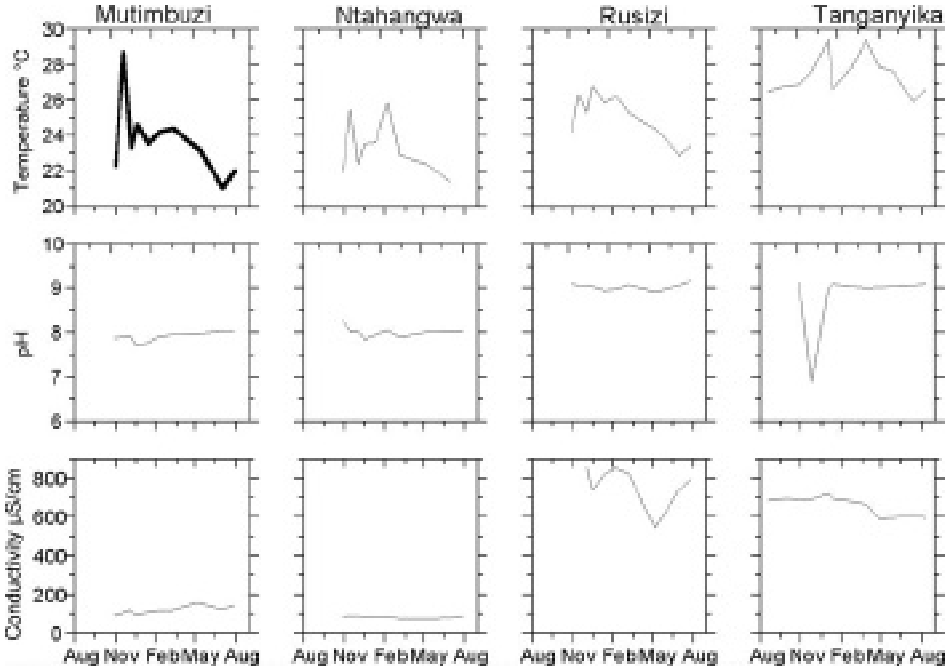

Figure 2. Seasonal variation of temperature, pH and conductivity at the outflow of rivers Mutimbuzi, Ntahangwa and Rusizi and at a station of lake Tanganyika.

4.3 SUSPENDED MATTER AND OXYGEN

Oxygen concentrations in the rivers and lake are all higher than 80 % except at one occasion in the Rusizi where it dropped to 65 %.

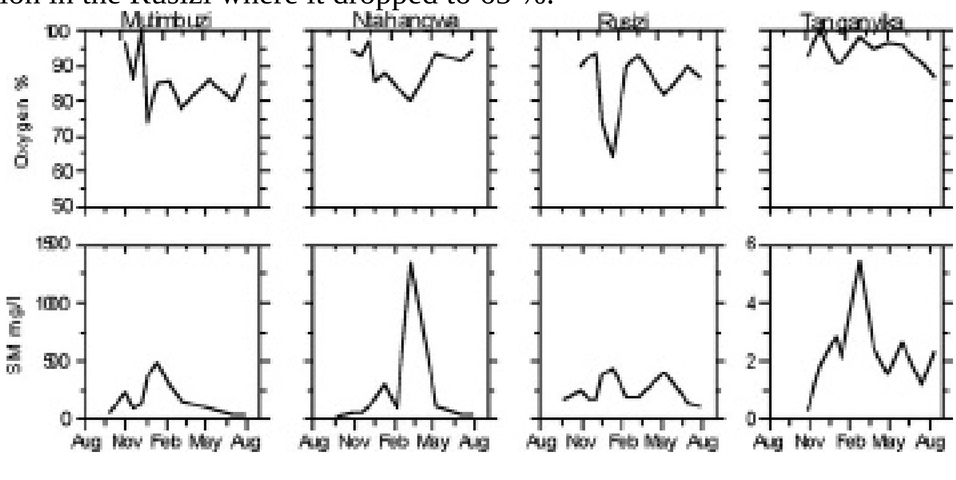

Figure 3. Seasonal distribution of oxygen and suspended matter (SM) at the outflow of rivers Mutimbuzi, Ntahangwa and Rusizi and at a station of lake Tanganyika.

Suspended matter concentrations (SM) are very low in the surface waters of the lake but increase regularly from less than 1 to 5 mg/l from October to February before decreasing in March and May. Since this offshore station is not in the direct influence of suspended material from rivers, we can reasonably assume that the SM profiles observed are linked to phytoplankton biomass development.

In the 3 rivers, especially in the Rusizi, SM are much higher with peaks corresponding probably to high river discharge situations.

4.4 AMMONIUM, NITRITE AND NITRATE

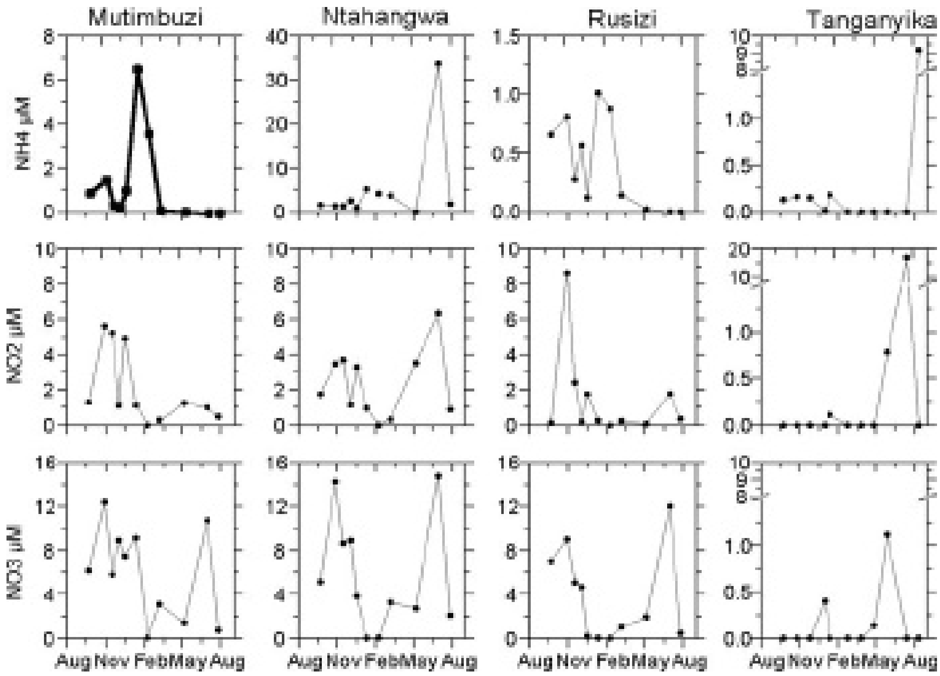

Figure 4. Seasonal distribution of ammonium (NH4), nitrite (NO2) and nitrate (NO3) at the outflow of rivers Mutimbuzi, Ntahangwa and Rusizi and at a station of lake Tanganyika.

In rivers, nitrate varied from 0 to 14 µM and nitrite from 0 to 9 µM with maximum concentrations in October and July and lowest in January or February. Ammonium concentration varied from less than 1 to 6.5 µM with the lowest value in December and highest values in January. One single measurement made in July in the Ntahangwa River showed a very high ammonium concentration of more than 30 µM.

Using these nutrient profiles and the average annual river discharge of the Rusizi, Ntahangwa and Mutimbuzi, we can calculate the annual DIN discharge to the lake (Table 2).

	m_/s Q	T/year NH4 load	T/year NO2 load	T/year NO3 load	T/year Ntot load
Mutimbuzi	3	1.6	2.3	7.5	11.4
Ntahangwa	2.5	7.0	2.8	6.4	16.2
Rusizi	182.4	28.2	108.7	312.5	449.4
Total river	187.9	36.8	113.9	326.3	477.0

Table 2: Annual ammonium (NH4), nitrite (NO2), nitrate (NO3), and total dissolved inorganic nitrogen (Ntot) load of the Mutimbuzi, Ntahangwa and Rusizi Rivers. Mean annual discharge of those rivers (Q).

The most important contributor is the Rusizi River with 450 T of nitrogen arriving every year, mostly under the oxidised forms of nitrate and nitrite (93 %). The

Mutimbuzi is also characterised by it's higher content in oxidised N (86 %) while the Ntahangwa river carries a high proportion of ammonium (44 %). This is easily understandable as the Ntahangwa river passes to Bujumbura and receives wastewater inputs that are rich in organic N and ammonium while the N from the Rusizi and Mutimbuzi have probably a more agricultural origin.

In the surface waters of the lake, nitrite and nitrate concentrations were all below the detection limit during the wet season except for one situation at the end of December and they increase suddenly in May. During the wet season, the most abundant dissolved inorganic nitrogen is ammonium although concentrations never exceed the 0.2 µM (Figure 5). Afterwards, during the dry season, total DIN increase and nitrate and nitrite become the most abundant.

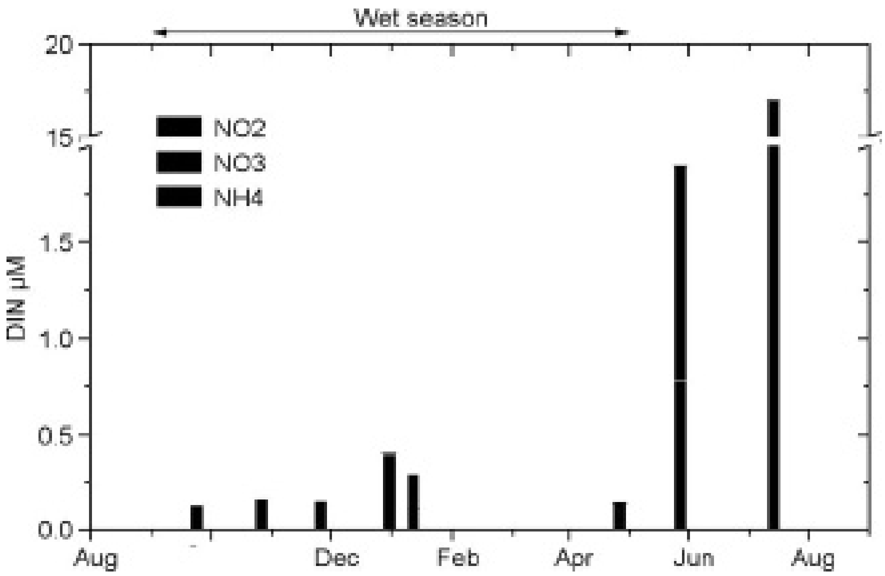

Figure 5: Relative contribution of ammonium, nitrate and nitrite to the total DIN concentration in Lake Tanganyika.

4.5 NITROGEN UPTAKE RATES

Specific nitrate and ammonium uptake rates by phytoplankton calculated for the 4 first cruises (Table 3) varied from 0.0002 to 0.02 h^{-1}. In January, the most important N source for phytoplankton is ammonium (f-ratio<0.5) while later, nitrate becomes the most utilised N-source. We have thus a variable N-uptake regime. It is to early at the present stage to draw any conclusions. However, we see that even with very low nutrient concentration, the N-uptake rates are quite important suggesting that there must be very rapid N-cycling in the surface waters with ammonium and nitrate being taken up at the same rates that they are produced.

Our specific uptake rate values can be compared to algal growth rate measurements made in the northern part of the lake by Hecky (1991). Indeed the specific N uptake corresponds to an apparent growth rate in term of nitrogenous biomass. They report an algal growth rate of 0.0042 to 0.079 h^{-1} for October 1975. These lay in the upper range of our findings.

Date	N-NO3 µM	N-NH4 µM	etaNH4 h^{-1}	etaNO3 h^{-1}	f-ratio %
31-12-98	0.40	0.01	0.0071	-	-
12-01-99	0.00	0.18	0.0247	0.0098	28.4
23-02-99	0.00	0.00	0.0002	0.0021	91.3
29-03-99	0.00	0.00	0.0004	0.0022	84.6

Table 3: Specific ammonium (etaNH4) and nitrate (etaNO3) uptake rates, and ammonium (NH4) and nitrate (NO3) concentrations measured in lake Tanganyika from December to March. The f-ratio represents the nitrate contribution to the total N-uptake.

5 CONCLUSION

During this work we showed that the northern part of Lake Tanganyika was subject to very rapid nitrogen cycling. Indeed, high amounts of inorganic N, especially nitrate, arrive from the rivers to the lake (477 T/year). In spite of this important N-source, the DIN concentration in the euphotic zone of Lake Tanganyika stay very low. At the same time, the uptake of nitrogen by phytoplankton is important, even in nutrient depletion conditions. This means that very active N cycling must occur in the water column preventing any accumulation of DIN.
More information concerning the particulate nitrogen pool, sampled but not yet analysed, and more N-uptake data (not yet analysed) should reinforce these first findings.

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