Final Report

Name	Loreto De Brabandere
Selection	BELSPO- Return Grant
Host institution	Vrije Universiteit Brussel
Supervisor	Prof. Dr. Willy Baeyens
Period covered by this report	from 01/08/2012 to 22/05/2015 * *maternity leave: 01/01/2014-21/10/2014
Title	NITRAPS: Nitrate Transformation Processes in the Schelde under Reduced Sewage Inputs

1. Objectives of the Fellowship

The overall aim of NITRAPS was to gain a renewed understanding of the sources and sinks of nitrate in the Scheldt Estuary after the implementation of waste water treatment from the Brussels region. The treatment of industry and household waste water presented an important step in the implementation of the European Nitrates Directive, which main aim is the reduction of the surplus nitrate in surface waters across Europe. Since the publication of the Nitrates Directive (1991), the Scheldt Estuary has shown signs of recovery from hyper-eutrophication as indicated by an overall decrease in the nitrogen load (Cox et al. 2009). However, nitrate concentrations have, in fact, increased in the Scheldt Estuary since the early 90-ies (Soetaert et al. 2006), although a slow decrease has been observed over the recent years. Nevertheless, concentrations are still very high with summer minima and winter maxima at the Dutch-Belgian border roughly between 150 and 350 μmol L^{-1} during 2012 (OMES, unpublished data).

Effective reduction strategies for nitrate in the Scheldt Estuary require a thorough and up-to-date knowledge of the nitrate sources and sinks, hence the focus of NITRAPS on the identification of the current nitrate sources and sinks in the Belgian part of the Scheldt Estuary. The hypothesis is that the biogeochemical processes involved in nitrate cycling in the freshwater part of the estuary have changed since the implementation of Brussels' waste water treatment as the latter caused a significant improvement of oxygen conditions (Brion et al. 2015).

The specific objectives were (1) to introduce and implement new techniques to measure nitrogen isotopic compositions of nutrients to the host laboratory and (2) to study the nitrogen and oxygen isotopic composition of nitrate in the Scheldt Estuary in order to infer the dominant processes responsible for nitrate cycling.

2. Methodology in a nutshell

Samples and environmental data were collected monthly between December 2009 and December 2011 at 15 stations along the freshwater Scheldt Estuary and at 11 stations in the tributaries of the Scheldt Estuary, in the frame of the OMES project (Onderzoek Milieu-Effecten Sigmaplan). Surface water was filtered for the analysis of nutrients and the stable nitrogen and oxygen isotopic compositions of nitrate+nitrite ($\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$). During 2012, additional samples were taken at the same stations along the freshwater estuary for the analysis of the $\delta^{18}O$

composition of dissolved oxygen. Oxygen concentrations, salinity and temperature were measured directly in the field.

Nitrate, ammonium and nitrite concentrations were measured using a QuAAtro auto-analyzer. The isotopic composition of N and O of nitrate were analyzed using the denitrifier method (Sigman et al., 2001) which is based on the bacterial conversion of NO_3^- and NO_2^- to N_2O using denitrifying bacteria from the *Pseudomonas aureofaciens* strain. The released N_2O gas was subsequently concentrated on a gas bench and measured by an isotope ratio mass spectrometer. The isotopic composition of dissolved oxygen was measured following the method of Gillikin an Bouillon (2007).

Values from each station were grouped per season in 2010 and 2011 and reported as median values to investigate the longitudinal trends along the estuary. Subsequently, stations were grouped in three zones which were delineated based on hydrological and geographical characteristics, with zone 1 being the most upstream region where residence times are short and there is no input of water from tributaries. Zone 2 is the stretch in which the tributaries Dender, Durme and Rupel join the Scheldt Estuary, while zone 3 is the zone where freshwater and seawater is increasingly mixed. The average values for these zones were compared between seasons and years using a Repeated Measures One-Way Anova, after data were tested for normality and equality of variances. Post-hoc tests for pairwise multiple comparisons were performed using the Holm-Sidak method.

3. Results

3.1. Implementation of methods and equipment to measure ^{15}N-enriched N_2, N_2O and NH_4^+.

An extraction line was built for the purification of low volumes of N_2 and N_2O enriched in ^{15}N from gas mixtures, and connected to the isotope ratio mass spectrometer for determination of $^{15}N/^{14}N$ ratios in N_2 and N_2O. Tests showed that the extraction line was leak-tight but that there is a relatively large blank caused by the injection procedure. This will be optimized by connecting a self-made leak-tight injection port (Korntheuer, unpublished results) to the system, which should then allow to measure natural abundances of ^{15}N in N_2 and N_2O as well.

A chemical method to measure ^{15}N-enriched ammonium was implemented and tested for its accuracy and detection limit. The detection limit was rather high, but this should be improved after the installation of the above-mentioned leak-tight injection port.

3.2. Nitrate sources and sinks in the freshwater Scheldt Estuary

Winter

In winter 2010, stable NO_x (NO_3^- + NO_2^-) concentrations along zones 1 and 2 in combination with relatively stable winter $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ values (Fig. 1) indicated negligible *in situ* microbial nitrate and nitrite production and consumption. However, during winter 2011, NO_x and $\delta^{18}O_{NOx}$ data suggested active in situ microbial processing, as NO_x concentrations showed the same pattern as during the warmer seasons (spring, summer and fall) and the range of $\delta^{18}O_{NOx}$ values were similar to the one of the warmer seasons. The latter is in contrast to 2010 when winter $\delta^{18}O_{NOx}$ values were clearly higher than during the other seasons.

Winter NO_x isotopic compositions were lower in $\delta^{15}N_{NOx}$ and higher in $\delta^{18}O_{NOx}$ (only 2010) than during the other seasons. In fact, they were close to values of nitrified mineral fertilizer and manure measured in drainage systems of agricultural land during winter ($\delta^{15}N_{NOx}$: 9.9±1.5‰; $\delta^{18}O_{NOx}$: 4.6±1.0‰; Deutsch et al. 2006). **This suggests that nitrate leaching from soils is a major contributor to nitrate in the Scheldt Estuary during winter**.

However, a recent study estimated equal inputs of household-derived and agricultural nitrogen inputs to the estuary (Vermaat et al. 2012). Ammonium regenerated from sewage organic matter has a δ^{15}N value in the range of 0.4 to 8.2‰ (Mattern et al. 2011). Complete nitrification of this ammonium would yield nitrate with similar δ^{15}N values which is below the range observed during winter (9.4-10.7‰). Nitrate with higher δ^{15}N values could be produced due to volatile ammonium loss in the sewage treatment plants as this highly fractionation process would leave the residual ammonium pool enriched in ^{15}N, and consequently also the nitrate and nitrite produced by nitrification (Kendall 1998). Winter δ^{18}O values in the Scheldt support the possibility that nitrate is partially derived from ammonium regenerated from waste water through nitrification. Indeed, winter $\delta^{18}O_{NOx}$ values (2.9-5.2‰) partially overlap with the range of δ^{18}O values (-6.4 and 3.6‰) calculated for NO_x produced by nitrification following a closed system Rayleigh fractionation model (Mariotti 1981). **This suggests that nitrate discharge from sewage treatment plants also contributes to the nitrate pool during winter.**

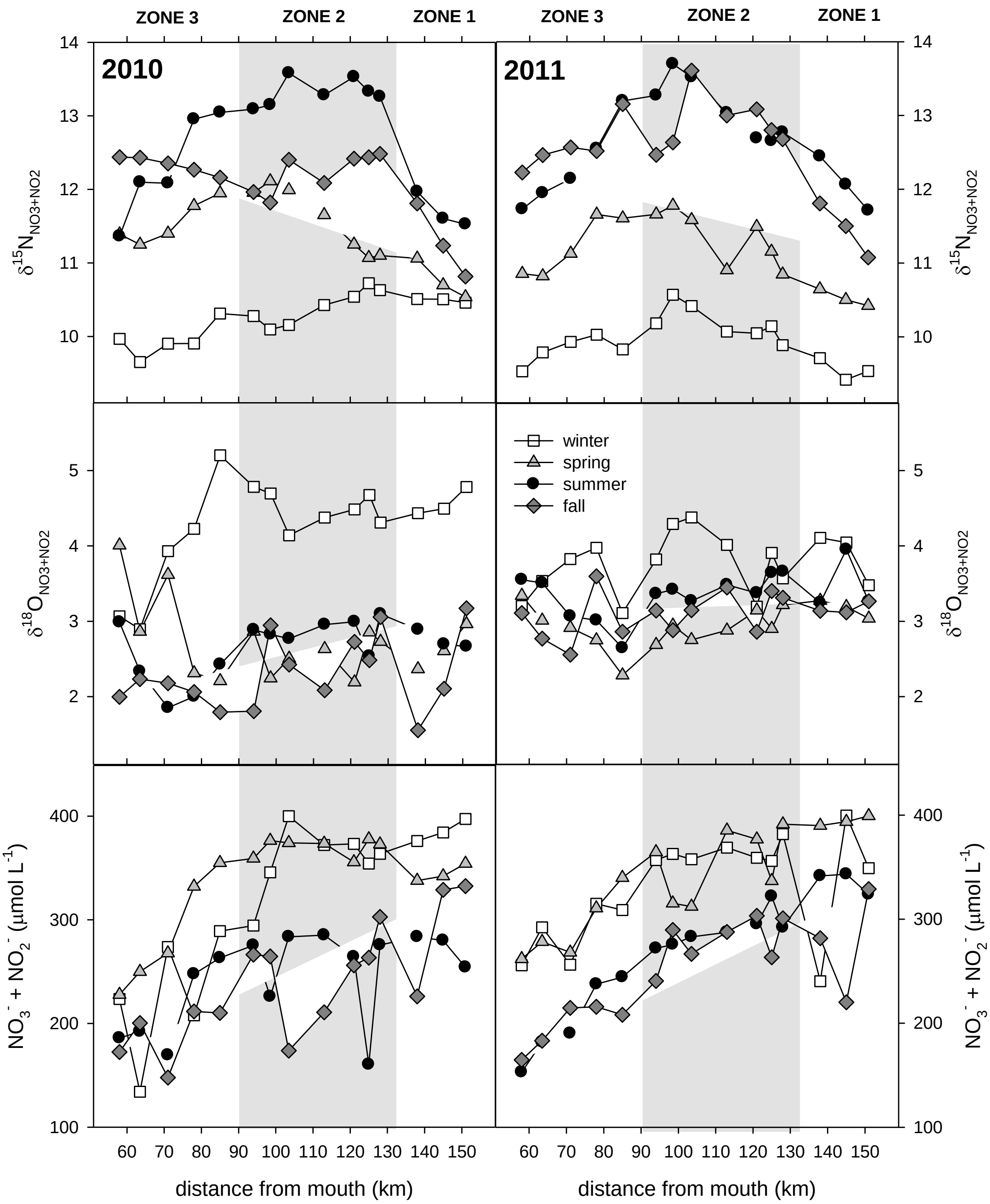

Figure 1: Seasonal shift in longitudinal NO_3^- concentrations and $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ patterns.

Spring, summer and fall

The distinct $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ values during spring, summer and fall compared to winter suggested intense microbial nitrogen cycling activity during these seasons (Fig. 2). The range and longitudinal variation in nitrate concentrations were similar during winter and spring and during summer and fall, suggesting that nitrate production and consumption were more or less balanced between winter and spring and between summer and fall. However, the significant decrease in nitrate concentrations between spring and summer indicated that nitrate consumption was relatively more important than nitrate production or external nitrate inputs between spring and summer.

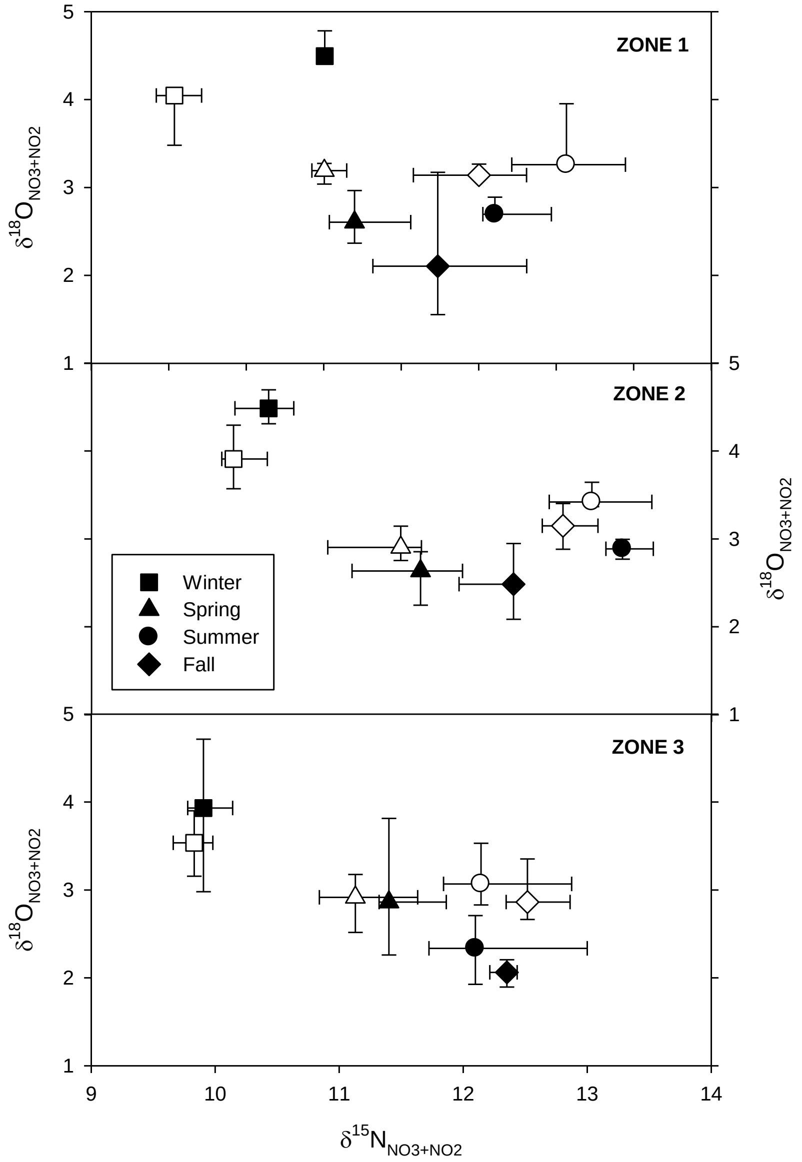

Figure 2: Seasonal variation in median $\delta^{18}O$ vs $\delta^{15}N$ of nitrate+nitrite at each zone for 2010 (black) and 2011 (white). Short and long error bars denote the 25% and 75% inter quartile ranges, respectively.

The general seasonal trend in $\delta^{15}N_{NOx}$ was to increase during spring and summer, and to decrease or stabilize during fall, while $\delta^{18}O_{NOx}$ did not show any seasonal pattern (Fig. 2). The two nitrate and nitrite consuming processes, denitrification and microbial assimilation, increase $\delta^{15}N_{NOx}$ as well as $\delta^{18}O_{NOx}$ due to discrimination against ^{15}N (Waser et al. 1998) and ^{18}O (Kendall et al. 1997), respectively. This is expressed as negative correlations between $\delta^{15}N_{NOx}$ or $\delta^{18}O_{NOx}$ and NO_x and nitrate. However, our results showed an increase in $\delta^{15}N_{NOx}$ coupled to a decrease in nitrate and NO_x but not for $\delta^{18}O_{NOx}$. The decoupling of the changes in $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ is indicative of active nitrification in the system because nitrification affects $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ differentially as

N is retained during nitrification while O is incorporated from the ambient environment (Buchwald et al. 2012). Negative correlations between $\delta^{15}N_{NOx}$ and ammonium and oxygen concentrations suggested that nitrification indeed causes $\delta^{15}N_{NOx}$ values to increase as a consequence of the depletion and ensuing ^{15}N-enrichment of the residual ammonium pool, a consequence of the highly fractionating ammonium consumption processes (Mariotti et al. 1981). Nitrification is also responsible for the decrease in $\delta^{18}O_{NOx}$ between winter and the other seasons, as the $\delta^{18}O_{NOx}$ values of nitrified nitrate are very low, ranging between -6.4 and 3.6‰ (see above).

However, a closer look at the observed ranged of $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ values showed that nitrification is not the only process affecting nitrate in the Scheldt Estuary. Indeed, the range of $\delta^{18}O_{NOx}$ produced during nitrification is lower than the range of $\delta^{18}O_{NOx}$ observed in the estuary outside the winter months. In addition, $\delta^{15}N_{NOx}$ values are slightly higher than the accumulated nitrate pool, of which the $\delta^{15}N$ value can be calculated assuming a closed system with Rayleigh type fractionation increase in $\delta^{15}N$ of ammonium and nitrate (Mariotti et al. 1981, De Brabandere et al. 2007). Moreover, the progressive ^{15}N-enrichment of ammonium due to depletion of the ammonium pool cannot explain the increase in $\delta^{15}N_{NOx}$ for the period over which ammonium concentrations are at steady state, as was the case between spring and summer. Indeed, the longitudinal variation in ammonium concentrations was rather limited during these seasons, suggesting the presence of a cryptic ammonium cycle in which ammonium regeneration and nitrification were more or less balanced. Under these circumstances, the isotopic composition of the produced nitrate will be stable and equal the one of the initial ammonium pool at the start of the season (Fry, 2003). The increase in $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ relative to the expected isotope compositions of nitrified nitrate and nitrite is most likely due to isotope fractionation during NO_x assimilation. Thus, **the shift in $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ during spring, summer and fall relative to winter reflects a combination of nitrification and assimilation processes.**

Between spring and summer, a marked decrease in nitrate concentrations was observed, which suggested higher nitrate consumption than input rates. At this point, nitrification was not further enriching the nitrate pool in ^{15}N, as ammonium concentrations were in steady state (see above). The enrichment in $\delta^{15}N_{NOx}$ was thus caused by nitrate and nitrite assimilation. However, the matching increase in $\delta^{18}O_{NOx}$ was not observed, which shows that nitrification is still active and counteracting the ^{18}O-enrichment of the nitrate pool by adding ^{18}O-depleted nitrate to the pool.

Between summer and fall, $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ values had a tendency to decrease, although not always significantly, and values remained higher than during spring. On the other hand, there was no marked change in nitrate and ammonium concentrations between summer and fall, suggesting that production and consumption were balanced for ammonium and nitrate. Nitrate consumption has been shown to decrease in fall (Andersson et al. 2006) and this was most likely also the case during our sampling campaigns as Chl-a concentrations generally decreased between summer and fall. Moreover, high Chl-a concentrations observed during fall most likely represent a resting and declining phytoplankton population (Muylaert et al. 2000) in which nitrogen assimilation is limited. Thus, the lack of change or slight decrease (N only) in nitrate isotopic compositions reflects the fact that nitrate assimilation has slowed down to a level that it will no longer increase the $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$ as was the case in summer while nitrification still adds nitrate with similar or slightly lower $\delta^{18}O_{NOx}$ and $\delta^{15}N_{NOx}$ values than the nitrate pool.

Summary

Nitrate N and O isotopic compositions showed that during winter, there is little *in situ* processing of nitrate, and the that bulk of nitrate originates from agricultural and sewage inputs. During spring, nitrate isotopic compositions changed mainly under the influence of nitrification, although nitrate consumption counteracts to some extend the changes imposed by nitrification. During summer, nitrate consumption dominates over nitrification, resulting in an increase in $\delta^{15}N_{NOx}$ while the increase in $\delta^{18}O_{NOx}$ is counteracted by inputs of ^{18}O-depleted nitrate from nitrification. Finally, in the fall, nitrate assimilation slows down, resulting in a stabilization or decrease in $\delta^{15}N_{NOx}$ and $\delta^{18}O_{NOx}$. Nitrification is the reason why nitrate isotopic compositions in fall do not return to the typical winter ones.

3.3. Seasonal variation in $\delta^{18}O$ of dissolved oxygen in the freshwater Scheldt Estuary

Dissolved oxygen (DO) in the Scheldt Estuary showed strong seasonal and spatial variation in $\delta^{18}O_{DO}$ composition (Fig. 3). Deviation from the equilibrium $\delta^{18}O_{DO}$ value (24.2‰) happens when the stable isotopic composition of oxygen dissolved in water is no longer in equilibrium with the one of air due to photosynthesis (<24.2‰) or respiratory processes (>24.2‰). Values were consistently above this equilibrium value, showing that the Scheldt is a net heterotrophic system.

During fall and winter, spatial variation was overall limited with slightly higher winter $\delta^{18}O_{DO}$ values. This shows that the processes affecting $\delta^{18}O_{DO}$ during fall and winter where similar along the estuarine continuum and that respiration was relatively more important during winter than during fall.

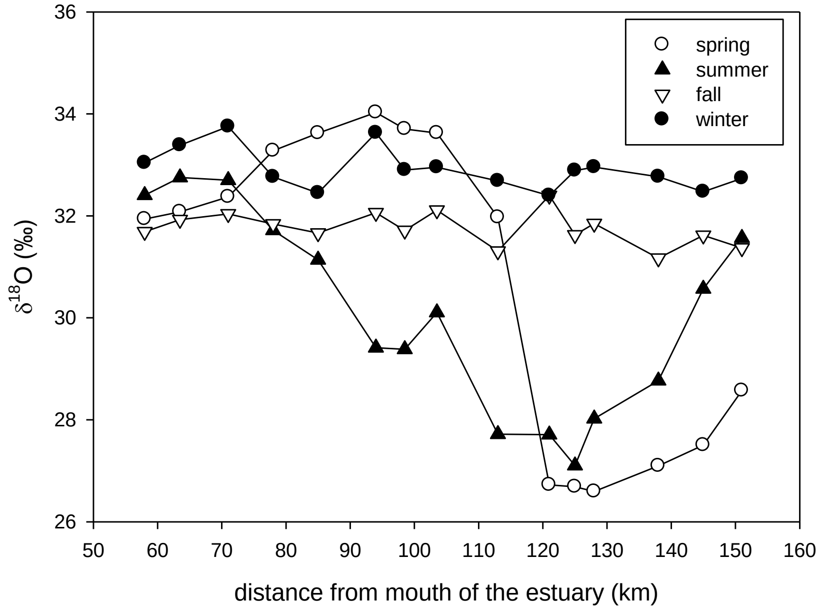

Fig. 3: Seasonal and spatial variation of $\delta^{18}O$ of dissolved oxygen in the Scheldt Estuary.

During spring, $\delta^{18}O_{DO}$ showed a strong decrease in the upper estuarine reaches, most likely as a result of high inputs of ^{18}O-depleted oxygen produced by photosynthesizing organisms. Indeed, phytoplankton typically reaches high biomass in spring in the upper reaches. The sharp increase at km 121 coincided with the confluence of the Scheldt and Dender River, suggesting that the Dender is more heterotrophic than the Scheldt during spring.

In summer, $\delta^{18}O_{DO}$ values still decreased in the upper reaches of the Scheldt Estuary, although slightly less pronounced than during spring. However, the summer phytoplankton bloom is typically larger than the one in spring, so the decrease should be more pronounced instead. On the other hand, phytoplankton is known to be severely light limited in the Scheldt Estuary (Kromkamp, unpublished results) suggesting that high phytoplankton biomass does not necessarily imply high photosynthetic activity. Phytoplankton could thus be spending a relative high amount of time respiring, which, in addition to the high back-ground respiration could lead to the limited decrease in $\delta^{18}O_{DO}$. In the middle region of the estuary, summer $\delta^{18}O_{DO}$ values were more depleted in ^{18}O than during spring, which could indicate that the tributaries have low $\delta^{18}O_{DO}$ values as well and no longer discharge water with ^{18}O-enriched dissolved oxygen into the Scheldt.

Summary

The $\delta^{18}O$ composition of dissolved oxygen on the Scheldt Estuary shows a dominant respiratory imprint, indicating that the estuary is a net heterotrophic system. During spring (upstream of the Dender tributary) and summer (freshwater reaches), photosynthesis is relatively more important than during fall and winter, as evidenced by a clear decrease in the $\delta^{18}O_{DO}$ signature relative to winter and fall $\delta^{18}O_{DO}$ values. However, despite that phytoplankton biomass typically peaks during spring and summer, the estuary remains heterotrophic all year round. This is explained by severe light limitation of phytoplankton, so that oxygen inputs from photosynthesis cannot compensate respiratory losses due to oxygen consumption by heterotrophic and nitrifying organisms.

4. Perspectives for future collaboration between units

- A proposal has been submitted in the frame of the Belspo 'BRAIN 2015' call. This proposal is linked to the current project and builds on information gathered during the NITRAPS project, amongst others. The BRAIN proposal is a collaboration between three Belgian universities: the Vrije Universiteit Brussel, the Université Libre de Bruxelles and the Mons University.

- Prof. W. Vyverman (Ghent University) has expressed interest in joint experiments to assess the role of N-nutrient speciation on phytoplankton size selection. For these experiments, he would need the expertise on nitrogen stable isotopes and the isotope facilities that are available at the Analytical and Environmental Geo-Chemistry Laboratory.

- As a result of successful collaborations with L. De Brabandere during the NITRAPS project, the Analytical and Environmental Geo-Chemistry Laboratory will remain actively collaborating with Prof. Dr. L. Triest (Biology Department, Vrije Universiteit Brussel) under the form of joint master theses and joint projects (e.g. VLIR fellowships).

- L. De Brabandere will submit her candidature for a BOF-grant at the Vrije Universiteit Brussel, in which she proposes to form a close collaboration between the Chemistry and Biology department of the VUB to study past and present carbon, nitrogen and oxygen cycling in aquatic systems.

- Dr. Kirstin Dähnke from Helmholtz Zentrum Geesthacht (Germany) is providing valuable support for the optimization of the chemical technique for the analysis of natural abundance ammonium N isotopic compositions.

- L. De Brabandere still collaborates with the University of Southern Denmark, Stockholm University and Gothenburg University for publications in international journals.

5. Valorisation/Diffusion (including Publications, Conferences, Seminars, Missions abroad...

- ***Publications in International Journals***

De Brabandere L., D.E. Canfield, T. Dalsgaard, G.E. Friederich, N.P. Revsbech, O. Ulloa, B. Thamdrup, 2013. Vertical partitioning of nitrogen-loss processes across the oxic-anoxic interface of an oceanic oxygen minimum zone. *In press* Environmental Microbiology. [Impact Factor 5.756]

Prokopenko M.G., M.B. Hirst, L. De Brabandere, W.M. Berelson, D.J. Lawrence, J. Granger, B.X. Chang, S. Dawson, E.J. Crane, L. Chong, B. Thamdrup, D.M. Sigman, 2013. Nitrogen losses in anoxic marine sediments driven by *Thioploca*-anammox consortia. *Nature* 500: 194-200 [Impact Factor 38.597]

Dalsgaard T., L. De Brabandere, P.O.J. Hall, 2013. Denitrification in the water column of the central Baltic Sea. Geochimica et Cosmochimica Acta 106: 247-260 [Impact Factor 4.259]

Stigebrandt A., B. Liljebladh, L. De Brabandere, M. Forth, Å. Granmo, P. Hall, J. Hammar, D. Hansson, M. Kononets, M. Magnusson, F. Nore'n, L. Rahm, A. Treusch, L. Viktorsson, 2015. An experiment with forced oxygenation of the deepwater of the anoxic By Fjord, Western Sweden. *Ambio* 44(1): 42-54. DOI 10.1007/s13280-014-0524-9. [Impact Factor 2.295]

Dalsgaard T., F.J. Stewart, C.R. Young, B. Thamdrup, L. De Brabandere, N.P. Revsbech, O. Ulloa, D.E. Canfield, E.F. DeLong. 2014 Oxygen at nanomolar levels reversibly suppresses process rates and gene expression of anammox and denitrification in the oxygen minimum zone off northern Chile. *mBio*, DOI:10.1128/mBio.01966-14.[Impact Factor 5.621]

De Brabandere L., S. Bonaglia, M.Y. Kononets, L. Viktorsson, A. Stigebrandt, B. Thamdrup, P.O.J. Hall. Oxygenation of an anoxic fjord basin strongly stimulates benthic denitrification and DNRA. Accepted with major revisions to *Biogeochemistry*.

De Brabandere L., A. Martinez-Useros, A. Beyene, N. Brion. Nitrate stable isotopes reveal the fate of anthropogenic nitrogen in an Ethiopian river system. *River Research and Applications*: In review.

De Brabandere L., A. Danoary Andrisoa, F. Fripiat, N. Brion, M. Elskens, W. Vyverman, P. Meire and F. Dehairs. Seasonal and spatial variation in nitrate stable nitrogen and oxygen isotopes in the eutrophic Scheldt Estuary , Belgium. *In preparation*.

- ***Master theses***

Andrisoa A., 2013. Seasonal variation of the nitrogen and oxygen isotopic composition of nitrate in the Scheldt River and Estuary. M.Sc. Thesis, Oceans & Lakes Programme, Vrije Universiteit Brussel, Belgium.

Damtew M.G., 2014. Spatial and temporal gradient of pollution and food web interactions along the inlet rivers of Gilgel Gibe Dam, Ethiopia. M.Sc. Thesis, Human Ecology, Vrije Universiteit Brussel, Belgium.

Martinez Useros A., 2014. Characterization of nitrate sources and trophic structure of the Gilgel Gibe I Reservoir using stable isotopes. M.Sc. Thesis, Oceans & Lakes Programme, Vrije Universiteit Brussel, Belgium.

Plante A., 2015. Etude de l'évolution de la composition isotopique des nitrates dans l'estuaire de l'Escaut. M.Sc. Thesis, Chemistry Department, Vrije Universiteit Brussel, Belgium and Institut Universitaire Européen de la Mer, Université de Bretagne Occidentale, France.

- ***Communications at Conferences with abstracts***

Dalsgaard T., F.J. Stewart, L. De Brabandere, B. Thamdrup, N.P. Revsbech, D.E. Canfield, L.A. Bristow, O. Ulloa, C.R. Young, E.F. DeLong. The effect of oxygen on process rates and the expression of anammox and denitrification genes in the eastern South Pacific oxygen minimum zone. ASLO Aquatic Sciences Meeting 2013, 17-22 February 2013, New Orleans, USA.

Darchambeau F., F. Roland, S.A. Crowe, L. De Brabandere, M. Llirós, T. Garcia-Armisen, O. Inceoglu, C. Michiels, P. Servais, C.D.T. Morana, S. Bouillon, F. Meysman, B. Veuger, P.M. Masilya, J.P. Descy, A.V. Borges. Denitrification, anammox and fixed nitrogen removal in the water column of a tropical great lake. EGU General Assembly 2013, 7-12 April 2013, Vienna, Austria.

Bonaglia S., L. De Brabandere, I. Klawonn, B. Deutsch, V. Brüchert. N_2 and N_2O production in the oxycline of the Baltic Sea. Bolin Days 2013, 20-21 November 2013, Stockholm, Sweden.

Andrisoa A., L. De Brabandere, N. Brion and F. Dehairs. Nitrification and uptake as drivers of seasonal $\delta^{18}O$ and $\delta^{15}N$ variation of nitrate. Ocean Sciences Meeting 2014, 23-28 February 2014, Honolulu, Hawaii.

Bonaglia S., I. Klawonn, L. De Brabandere, B. Deutsch, B.Thamdrup and V. Brüchert. The Baltic Sea oxycline hosts a complete microbial nitrogen cycle. ASLO Aquatic Sciences Meeting 2015, 22-27 February 2015, Granada, Spain.

De Brabandere L., S. Bonaglia, M. Kononets, L. Viktorsson, A. Stigebrandt, B. Thamdrup and P.O.J. Hall. Response of benthic nitrogen cycling to a whole-fjord oxygenation experiment. ASLO Aquatic Sciences Meeting 2015, 22-27 February 2015, Granada, Spain.

Plante A, L. De Brabandere, F. Fripiat, F. Deman, N. Brion, D. Fonseca Batista and F. Dehairs. Seasonal evolution of the River Scheldt nitrate isotopic composition. Goldschmidt 2015, 16-21 August 2015, Prague, Czech Republic.

- ***Dissemination***

February 2013: Visit Dr. Kirstin Dähnke (Institute for Coastal Research, Helmholtz Zentrum Geesthacht, Germany): Discussion of possible future collaborations on the Elbe and Scheldt Estuaries between Kirstin Dähnke's group and the Analytical and Environmental Geo-Chemistry group from the VUB.

June 2013: Isotope Pairing Training, Askö Marine Station, Department of Geological Sciences, Stockholm University.

6. Skills/Added value transferred to home institution abroad

Not applicable.