BELGIAN SCIENCE POLICY

Scientific Support Plan for a Sustainable Development Policy (SPSD I)
Sustainable Management of the North Sea

IDENTIFICATION OF BELGIAN MARITIME ZONES AFFECTED BY EUTROPHICATION (IZEUT)

Towards the establishment of ecological criteria for the implementation of the OSPAR Common Procedure to combat eutrophication

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1 ABSTRACT

As Contracting Parties of the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, Belgian authorities adopted the Common Strategy to combat eutrophication in the OSPAR maritime area. The long-term objective for 2010 is to achieve and maintain a healthy marine environment where eutrophication does not occur. In this scope Belgian authorities agreed to classify their maritime areas as 'problem' areas, 'potential problem' areas and 'non-problem' areas with respect to eutrophication using as a tool the Common Procedure for the identification of the eutrophication status of the maritime area edited by OSPAR (OSPAR 97/15/1-annex 24). The development of appropriate assessment criteria is fundamental in the Common Procedure as these will be used for identification of the current eutrophication status of marine coastal water but also for assessment of the effectiveness of measures implemented for nutrient reduction.

The global objective of IZEUT is to provide to Belgian authorities a scientific support to implement the OSPAR *Common Procedure* to combat eutrophication in BCZ. With this aim, the sensitivity of BCZ to cultural eutrophication is assessed based on the quantitative and qualitative inventory of anthropogenic emissions and loads of nutrients to BCZ. The impact of nutrient loads on the global enrichment and coastal phytoplankton blooms is analysed using the current knowledge on eutrophication mechanism. In addition, the adverse effects of eutrophication in BCZ are assessed based on the qualitative perception of the eutrophication phenomenon and socio-economic assessment of related damages amongst potentially affected sectors.

Eutrophication-related problems in the Belgian coastal waters

The Belgian Coastal Zone (BCZ) is part of the nutrient-enriched eastern Southern Bight of the North Sea invaded every spring by undesirable algal blooms reaching biomass higher than 30 mg Chl *a* m^{-3}. BCZ is a highly dynamic system with water resulting of the mixing between the in-flowing Atlantic water and freshwater inputs from the Yser, Scheldt and coastal tributaries. Nutrient enrichment of BCZ is therefore a complex process resulting from the combined effects of anthropogenic and meteorological forcings.

The overall nutrient enrichment of BCZ reflects mainly the cumulative inputs from the Scheldt and Yser rivers, coastal tributaries, in-flowing Atlantic water itself enriched by nutrient loads of rivers Seine and Somme and atmospheric deposit. The global nutrient enrichment is characterized by a large excess of NO_3 over P and Si when compared to stoechiometry, [i.e. N:P=16 for marine phytoplankton (Redfield *et al.*, 1963) and N:Si=1 for coastal diatoms (Bzrezinski, 1985)]. The nutrient enrichment reflects the influence of riverine inputs of nutrients which present a large excess of N (mainly NO_3) over P and Si. This unbalance of nutrient loads is related to land use

and human activities in the watershed where agriculture and household being the major source of N and P to BCZ watershed. It is also related to biogeochemical processes leading to transformation, retention or elimination of nutrients during their transfer along the aquatic continuum.

Eutrophication phenomenon in the eastern Southern Bight of the North Sea is related to *Phaeocystis* colony blooms. The success of this non-siliceous phytoplankter results from both its ability to use the NO_3 excess left over after the silicate-limited diatom spring growth in P-regenerated conditions and its resistance to grazing. *Phaeocystis* colony blooms occurs in the whole BCZ area and display a clear inshore-offshore gradient. Understanding the link between *Phaeocystis* blooms and anthropogenic nutrient emissions is however difficult due to the complex interaction between natural and human-induced variability of the ecosystem.

Perception of the eutrophication phenomenon and socio-economic assessment of *Phaeocystis*-related damages

Most adverse impact of *Phaeocystis* colony blooms has been reported as deposits of foam on the beaches or as clogging fishing nets. These reports of *Phaeocystis*-related damages were up to now mostly anecdotal. The qualitative perception of *Phaeocystis* blooms and their related-damage was for the first time assessed by conducting surveys amongst the coastal civilian and fishing communities. The coastal civilian community, composed of a majority of tourists, are weakly familiar with the eutrophication phenomenon. Foaming is considered as a minor nuisance compared to other forms of environmental disturbance such as oil pollution, garbage or dead jelly fishes on the beaches, bad weather conditions. The socio-economic impact of foam-related events was assessed by estimating the resulting economic losses for the tourism industry. On the basis of the survey results and considering the recurrent presence of foam on the beaches, the negative economic effects of foam was estimated to 3.85-5 10^6 euros.

The impact of eutrophication on fishing activities was assessed by surveying fishermen working in Belgian coastal waters. The main reported fished species in the period February - June, are flatfish (sole, plaice, limon sole), shrimp and roundfish (cod, whiting). Most of the fishing grounds were shown located relatively closed to the coast. Fishermen were familiar with the ocurrence of algal blooms but generally did not perceive them as a major nuisance. Some of them acknowledge however that algal blooms impact their fishery activities by clogging of nets and consequently a more frequent net raising during bloom periods.

This study suggests that *Phaeocystis* blooms are not perceived as a nuisance and would induce only a very limited economic losses. A better scientific knowledge on possible adverse effects of *Phaeocystis* blooms is however required. In particular the impact of *Phaeocystis* blooms on biological ressources (ichtyofauna, fish nurseries and benthos) need to be estimated.

Despite the substantial research on the mechanisms behind eutrophication, it appears that our current knowledge of eutrophication in BCZ is too limited for a well-sound definition of ecological quality criteria used for the identification of BCZ areas affected by eutrophication. The occurrence of *Phaeocystis* colonies in the whole BCZ together with their potential impact on natural ressources, lead us, according to the Precautionary Principle, to classify the whole BCZ as eutrophicated area.

The development and implementation of pertinent quantitative ecological criteria and thresholds are required to translate the scientific knowledge into tools readily applicable for a rational management of coastal ecosystems through sustainable policies. Addressing these crucial scientific and societal questions is one of the most important challenging research option for developing well-sound ecological criteria in the context of sustainable development. Only transdisciplinary approach combining social (economy, geography, sociology) and natural sciences (ecology, agriculture, limnology, oceanography) would be able to face this challenge in the future years.

2 INTRODUCTION

2.1 Coastal eutrophication and sustainability

Coastal seas are valuable habitats for recreational activities and harvestable resources. Exposed to socio-economic pressures at sea and from the watershed, these areas constitute ecologically sensitive and vulnerable zones. One major threat hanging over marine coastal ecosystem health results from increased delivery of anthropogenic nutrients (industrial effluents, agricultural runoff and municipal sewage) causing eutrophication problems. These nutrient loads also modify qualitatively the nutrient environment of coastal phytoplankton (Billen *et al.*, 1991, Lancelot, 1995). The land-based sources of nutrients are indeed considerably enriched in nitrogen (N) and phosphorus (P) compared to silicon (Si) due to agricultural, industrial and household activities. Freshwater nutrient sources therefore strongly modify the nutrient balance N:P:Si of coastal waters with respect to functional need of coastal phytoplankton (N:P= 16; Redfield *et al.*, 1963) and diatom (N:Si:P= 16:16:1; Brzezinski, 1985). Both the total increase of nutrient loads and the change in nutrient composition induce a modification of the phytoplankton community structure with dominance of opportunistic non-siliceous species. These latter occur as harmful algal blooms (HAB) either toxic or forming high biomass. Both impact negatively on the marine environment and its resources by causing structural changes in the natural foods webs (shifts from the linear to loop food chains, from crustacean to gelatinous trophic chains). These blooms also constitute a serious hindrance to the socio-economic development of coastal areas through their negative impact on tourism, recreational activities and fisheries. Few beneficial effects of human-made eutrophication, such an increase of biological resources, have indeed been reported.

Since the late eigthies, there is awareness of the need to safeguard the marine ecosystems and implement sustainable development concepts. Increased understanding of the link between human pressures and ecosystem function is essential for the development and implementation of effective measures to achieve sustainable use of marine resources. In this respect, coastal eutrophication has been identified as one of the "first priority class" of human pressures to combat according to their impact on the ecosystem, including sustainable use (OSPAR, 2000).

2.2 Combating coastal eutrophication in the North Sea: the OSPAR Common Procedure

The Second Ministerial North Sea Conference agreed in 1987 to aim between 1985 and 1995, at a 50 % reduction of N and P inputs into sensitive river and coastal areas. This decision was reconducted in 1990 at the Third International Conference on the protection of the North Sea. In 1992 the OSPAR Ministerial Meeting endorsed the Action Plan which aims at the establishment of measures for achieving the 50 % reduction goal. These measures were endorsed by the European Commission through publication of EC Council Directives 91/271/EC and 91/676/EC on urban waste treatment and nitrate from agricultural sources.

In order to implement these international agreements, the OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, adopted in 1998 the *Strategy to Combat Eutrophication* with the aim to achieve and maintain by 2010 a healthy marine environment where eutrophication does not occur. As a tool for implementing *the Strategy to Combat Eutrophication*, the ASsessment and MOnitoring Committee (ASMO) has developed the *Common Procedure* for a holistic assessment of the eutrophication status by means of linking biological, chemical and physical assessment criteria (OSPAR 97/15/1-annex 24; see annex 1). The objective of the *Common Procedure* is to enable a classification of the maritime areas in terms of 'problem' areas', 'potentially problem' areas and 'non problem' areas with respect to eutrophication on the basis of internationally agreed assessment criteria. The *Common Procedure* consists in an iterative stepwise process, including a Screening and a Comprehensive Procedure. The Screening Procedure aims to identify the sensitivity of coastal waters to eutrophication-related problems. The Comprehensive Procedure aims to identify quantitative assessment criteria common to all Contracting Parties for determination of the eutrophication status of coastal water.

The development and implementation of appropriate quantitative assessment criteria specific to the eutrophication-related problems is fundamental for the identification of its current eutrophication status but also for assessment of the effectiveness of measures implemented for nutrient reduction. The current situation of OSPAR recommendations in this matter is the arbitrary nutrient and chlorophyll *a* threshold defined as 150 % of the background (historical or geographical) value.

As Contracting Party of the OSPAR Convention, Belgium adopted *the Common Strategy to combat eutrophication* and has therefore the obligation to classify its maritime areas with respect to eutrophication. As scientific support to fulfil this obligation, the project IZEUT aims to develop scientifically-based eutrophication criteria for the identification of ‘problem’, ‘potential problem’ and ‘non-problem’ areas in the Belgian coastal waters.

2.3 Application of the OSPAR Common Procedure to the Belgian coastal zone

2.3.1 The Belgian coastal zone (BCZ) and its watershed

The BCZ is located in the southeastern part of the Southern Bight of the North Sea (Fig. 1). It is bordered in the south, north and northeast by respectively the French, English and Dutch coastal zones. Its superficy, which coincides with that of the Belgian Exclusive Economic Zone (EEZ), covers some 3500 km^2. The overall length of the Belgian coastline is 67 km. BCZ is a relatively shallow area (average depth 20 m) with a depth of 40 m in the northwest part. The tidal motion, in particular the semi-diurnal M2 component, is the dominant energetic feature inducing strong along-shore currents (0.6-1.1 m s^{-1}). Shallow depths and strong tidal currents ensure a permanent complete mixing of these coastal water.

The main residual circulation pattern of water masses generally results in a northeastwardly flow of Atlantic water through the Dover Strait. The hydrological signature of BCZ is determined by the mixing between of inflowing Atlantic water and freshwater from the rivers Yser, Scheldt and Rhine. Hydrographical properties strongly varies from year to year depending on the wind regime with events of strong dominant southwesterly winds increasing the propagation of in-flowing Atlantic water via the Channel (Breton *et al.*, in preparation).

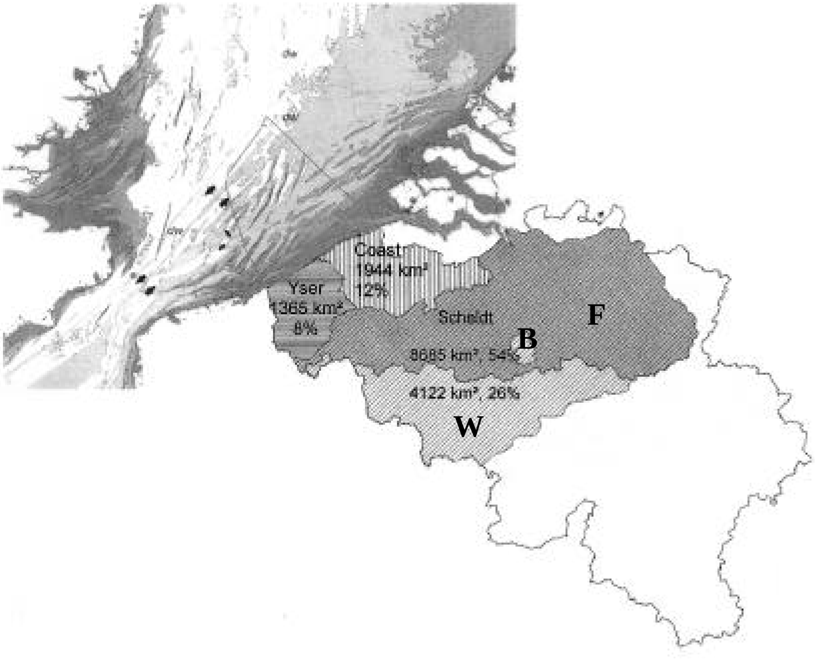

Figure 1: The Belgian Coastal Zone (BCZ) and its watershed in Belgium. Borders of the Scheldt, Yser and Coast watersheds, their respective superficy and contribution to the total watershed are indicated. The 3 administrative regions of the Scheldt watershed are indicated (F : Flanders, B : Brussels and W : Wallonia). Redrawn on basis of map originating from the Limited Atlas of the Belgian part of the North Sea (Maes *et al.,* 2000, with permission of OSTC).

The BCZ watershed covers some 25172 km^2, including the watershed of rivers Scheldt, Yser and coastal tributaries (Fig. 1). The river Scheldt, with a length of 355 km, drains a lowland watershed of 21863 km^2 distributed in the northwest France (31%), west Belgium (61%) and southwest Netherlands (9%). High population density, intensive agriculture and industrialisation developed mainly in the northern part of its watershed make of the Scheldt one of the most heavily polluted rivers in Europe (Billen *et al.*, 2003). The Yser watershed (1364 km^2) drains the western coastal area of Belgium. Its hydrographic system receives mainly polder effluents. The Coast watershed (1914 km^2; Fig. 1) drains the maritime plain in the northeastern part of the BCZ watershed. Its main watercourse consists of canals whose mainly receive polder drainage and flow seaward via harbour channels.

2.3.2 Eutrophication of BCZ

Recurrent spring blooms of the colonial haptophyte *Phaeocystis globosa* are reported as the consequence of europhication in BCZ (Lancelot *et al.*, 1987). The overall nutrient enrichment of BCZ reflects mainly the inputs from the Scheldt and Yser rivers, coastal tributaries, in-flowing Atlantic water itself enriched by nutrient loads of rivers Seine and Somme and atmospheric deposition (Fig. 2). The relative importance of these nutrient sources in the global enrichment of BCZ is not known yet but varies locally and seasonally.

Riverine nutrient loads depends on land use and human activity activities (agriculture, industry, household) in the watershed but also on biogeochemical processes leading to transformation, retention or elimination of chemical species during their transfer along the aquatic continuum (Fig. 2 ; Billen *et al.*, 1991).

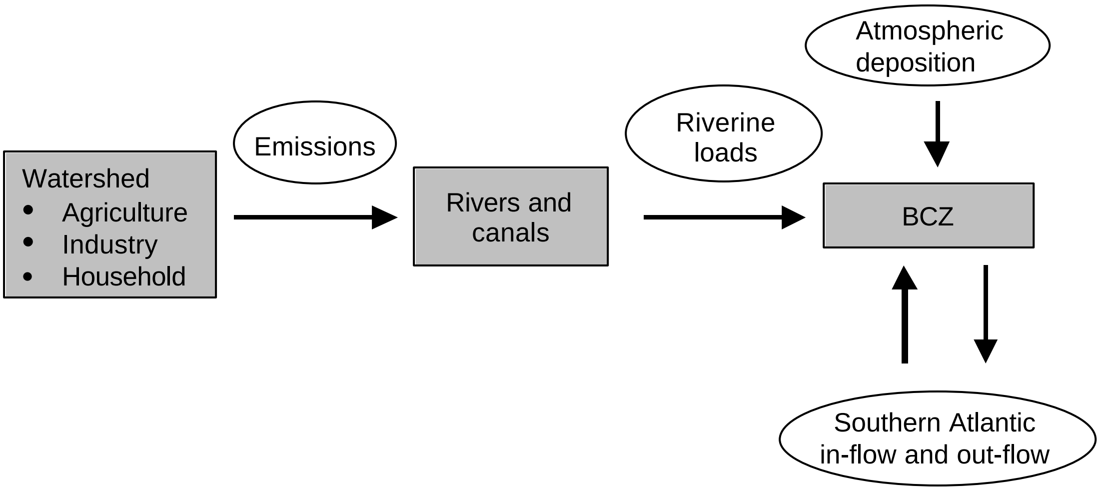

Figure 2 : Schematic representation of the nutrient loads resulting in the enrichment of BCZ. Riverine loads result from the transfer along the aquatic continuum of nutrient emitted in the watershed.

2.3.3 Developing eutrophication assessment criteria in BCZ : the IZEUT project

The two-year strategic research project IZEUT was funded by the Belgian Office of Scientific, technical and Cultural affairs (OSTC) in the framework of the Program Sustainable Management of the North Sea of the 1997-2001 Scientific support Plan for a Sustainable Development Policy (PADD-I). The global objective of IZEUT is to provide to Belgian authorities a scientific support to implement the OSPAR *Common Procedure* to combat eutrophication in BCZ.

The sensitivity of BCZ to cultural eutrophication is assessed based on the quantitative and qualitative inventory of anthropogenic emissions and loads of nutrients to BCZ. The impact of nutrient loads on the global enrichment and coastal phytoplankton blooms is analysed using the current knowledge on eutrophication mechanism. In addition, the adverse effects of eutrophication in BCZ are assessed based on the qualitative perception of the eutrophication phenomenon and socio-economic assessment of related damages amongst potentially affected sectors.

The research methodology combines the collection and comprehensive synthesis of existing data on nutrient emissions and loads provided by regional and national authorities but also nutrient and biological data recorded in BCZ and neighboring water in the scope of past and current national and EU-funded projects.

3 MATERIAL AND METHODS

3.1 Data bases and calculation methods

3.1.1 Continental nutrient sources

Anthropogenic nutrients have three origins: households, industry and agriculture. They mostly concern N and P forms. However, silicate should also be considered due to the substitution of polyphosphates by zeoliths (aluminosilicates) in washing powders. This substitution is however too recent to estimate the related changes in Si sources in this study. Basic data for estimating N and P sources were collected from different regional and federal institutions and were sorted according to their origin and geographical domain (Table I).

Table I: Data type, geographical domain, period and source collected for the estimation of continental nutrient sources.

Data type	Geographical domain (unit)	Period	Source
Town limit and superficy	Belgium (town)	2000	IGEAT(1) NIS (2)
River basin border and superficy	Flemish community Belgium (river watershed)	2000	VHA (3) IGEAT(1)
Population density	Belgium (town)	2000	NIS (2)
Population connected to Sewer system or WWTP	Belgium (region, town)	2000	MUMM (4)
Industrial N & P emissions into surface water and to waste water treatment plant (WWTP)	Belgium (region, town)	2000	MUMM (4)
N and P emissions by WWTP	Belgium (region, town)	2000	MUMM (4)
Animal species and number	Belgium (town)	2000	NIS (2)
Agricultural surface	Belgium (town)	2000	NIS (2)
Animal manure production	Flemish community (town)	1999	FMB (5)
Manure use	Flemish community (town)	1999	FMB (5)
Fertilizer use	Flemish community (town)	1999	FMB (5)
Agricultural N and P loss	Belgium (watershed)	1999	SENTWA model (6)

(1) IGEAT: Institut de Gestion de l'Environnement et d'Aménagement du territoire,ULB

(2) NIS : National Institute of Statistics

(3) VHA: Vlaamse Hydrografische Atlas (Flemish hydrographical atlas)

(4) MUMM: Management Unit of North Sea Mathematical models (M. Kyramarios, pers. comm.) based on data provided by the Regions (VMM for Flanders, DGRNE for Wallonia and IBGE-BIM for Brussels).

(5) FMB: Flemish Manure Bank

(6) SENTWA: System for the Evaluation of Nutrient Transport to Water (Ministry of Agriculture)

Calculation of the various N and P emissions was performed specifically for the Yser, Scheldt and Coast watersheds based of their geographical limits and corresponding data. The watershed of river Scheldt was limited to the Belgian territory. Nutrient emissions in the watershed of the river Leie, a Scheldt tributary, were accounted with those of the Coast watershed due to the Terneuzen Canal derivation.

The data sets provided by the different governmental institutions were however heterogeneous due to their respective missions, calculation methods and the ongoing legislative changes. Harmonisation of the data was performed as much as possible. Quality control of the data was that performed by the delivering administration.

3.1.2 Nutrient loads

Nutrients originating from the BCZ watershed are discharged into BCZ via the Scheldt and Yser rivers as well as coastal tributaries (see annex 2 for details).

Riverine and coastal tributary nutrient inputs were basically calculated as the product of nutrient concentrations and corresponding river runoffs, both measured at downstream monitoring stations (Fig. 3; Annex 8.2). Various calculation methods were however applied depending on the origin and availability of collected data (Table II).

Nutrient data were collected from 4 Belgian and Dutch institutions responsible for the control of freshwater quality (Table II). As a general trend, concentrations of dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4) as well as total N (Tot N) and P (Tot P) were measured by all institutions but the frequency and sampling periods were quite variable (Table II). Dissolved silicic acid (DSi) concentrations were measured for the only Scheldt river.

River and coastal tributary runoffs were all provided by the Administratie Waterwegen en Zeewezen (AWZ) of the Ministry of Flemish Community (Table II). Scheldt runoffs at station Schelle (Fig. 3) were reported as 10-days average values. Due to the lack of regular and accurate measurements, runoffs of Yser and coastal tributaries were only available as Long Term Average (LTA) yearly runoffs (see details in Annex 8.2).

Table II: Nutrient concentration and runoff (Q) data for the Scheldt (S), Yser (Y) and coastal tributaries (C). Data source, measured nutrient, sampling periods and annual frequency (F) are indicated.

Source	River	Q	Nutrients							Period	F
			NH_4	NO_3	NO_2	PO_4	Tot N	Tot P	DSi		
VMM (1)	S, Y, C		X	X	-	X	X	X	-	1991-1998	0-12
IHE (2)	S		X	X	X	X	X	X	-	1975-1986	0-10
RIKZ (3)	S		X	X	X	X	X	X	X	1968-2000	12-48
AWZ (4)	S	X								1968-1999	36
	Y, C	X								LTA (5)	-

VMM (1) : Vlaamse Milieumaatschappij (Flemish Environmental Institute)
IHE (2) : Institut pour l'Hygiène et l'Epidémiologie (Ministery of Public Health)
RIKZ (3) : Rijk Waterstaat Instituut voor Kust and Zee (The Netherlands)
AWZ (4) : Administratie Waterwegen en Zeewezen, (Ministry of Flemish Community)
LTA (5) : Long Term Average

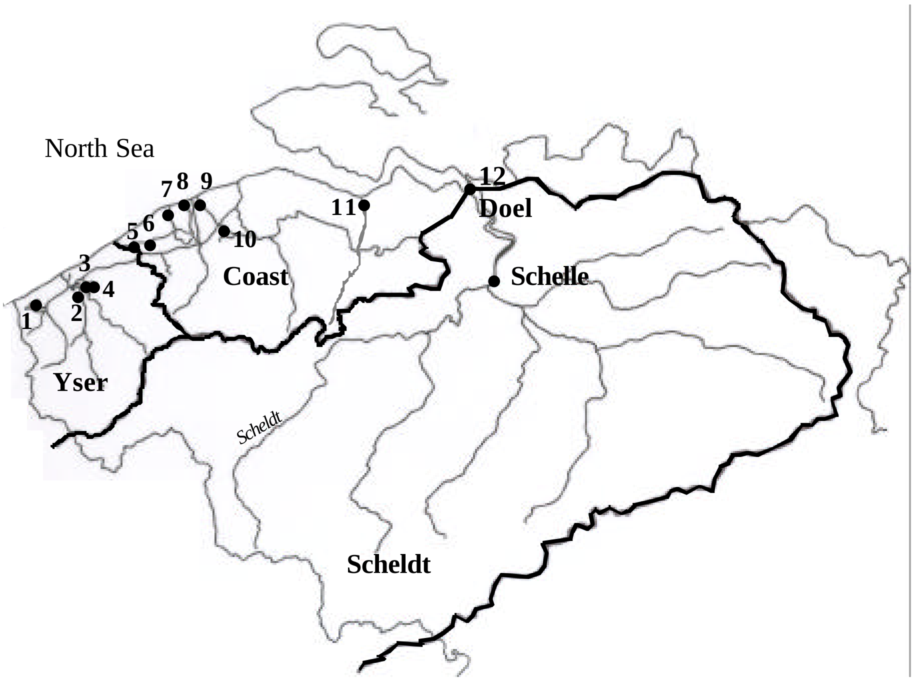

Figure 3: Hydrographic map of the BCZ watershed. Monitoring stations used for the estimation of nutrient loads to BCZ are indicated. Station coordinates and river runoffs are given in annex 8.2.

3.1.2.1 Nutrient loads from river Scheldt

Nutrient concentrations in the river Scheldt were monitored at station Doel (N 51°21 09 - E 4° 13 50) located at the Belgian-Dutch border in the Scheldt estuary (Station 12 on Fig. 3). This station has an average salinity of 12 corresponding to the mixing of marine and freshwater. Station Doel is appropriate for estimating Scheldt loads to BCZ due to the nearly conservative mixing pattern of nutrients in the downstream part of the estuary. Its is indeed located downstream the maximum turbidity zone (salinity 0-10) of the estuary (Bayens *et al.*, 1998; Herman and Heip, 1999) where most of microbiological (nitrification, denitrification) and physico-chemical (co-precipitation of PO_4 adsorbed on iron oxy-hydroxides) estuarine processes are achieved (Zwolman, 1994 ; Van Damme *et al.*, 1995; Herman and Heip, 1999).

Scheldt nutrient loads were calculated for the period 1968-1998 making use of nutrient concentrations at station Doel and runoff at the upstream station Schelle (Fig. 3). The Scheldt runoffs were multiplied by an empirically determined correction factor of 1.15 in order to include lateral freshwater inputs between Schelle and Doel (M. Moens, pers.comm.). On the other hand, nutrient concentrations were corrected for the contribution of nutrients from marine origin using the equation recommanded by OSPAR (1992):

$$\mathrm{C}_{\mathrm{freshwater}} = \frac{18000 \times C_{meas}}{18000 - \left[\mathrm{Cl}^{-}\right]}$$

Where C_{meas} is the nutrient concentration measured at Doel

$[Cl^-]$ is is the chloride concentration (mg l^{-1}) at sampling time

Finally, annual nutrient loads were calculated according to the OSPAR (1992) equation, weighing nutrient concentrations with the yearly average runoff of the river:

$$Load = Q_{year}\left(\frac{\sum_{i=1}^{n}(C_i Q_i)}{\sum_{i=1}^{n}(Q_i)} \right)$$

Where C_i is the concentration of sample i

Q_i is the 10-day average Scheldt runoff during the sampling period.

Q_{year} is the yearly average Scheldt runoff

The error associated to the use of 10-day average runoffs instead of daily runoffs was estimated for 1998 for which daily runoffs were available. Calculations indicate a

2% error for $NO_3 + NO_2$, Tot N and Tot P, 4.4% for NH_4 and DSi while 6 % for PO_4 loads (not shown).

3.1.2.2 Nutrient loads from Yser and coastal tributaries

Monitoring stations used for calculating nutrient loads from the Yser and coastal tributaries were those located the most downstream but outwards the limit of marine water intrusion (Stations 1-4; 5-11 on Fig. 3; Annex 8.2). Annual nutrient loads were calculated for the period 1991-1999 according to the OSPAR (1992) equation that takes into account the varying sampling frequency :

$$Load = \frac{Q_{LTA}\sum_{i=1}^{n} C_i}{n}$$

Where Q_{LTA} is the long term average runoff
C_i is the nutrient concentration of sample i
n is the number of sampling during the year

3.1.3 Transboundary fluxes of nutrients

Transboundary fluxes of inorganic nutrients (DIN, PO_4, DSi) flowing through BCZ were estimated from southwesterly Atlantic water fluxes and nutrient concentrations at the BCZ southwestern (French-Belgian) and northeastern (Belgian-Dutch) borders (Fig. 4). Lateral advective processes were considered as negligible.

The residual southwesterly water fluxes across the BCZ were calculated on a monthly basis using a conventional, vertically integrated, two-dimensional (2.5' latitude, 5' longitude) 'shallow water wave equations' model (Ozer, pers. comm.). This model is driven by 8 tidal constituents and meteorological forcing (6 hourly wind and atmospheric pressure fields obtained from the UK Meteorological Office).

Nutrient data from stations located along the southwestern (d3, d4, 315 and 421) and northeastern (WC2, WC20, WC30, 545, WC50, 800 and WC70) borders were used to estimate nutrient inflows and outflows respectively (Fig. 4). Stations d3 and d4 were monitored by IFREMER (Institut Français de Recherche pour l'Exploitation de la Mer); 421, 315, 800 and 545 by MUMM (Management Unit of North Sea Mathematical Models) and WC2, WC20, WC30, WC50 and WC70 by RIKZ (Rijk Waterstaat Instituut voor Kust and Zee). Co-ordinates of these stations are given in annex 3. The two selected transects showed horizontal salinity gradient with lower salinity close to the coast. Nutrient concentrations used in nutrient flow estimation were therefore corresponding to the average concentration of each transect.

Transboundary nutrient fluxes through the BCZ were estimated from computed water flows multiplied by the monthly concentration of nutrients.

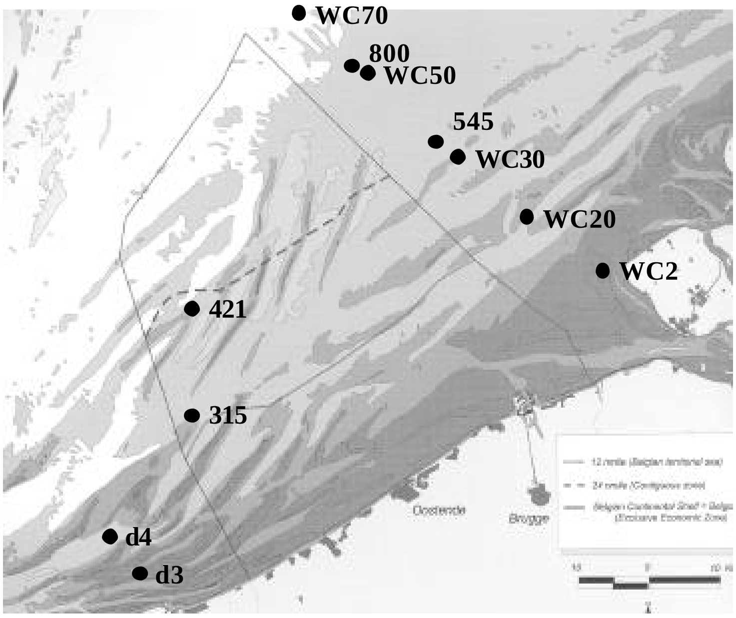

Figure 4: Nutrient sampling stations located along the southwestern and northeastern borders of BCZ used to calculate nutrient inflows and outflows. Map reproduced from Maes *et al.,* 2000, with permission from OSTC.

3.1.4 Nutrient enrichment of BCZ

The global nutrient enrichment of temperate aquatic systems can be determined from the winter nutrient concentration level, *i.e.* when biological activities are reduced. The nutrient (NH_4, NO_3+NO_2, PO_4, DSi) enrichment of BCZ was estimated from winter nutrient-salinity distribution curves in the salinity range 28-35. The average nutrient enrichment was defined as the nutrient concentration statistically calculated at salinity 33.5, considered as the average salinity of Belgian coastal water (Rousseau, 2000; Fig. 5). These calculations were conducted on the BCZ data set covering the 1972-1999 period (Table III). For this analysis, some data from the nearest adjacent waters were considered (Table III). Data of insufficient quality were eliminated.

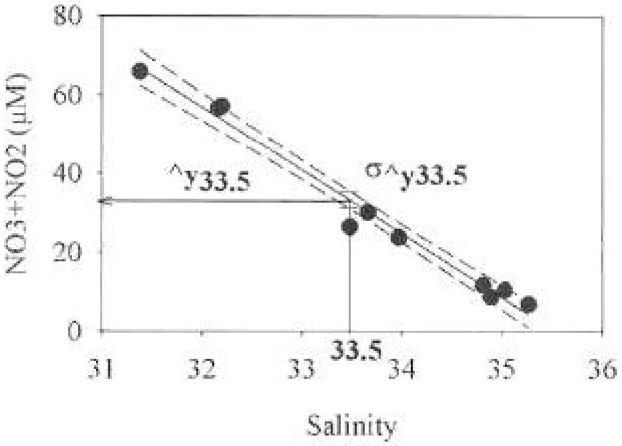

Figure 5: Relationship between winter NO_3+NO_2 concentrations and salinity (Source MUMM: 1998). $\hat{y}_{33.5}$ is the predicted average nutrient concentration typical of BCZ as determined from the linear regression. $\hat{s}_{33.5}$ is the standard error of $\hat{y}_{33.5}$. Dotted line shows the 95% confidence interval.

Table III: Description of the winter nutrient data sets collected for Belgian and adjacent coastal water

Source	Geographical domain		Period	References
	Latitude (°N)	Longitude (°E)		
IFREMER	50.9-51.1	1.4-1.9	1976-1983	CNEXO reports
IFREMER	50.9-51.1	1.4-1.9	1992-1996	A.Morel, unpublished
ICES	51.0-53.0	1.0-5.0	1974-1989	www.ices.dk
CIPS (1)	51.0-52.4	1.4-4.3	1972-1975	CIPS (1) reports
MUMM-BMDC(2)	51.0-52.0	2.1-3.3	1978-1998	www.mumm.ac.be /datacentre

(1) CIPS : Commission Interministérielle de la Politique Scientifique (Belgian Ministry of Science Policy).

(2) MUMM-BMDC : Management Unit of the North Sea Mathematical models-Belgian Marine Data Centre.

3.1.5 Phytoplankton data

Chlorophyll *a* (Chl *a*) as indicator of phytoplankton biomass, and phytoplankton (enumeration and identification) data were retrieved from CIPS, IFREMER, ULB-ESA and MUMM data bases (Table IV). Although characterized by different spatio-temporal resolution, two types of information could be extracted from this dataset.

The spatial grid with low sampling frequency (1 to 2 per season and station) was used for assessing the geographical extent of phytoplankton blooms. The high time resolution monitoring data at station 330 located in the central BCZ was used as indicator of the timing, duration and magnitude of phytoplankton spring bloom and species succession.

Table IV : Description of the Chl *a* and phytoplankton data sets collected for Belgian and adjacent coastal water.

Source	Geographical domain	Period	Frequency	References
IFREMER	d1: N 51°04 17-E 2° 20 09 d3: N 50°06 59-E 2° 27 10 d4: N 51° 09 13-E 2° 15 13	1988-1999	2/month	A. Lefebvre, pers.comm.
CIPS	N 51.0-52.4-E 1.4-4.3	1971-1975	1-2/spring	CIPS reports
	Calais: N 50°57 30-E 1°23 30 Ostende: N 51°45 10-E 2°27 00	1977-1979	1/week	
ULB-ESA	330: N 51° 26 00-E 2°48 50	1988-2000	2-4/month	Rousseau, 2000
	240: N 51°25 30-E 2°03 80	1988	1/week	Unpublished
	420: N 51°27 30-E 2°28 50	1988	1/week	Unpublished
	N 51°- 52° - E 2°.1-3°.3	1999	3/spring	Unpublished
MUMM	N 51°- 52° - E 2°.1-3°.3	1990-2000	1/spring	www.mumm.ac.be /datacentre

3.2 Long-term trend analysis

Significant monotonous trends over time of riverine nutrient loads and nutrient enrichment were detected using the non-parametric Kendall's τ-b test for trend significance (Kendall, 1975). For significant trends, regression analysis were performed on the time-serie data by fitting the best model of regression (linear, power, exponential….).

3.3 Eutrophication-related damage perception

The study of damage related to coastal eutrophication of BCZ was estimated based on the impact assessment of algal blooms and/or presence of foam. It was assessed through questionnaires distributed among tourists and fishermen. Some 323 tourists were surveyed during the Easter holiday 2000 at the coastal municipalities of Blankenberge, Knokke, Nieuwpoort and Oostende. The questioning took place for 49% at the dike, 19% at shopping malls, 11% on the beach and the remaining 21% at the pier and yachting harbour. Both the extent to which users are familiar with eutrophication and consider foam as adverse impact were investigated in the questionnaire (Annex 8.4). Foaming was selected as key question because of its link with eutrophication in BCZ. The questionnaire was illustrated with several photographs. In order to prevent bias in the responses, t.he relative impact of foam was established by comparison to other environmental disturbances such as oil pollution, dead fish and jellyfish, garbage on the beaches as well as bad weather and overcrowding.

A second questionnaire (Annex 8.5) was conducted among 21 fishermen from 16 ships mainly fishing in BCZ, and two representatives of the fishermen's organisations. Currently some 29 ships report more than 50% of their fishing efforts in BCZ (Rederscentrale, pers. comm.). The purpose of the questionnaire was to assess the subjective perception by fishermen of the occurrence, causes and effects of algal blooms in the Belgian part of the North Sea relevant for fishery activities. Fishermen were asked to point algal bloom areas in BCZ on a map. These areas were thereafter used as qualitative indicator of the presence of algal blooms. Fishermen were also asked to locate their fishing grounds for each month between February and June as well as the species fished as main catch or as by-catch.

4 RESULTS AND DISCUSSION

4.1 Nutrient enrichment of BCZ

The global nutrient enrichment of BCZ results from the nutrient loads associated to freshwater discharges, Southwesterly Atlantic water and atmospheric deposit. These different nutrient loads and, when possible, their historical trends were therefore estimated in this study. Their relative contribution to the nutrient enrichment of BCZ is further deduced from a nutrient budget. We also determined molar N:P:Si ratios of nutrient fluxes and concentrations which, when compared to phytoplankton stoechiometry, [i.e. N:P=16 for marine phytoplankton (Redfield *et al.*, 1963) and N:Si=1 for coastal diatoms (Bzrezinski, 1985)], can be used as an indicator of phytoplankton growth limitation.

Riverine nutrient loads from the BCZ watershed were here estimated from downstream monitoring station data and were further related to nutrient land-based emissions. These latter were appraised from a current inventory of human activities (agriculture, industry, household) in the BCZ watershed.

4.1.1 Nutrient land-based emissions: current status

In this section, we compare nutrient emissions to continental surface water for the Yser, Coast and Scheldt sub-watersheds. This comparison is based on current available data for 1999 and 2000 on agricultural, industrial and domestic activities.

4.1.1.1 Agriculture

Agricultural nutrient loss to surface water depends mainly on fertilization and husbandry intensity but is modulated by meteorological conditions, lithology and regulation of agricultural practice. Agricultural N and P contamination of surface water of the Yser, Coast and Scheldt watersheds was estimated using the semi-empirical model SENTWA (Fig. 6). This model is based on reliable statistical data on land use, livestock density, spreading of animal manure and fertilizers taking into account lithology, nutrient forms and meteorology. It calculates N and P fluxes to surface water resulting from atmospheric deposit, direct flow, drainage, groundwater overflow, excess fertilizer or manure use, erosion and run-off. The SENTWA model has been validated in the watershed of two Scheldt tributaries, the Mark and Zwalm. Errors on N and P loss are about 33% and 60% respectively.

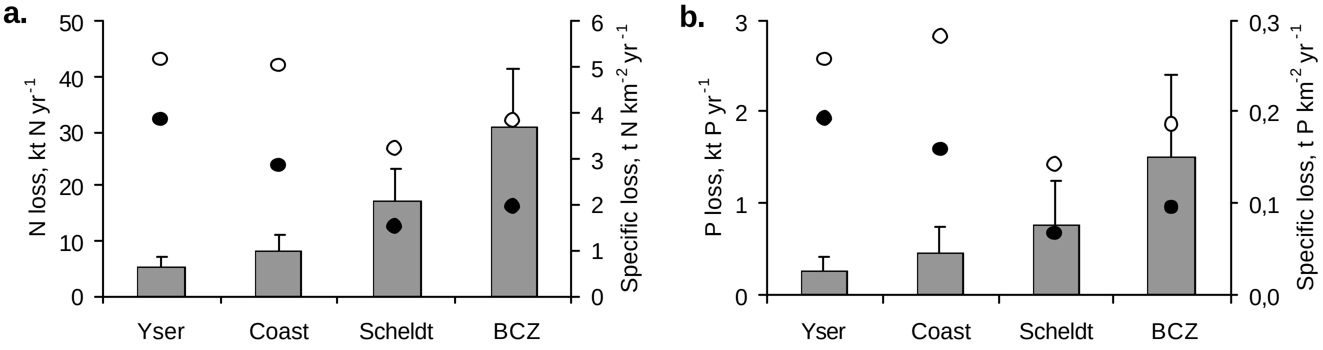

Figure 6: Annual agricultural losses (block, left axis) of N (a) and P (b) calculated by the SENTWA model for the Yser, Coast, Scheldt and the whole BCZ watersheds for 1999. Specific losses (right axis) related to watershed superficy (●) and to agricultural ground superficy (○) are indicated.

Results generated with the SENTWA model for 1999, show that the Scheldt watershed contributes to the major part (54%) of the N and P agricultural contamination of surface waters of the BCZ watershed (31 kt N yr^{-1} and 1.5 kt P yr^{-1}; Fig. 6). The Coast and the Yser watersheds contribute to 29% and 17% respectively (Fig. 6). On the other hand, specific losses of N and P are much higher in the Yser and Coast (Fig. 6) and reflect the difference between the superficy of the Yser (1365 km^2), Coast (2926 km^2) and Scheldt (11637 km^2) watersheds. When related to agricultural ground superficy, these numbers reflect a difference in land use with a varying part of the watershed affected to cultured grounds (47% for the Scheldt, 75% for the Yser and 57% for the Coast watershed) and agricultural practices.

As shown on figure 7, the specific use of manure, the major source of N (77%) and P (89%) spread on fields, is the highest in the Yser and the lowest in the Scheldt watersheds in 1999 (data restricted to the Flemish part of the Scheldt watershed; Fig. 7ac). The distribution of specific use of N fertilizer is not so contrasted (Fig. 7b) but that of P fertilizer is inverted (Fig. 7d). This is due to the fact that P fertilizer is only used as a complement to manure for soil fertilization.

Globally, the spreading of manure and fertilizer is much higher in the Scheldt, representing 52% of the total amount of N and P used in the BCZ watershed (Fig. 7). This contribution is 20% and 28% for the Yser and Coast watersheds respectively (Fig. 7).

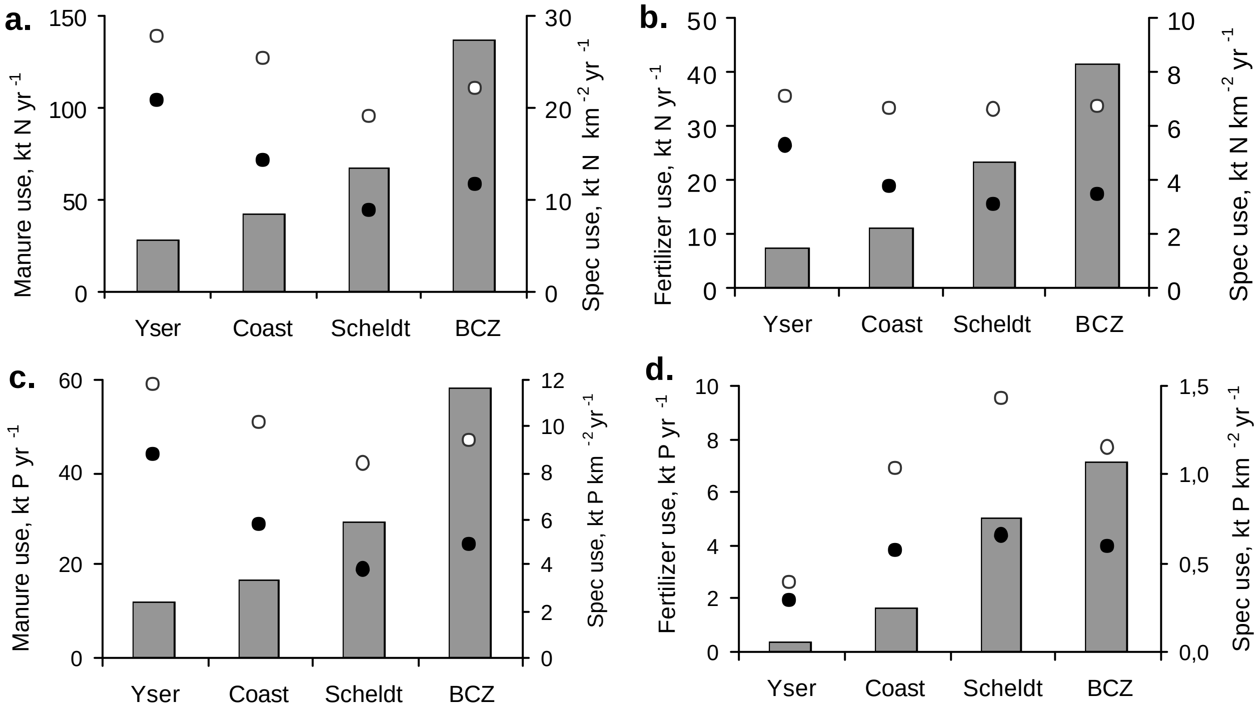

Figure 7: Amount (block, left axis) of N (a) and P (c) manure and N (b) and P (d) fertilizers spread in the Yser, Coast, Flemish part of the Scheldt and the BCZ watersheds in 1999. The specific use of manure and fertilizers (right axis) related to watershed superficy (●) and to agricultural ground superficy (○) is indicated.

The amount of manure spread in each watershed is equivalent to manure production (not shown), suggesting a local utilization. Manure production in 1999 is estimated to 139 kt N and 60 kt P based on animal density and manure excretion coefficients, the latter being determined on basis of animal species, weight, age, race, sex and diet.

The specific manure production is in turn directly related to the animal husbandry. As can be seen on figure 8, the elevated manure production in the Yser and Coast watersheds compared to that of the Scheldt, is explained by the elevated density of cattle (Fig. 8a), pig (Fig. 8b) and poultry (Fig. 8c) in these watersheds. Pig farming is particularly intensively developed in the Yser watershed with animal density being eight-fold that of the Scheldt (Fig. 8b).

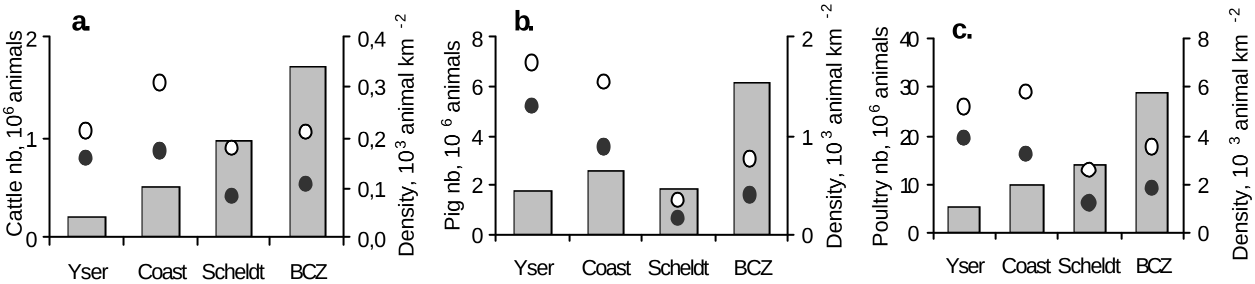

Figure 8: Main animals bred in 2000 in the Yser, Coast, Scheldt and BCZ watersheds: cattle (a); pigs (b) and poultry (c). Number (block, left axis) and density (right axis) related to watershed superficy (●) and to agricultural ground superficy (○) are indicated.

4.1.1.2 Industry

Figure 9 shows for the BCZ watershed and its 3 watersheds, the total industrial emissions of N and P in 2000. This calculation considers the direct release to surface water, the discharge to public WWTP and sewerage. For the whole BCZ watershed, N and P emissions amount to 5.56 kt N (Fig. 9a) and 0.77 kt P (Fig. 9b). Industrial emissions discharged to WWTP are reduced, in average for the BCZ watershed, by 32% for N and 41% for P. The net discharge of industrial N and P to surface water, after treatment of industrial effluents in WWTP, is therefore estimated to 4.94 kt N (Fig. 9a) and 0.64 kt P (Fig. 9b).

The Scheldt watershed is the major source of industrial N and P to BCZ in 2000 and contributes to some 80% of N (Fig. 9a) and 66% of P (Fig. 9b) industrial emissions. The contribution of the Coast watershed is 18% for N (Fig. 9a) and 24% for P (Fig. 9b) while that of the Yser is 2% for N (Fig. 9a) and 10% for P (Fig. 9b).

Industrial N and P emission pathways are globally similar in the 3 watersheds. As an average, most N (64%; Fig. 9a) and P (55%; Fig. 9b) are directly discharged in surface water of the BCZ watershed. About one third of N and P emissions is discharged towards WWTP. Sewerage of industrial effluents is generally limited in the 3 watersheds, contributing to 5% of N (Fig. 9a) and 8% of P (Fig. 9b) total emissions.

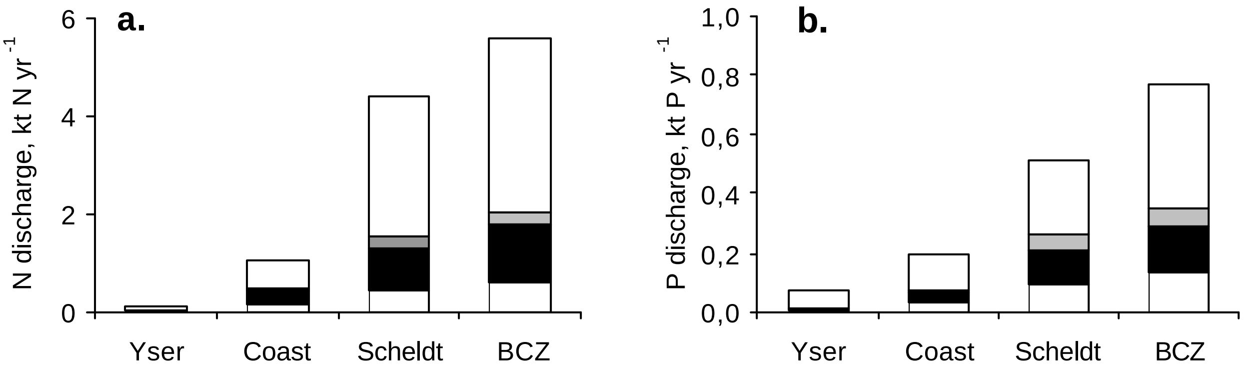

Figure 9: Industrial emissions of N (a) and P (b) to surface water of the Yser, Coast, Scheldt and whole BCZ watersheds in 2000. Black, grey and white blocks represent emissions to WWTP, sewerage and through direct discharge in surface water respectively. The hatched blocks represent the part of N and P removed after treatment of industrial effluents in WWTP.

4.1.1.3 Household

Household discharge of N and P to surface water depends on population density in the watershed and also on the extent of wastewater treatment in WWTP. The total number of inhabitants in the BCZ watershed in 2000 amounts to 7.81 millions distributed for 86% in the Scheldt, 10% in the Coast and 4% in the Yser watersheds. The population density differs considerably between the three basins with 522, 417 and 227 inhab km^{-2} for the Scheldt, Coast and Yser watersheds respectively. The higher population density in the Scheldt basin is mainly due to the presence of the large cities Antwerp, Brussels and Gent. These statistics, however, do not consider the two- or even three-fold summer increase caused by tourist population in the Yser and Coast watersheds.

Household emissions of N and P are estimated on basis of watershed population and per capita load specific for western european countries in the late nineties, *i.e*. 12.5 g N and 2 g P inhab^{-1} d^{-1} (Billen *et al.*, 1999). This calculation estimates household emissions to WWTP, sewerage and through direct discharge in surface water to 34.7 kt N (Fig. 10a) and 5.6 kt P (Fig. 10b) in the BCZ watershed in 2000. Similarly to industrial discharges, the Scheldt watershed is the major source of household emissions, contributing to 81% of N (Fig. 10a) and P (Fig. 10b) emissions in the BCZ watershed. The Coast watershed contributes to 16% and the Yser to 4% of N and P household discharges (Fig. 10).

In average for the BCZ watershed, 49% of household wastewater is treated in WWTP before reaching surface water while 38% is collected in sewerage and 13% is rejected directly in surface water (Fig. 10). Total net emissions after treatment in WWTP are estimated to 29.1 kt N (Fig. 10a) and 4.4 kt P (Fig. 10b).

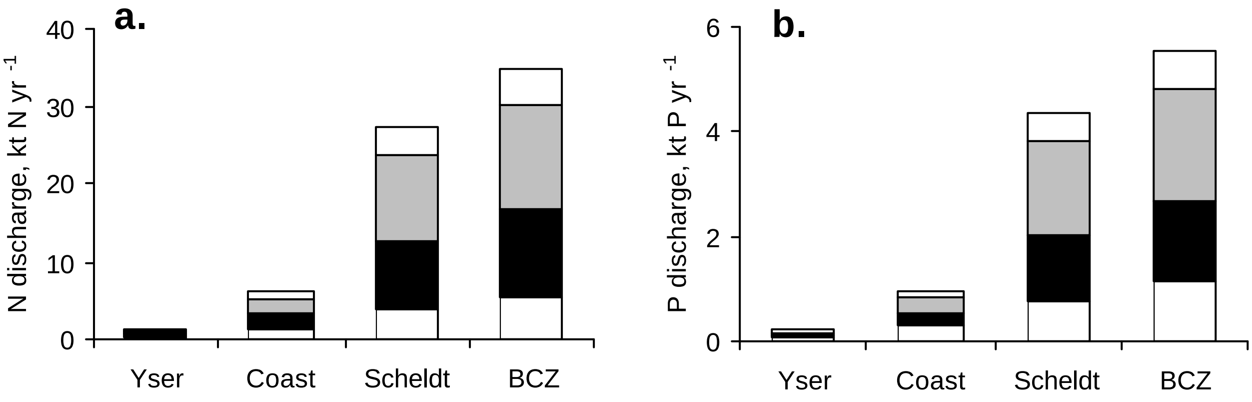

Figure 10: Household emissions of N (a) and P (b) to surface water of the Yser, Coast, Scheldt and BCZ watersheds in 2000. Black, grey and white blocks represent emissions to WWTP, sewerage and through direct discharges in surface water respectively. The hatched blocks represent the part of N and P removed by treatment in WWTP.

4.1.1.4 Total emissions of N and P in the BCZ watershed

Figures 11 and 12 show respectively the total N and P emissions to surface water of the Yser, Coast, Scheldt and BCZ watersheds and the relative contribution of agriculture, industry and household as calculated from estimations reported on Fig. 6-10. Although these calculations combine statistics for the years 1999 and 2000, we however assume they illustrate the actual situation.

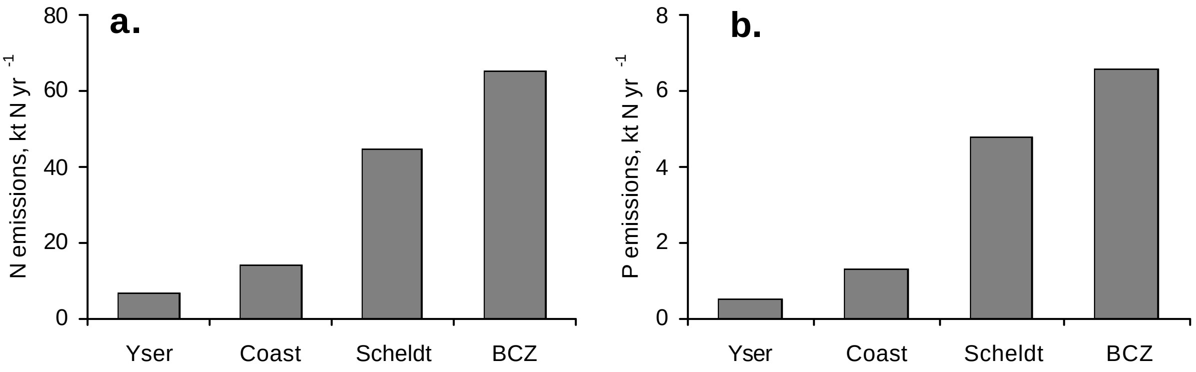

Figure 11: Total emissions of N (a) and P (b) to surface water of the Yser, Coast, Scheldt and BCZ watersheds.

Actual emissions of nutrients to surface water of the BCZ watershed amount to 65.2 kt N (Fig. 11a) and 6.6 kt P (Fig. 11b). As expected from the previous sections, the Scheldt watershed is the main source of N (69%; Fig. 11a) and P (73%; Fig. 11b) emissions. The Coast watershed is responsible for 20% of N and P discharge while the Yser contributes to only 11% of N and 7% of P total emissions (Fig. 11).

Agriculture and household are by far the major source of N and P to the BCZ watershed although the relative contribution of these two sectors varies significantly whether N (Fig. 12a) or P (Fig. 12b) emissions are considered. Agriculture (47%) and household (45%) contribute quite equally to N emissions in the BCZ watershed (Fig. 12a) while the major source of P in surface waters of the BCZ watershed is by far issued from household (67%; Fig. 12b). Industry contributes only to a minor part (8-10%) of both N and P emissions (Fig. 12).

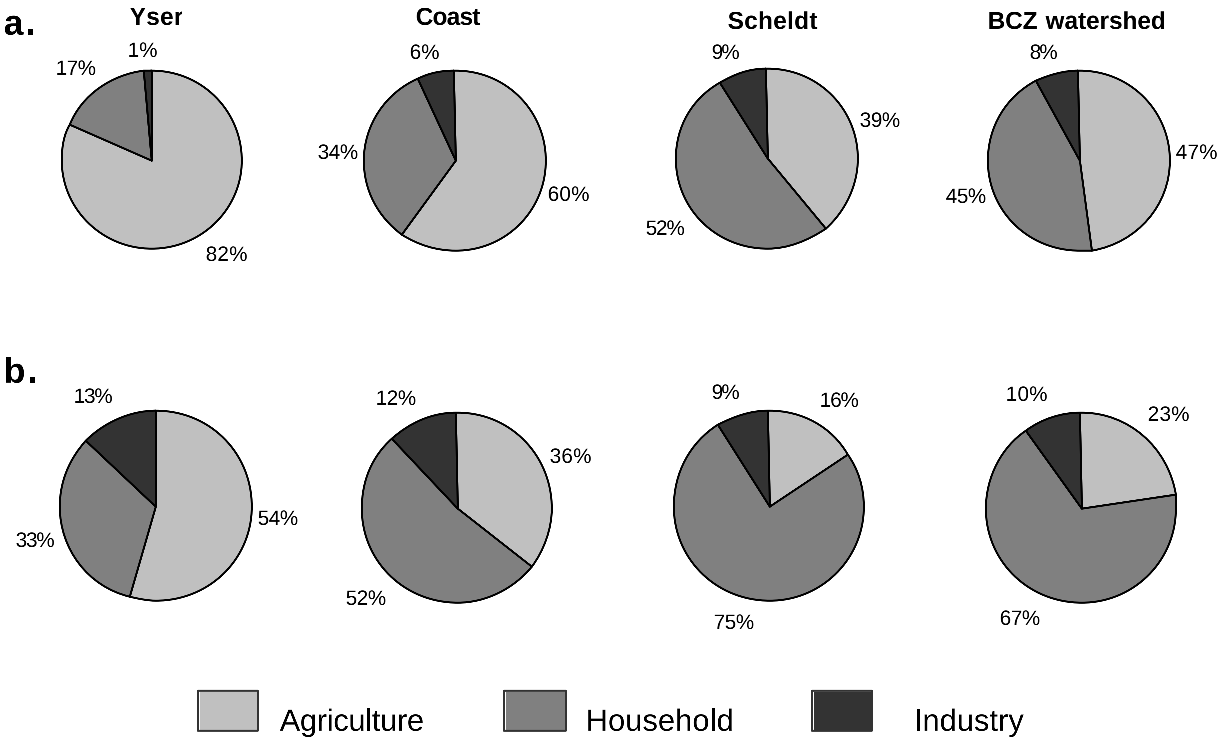

Figure 12: Relative contribution of agriculture, industry and household to the total N (a) and P (b) emissions to surface water of the Yser, Coast, Scheldt and BCZ watersheds.

At the scale of each watershed, contrasted figures appear however, reflecting well the different land use. Agriculture is indeed the major source of N (82%) and P (54%) in the Yser watershed, due to the relatively intensive agricultural practices developed in this least populated watershed (section 4.1.1.1). In the densely populated Scheldt watershed (section 4.1.1.3.) on the contrary, household wastewater is responsible for most N (52%) and P (75%) emissions (Fig. 12b). The Coast watershed shows an intermediate situation with agriculture as the main source of N (60%; Fig. 12a) but a major household contribution (52%; Fig. 12b) to P emissions.

4.1.2 Nutrient loads to BCZ

4.1.2.1 Riverine nutrient loads to BCZ

Nutrient loads : current situation

Figure 13 synthesizes the most recent data (1999) on N and P riverine loads discharged to BCZ by the different watersheds. The share between organic and inorganic forms is indicated too. According to this, current riverine loads from the BCZ watershed are estimated to 48.2 kt N (Fig. 13a) and 4.2 kt P (Fig. 13b). River Scheldt is the most important and contributes to 64% of N (Fig. 13a) and 51% of P (Fig. 13b) riverine loads. Coastal tributaries discharge some 29% of N (Fig. 13a) but 40% of P (Fig. 13b) loads to BCZ. River Yser is a minor source of N (7%; Fig. 13a) and P (9%; Fig. 13b) for BCZ.

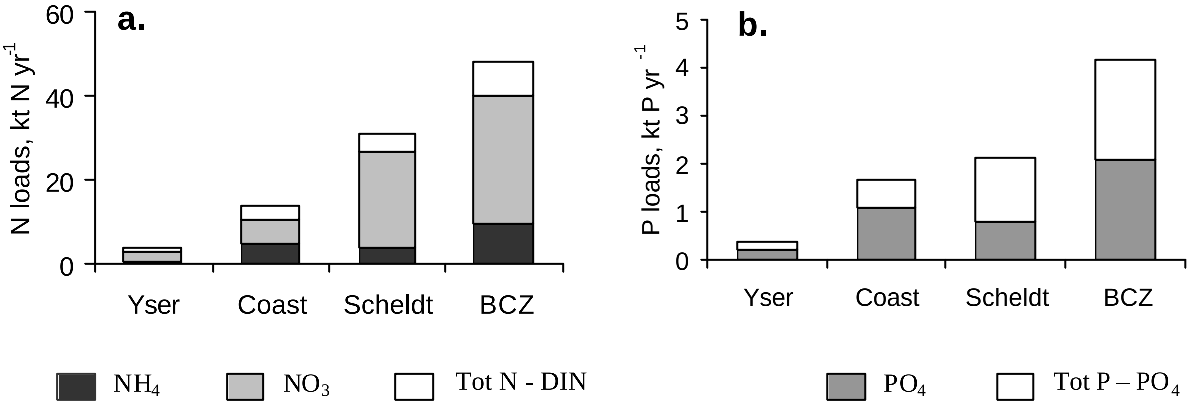

Figure 13 : N (a) and P (b) riverine loads discharged to BCZ by the Yser, Coast, Scheldt and whole BCZ watersheds in 1999.

At station Doel in the lower Scheldt estuary, dissolved inorganic nitrogen (DIN) represents more than 80% of the total N delivered by rivers to sea. Oxidized forms (NO_3+NO_2) contribute to some 70% of N loads for Scheldt and Yser but 40% for the Coast watershed (Fig. 13a). For the latter, NH_4 loads are much more significant (Fig. 13a). Globally, half of the P riverine load is brought to BCZ as PO_4 (Fig. 13b). In the

Coast watershed however, PO_4 contributes to about two thirds of P loads (Fig. 13b). Part of the NO_3+NO_2 loads of the Scheldt results from the intensive nitrification process taking place in the upstream maximum turbidity zone between salinity 0 and 5 (van Damme *et al.*, 1995; Reignier, 1997; Herman and Heip, 1999). On the other hand, the low oxygen conditions in the tributaries of the Coast watershed probably prevents nitrification and low P adsorption and explains the still elevated NH_4 and PO_4 loads originating from cattle-farming and urban waste waters (section 4.1.1.).

Nutrient retention

The filtering capacity of the different sub-watersheds was estimated based on a comparison between nutrient loads to BCZ and emissions in the BCZ watershed (Table V). This calculation evaluates to 26 and 37% the global retention of N and P emissions in the BCZ watershed during their transfer to the sea (Table V). The efficiency of nutrient reduction varies however between sub-watersheds. The N retention is the highest in the Yser watershed, reaching 42% of N emissions compared to 31% in the Scheldt watershed. N retention in the Scheldt has been attributed to denitrification process occurring in anaerobic zones of Scheldt tributaries and estuary (Billen *et al.*, 1985; van Damme *et al.*, 1995).

P retention is very efficient in the Scheldt river system where only 44% of P emissions reaches the BCZ (Table V). This is mostly due to important adsorption of PO_4 on iron oxy-hydroxydes precipited in the maximum turbidity zone of the Scheldt estuary (Zwolman, 1994; van Damme *et al.*, 1995; Bayens *et al.*, 1998).

In the Coast watershed, N retention is estimated to only 1% of N emissions (Table V). Unexpected our calculations suggest that P outputs are higher by some 28% than P emissions (Table V). This is the probably due to an overestimation of nutrient loads by the main canals due to runoff overestimation.

Table V: Nutrient retention in the Yser, Coast, Scheldt and BCZ watersheds.

kt N y^{-1}	Yser	Coast	Scheldt	BCZ
Inputs (emissions)	6.5	13.9	44.8	65.2
Outputs (loads)	3.7	13.7	30.8	48.2
Retention (%)	42	1	31	26

kt P y^{-1}	Yser	Coast	Scheldt	BCZ
Inputs (emissions)	0.37	1.67	2.12	6.56
Outputs (loads)	0.48	1.3	4.77	4.16
Retention (%)	23	- 28	56	37

Nutrient ratios

The specific nutrient retention in the different watersheds modifies the N:P ratios of nutrient delivered to BCZ. This can be seen on Table VI which compares N:P ratios of current emissions and loads for the different watersheds. Both emissions and loads are over-enriched with N compared to the N:P Redfield's ratio of 16. At the scale of the BCZ watershed, the biogeochemical processes affecting the nutrients during their transfer from land to sea do not significantly modify the balance of total N and total P (Table VI). The N excess increases however during the transfer of nutrients in the Scheldt watershed (Table VI) due to the substantial P retention in the river system (Table V). On the contrary, the ratio of total N to total P decreases in the Yser and Coast watersheds (Table VI).

Table VI: Molar ratios of Total N to Total P of land-based emissions and riverine loads in 1999 from the Yser, Coast, Scheldt and BCZ watersheds.

	Yser	Coast	Scheldt	BCZ
Emissions	30	24	21	22
Loads	22	18	32	26

Trends for the period 1991-1999

Figure 14 shows the interannual variability of N and P loads discharged to BCZ from the Yser, Coast, Scheldt and BCZ watersheds for the 1991-1999 period. At the scale of the BCZ watershed, a pronounced decrease of NH_4 (54%; Fig. 14a) and PO_4 (53%; Fig. 14d) loads occurs over the period 1991-1998. In 1999, an increase of loads, more pronounced for NH_4 than PO_4 is observed (Fig. 14a, d). The total loads of NO_3+NO_2 vary significantly from year to year without showing significant trend (Fig. 14b). Tot N loads (Fig. 14c), while reflecting NO_3+NO_2 loads (Fig. 14c), slightly decrease after 1994 due to NH_4 reduction (Fig. 14a). Similarly, the decrease in PO_4 loads is clearly visible in the Tot P load trend (Fig. 14e). The increase of the Tot N: Tot P molar ratio from 18 in 1991 to 26 in 1999 results from these changes. The N excess is however more pronounced when considering the only dissolved inorganic nutrients. The molar ratios of DIN:DIP varies indeed from 24 in 1991 to 42 in 1999.

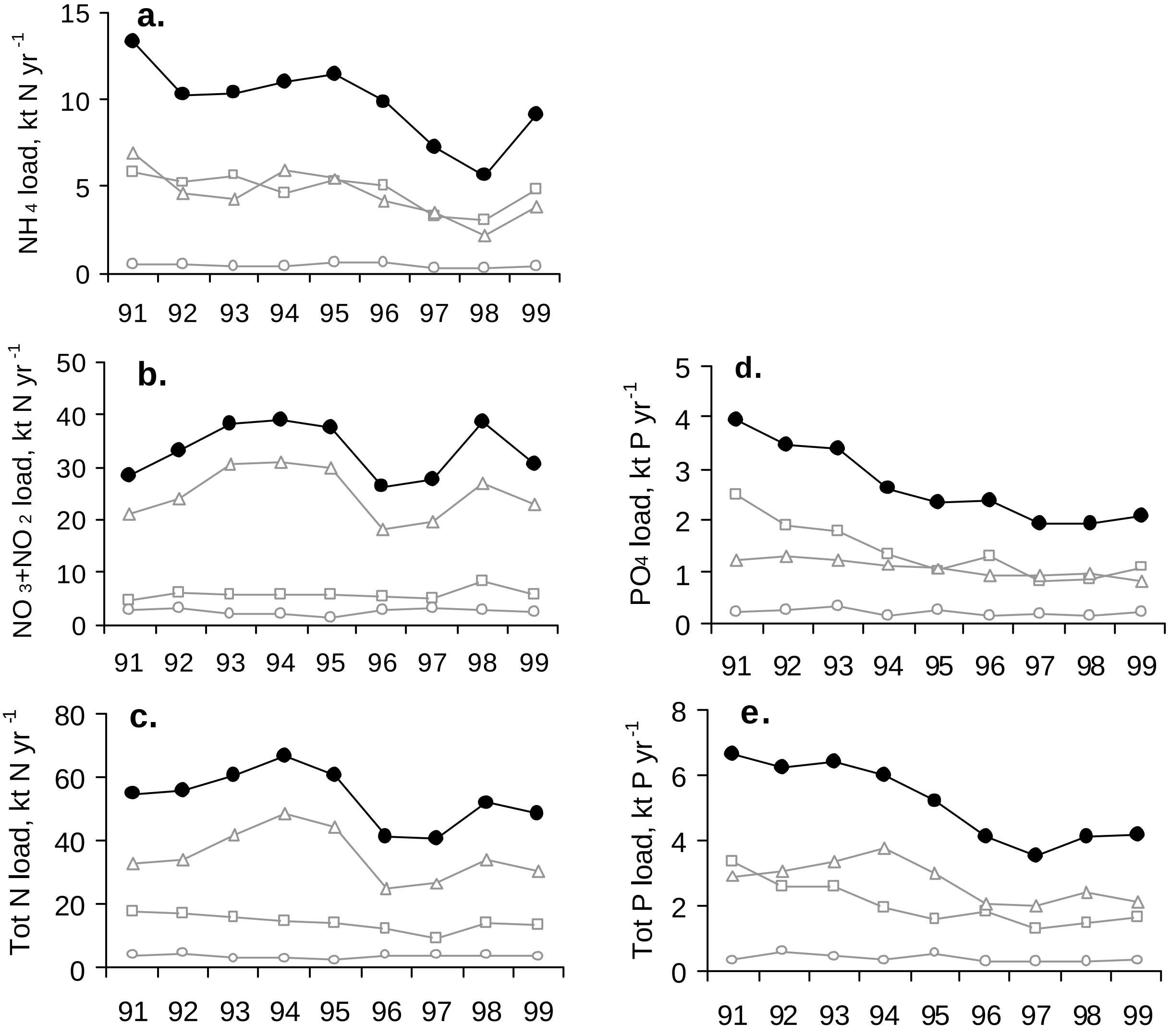

Figure 14: 1991-1999 interannual variability of NH_4 (a); NO_3+NO_2 (b); Tot N (c); PO_4 (d) and Tot P (e) loads calculated for the BCZ (?), Scheldt (?), Yser (?) and Coast (?) watersheds.

The trends observed in the N and P loads from the BCZ watershed mainly reflect those of the Scheldt and coastal tributaries, the Yser being a minor source of nutrients (Fig. 14a-e). The Scheldt remains the major source of NO_3+NO_2 and Tot N delivered to BCZ over the 1991-1999 period (Fig. 14b, c). On the contrary, the observed decrease of PO_4 loads (Fig. 14d) mainly results from the significant PO_4 decrease in the Coast watershed (Fig. 14e).

Trends in Scheldt loads for the period 1966-1999

The combination of different data sets provides a much longer time-serie of nutrient loads for the Scheldt that traces back to 1966. Figure 15 compares the results obtained from the different nutrient data sources (IHE, VMM, RIKZ). A reasonable agreement between data sets is observed except for the 1974-1984 data set of Tot N and Tot P (Fig. 15).

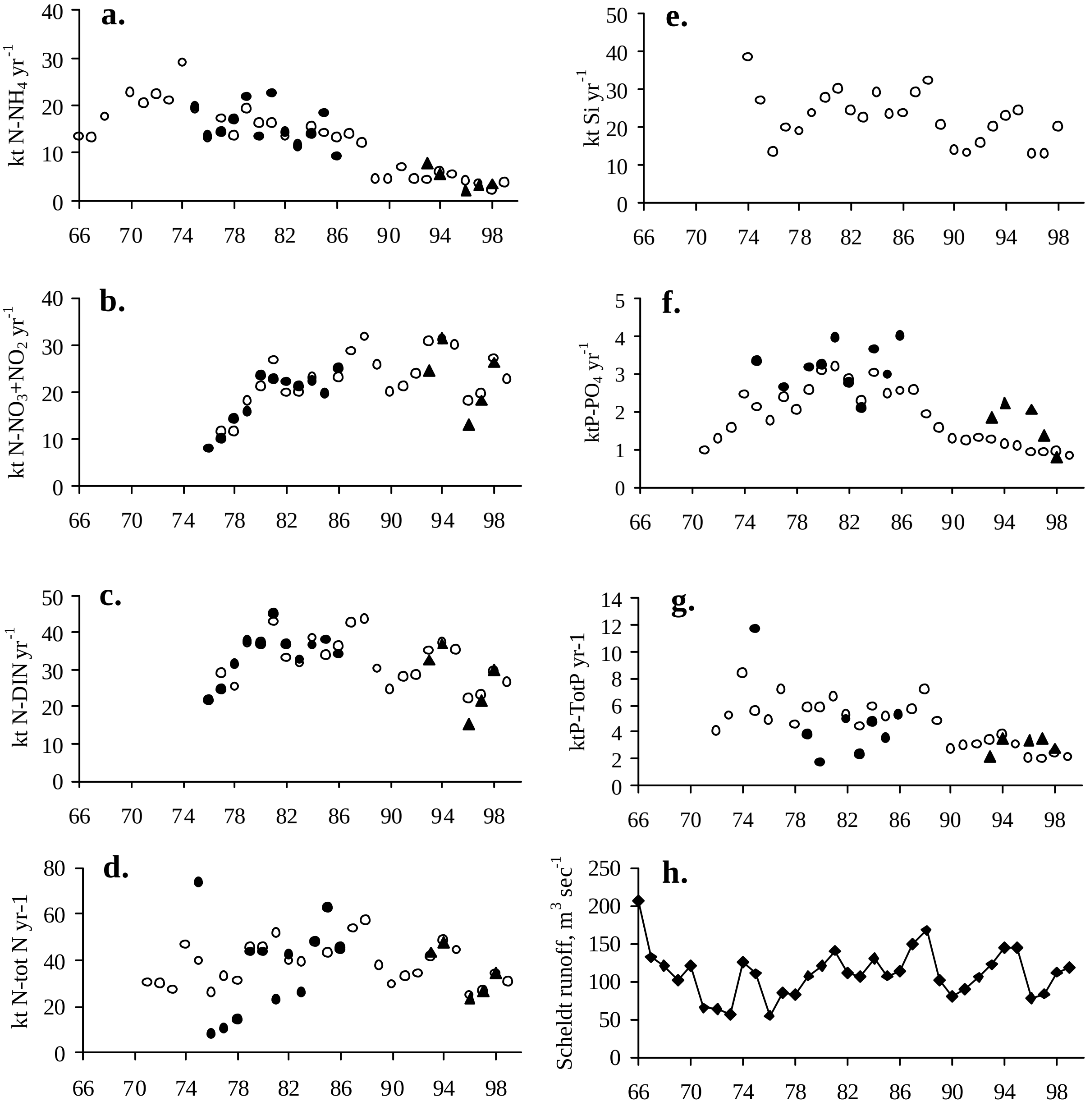

Figure 15: Interannual variations between 1966 and 1999 of Scheldt loads of NH_4 (a); NO_3+NO_2 (b); DIN (c); Tot N (d); DSi (e); PO_4 (f) ; Tot P (g) and mean yearly runoff (h). Loads were calculated from IHE (●), VMM (▲) and RIKZ (○) data.

Trends in Scheldt nutrient loads were analysed from the only RIKZ data set as the latter covers the whole 1966-1999 period. N, P and Si loads show marked variations during this period with however different timing. After a two-fold increase between 1966 and 1970, NH_4 loads decrease linearly by some 91% (n= 29; r^2= 0.85; p< 0.001) over the 1972-1999 period, reaching a minimum of 2.23 kt N in 1998 (Fig. 15a). On the other hand, a three-fold increase of NO_3+NO_2 loads is observed between the mid-70's and the early 80's (Fig. 15b). Thereafter, NO_3+NO_2 loads display some random fluctuation around 20 kt N yr^{-1} without clear trend (Fig. 15b). As a result of the NH_4 and NO_3+NO_2 variations, DIN loads increase up to the early 80's before slightly diminishing from 1982 up to 1999 (Fig. 15c). The 1975-1980 increase reflects that of NO_3+NO_2 while the decrease in the late 80's is driven by NH_4 over the 1976-1999 period, the contribution of NO_3+NO_2 and NH_4 to DIN loads is completely reversed with NH_4 representing 60% in 1976 but less than 14% in 1999. Tot N does not exhibit clear long-term change over the 1972-1999 period (Fig. 15d).

A four-fold increase of yearly PO_4 loads occurs between 1966 and 1981 when a maximum of 3.21 kt P is reached before gradually decreasing by 77% (n= 17; r^2= 0.86; p< 0.001) up to 1999 (fig. 15f). Over 10 years, PO_4 loads drop to levels prevailing in the early seventies, i.e. 0.8 kt P yr^{-1}. Such a decrease is reflected in Tot P loads which drop by some 65% (n= 27; r^2= 0.63; p< 0.001) between 1974 and 1999 (Fig. 15g). Although fluctuating largely, annual loads of DSi globally decrease by some 43% (n= 25; r^2= 0.4; p< 0.001) between 1978 and 1999 (Fig. 15e).

Nutrient loads are determined by fluctuations of both concentrations and hydrological conditions (i.e. runoff). As suggested by comparison between figures 15b, 15e and 15h, Scheldt runoff (Fig. 15h) modulates the shorter time scale variations of both NO_3+NO_2 (p<0.01; Fig. 15b) and DSi (p<0.01; Fig. 15e) loads. This is supported by the highly significant relationships existing between both daily loads of NO_3+NO_2 (Fig. 16a), DSi (Fig. 16b) and Scheldt runoff. This is due to the predominantly diffuse origin of these nutrients.

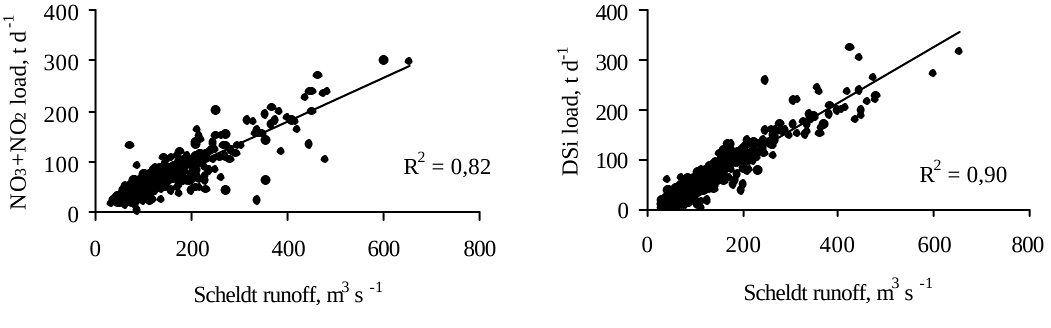

Figure 16: Relationships between daily loads of NO_3+NO_2 (a) and DSi (b) and Scheldt runoff for the period 1966-1999.

Changes of Scheldt loads are substantially modifying the balance of riverine nutrients discharged to the BCZ. Figure 17 shows fluctuations of ratios between dissolved inorganic nutrients for the two last decades. The key period for major shifts is the late eighties. Up to that time, the molar DIN:PO_4 is superior to the Redfield's value of 16 and remains around a value of 30. From the late 80's, it increases by more than a factor 2, stressing dramatically the excess of N over P (Fig. 17a). This shift is caused by a stronger reduction of PO_4 loads relatively to that of NH_4 (Fig. 17). Compared to the N:Si stoechiometry of diatoms, N largely exceeds Si (DIN:DSi ~ 3) from the mid-70's. This excess is exacerbated in the 1990's although slightly relieved during the last years (Fig. 17b). Molar ratios of DSi:PO_4 present value close to 10 from mid-70's up to mid-80's, lower than the diatom Si:P (i.e. 16) indicating a deficit of DSi for diatom growth. This situation shifts in the late eighties when DSi:PO_4 ratios increase up to 25 indicating at that time a potential PO_4 limitation for diatom growth (Fig. 17c).

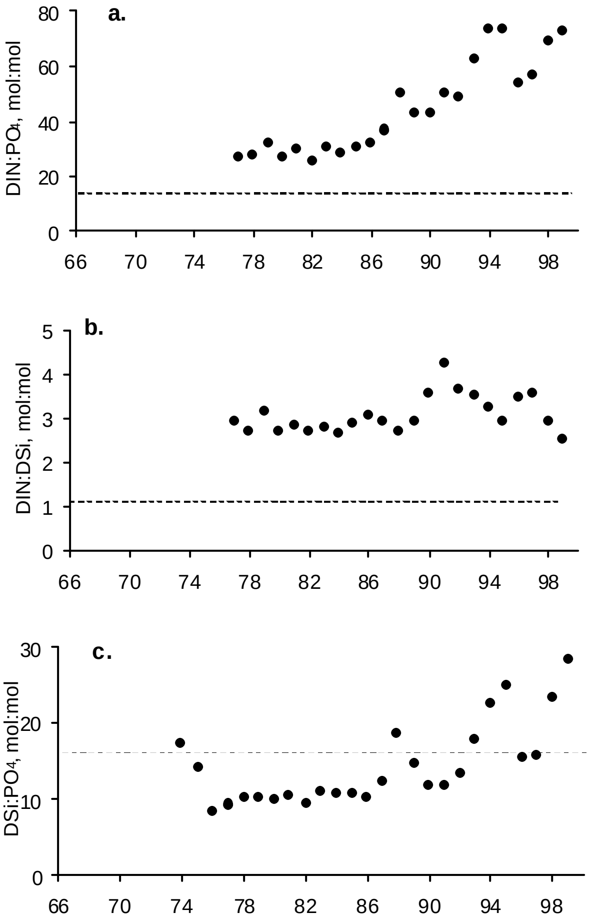

Figure 17: Interannual variations (1972-1999) of Scheldt load molar ratios DIN:PO_4 (a); DIN:DSi (b); Si:PO_4 (c) compared to phytoplankton N:P (Redfield *et al.*, 1963) and diatom N:Si and Si:P (Brzezinski, 1985) stoechiometry (hatched lines).

Discussion

Long-term trends of N and P loads integrate changes in both nutrient emissions and biogeochemical transformations within the river system. These are discussed in this section with particular attention paid to the data series of the Scheldt watershed. The global increase of Scheldt N loads which reached their maximum in the eighties (Fig. 15) was caused by the intensification of urbanisation, industrialisation and agricultural practices with large-scale use of fertilizers and intensive cattle-farming (Billen *et al.*, 2001; 2003). During the sixties, the increase of NH_4 loads resulted from higher urban population and rate of sewage collection with however very few waste water treatment (Billen *et al.*, 2003). Billen *et al.* (1985) estimated that, in the late seventies, some 31% of the total N discharged into the river system ultimately reached the sea. This contrasts with our current estimation suggesting that about 74% of N emissions in the Scheldt watershed is delivered to sea (section 4.1.2.1). The net improvement of the oxygenation of the Scheldt tributaries and estuary due to the implementation in the mid-seventies of secondary waste water treatment, decreased the importance of denitrification but also enhanced nitrification (Billen *et al.*, 1985; 1986; Van Damme *et al.*, 1995; Billen *et al.*, 2003).

The considerable decrease of NH_4 Scheldt loads observed from the early seventies up to nowadays (Fig. 15) results therefore from implementation of waste water treatment and intensification of estuarine nitrification (van Damme *et al.*, 1995). The capacity of secondary waste water treatment increased indeed in the Scheldt watershed from 1 to 5 M eqinhab between 1970 and 2000, (Billen *et al.*, 2003). In other respects, the reduction of N emissions from point sources was estimated to 60% between 1985 and 2000 at the scale of the Belgian watershed (Kyramarios, 2001). This reduction mainly results from the industrial sector which decreased its N emissions by some 80% while household emissions were reduced by only 4% (Kyramarios, 2001). These global estimations could explain the low contribution of industry (9%) to N emissions to surface water of the Scheldt (9%) but also Yser (1%) and Coast (6%) watersheds (Fig. 12). On the other hand, the long-term change of NO_3+NO_2 Scheldt loads could be explained by the increasing contribution of diffuse sources to the N loads, *i.e*. from 15-25% in the early 1970’s to 50-65% in the recent years (Billen *et al.*, 2003). This is in good agreement with the significant contribution of agriculture (82%) to N emissions of surface water estimated in the Scheldt watershed (Fig. 12).

The considerable increase of P Scheldt loads observed in the seventies (Fig. 15) was mainly caused by the use of polyphosphate-containing detergents for domestic and industrial purposes, a common practice in most western european countries (Billen *et al.*, 1999; 2001). The marked decrease of P Scheldt loads observed from 1985 up to nowadays (Fig. 15) resulted from the progressive ban of phosphate-containing detergents but also increased wastewater treatment capacity implemented in the early eighties (van Damme *et al.*, 1995; Billen *et al.*, 2001; 2003). Between 1985 and 2000, a 60% decrease of P emissions was recorded in the Belgian watershed, largely driven by reduction of point sources (56% for household; 85% for industry; Kyramarios, 2001). Despite their significant reduction, domestic emissions represent still nowadays the major part of P emissions in the Scheldt but also the Coast watersheds (Fig. 12). Enhanced co-precipitation of PO_4 with Fe(oxy)hydroxydes in the re-oxygenated zone of the Scheldt estuary (Zwolman 1994; Van Damme *et al.*, 1995) could also have contributed to the significant P loads decrease.

The moderate downward trend of DSi Scheldt loads (Fig.15) could be explained by a higher upstream retention of Si due to higher riverine diatom blooms followed by sequestration in the sediments (Van Damme, pers. comm).

4.1.2.2 Atmospheric inputs of nutrients to BCZ

Besides rivers, atmospheric deposition is also contributing to the nutrient enrichment of BCZ. The tropospheric environment of the North Sea and more particularly the Southern North Sea is indeed surrounded by industrialised countries which constitute important sources of atmospheric nutrients, mainly N (Rendell *et al.*, 1993). Atmospheric deposition of P is much more reduced (Stalnacke, 1996) while that of Si has never been assessed.

Our estimation of atmospheric N deposition into BCZ was based on a review of literature data on the North Sea and Southern North Sea (Table VII). These data trace back to the late 1980's-early 1990's and are based on measurements at sea or coastal stations and/or modelling. They consider atmospheric inputs to surface water through dry deposition of gases and aerosol particles and wet deposition. As expected from the inshore-offshore gradient of atmospheric N gas and particle concentrations, specific fluxes are generally lower for the North Sea (0.34-0.65 kt N km^{-2} yr^{-1}) than for the Southern North Sea (0.96-1.04 kt N km^{-2} yr^{-1}).

N atmospheric deposit in BCZ is thus calculated based on the superficy of BCZ and making use of 1 kt N km^{-2} yr^{-1} considered as an average of N deposit for the Southern North Sea in the early nineties (Table VII). This calculation estimates to 3.5 kt N yr^{-1} the atmospheric deposition of N to the BCZ at that period. A specific deposition of 45 kg P km^{-2} yr^{-1} is considered as specific to the continental coastal water of the North Sea (Nelissen and Stefels, 1988). This estimates to 0.091 kt P yr^{-1} the atmospheric input of P to the BCZ.

Atmospheric deposition has a N:P molar ratio of 85, exceeding largely the Redfield's value of 16.

Table VII: Literature review of atmospheric deposition fluxes of N estimated for the North Sea and the Southern North Sea. The Southern North Sea represents the domain between the Straits of Dover and 56°N.

Area	N species	Specific flux t N km^{-2} yr^{-1}	Method	Reference
North Sea	$NH_3 + NH_4^+$	0.270	Model	Van Jaarsveld, 1992
	$NO + NO_2$	0.380		
	Total	0.650		
Southern North Sea	$NH_3 + NH_4^+$	0.369	Measurement	Rendell *et al.*, 1993
	$HNO_3 + NO_3$	0.587		
	DON	0.035		
	Total	0.992		
Southern North Sea	$NO + NO_2 + NH_3 + NH_4^+$	0.957	Measurement	Nelissen & Stefels, 1988
Continental coastal water of the Southern North Sea	$NO + NO_2 + NH_3 + NH_4^+$	1.039	Measurement	Nelissen & Stefels, 1988

4.1.2.3. Transboundary fluxes and nutrient budget in BCZ

Figure 18 presents the annual budget of DIN (Fig. 18a), PO_4 (Fig. 18b) and DSi (Fig. 18c) established at the scale of BCZ and based on riverine, atmospheric and transboundary loads. This budget is drawn up for the year 1992 based on the best available data set. This year is characterized by average meteorological conditions.

Riverine and atmospheric loads are those previously determined in sections 4.1.2.1 and 4.1.2.2. Transboundary nutrient fluxes are those associated to the northeastward water fluxes resulting from the SW-NE residual circulation. Annual inflow of DIN, PO_4 and DSi amounts to 179 kt N yr^{-1} (Fig. 18a), 25 kt P yr^{-1} (Fig. 18b) and 152 kt Si yr^{-1} (Fig. 18c) respectively. Annual outflow represents 235 kt N yr^{-1} for DIN (Fig. 18a), 26 kt P yr^{-1} for PO_4 (Fig. 18b) and 179 kt Si yr^{-1} for DSi (Fig. 18c). These estimations indicate that PO_4 outflow is of the same order of magnitude than inflow. DIN and DSi outflows are respectively 30% and 20% higher than inflows, indicating a net annual export of DIN and DSi.

Molar N:P:Si ratios of winter nutrient in- and out-flow are comparable, indicating an excess of DIN over PO_4 and DSi but excess of PO_4 over DSi compared to phytoplankton and diatom needs (Table VIII). This suggests that the signature of inflowing Atlantic waters is deficient in DSi. These N:P:Si ratios are significantly lower than those of Scheldt winter loads estimated for 1992 (Table VIII).

Table VIII: Winter molar ratios of transboundary and Scheldt nutrient loads to BCZ .

Molar ratio	Inflow	Outflow	Scheldt
DIN:PO_4	26	28	48
DIN:DSi	2.8	2.8	3.6
DSi:PO_4	9	10	13

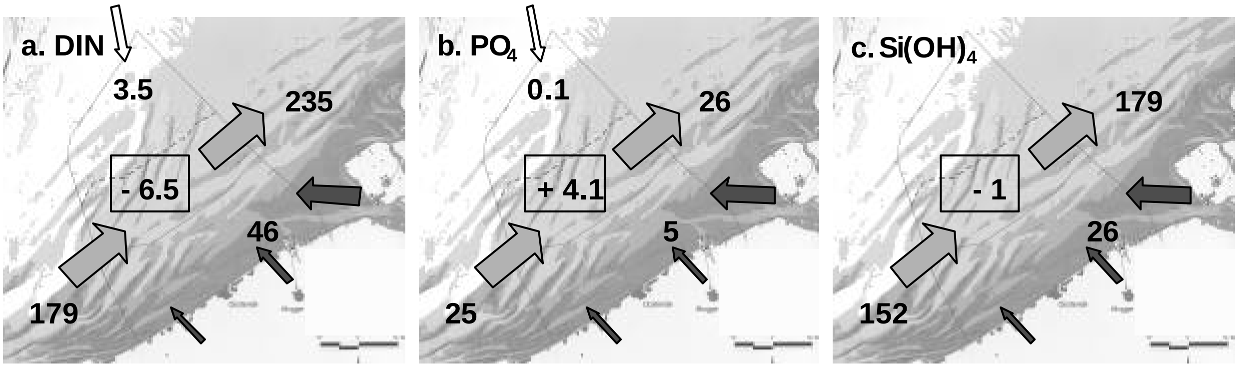

Figure 18: 1992 annual budget of DIN (a); PO_4 (b) and DSi (c) inputs (kt yr^{-1}) established at the scale of BCZ. Arrows represent the riverine (dark grey); transboundary in- and outflows (light grey) and atmospheric (white) loads.

In our budget, nutrient input to BCZ is corresponding to riverine inputs, transboundary inflow and atmospheric deposition. The northeastward nutrient outflow represents the budget outflow (Fig. 18).

Annual nutrient inputs to BCZ in 1992, represent 228.4 kt N yr^{-1} (Fig. 18a) and 30.1 kt P yr^{-1} (Fig. 18b). Data on DSi loads are unfortunately lacking for the Yser and Coast watersheds. We however estimated them based on their N loads and the assumption that their N:Si molar ratio was that of the Scheldt river (i.e. 3.6). In this way, riverine DSi loads are evaluated to 26 kt Si yr^{-1} and the DSi total input to BCZ to 178 kt Si yr^{-1}.

This bugdet suggests that a minor part (3%) of DIN inputs is exported towards adjacent northern areas (Fig. 18a). On the contrary, some 11% of PO_4 inputs are retained in the BCZ, probably in the sediments (Fig. 18b). DSi budget is well equilibrated with only 0.6% of inputs retained in BCZ (Fig. 18c).

This budget shows the major role of transboundary loads which contribute to 80% of DIN, 84% of PO_4 and 91% of DSi. At the scale of BCZ, riverine loads contribute to 20%, 15% and 9% of total DIN, PO_4 and DSi inputs respectively. Atmospheric inputs to BCZ are negligible.

These conclusions are however strongly dependant of the geographical domain chosen for establishing the budget. Drawing such a budget on a coastal fringe would stress the local effect of riverine inputs, principally from the Scheldt who represents by itself some 69% of riverine inputs of NO_3.

4.1.3 Global nutrient enrichment of BCZ

4.1.3.1 Spatial distribution of winter nutrients in BCZ: interannual variability

The nutrient enrichment of BCZ can be determined based on the spatial distribution of nutrients during late winter, i.e. when biological activity is low. However, due to the complex hydrodynamics, the pattern of nutrient distribution displays strong variability.

The high hydrological variability of BCZ is clearly illustrated when comparing the distribution of salinity during winter (end January) 1990 (Fig. 19a) and 1997 (Fig. 19b) characterized by contrasted meteorological conditions. During January 1990, the persistence of strong southwesterly winds induced a large intrusion of Atlantic water into BCZ resulting in high salinity field (>34) on the whole BCZ and a weak extent of the Scheldt plume (Fig. 19a). Conversely, the absence of southwesterly winds during January 1997 allowed a larger spreading of river plume resulting in lower salinity field on BCZ (Fig. 19b).

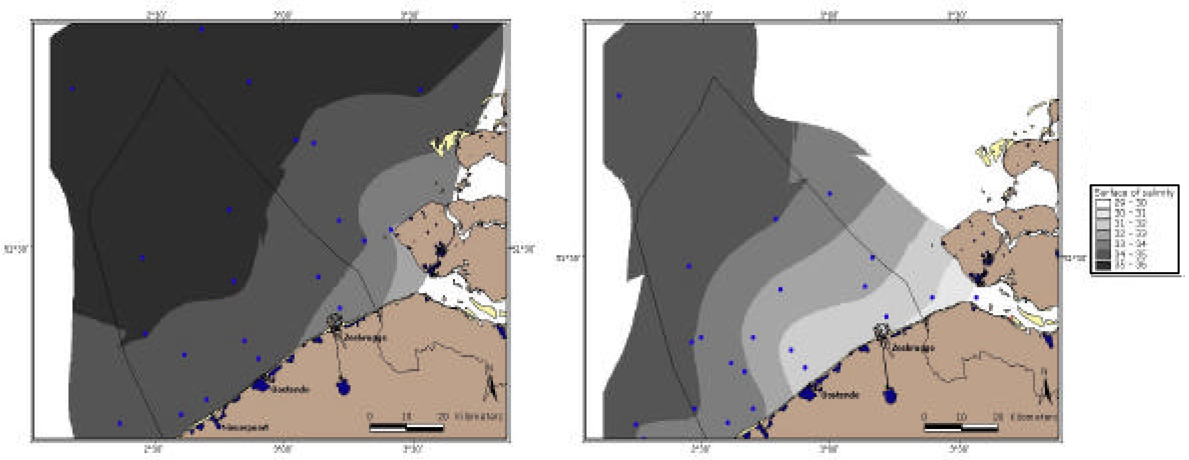

Figure 19 : Spatial distribution of salinity in BCZ during winter (end January) 1990 (a) and 1997 (b).

As a consequence, the global nutrient enrichment of BCZ varies considerably between the two years even though a similar distribution pattern is observed (Fig. 20). All nutrients display indeed a clear gradient from the Scheldt mouth to offshore with higher concentrations close to canal mouths (Fig. 20). These observations show that during late winter the Scheldt could have a major role as nutrient sources in BCZ while Yser and coastal tributary loads have local effects.

A much higher global nutrient enrichment of BCZ is observed during winter 1997 (Fig. 20). At that time, DIN concentrations higher than 60 µM are recorded close to the coast decreasing progressively to the northwest where concentrations between 10 and 20 µM, i.e. higher than the signature of Atlantic waters (8 µM), are still measured (Fig. 20a). On the contrary, DIN concentrations of less than 10 µM prevail over the northern half of BCZ during winter 1990 (Fig. 20a). In 1997, almost half of the southern part of BCZ is characterized by PO_4 concentrations higher than 1.2 µM (Fig. 20b). In 1990, the maximum PO_4 concentrations (1.2-1.5 µM) are recorded locally close to Zeebrugge harbour (Fig. 20c). This contrast also exists for DSi where concentrations higher than 15 µM prevail over half of the BCZ area in 1997 but are enclosed to Scheldt mouth during winter 1990 (Fig. 20c).

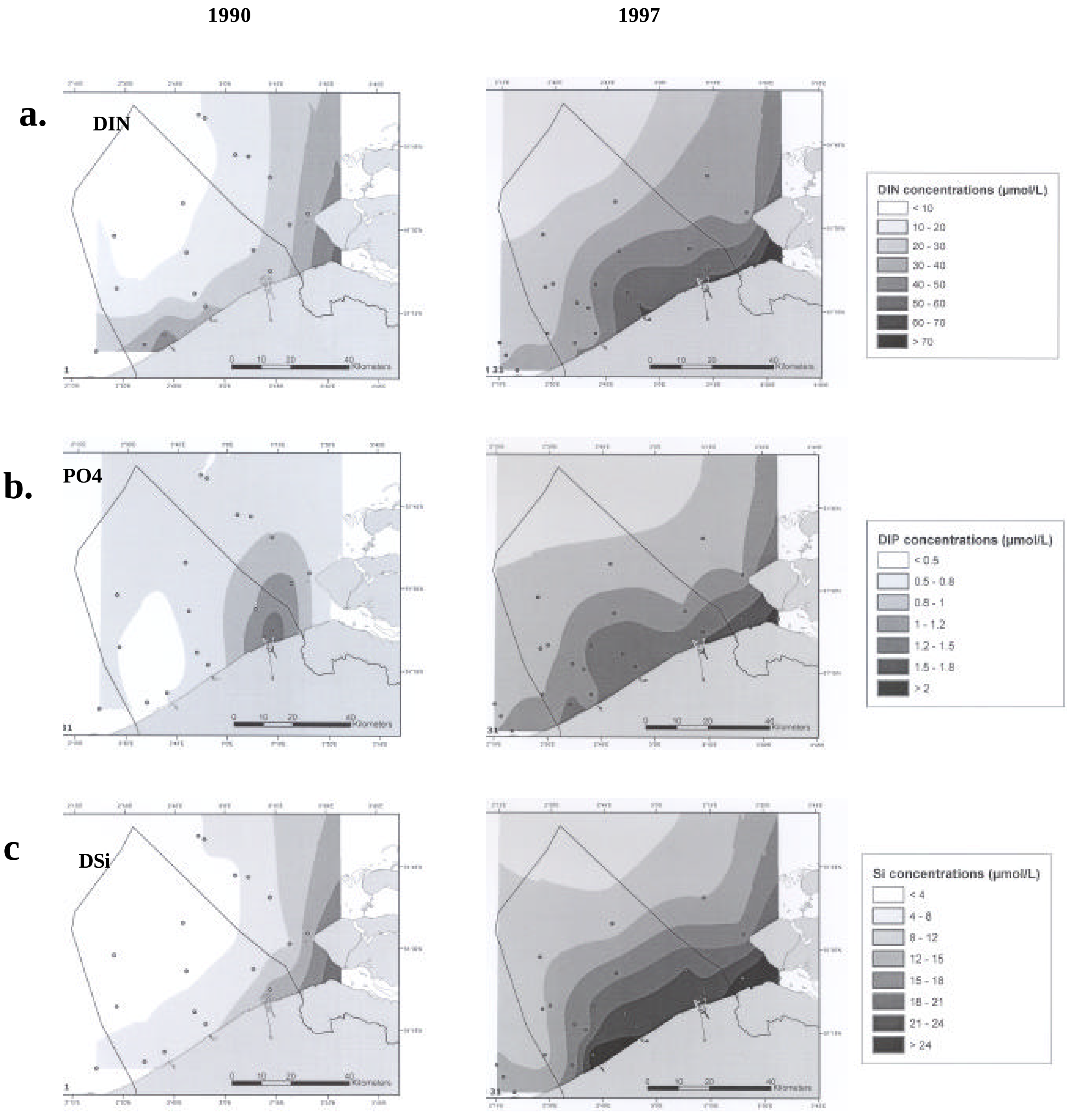

Figure 20: Spatial distribution during winter (end January) of DIN (a); PO_4 (b) and DSi (c) concentrations in 1990 (left panel) and 1997 (right panel) in BCZ.

4.1.3.2 Average enrichment : 1974-2001 interannual variability

The average enrichment of BCZ and its interannual variations were estimated using long-term series data of winter nutrient concentrations and salinity. In order to encompass hydrological variability, we chosen to discuss variability of the average nutrient enrichment determined as nutrient concentration extrapolated at the BCZ long-term average salinity of 33.5 (Rousseau, 2000).

The evolution of the average enrichment of BCZ in NH_4, $NO_3 + NO_2$, DIN, PO_4 and DSi over 1974-2001 is shown in figure 21A. No significant change in DIN concentrations (in average 29 µM) is observed over the period (Fig. 21A). DIN presents however higher concentrations between 1985 and 1993 compared to the 1970’s and mostly reflects the evolution of $NO_3 + NO_2$ which account for ca 90% of N form in BCZ (Fig. 21A). A slight decrease of NH_4 concentrations is recorded. DSi decreased weakly but significantly ($p < 0.05$) (Fig. 21A). Most spectacular is the observed decrease in PO_4 concentrations ($p > 0.005$) from ~2 µM in 1974-1984 to 0.8 µM in 2001 (Fig. 21A).

Interestingly, long-term trends of the global nutrient enrichment of BCZ (Fig. 21-A) reflects the evolution of Scheldt nutrient loads (Fig. 15). This is particularly evident for NH_4 and PO_4 whose decrease recorded at sea corresponds to the marked drop in loads reached during the late eighties in the upper Scheldt estuary (Fig. 15) as a result of wate water treatment policy implemented in the mid-seventies (section 4.1.2.1). PO_4 decrease is however much less pronounced at sea than in the Scheldt estuary where it drops by a factor 7. The role of other P sources such diagenetically remineralised P in such shallow waters or those associated to P-enriched Atlantic in-flowing waters together with the complex biogeochemistry of P could explain the lower P decrease at sea.

The contrasted changes in PO_4 and DIN winter concentrations (Fig. 21A) alter the N:P:Si balance of nutrients. The extent of this change can be appraised on Fig. 21B which compares DIN: PO_4, DIN :DSi and DSi: PO_4 winter molar ratios over the 1974-2001 period with nutrient requirements of coastal phytoplankton (Redfield *et al.*, 1963) and diatoms (Brzezinski, 1985). One major observation is the marked shift of N:P ratios from values closed to Redfield ratio during the 1972-1985 period to N excess conditions after the mid-1980’s. The largest changes are observed during the 1990’s when DIN: PO_4 increased from values around 20 to more than 30.

On the other hand the interannual evolution of DIN:DSi and DSi: PO_4 molar ratios shows that DIN availability largely exceeded the DSi requirement of diatom during the whole period (Fig. 21B). The evolution of DSi: PO_4 ratio clearly indicates diatom DSi limitation during the 1974-2001 period (Fig. 21B). However, since the mid-1990’s the coastal system looks more balanced in terms of DSi and PO_4 availability.

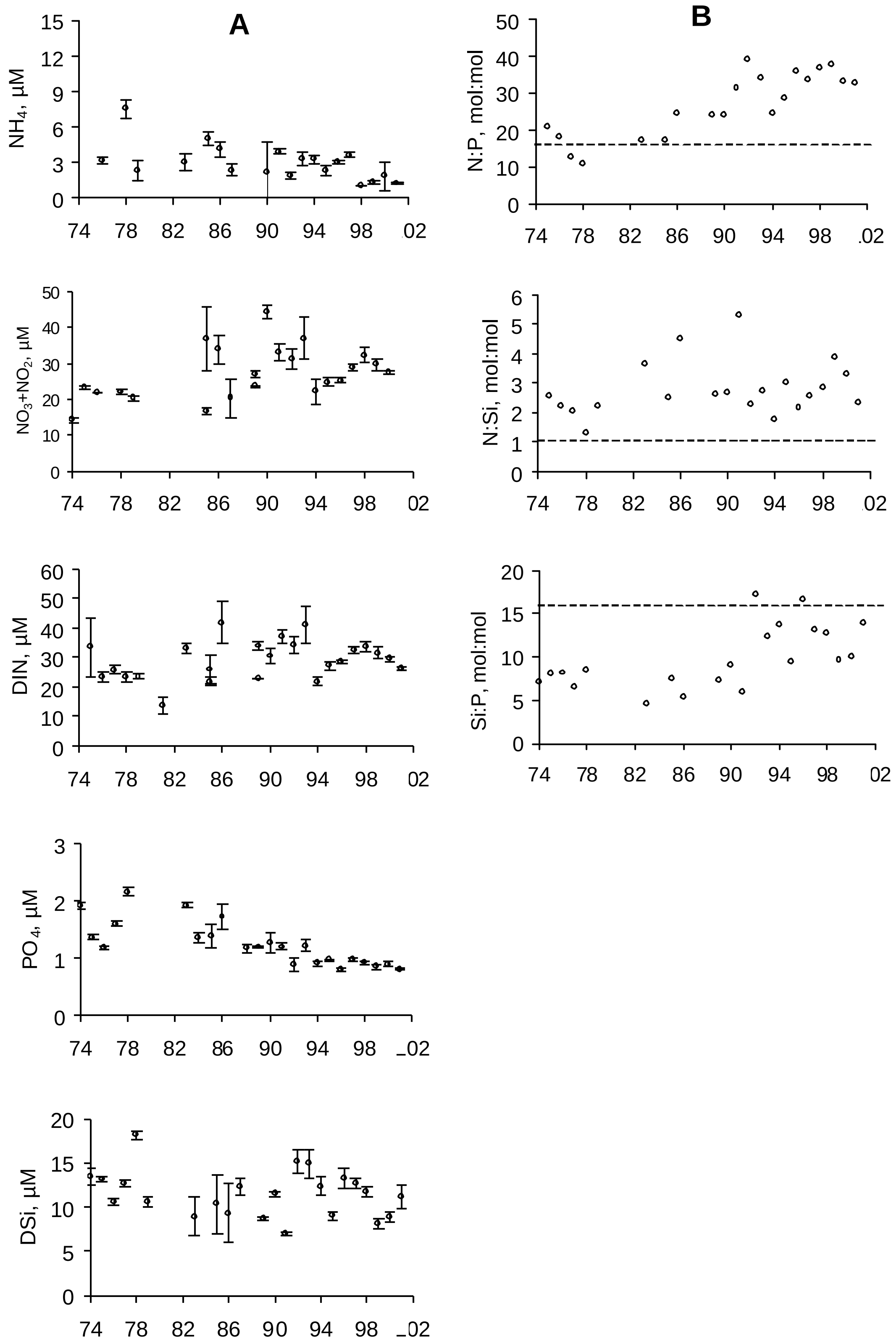

Figure 21: 1974-2001 evolution in BCZ of NH_4, NO_3+NO_2, DIN, PO_4 and DSi average concentrations (Panel A) and DIN:PO_4, DIN:DSi, DSi:PO_4 winter molar ratios (Panel B). Hatched line indicates phytoplankton N:P (Redfield *et al.*, 1963) and diatom N:Si and Si:P (Brzezinski, 1985) stoichiometry.

4.2 Phytoplankton blooms in BCZ

The global nutrient enrichment of BCZ, characterized by a large excess of N (mostly NO_3) over P and Si compared to diatom Si requirements (Bzrezinski, 1985) and P phytoplankton needs (Redfield *et al.*, 1963) affects the magnitude and specific composition of coastal phytoplankton blooms. The seasonal and geographical distributions and interannual variations of Chl a and phytoplankton key species are analysed in this section making use of the current knowledge of eutrophication mechanisms. The study of seasonal and geographical variations focus on those observed in 1999 due to the availability of a complete data set for this year.

4.2.1 Spatio-temporal variability of phytoplankton blooms in BCZ

The distribution of Chl a concentrations during winter (Fig. 22a), spring (Fig. 22b), summer (Fig. 22c) and fall (Fig. 22d) reflects the high spatial and seasonal variations of phytoplankton blooms. The spatial distribution of Chl a concentrations has a similar pattern during the different seasons with higher concentrations close to the coast and progressively decrease offshore (Fig. 22). In coastal areas, the highest Chl a concentrations are recorded in the Southwestern part and close to the Scheldt mouth (Fig. 22).

The highest values are recorded during spring. At the end of April 1999, Chl a concentrations vary from 40-50 mg m^{-3} at the coast to 10 mg m^{-3} in the northern part of BCZ (Fig. 22b). These high levels reflect the occurrence of a *Phaeocystis globosa* bloom but diatoms are also present. In july 1999, Chl a concentrations fluctuate between 5.5 mg m^{-3} at the coast and 1 mg m^{-3} offshore (Fig. 22c). The summer phytoplankton community is dominated by diatoms (*Guinardia* spp., *Rhizosolenia* spp.). During fall (early October), Chl a concentrations ranging from 2 to 4 mg m^{-3} prevail on most of BCZ with values higher than 4 mg m^{-3} in the southwestern coastal part and close to the Scheldt mouth (Fig. 22d). At that time, diatoms dominate the phytoplankton assemblage with small neritic species (*Skeletonema costatum*, *Thalassiosira* spp), some *Chaetoceros* spp. and *Coscinodiscus* spp. In mid February 1999, winter Chla concentration levels vary from 2 to 3.8 mg m^{-3} at the coast to less than 1 mg m^{-3} offshore (Fig. 22a). At that time, low cell densities of small neritic diatom species (*Thalassiosira* spp, *Skeletonema costatum*, *Thalassionema nitzschioides*, *Plagiogramme brockmanii*, *Asterionnellopsis glacialis*) compose the phytoplankton community.

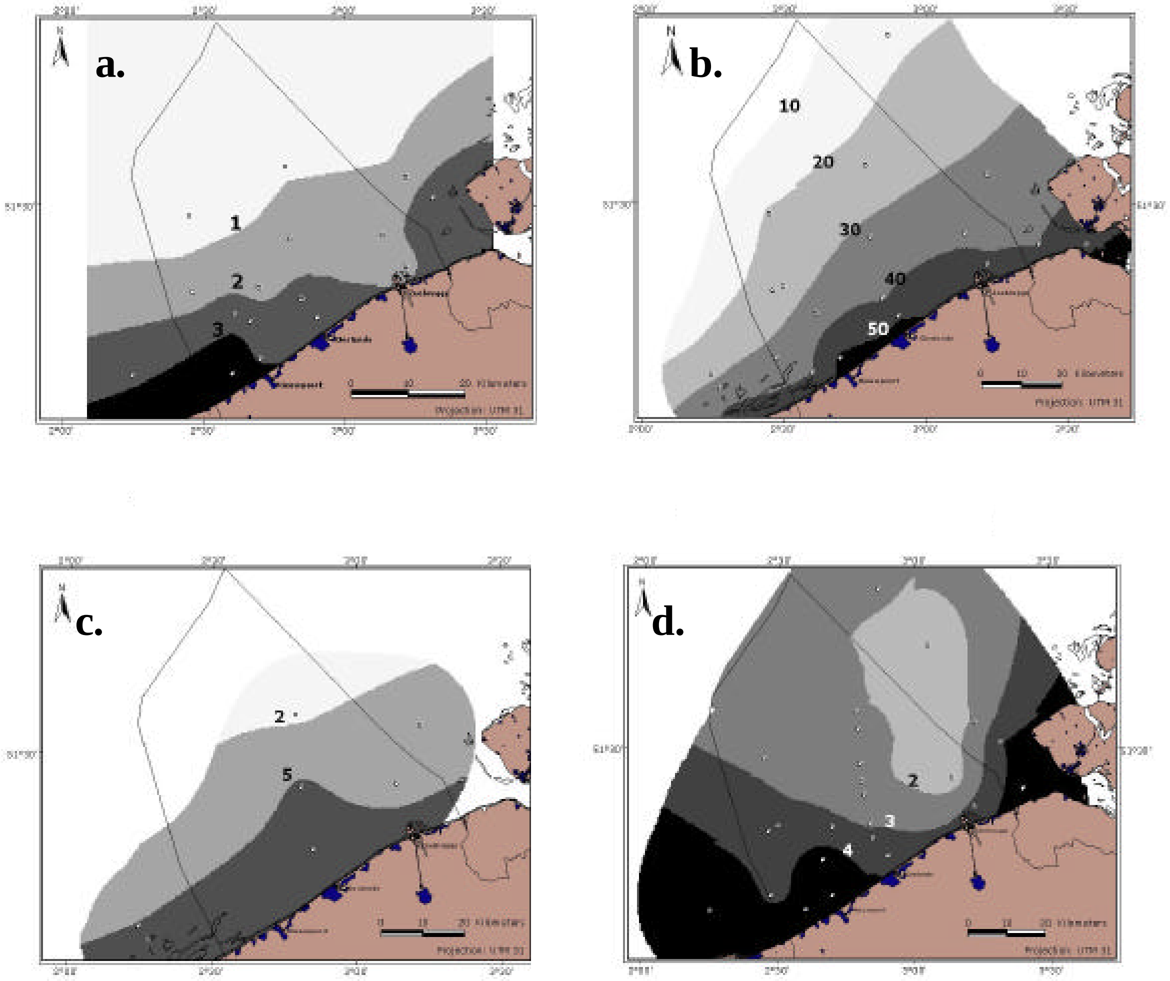

Figure 22: Seasonal and geographical distribution of Chl a concentrations (mg m^{-3}) in BCZ during winter (a), spring (b), summer (c) and fall (d) 1999.

Seasonal changes of phytoplankton blooms in BCZ are better evidenced by the annual cycle of Chl a concentrations at station 330 in the central BCZ in 1999 (Fig. 23). A well pronounced spring outburst with the maximum (23 mg m^{-3}) reached at the end of April is observed after a moderate increase in March. During May, Chl a concentrations suddenly decrease between 2 and 4 mg m^{-3}. In and summer and fall, Chl a concentrations vary to a less extent before reaching the winter level in mid-November at the end of the vegetative season (Fig. 23).

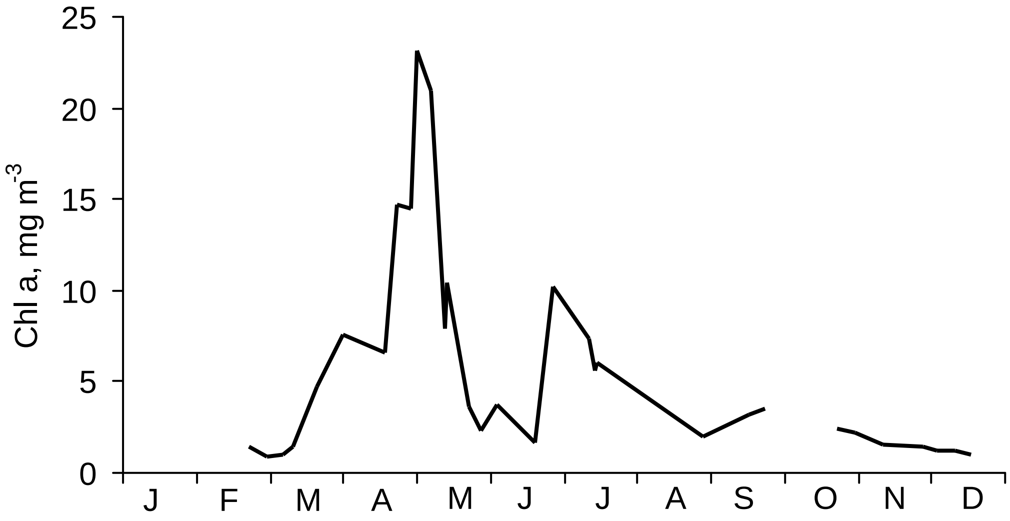

Figure 23: Seasonal changes in 1999 of Chl a concentrations (mg m^{-3}) at station 330 in the central BCZ.

Besides seasonal variations, interannual variability of Chl a levels is significative (Rousseau, 2000). For the 1988-2000 period, maximum spring Chl a concentrations at station 330 vary by a factor 3, ranging between 14 mg m^{-3} in 1992 and 45 mg m^{-3} in 1993 and 1994. Maximum Chl a concentrations vary between 10 and 16 mg m^{-3} in summer and between 1.7 and 6 mg m^{-3} in fall. Winter levels fluctuate between 0.9 and 2.1 mg m^{-3}.

The ephemeral nature of phytoplankton blooms, their significant year-to-year and seasonal variability stress the need, to properly assess their magnitude and extent, for sufficient geographical and temporal coverage of the area, in particular during spring.

4.2.2 Spring blooms in BCZ

The elevated Chl a concentrations observed in spring result from the accumulation of the non-siliceous haptophyte *Phaeocystis globosa*. These blooms are reported as the eutrophication-related event in BCZ and more generally in the eastern part of the Southern Bight of the North Sea (Lancelot *et al.*, 1987; Cadée and Hegeman, 1991). *Phaeocystis* has a complex life cycle alternating nanoplanktonic cells and colonies (Rousseau *et al.*, 1994) but blooms almost exclusively under its colonial stage. At the stationary phase of the blooms, the colonies are composed of thousands of cells embedded in a mucilaginous matrix (Fig. 24) and are largely resistant to grazing by indigenous copepods (Gasparini *et al.*, 2000).

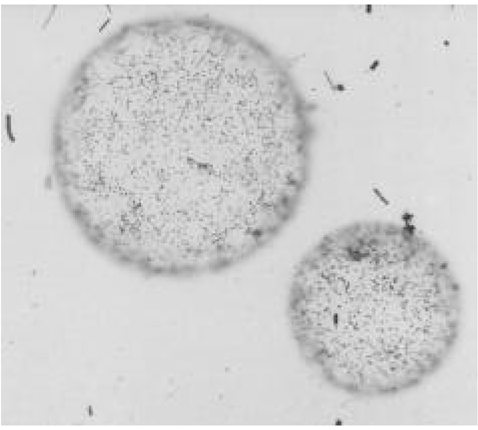

Figure 24: Eutrophication-related event in BCZ: spring blooms of the colonial Haptophyte *Phaeocystis globosa*

4.2.2.1 The 1999 spring succession in BCZ

The phytoplankton spring event of 1999 and related nutrient dynamics in the central BCZ is illustrated on figure 25. In early March, diatoms initiate the phytoplankton succession and reach a maximum of 250 10^3 cells l^{-1} some 3 weeks later (Fig. 25a). At this time, *Phaeocystis* colony bloom starts and reaches its maximum (25 10^6 cells l^{-1}) at the end of April. During the first half of May, *Phaeocystis* suddenly declines and disappears completely from the water column while *Guinardia* spp. and *Rhizosolenia* spp are still persisting. The diatom outburst is composed of a succession of 3 communities dominated respectively by small colony-forming species (*Thalassiosira* spp, *Skeletonema costatum*, *Thalassionema nitzschioides*, *Asterionellopsis glacialis*), by *Chaetoceros* spp. (mainly *C. socialis*) and by *Guinardia* spp. (mainly *G. delicatula*) and *Rhizosolenia shrubsolei*. The latter assemblage co-occurs with *Phaeocystis* colonies.

Seasonal changes of nutrients indicate that the growth of the early spring diatom community is controlled by DSi availability (Fig. 25a, b). DSi concentrations are indeed at their minimum levels (3 µM) after their growth while some 15 µM of NO_3 and 0.4 µM PO_4 are still available for *Phaeocystis* and the *Guinardia*-dominated assemblage (Fig. 25b). During *Phaeocystis* bloom, PO_4 concentrations are at their lowest levels (Fig. 25c) but dramatically increase up to 1.7 µM at the wane of *Phaeocystis* bloom (Fig. 25a, c), probably due to intensive remineralisation processes.

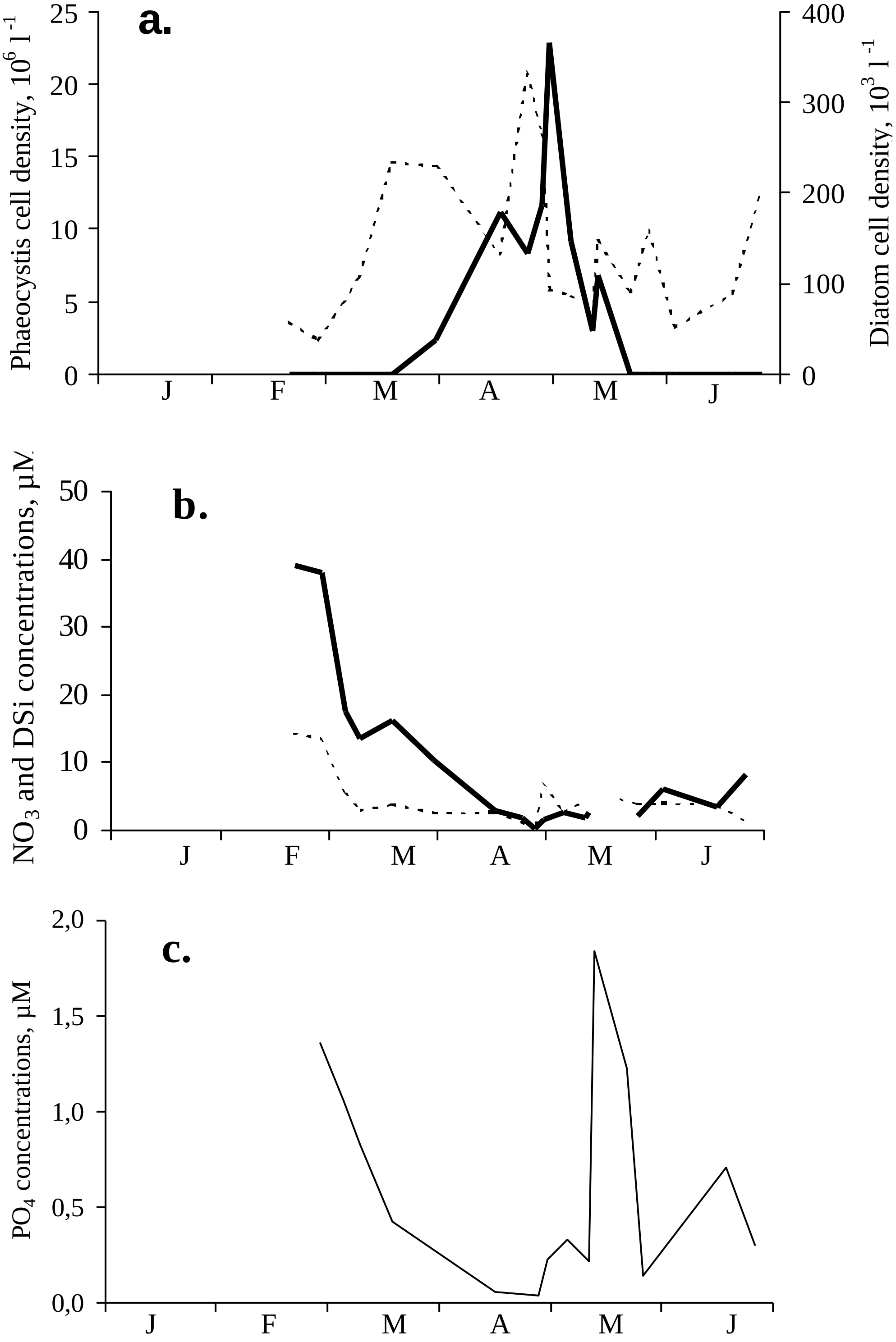

Figure 25 : Seasonal changes of (a) diatom (dotted line) and *Phaeocystis* cell density (bold line), (b) DSi (dotted line) and NO_3 (bold line) and (c) PO_4 concentrations during spring 1999 at station 330 in the central BCZ.

4.2.2.2 Geographical extent of *Phaeocystis* blooms in BCZ in 1999

The geographical distribution of *Phaeocystis* (Fig. 26a) and diatoms (Fig. 26b) cell densities at the end of April 1999, indicate the two taxa are blooming in the whole area with however significant variations in their respective extent and magnitude. The onset of *Phaeocystis* blooms is synchronous in the whole area (not shown). During spring 1999, *Phaeocystis* colonial cell densities show a clear in-off shore gradient varying from 40-50 10^6 cells l^{-1} in the coastal area off Nieuwpoort and Ostende to less than 10 10^6 cells l^{-1} offshore (Fig. 26a). *Phaeocystis* cell densities are lower (20 10^6 cells l^{1}) close to the Scheldt mouth (Fig. 26a) possibly due to light limitation. On the contrary, diatoms are more numerous close to the Scheldt mouth and present a clear Scheldt–offshore gradient with cell densities higher than 400 10^3 cells l^{1} close to the Scheldt and less than 100 10^3 cells l^{-1} in the northwestern part of BCZ (Fig. 26b). The diatom species distribution is quite homogeneous in the whole area being largely dominated by *Guinardia delicatula* (87% in average) and to a least extent by *Rhizosolenia shrubsolei* (10% in average). Close to the Scheldt mouth however, *Eucampia zoodiacus* contributes to 15-30% of the diatom cell number.

Using the experimentally determined factor of 0.5 pg Chl *a* cell^{-1} (Rousseau *et al.*, 1990), the contribution of *Phaeocystis* cells to the bulk Chl a (Fig. 22) is estimated to 60% in average for BCZ. This contribution however increases to 85% close to the coast and represent 36-56% offshore.

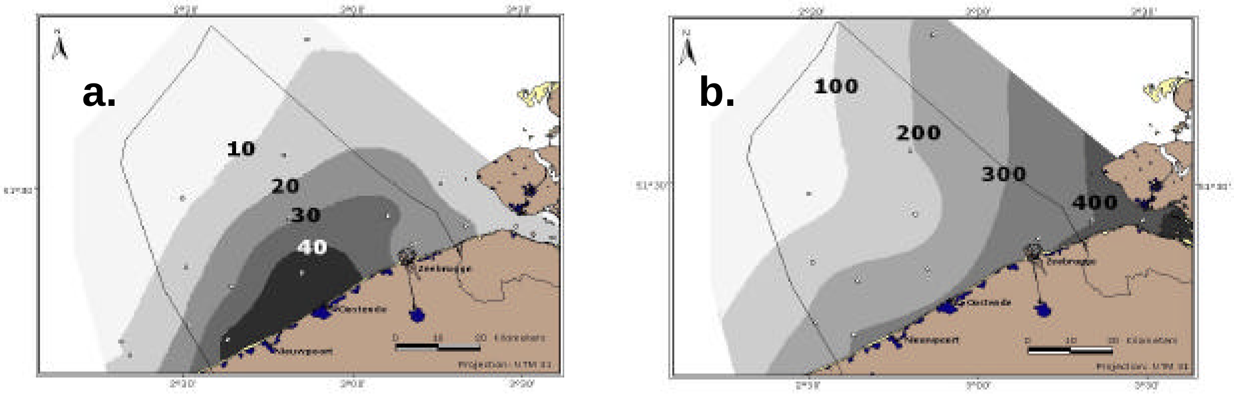

Figure 26: Geographical distribution of cell density of *Phaeocystis* (a; 10^6 cells l^{1}) and diatoms (b; 10^3 cells l^{-1}) in BCZ for the period 26-30 April 1999.

The salinity distribution at the end of April 1999 is illustrated on figure 27 which shows a progressive decrease from 30 close to the Scheldt mouth to more than 35.3 in the northwestern part of BCZ. Clearly, the diatom distribution is associated to this salinity gradient with the highest cell densities at lowest salinities (Fig. 26b, 27). *Phaeocystis* maximum cell densities are associated to salinity 30-33 while occurring at lower cell density (Fig. 26a) at highest salinity (Fig. 27).

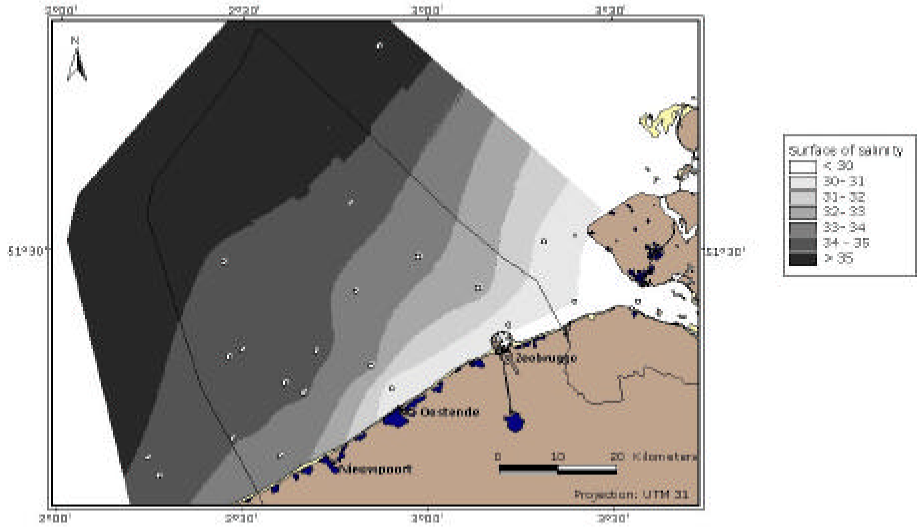

Fig. 27: Salinity distribution in BCZ from 26-30 April 1999 at the time of Phaeocystis maximum cell density.

No direct link is evidenced between the nutrient winter enrichment of BCZ and the magnitude of *Phaeocystis* blooms. Except in the Scheldt mouth area, a good correspondance is however observed between the spatial distribution of *Phaeocystis* cell densities (Fig. 26a) and that of NO_3 excess at the end of the early spring silicate-limited diatom growth (Fig. 28). The NO_3 excess was calculated from the 1999 winter concentrations of NO_3 and DSi using a diatom C:N:P and Si:C molar ratio of respectively 103:16:1 (Redfield *et al.*, 1963) and 0.26. The latter value was calculated from a compilation of existing Si stoichiometry for the dominant early spring diatom species in the area (Rousseau *et al.*, 2002). On this basis the early spring diatom Si:N is estimated to 1.72. The NO_3 excess was therefore calculated according to the following equation:

$$NO_{3\,excess} = NO_{3\,winter} - \frac{DSi_{winter}}{1.72}$$

where $NO_{3\,excess}$ is the excess NO_3 after the early spring diatom

$NO_{3\,winter}$ is the NO_3 concentration during winter

DSi_{winter} is the DSi concentration during winter

According to this calculation, the maximum *Phaeocystis* cell densities (40-50 10^6 cells l^{-1}; Fig. 26a) occurs when the NO_3 excess is the highest (>50 µM; Fig. 28). Reversely, the lowest *Phaeocystis* cell densities (10 10^6 cells l^{-1}, Fig. 26a) are associated to a NO_3 excess lower than 15 µM (Fig. 28). In the central BCZ, cell density of 20-30 10^6 cells l^{-1} (Fig. 26a) corresponds to intermediate NO_3 excess (Fig. 28). The lower *Phaeocystis* but higher diatom cell densities observed in the area of the Schedlt mouth (Fig. 26) indicate that diatoms would be more competitive to use the excess nutrients in the more turbid waters of BCZ.

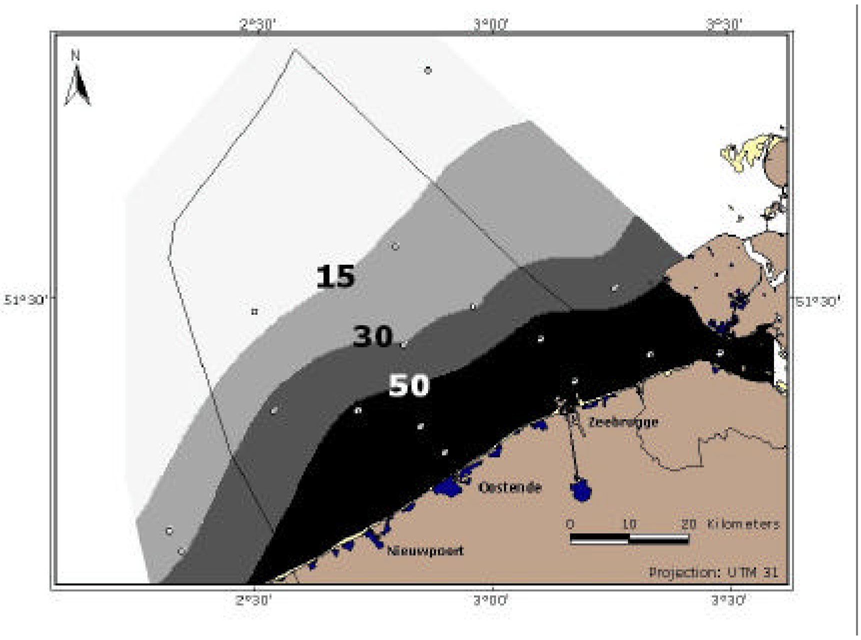

Figure 28: Distribution of nitrate excess (µM) calculated on basis of winter NO3 and DSi concentrations (µM) and diatoms stoechiometry (see text).

4.2.2.3 Interannual variations of *Phaeocystis* blooms in the central BCZ

Long term time series (1988-2000) of phytoplankton data at one station in the central BCZ (station 330) show that the diatom/*Phaeocystis* spring succession is recurrent (Rousseau, 2000). Diatoms initiate the spring bloom succession and are present throughout the spring period. A significant interannual variability is however observed in the timing and duration of phytoplankton spring blooms (Fig. 29). A one and a half month shift is observed in the onset of the diatom spring bloom which occurs between mid-February and early April but the more frequently in the first half of March (Fig. 29). The onset of the spring succession occurs when a light threshold of 12 µmol m^{-2} s^{-1} is reached in average in the water column. This threshold is reached between mid-February and early-April and is determined by the load of suspended matter in BCZ (Rousseau, 2000). *Phaeocystis* colony blooms start between early-March as in 1997 and the end of April as in 1988 (Fig. 29). Their duration varies from a factor 3 with a minimum of 28 days in 1988 and a maximum of 75 days in 1991 (Fig. 29).

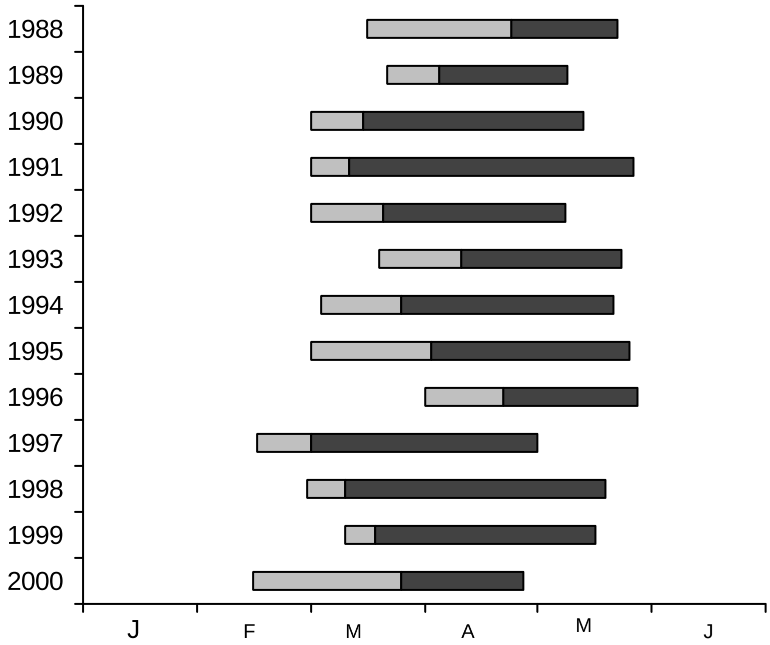

Figure 29 : Year-to-year variability of timing and duration of spring diatoms (light grey) and *Phaeocystis* (dark grey) blooms in the 1988-2000 in the cenral BCZ.

The magnitude of *Phaeocystis* colony and diatom spring blooms also display significant interannual variability. Time series data (1988-2000) in the central BCZ show that both diatom and *Phaeocystis* maximum cell density reached during the spring bloom are highly variable (Fig. 30). The maximum *Phaeocystis* colonial cell density varies from 7 10^6 cells l^{-1} in 1996 to 60 10^6 cells l^{-1} in 1993 (Fig. 30). Diatoms are particularly predominant in 1994 with a maximum cell density of 1721 10^3 cells l^{-1} while the lowest value (18 10^3 cells l^{-1}) was recorded in 1997 (Fig. 30). No long-term trend could be detected during the 1988-2000 period. The relative importance of the 2 taxa would be linked to the variability of hydrological conditions with higher diatom occurrence related to higher intrusion of Southwesterly Atlantic waters (Breton *et al.*, in preparation).

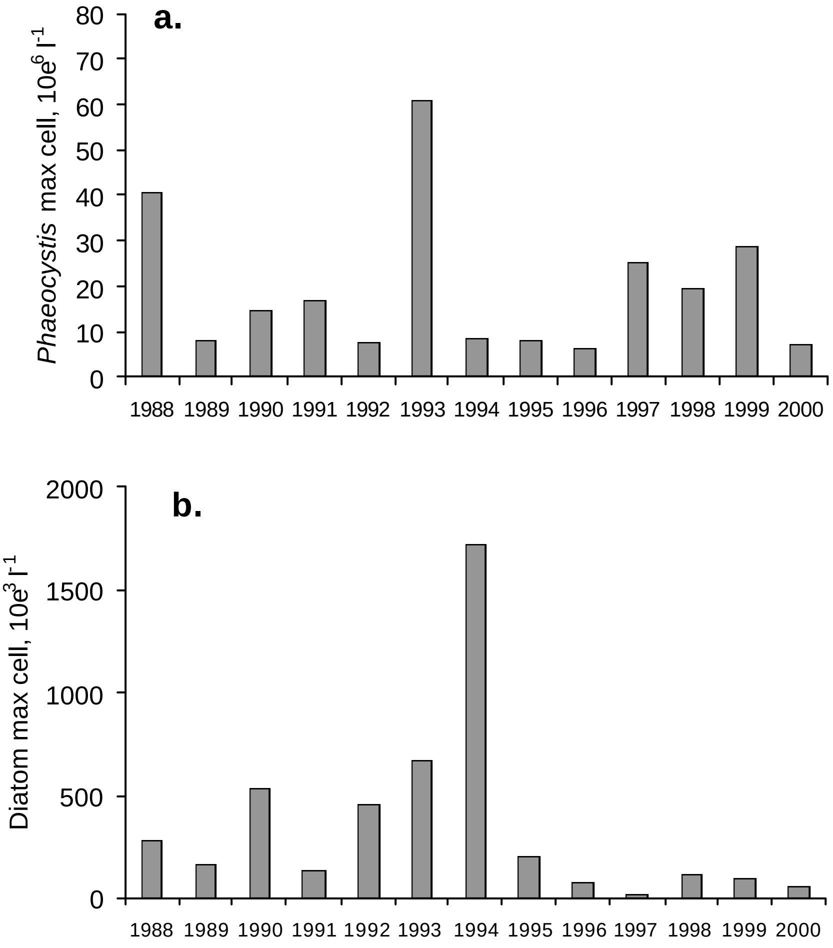

Fig. 30: Year-to-year variability of the *Phaeocystis* and diatom maximum cell density reached during the spring blooms during the 1988-2000 period.

The interannual variability of the magnitude of *Phaeocystis* colony blooms has been related to the availability of NO_3 at their onset. A relationship exists indeed between the maximum *Phaeocystis* cell density reached during the bloom and the NO_3 excess observed at the end of the early spring silicate-limited diatom (Fig. 31; Lancelot, 1995; Lancelot *et al.*, 1998). This relationship has been established from field data in the central BCZ, French and Dutch coastal water. In this latter area, cell densities as high as 150 10^6 cells l^{-1} are related to NO_3 excess of 75 µM (Fig. 31)

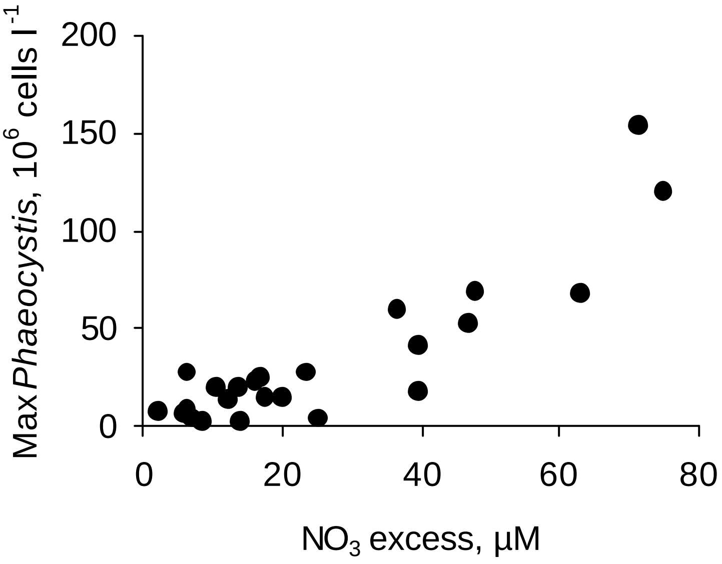

Figure 31: Relationship observed between the maximum *Phaeocystis* cell density and NO_3 in field conditions in Belgian, French and Dutch coastal water (Southern Bight of the North Sea).

While *Phaeocystis* blooms are sustained by NO_3, PO_4 availability seems to play a key role in their control. Seasonal changes of phytoplankton and nutrients in the central BCZ show indeed that very few PO_4 is available during the bloom and suggest a possible limitation by this nutrient (Fig. 25c). The PO_4 limitation of *Phaeocystis* bloom magnitude is indirectly evidenced by comparing the relationship between *Phaeocystis* maximum cell densities and NO_3 excess in the field and in P sufficient cultures (Fig 32). *Phaeocystis* cell densities reached in non-limited P conditions are clearly higher than the maximum denity recorded in the field. Interestingly, the asymptotical trend observed in both field and cultures suggests that the maximum carrying capacity would be 200 10^6 cells l^{-1}. That would correspond to Chl *a* concentration of 100 mg m^{-3} using the factor of 0.5 pg Chl *a* $cell^{-1}$ (Rousseau *et al.*, 1990).

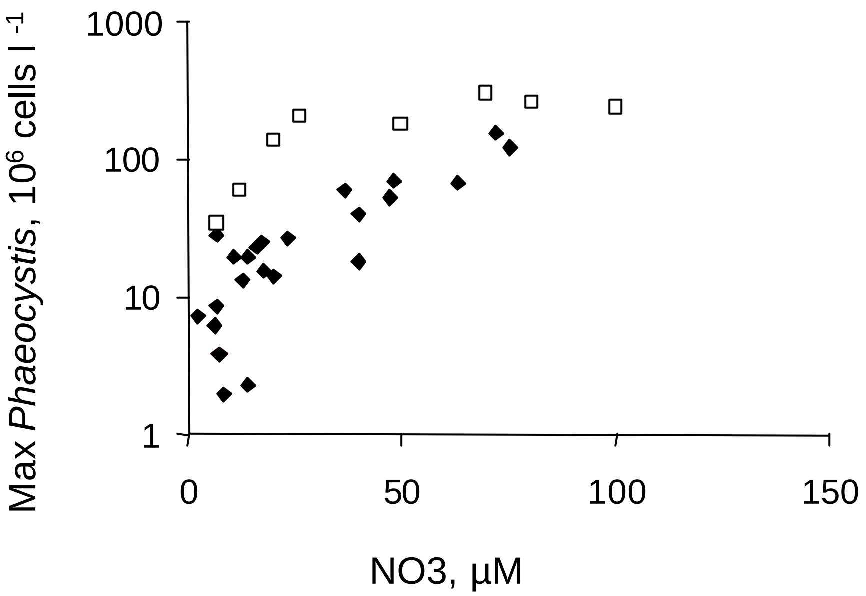

Figure 32: Relationship observed between the maximum *Phaeocystis* cell density and NO_3 in field conditions (◆) and P sufficient cultures (□). Field data from the Southern Bight of the North Sea.

Paradoxally the 50% reduction of PO_4 enrichment of the BCZ during the 1988-2000 (Fig. 21) did not impact on the magnitude of *Phaeocystis* blooms which do not display decreasing trend during this period (Fig. 29). This is explained by the capacity of *Phaeocystis* to grow on regenerated P, particularly that from early spring diatom-derived organic matter. The ability of *Phaeocystis* cells to hydrolyze organically bound P under low PO_4 concentrations has indeed been demonstrated (Veldhuis *et al.*, 1987; van Boekel and Veldhuis, 1990; van Boekel, 1991).

4.3 Adverse effects of *Phaeocystis* blooms and their qualitative perception

4.3.1 Impact of *Phaeocystis* blooms

Most of adverse effect of *Phaeocystis* colony blooms in BCZ are mainly reported as deposit of thick layers of odorous foam on the beaches (Fig. 33) and as clogging of fishing nets as consequences of the accumulation of ungrazed gelatinous colonies in the water column. Reports of this damage are however mostly anecdotal (Grossel, 1985) and the socio-economical loss for tourism and fishing industry of this region is not yet established. Most of *Phaeocystis*-derived organic matter is remineralized in the water column by intense bacterial activity (Rousseau *et al.*, 2000). Although this could create locally some transient oxygen depletion, no serious oxygen problems have been reported in the area due to the prevailing hydrodynamical conditions that ensure full oxygenation of these coastal water. Besides *Phaeocystis*-related problems, no other manifestations of eutrophication such as human diseases derived from algal toxins, blooms of ichtyotoxic species, have been recorded in BCZ.

Figure 33 : Foam accumulation on beaches (Ostende, May 1998) is one of the adverse effect of *Phaeocystis* colony blooms in BCZ.

4.3.2 Qualitative perception of *Phaeocystis* blooms

The qualitative perception of *Phaeocystis* blooms and their impact (foam deposit and clogging of fishing nets) were assessed through questionnaires amongst tourists and fishermen, two communities possibly affected by *Phaeocystis*-related damage in BCZ.

<u>Perception of eutrophication by tourists</u>

The sample of coastal civilian surveyed during Eastern hollidays was composed at 84% of tourists and 16% of residents. Most of the tourists (66%) were staying for 2-7 days and only 8% were one-day tourists.

Only 10% of respondents considered accumulation of foam on the beaches as a major problem. Foam is considered as a minor problem compared to other forms of environmental problems such as oil pollution, garbage or dead jelly fish accumulation on the beaches or bad weather conditions (Fig. 34). Some 87% of people considers however foam as a nuisance. Only 7% of people relates accumulation of foam on the beaches to environmental disturbance while this link is clearly established in case of oil pollution (70%) and dead fish (51%). Few respondents (7%) attribute the cause of the foam event to algal blooms whereas most of them relates it to undetermined environmental pollution (46%) or to detergents (34%).

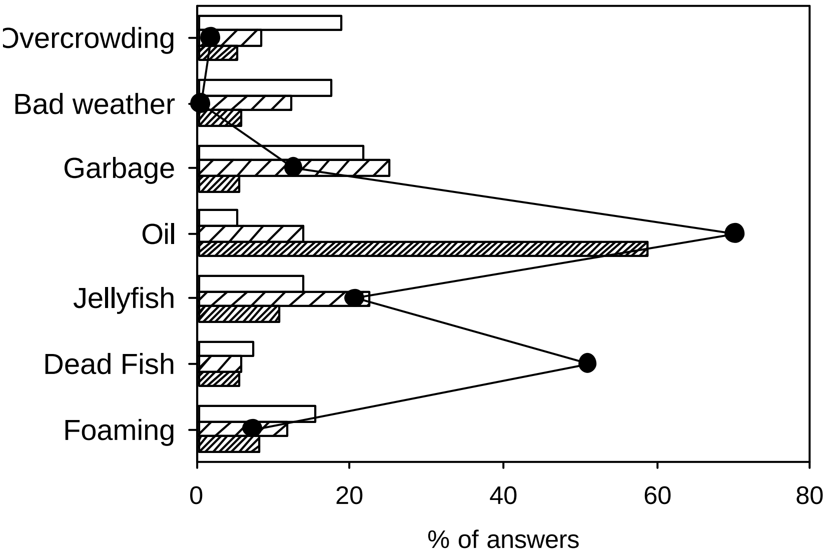

Figure 34: Perception of different environmental problems on beaches by the civil population surveyed during Eastern hollidays in 2001. First (close hatch), second (large hatch) and third (white) choice are indicated. The percentage of respondents relating each problem to environmental disturbance is indicated (?).

The socio-economic impact of foam events on tourism industry has been previously assessed based on the duration of the stay, density and behaviour when facing foam events compared to the normal tourist occupation (Persoone *et al.*, 1994). The tourist behaviour was investigated in summer 1993 during a survey conducted on 1200 respondents in 8 Belgian coastal cities (Persoone *et al.*, 1994). This study indicated that foam event would have little impact on beach-going, preventing only 6.5% of respondents to frequent beaches or encouraging 2.3% to move to other beaches. The impact of foam on tourism would depend on the duration of the stay. Cancellation decreased indeed from 11% for “one-day tourists” to 2.2% for “one-month tourists" (Persoone *et al.*, 1994). Considering that foam on beaches was a recurrent event and based on the results of this survey, the annual economic loss for tourism industry is estimated to 3.8-5 10^6 euros, i.e. 0.4–0.6% of the tourism revenues (Persoone *et al.*, 1996). An increase of duration or frequency of foam events during the tourist high season would however result in losses up to 11 10^6 euros (Persoone *et al.*, 1996).

Perception of eutrophication by fishermen

The impact of eutrophication on fishing activities was assessed by surveying 21 fishermen working on 16 ships fishing in BCZ. The main fished species in the period February-June, are flatfish (mostly sole, plaice and limon sole), shrimp and roundfish (mostly cod and whiting). Herrings, sprats, mackerels, eels, rays and lobsters constitute minor catches at that period of the year.

Most of the fishing grounds for the flatfish (Fig. 35a), roundfish (fig. 35b) and shrimp (Fig. 35c) are located near the coast with however further extension of flatfish grounds in the shallow water around banks.

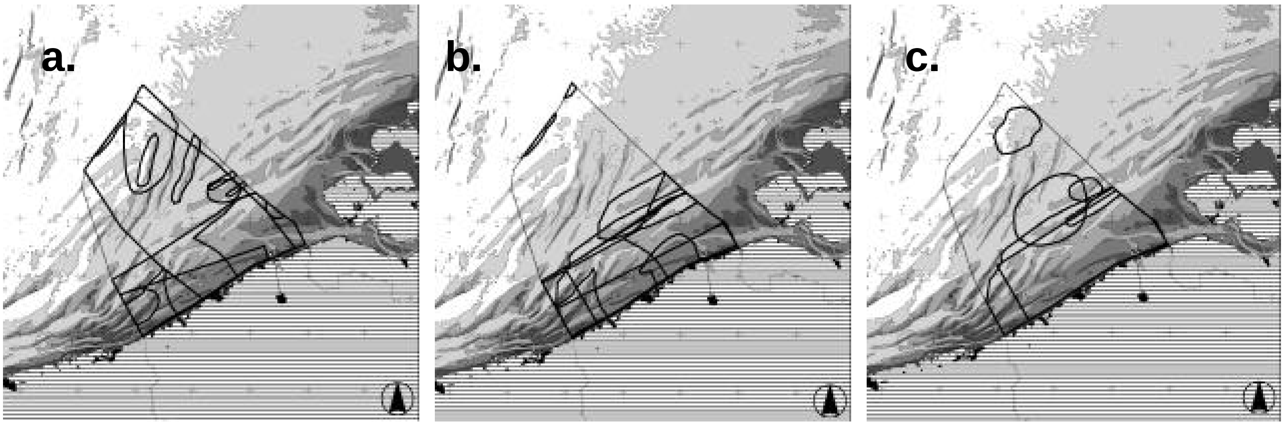

Figure 35: Fishing grounds in BCZ reported by fishermen for the February - June period: (a) flatfish (sole, lemon sole and plaice); (b) roundfish (cod and herring) and (c) shrimps.

Fishermen are generally familiar with the occurrence of algal blooms during the February-June period as they provided detailed information on the geographical and seasonal distribution of bloom events and consequences. This is of crucial importance when evaluating their ability to estimate the impact of *Phaeocystis* blooms on fishing activities. Figure 36 shows the geographical distribution of blooms (no bloom to high bloom) as reconstructed from the information given by fishermen.

Clearly, fishermen identified a gradient along a SE-NW axis, from the coastal shallow water to offshore (Fig. 36). A bias in the results could however not be excluded. It is likely that observation of blooms by fishermen is restricted to fishing areas and that less knowledge on the bloom distribution is available outside these fishing areas.

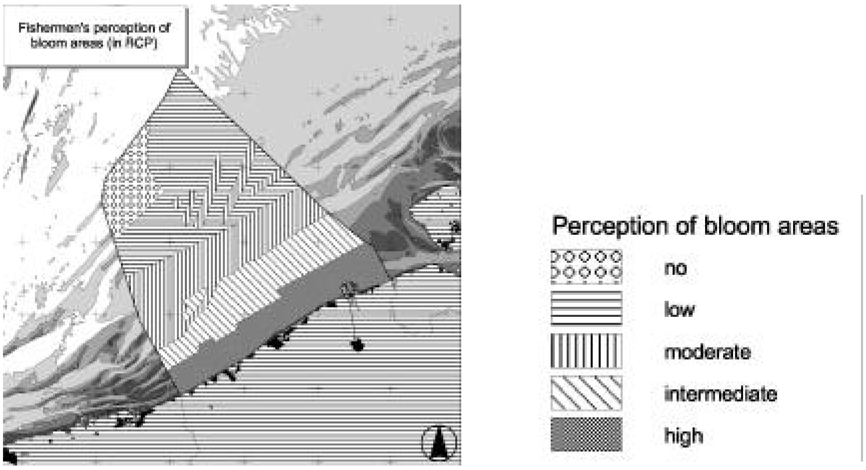

Figure 36: Composite of bloom perception areas in BCZ by fishermen.

The results of the survey also indicate that fishermen are used to experience algal blooms and foaming events from early March to the end of May. The occurrence of foam is reported in May but disappears at the same time than algal blooms. The reported distribution of both blooming and foaming event reflects well the interannual variability in the timing and duration of blooms observed by scientists.

However, fishermen did not related blooms to eutrophication. The majority (75%) of them attributes the cause of algal blooms to temperature increase of seawater, (10%) fertilizers and (10%) wastewater. Fishermen do not consider algal blooms or foam as dangerous either for humans, fishes or shrimps. They believe that algal bloom is important for marine food chain and that there is a direct causal relationship between foam and algal bloom.

Positive and negative impact of algal blooms on fishing activities are listed during the survey (Fig. 37). About 30% of fishermen, all catching fish with large size nets, indicates that algal blooms has no effect on fishing efforts (Fig. 37). Some 35 % of shrimp fishermen reports smaller shrimp catches during the bloom while an of 25% of fish catches. Some fishermen indicate a positive influence of the bloom on fish quality (Fig. 37). Some of them acknowledge however that algal blooms impact their fishery activities by clogging of nets (55%) and increased frequency of net raising during bloom periods (55%; Fig 37). This drawback was generally not perceived as a possible cause for income losses.

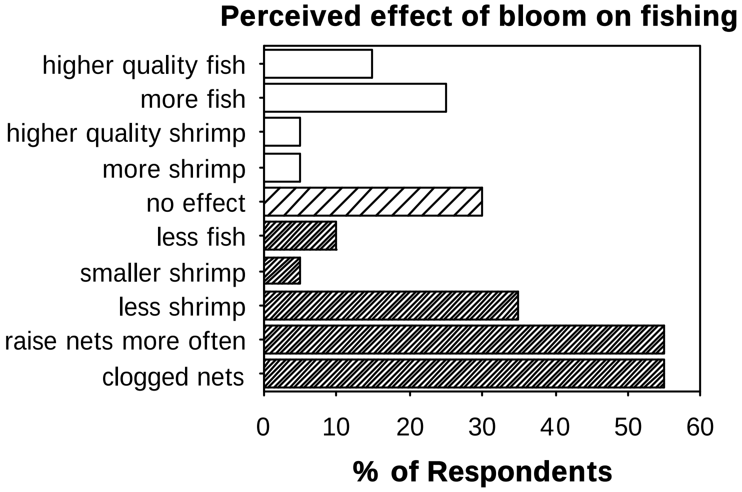

Figure 37: Effects of algal blooms on fishing activities in BCZ expressed as % of respondents.

4.3.3 Phaeocystis-related damage

This study on the perception of *Phaeocystis* blooms and related damage by tourists and fishermen suggests that *Phaeocystis* blooms are not perceived as a nuisance by thse two populations and probably induce very limited economic losses.

Besides this damage, the impact of *Phaeocystis* blooms on biological ressources is poorly known. Most of the reported adverse effects of these blooms on ichtyofauna, fish nurseries and benthic animals remain anecdotal or even contradictory. They has never been explored directly though the coastal areas of the Southern Bight are indeed known as important nursery grounds for flatfish (Rijnsdorp *et al.*, 1992 ; Amara *et al.*, 2000) The presence of anoxic sediments resulting from massive *Phaeocystis* sedimentation and bacterial degradation could indeed be a problem in these sensitive areas.

Up today, no deleterious effects of *Phaeocystis* blooms on filter feeders (*e.g.* mussels) has been reported due to the nearly absence of aquaculture activities in BCZ. This problem is however seriously taken into consideration by the Dutch mussel industry due to massive mortality events, and impact on feeding and reproduction activities due to clogging of gills (Pieters *et al.*, 1980).

Exportation of organic material to the Wadden Sea, the stratified German and Danish coastal waters resulting in anoxic bottom waters is another adverse effects associated to the massive blooms of *Phaeocystis* colonies (Lancelot, 1995).

5 CONCLUSIONS

Eutrophication phenomenon in BCZ is related to *Phaeocystis* colony spring blooms sustained by NO_3 excess left over after the growth of silicate-limited diatoms in P-regenerated conditions. The success of this non-siliceous phytoplankter results also from its resistance to grazing. Despite the substantial research on the mechanisms behind eutrophication, the link between *Phaeocystis* colony blooms and nutrient enrichment is still not fully understood due to the complexity of processes involved. Retention and/or elimination of nutrients during their transfer along the aquatic continuum from the watershed to the coastal zone, mechanisms linking nutrient delivery to the coastal area and its enrichment, the response of the coastal ecosystem are different processes which must be considered into an integrated approach for a complete understanding of eutrophication. The complex interaction between natural and human-induced variability of the ecosystem adds to the difficulty of understanding the link between eutrophication and anthropogenic nutrient emissions. In particular, the hydrodynamics of the area, driven by natural variability, makes the link between nutrient inputs and *Phaeocystis* blooms difficult to appraise. The persistence of high *Phaeocystis* biomasses in nitrate-enriched but low PO_4 conditions suggests that measures taken for nutrient reduction at the source are at the present time insufficient. The effects of future reductions of land-based nutrient inputs required a better knowledge of *Phaeocystis* physiology, in particular the understanding of *Phaeocystis* P uptake mechanisms but also P cycling within the coastal zone. Our preliminary study of the qualitative of *Phaeocystis* blooms and related damage suggests that *Phaeocystis* colony blooms are not perceived as nuisance and would have little socio-economical impact. A better scientific knowledge on possible adverse effects of *Phaeocystis* blooms, in particular on ichtyofauna, fish nurseries and benthos, is however required to assess the *Phaeocystis*-related damage.

Despite the substantial research on the mechanisms behind eutrophication, it appears that our current knowledge of eutrophication in BCZ is too limited for a well-sound definition of ecological quality criteria used for the identification of BCZ areas affected by eutrophication. The occurrence of *Phaeocystis* colonies in the whole BCZ together with their potential impact on natural ressources, lead us, according to the Precautionary Principle, to classify the whole BCZ as eutrophicated area.

This study stress the necessity of future research for the identification of ecological quality criteria, *i.e.* a *Phaeocystis* bloom magnitude beyond which no adverse effects are perceived. This would allow, using dose-response relationships, to quantify a nutrient threshold beyond which nutrient enrichment is perceived as harmful. Quantifying of the threshold must however be combined to an economic assessment through cost-benefit analysis in order to balance the costs of the benefit of reducing nutrient and the pollution abatment cost.

The development and implementation of pertinent quantitative ecological criteria and thresholds are required to translate the scientific knowledge into tools readily applicable for a rational management of coastal ecosystems through sustainable policies. Addressing these crucial scientific and societal questions is one of the most important challenging research option for developing well-sound ecological criteria in the context of sustainable development. Only transdisciplinary approach combining social (economy, geography, sociology) and natural sciences (ecology, agriculture, limnology, oceanography) would be able to face this challenge in the future years.

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8 ANNEXES

8.1 Annex 1: Common Procedure for the Identification of the Eutrophication Status of the Maritime Area of the Oslo and Paris Conventions

Joint meeting Brussels : 2-5 September 1997 ; Annex 24 (Ref. § 8.11)

Preface

This document defines a common procedure for the identification of the eutrophication status of the maritime area of the Oslo and Paris Conventions (the "Common Procedure"). The Common Procedure will be an integral part of a Strategy to Combat Eutrophication. The purpose of the Common Procedure is to characterise the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication. Action with respect to measures required following the identification of the eutrophication status of the maritime area will be specified within a Strategy to Combat Eutrophication.

The procedures specified in this document are without prejudice to existing and future legal requirements, including European Community legislation where appropriate.

1. Introduction

The Common Procedure comprises a stepwise process. The purpose of the Common Procedure is to characterise the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication and to enable regional comparisons of eutrophication status on a Convention-wide basis. The intention of the Common Procedure is to enable regional comparisons of eutrophication status on a common basis.

The first step in the Common Procedure comprises a screening procedure. This is a preliminary ("broad brush") process which is likely to be applied once only in any given area. The screening procedure is intended to identify those areas which in practical terms are likely to be non-problem areas with regard to eutrophication, but for which there is insufficient information to apply the comprehensive procedure.

Following the application of the screening procedure, all areas which are not identified as non-problem areas with regard to eutrophication shall be subject to the comprehensive procedure and monitoring shall be undertaken in accordance with the minimum monitoring requirements for potential problem areas with regard to eutrophication in accordance with the Nutrient Monitoring Programme[1].

The second step in the Common Procedure is the comprehensive procedure. The comprehensive procedure is an iterative procedure and may be applied as many times as necessary. The outcome of the comprehensive procedure should enable a classification of the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication.

The screening procedure is to be applied to all areas for which there is insufficient information to apply the comprehensive procedure. The selection of the size of the area to be assessed using the screening procedure is critical. Selection of areas should take into account hydrodynamic characteristics and proximity to nutrient sources. It is for the Contracting Parties concerned to decide on the size of the areas to be assessed.

2. Aim

The purpose of the Common Procedure is to characterise the maritime area in terms of problem areas, potential problem areas and non-problem areas with regard to eutrophication

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[1] The Nutrient Monitoring Programme was adopted by OSPAR 1995 (cf. OSPAR 95/15/1, Annex 12).

in accordance with the assessment procedure specified at Section 4. These areas are defined as follows:

a. problem areas with regard to eutrophication are those areas for which there is evidence of an undesirable disturbance to the marine ecosystem due to anthropogenic enrichment by nutrients;

b. potential problem areas with regard to eutrophication are those areas for which there are reasonable grounds for concern that the anthropogenic contribution of nutrients may be causing or may lead in time to an undesirable disturbance to the marine ecosystem due to elevated levels, trends and/or fluxes in such nutrients;

c. non-problem areas with regard to eutrophication are those areas for which there are no grounds for concern that anthropogenic enrichment by nutrients has disturbed or may in the future disturb the marine ecosystem;

3. The Screening Procedure

In their assessment of eutrophication status Contracting Parties are invited to obtain information to the extent possible for the following types of information, *inter alia*:

a. demographic/hydrodynamic/physical information
  - demographic data: population and waste water treatment;
  - agriculture and industry;
  - hydrodynamic/physical features (for example fronts, upwelling, turbidity, flushing rates, residence times, water transport and currents);

b. optical observations
  - relevant optical observations made by ship, aircraft or satellite (for example the presence of, or evidence to the contrary of, algal blooms or fish kills);

c. nutrient-related information
  - voluntary data held by ICES, such as nutrient concentrations from international research cruises. ICES data is useful for screening large areas, but in coastal areas, fjords and small estuaries other data may be more appropriate (although such data may not be easily available);
  - input data (for example, atmospheric inputs, riverine inputs or direct discharges);
  - nutrient budgets (including the total nutrient component and the anthropogenic nutrient component);
  - information from monitoring carried out under European Community Directives (where applicable).

When applying the screening procedure Contracting Parties are encouraged to use the sequence of information types specified at points a-c above. Reporting procedures are specified at Section 5.1.

4. The Comprehensive Procedure

4.1 Scope of the comprehensive procedure

The comprehensive procedure should be applied to all areas except those classified as non-problem areas with regard to eutrophication following the application of the screening procedure described in Section 3. Repeated applications of the comprehensive procedure should identify any change in the eutrophication status of a particular area.

4.2 Principles of the comprehensive procedure

The comprehensive procedure consists of a set of assessment criteria that may be linked to form an holistic assessment of the eutrophication status of the maritime area. The biological, chemical and physical assessment criteria may be organised into five categories of information.

These categories comprise:

a. the causative - nutrient enrichment related - factors;
   and

b. the supporting environmental factors;
   which together produce

c. the direct effects of nutrient enrichment;
d. the indirect effects of nutrient enrichment;
and
e. other possible effects of nutrient enrichment.

It should be noted however that some anthropogenic activities other than those leading to nutrient enrichment may result in a number of these effects. The different assessment parameters in each category are listed at Section 4.2.1, the assessment process that links the assessment parameters is described at Section 4.2.2 and the application of quantitative assessment criteria is described at Section 4.2.3.

4.2.1 checklist for an holistic assessment

The qualitative assessment parameters are as follows:

a. the causative factors

   the degree of nutrient enrichment
   - with regard to inorganic/organic nitrogen
   - with regard to inorganic/organic phosphorus
   - with regard to silicon

   taking account of:
   - sources (differentiating between anthropogenic and natural sources)
   - increased/upward trends in concentration
   - elevated concentrations
   - increased N/P, N/Si, P/Si ratios
   - fluxes and nutrient cycles (including across boundary fluxes, recycling within environmental compartments and riverine, direct and atmospheric inputs)

b. the supporting environmental factors, including:
   - light availability (irradiance, turbidity, suspended load)
   - hydrodynamic conditions (stratification, flushing, retention time, upwelling, salinity, gradients, deposition)
   - climatic/weather conditions (wind, temperature)
   - zooplankton grazing (which may be influenced by other anthropogenic activities)

c. the direct effects of nutrient enrichment
   i. phytoplankton;
      - increased biomass (e.g. chlorophyll a, organic carbon and cell numbers)
      - increased frequency and duration of blooms
      - increased annual primary production
      - shifts in species composition (e.g. from diatoms to flagellates, some of which are nuisance or toxic species)
   ii. macrophytes, including macroalgae;
      - increased biomass
      - shifts in species composition (from long-lived species to short-lived species, some of which are nuisance species)
      - reduced depth distribution
   iii. microphytobenthos;
      - increased biomass and primary production

d. the indirect effects of nutrient enrichment
   i. organic carbon/organic matter;
      - increased dissolved/particulate organic carbon concentrations
      - occurrence of foam and/or slime
      - increased concentration of organic carbon in sediments (due to increased sedimentation rate)
   ii. oxygen;
      - decreased concentrations and saturation percentage
      - increased frequency of low oxygen concentrations
      - increased consumption rate
      - occurrence of anoxic zones at the sediment surface (“black spots”)

- iii. zoobenthos and fish;
  - mortalities resulting from low oxygen concentrations
- iv. benthic community structure;
  - changes in abundance
  - changes in species composition
  - changes in biomass
- v. ecosystem structure;
  - structural changes

e. other possible effects of nutrient enrichment

- i. algal toxins (still under investigation - the recent increase in toxic events may be linked to eutrophication)

4.2.2 Principles for using the qualitative assessment parameters

4.2.2.1 selection of the qualitative assessment parameters

Regional differences with respect to demographic and hydrodynamic conditions will influence the selection of assessment parameters for different areas. Since it is the intention of the Common Procedure to enable regional comparisons of eutrophication status on a common basis, Contracting Parties shall harmonise the selection of assessment parameters to the extent possible. The basic assessment parameters to be used for assessment throughout the whole maritime area are those contained in the Nutrient Monitoring Programme. Additional parameters (e.g. the list at appendix 1) may be applied where necessary to aid the assessment process and to increase our current understanding. Assessments can take account of information supplied from monitoring, research and modelling.

4.2.2.2 links between the assessment parameters

The overall assessment of the eutrophication status of an area will take into account the interaction of the causative - nutrient-enrichment related - factors and the supporting environmental factors (cf. 4.2.1). For example, apart from nutrients, sufficient light is required to allow phytoplankton to grow and reduced zooplankton grazing could allow increased phytoplankton biomass. Linking these categories of information will enable the cause of the direct and indirect effects of nutrient enrichment to be established and will allow appropriately targeted measures to be applied where necessary. Control measures are generally applied to the causative - nutrient-enrichment related - factors as these are the factors most directly influenced by anthropogenic activities.

4.2.3 Application of the quantitative assessment criteria

All relevant assessment parameters should be considered when applying the comprehensive procedure, although there is a need to recognise that regional differences (for example in terms of hydrography) and differences in data availability are likely to affect the assessment parameters actually used in the assessment procedure. It should also be noted that although the assessment tools (eg. background/reference concentrations) may be region-specific the methodology for applying the assessment criteria is based on a common approach.

Many areas are likely to be assessed using a stepwise approach: a preliminary investigation using the screening procedure followed by the comprehensive procedure. The stepwise approach has several advantages including *inter alia*:

a. the outcome of the screening procedure applied as a broad brush technique to a large area may, in some cases, indicate areas for which more detailed investigations using the comprehensive procedure would be appropriate;

b. the outcome of the screening procedure may help focus the selection of assessment parameters for use in the comprehensive procedure;

c. the outcome of the screening procedure may be of use in helping to refine particular assessment criteria.

Areas for which there is much existing information (for example parts of the North Sea) are likely to be subject to the comprehensive procedure at an earlier date than areas for which there is little information. Nevertheless the first iteration of the comprehensive procedure should be undertaken soon after applying the screening procedure. This is particularly important for areas which will be identified as problem areas and potential problem areas with regard to eutrophication, since it will be necessary to start rapidly appropriate monitoring activities and to initiate action programmes in these areas.

It should be pointed out that despite large anthropogenic nutrient inputs and high nutrient concentrations an area may exhibit few if any adverse effects. However, Contracting Parties should take into account the risk that nutrients input may be transferred to adjacent areas where they can cause detrimental environmental effects and Contracting Parties shall recognise problem areas and potential problem areas with regard to eutrophication outside their national jurisdiction.

8.2 Annex 2: Sampling stations used for the estimations of nutrient loads to BCZ.

Rivers and tributaries	Runoff 1000 $m^3\ d^{-1}$	Nutrient Sampling station	Station n° (4)
Yser watershed			
Langeleed	25.9 (1)	VMM 6850	1
Veurne-Nieuwpoort canal	- (3)		
Koolhofvaart	- (3)		
Beverdijkvaart	69.1 (1)	VMM 6760	2
Yser	561.6 (2)	VMM 9100	3
Vladslovaart	51.8 (1)	VMM 6910-6909	4
Nieuwpoort-Plassendale canal	- (3)		
Coastal watershed			
Gent-Oostende canal	432.0 (1)	VMM 7700	5
Noordede	69.1 (1)	VMM 8660-8658	6
Blankenbergse vaart	34.6 (1)	VMM 8770	7
Lissewege vaart	17.3 (1)	VMM 8780	8
Boudewijn canal	- (3)		
Leopold canal	302.4 (1)	VMM 60	9
Schipdonk canal	820.8 (2)	VMM 7650	10
Gent-Terneuzen canal	annual average	VMM 300	11
Scheldt watershed			
Scheldt	10-day average	IHE 510 VMM 154100 RIKZ (boei 87)	12

(1) Long-term average yearly runoff estimated over 40 years.

(2) Average yearly runoff over the 1987-1992 period.

(3) Yearly runoff negligible.

(4) Station n° cross-refers to the station number in figure 3.

8.3 Annex 3 : Co-ordinates of monitoring stations used for transboundary nutrient fluxes and Chl a concentrations

Stations	Coordinates
d1	N 51° 04 17 – E 2° 20 09
d3	N 51° 06 59 – E 2° 17 01
d4	N 51° 09 13 – E 2° 15 13
240	N 51° 25 30 – E 3° 03 80
315	N 51° 19 37 – E 2° 27 84
330	N 51° 26 00 – E 2° 48 50
420	N 51° 27 30 – E 2° 28 50
421	N 51° 28 83 – E 2° 27 00
545	N 51° 43 60 – E 3° 03 00
800	N 51° 50 83 – E 2° 52 00
Calais	N 50° 57 30 – E 1° 23 30
Oostende	N 51° 45 10 – E 2° 27 00
NZRWC2	N 51° 32 56 – E 3° 24 40
NZRWC20	N 51° 39 32 – E 3° 13 16
NZRWC30	N 51° 43 15 – E 3° 06 54
NZRWC50	N 51° 50 13 – E 2° 53 49
NZRWC70	N 51° 57 25 – E 2° 40 44

8.4 Annex 4: Questionnaire conducted among tourists

Project : Identificatie zones van eutrofiëring

Interviewer :

Dag/Maand:______________________ 2000

Start interview: ____________________ Einde interview :____________________

Vragenlijstnummer: ________________

Badstad : ________________________

Q1. Plaats:

Dijk	0
Strand	1
Winkelcentrum	2
Andere	3

Q2. Weer:

Mooi – zonnig	0
Bewolkt	1
Veel wind	2
Regen	3

Q3. Geslacht:

Man	0
Vrouw	1

INLEIDING: Wij voeren een onderzoek uit naar de impact van zee- en strandverontreiniging in opdracht van het milieustudiebureau ECOLAS. Het merendeel van de vragen gaat over persoonlijke houdingen en meningen. Er zijn geen goede of foutieve antwoorden. Het beantwoorden van de vragen vereist ook geen speciale opleiding of kennis. Uw antwoorden zijn ook volledig vertrouwelijk. De vragen zullen ongeveer 5 minuten in beslag nemen. Mag ik verder gaan ?

Q4.: Woont u aan de kust ?

Ja	0	Q8
Neen	1	Q5

Q5.: Bent u op verlof ?

Ja	0	Q7
Neen	1	Q6

Q6.: Wat is de reden van uw komst ? __________________________________**Q9**_______

Q7.: Hoe lang verblijft u aan de kust ?

1 dag	0
> 1 dag – 1 week	1
> 1 week – 1 maand	2
> 1 maand	3

Q8.: Wat trekt u aan de kust aan ?
Meerdere kunnen aangeduid worden

Strand	0
Zee	1
Baden	2
Rust	3
Winkelen	4
Andere	5

Q9.: Er zijn meerdere oorzaken van vervuiling van de zee en het strand ? Ik leg u nu 7 problemen voor, kan u mij a.u.b. zeggen welke de 3 problemen zijn die u het belangrijkste vindt?

TOON TER VERDUIDELIJKING DE FOTO'S

Q9a. schuim	0
Q9b. dode vissen	1
Q9c. olie	2
Q9d. kwallen	3
Q9e. afval	4
Q9f. slecht weer	5
Q9g. teveel mensen	6

Q10.: Welke van de foto's zijn volgens u een gevolg van milieuverstoring ?
TOON TER VERDUIDELIJKING DE FOTO'S – meerdere kunnen aangeduid worden

Q10a. schuim	0
Q10b. dode vissen	1
Q10c. olie	2
Q10d. kwallen	3
Q10e. afval	4
Q10f. slecht weer	5
Q10g. teveel mensen	6

Q11.:Weet u wat volgende foto betekent ?
TOON FOTO MET OPRUIMING OLIEVERONTREINIGING OP HET STRAND

Ja	0	Q13
Neen	1	Q12

Q12.: De foto is ook niet zo duidelijk. Hier wordt aangespoelde olie op het strand verwijderd.

Q13. Weet u wat volgende foto betekent ?: *TOON FOTO MET SCHUIM OP STRAND*

schuim op het strand	0	Q14
Neen	1	Q16
andere uitleg : hier invullen	2	Q16

Q14.: Dit is een schuim op het strand. Weet u wat de oorzaak is van dit schuim ?:

Algenbloei	0	Q15
Milieuverontreiniging	1	Q16
chemische stoffen, kuisproducten	2	Q16
andere uitleg : hier invullen	3	Q16

Q15.: Inderdaad. *VERVOLG MET Q16*

Q16.: Jaarlijks komen er enorme hoeveelheden nutriënten door de landbouw, de industrie, de huishoudens en de natuur in de Noordzee terecht. Door het steeds grotere aanbod van deze nutriënten beginnen algen (een soort planten in de zee) meer en meer te bloeien. Dezé scheiden op het einde van de groei een gelei af, dat door de golven tot schuim wordt opgeklopt en op het strand terechtkomt, vooral in de maanden maart en april. *TOON FOTO'S MET KOLONIES EN ALGENGROEI EN GEEF KORT UITLEG*

Q17.:Denkt u dat dit te maken heeft met verontreiniging ?

Ja	0
Neen	1

Q18.: Vindt u dit storend ?

Ja	0
Neen	1

Q19.: Zou u X BEF wensen te betalen om dit te vermijden ?

50 – 100 – 150 – 200 – 250 – 300 – 350

Ja	0
Neen	1

Q20.: Wat is uw geboortejaar ? ____________

8.5 Annex 5: Questionnaire conducted among Belgian coastal fishermen

Uitgevoerd door het Studiebureau Ecolas

Datum :

Enquêteur :

Ecolas is een milieustudiebureau dat in het kader van een onderzoek naar eutrofiering onder andere de impact van algenbloei en schuim op de visserij tracht in te schatten. Aangezien de vissers veel op zee aanwezig zijn, zijn zij de aangewezen personen om informatie bii te verzamelen.

1. Kan U op de kaartjes aanduiden, door de gebieden te omcirkelen; waar U in de maanden Februari, Maart, April en Mei vist
2. Kan U op het kaartje aanduiden waar volgens U algenbloei voorkomt
3. Is volgende uitspraak volgens U het geval aan de BELGISCHE kust.

Er is slechts één algenbloei in het voorjaar

Ja Neen Weet niet

Er zijn verschillende algenbloei's die elkaar opvolgen in het voorjaar

Ja Neen Weet niet

Algenbloei is het gevolg van het warmer worden van het zeewater in het voorjaar

Ja Neen Weet niet

Algenbloei is het gevolg van meststoffen (van de landbouw) die in zee terecht komen

Ja Neen Weet niet

Algenbloei is het gevolg van afvalwater van de huishoudens die in zee terecht komt

Ja Neen Weet niet

Algenbloei is belangrijk als voedsel voor de vissen en garnalen

Ja Neen Weet niet

Algenbloei veroorzaakt sterfte van vissen

Ja Neen Weet niet

Algenbloei verjaagt vissen

Ja Neen Weet niet

Algenbloei veroorzaakt garnaalsterfte

Ja Neen Weet niet

Algenbloei veroorzaakt ziekten bij vissen, garnalen en schelpdieren

Ja Neen Weet niet

Algenbloei is gevaarlijk voor de gezondheid van de mensen

Ja Neen Weet niet

Algenbloei is de oorzaak van het schuim op de stranden

Ja Neen Weet niet

Schuim op het strand is gevaarlijk voor de gezondheid van de mensen

Ja Neen Weet niet

Algenbloei over de laatste 20 jaar :

Komt vaker voor dan vroeger

Is heviger dan vroeger

Is niet veranderd gedurende de laatste 20 jaar

Komt minder vaak voor dan vroeger

Is minder hevig dan vroeger

4. Hebt U als visser nadeel of voordeel van de algenbloei ?

Geen voordeel of nadeel

Nadeel doordat :	Voordeel doordat
? Minder vis wordt gevangen	? Meer vis wordt gevangen
? Minder garnalen worden gevangen	? Meer garnalen worden gevangen
? De kwaliteit van de vis is lager	? De kwaliteit van de vis is hoger
? De kwaliteit van de garnalen is lager	? De kwaliteit van de garnalen is hoger
? De vissen zijn gemiddeld kleiner	? De vissen zijn gemiddeld groter
? De garnalen zijn gemiddeld kleiner	? De garnalen zijn gemiddeld groter
? De netten raken verstopt	?
? De netten moeten vaker opgehaald worden	

Dit komt overeen met een inkomsten verlies van	Dit komt overeen met een inkomsten toename van
? 0-2 %	? 0-2 %
? 2-5 %	? 2-5 %
? 5-10 %	? 5-10 %
? 10-15 %	? 10-15 %
? 15-20 %	? 15-20 %
andere	andere

Hebt U als visser nadeel of voordeel van schuim ?

Geen voordeel of nadeel

Nadeel doordat :	Voordeel doordat
? Minder vis wordt gevangen	? Meer vis wordt gevangen
? Minder garnalen worden gevangen	? Meer garnalen worden gevangen
? De kwaliteit van de vis is lager	? De kwaliteit van de vis is hoger
? De kwaliteit van de garnalen is lager	? De kwaliteit van de garnalen is hoger
? De vissen zijn gemiddeld kleiner	? De vissen zijn gemiddeld groter
? De garnalen zijn gemiddeld kleiner	? De garnalen zijn gemiddeld groter
? De netten raken verstopt	
? De netten moeten vaker opgehaald worden	

Dit komt overeen met een inkomsten verlies van	Dit komt overeen met een inkomsten toename van
? 0-2 %	? 0-2 %
? 2-5 %	? 2-5 %
? 5-10 %	? 5-10 %
? 10-15 %	? 10-15 %
? 15-20 %	? 15-20 %

Andere	Andere

Gelieve aan te duiden met een blauwe stift wanneer er op welke soorten gevist wordt

Gelieve ook aan te duiden met rode stift wanneer de vissen gevangen worden als "bycatch" (nevenvangst)

Gelieve aan te duiden wanneer volgens U algenbloei of schuim voorkomt

	Februari Week				Maart Week				April week				Mei week				Juni week			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Tong																				
Tongschar																				
Schol																				
Rog																				
Wijting																				
Kabeljauw																				
Sprot																				
Paling																				
Garnalen																				
Andere																				
Algenbloei																				
Schuim																				