JOINT GLOBAL OCEAN FLUX (JGOFS) and

LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

Core Projects of the
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REPORT ON THE INTERNATIONAL WORKSHOP ON CONTINENTAL SHELF FLUXES OF CARBON, NITROGEN AND PHOSPHORUS

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LOICZ REPORTS & STUDIES NO. 9
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Contents

1. EXECUTIVE SUMMARY

The aim of the International Geosphere-Biosphere Programme (IGBP) is to describe and understand the interactive physical, chemical and biological processes that regulate the Earth system. The Joint Global Ocean Flux Studies (JGOFS) and the Land Ocean Interactions in the Coastal Zone (LOICZ) are the two IGBP Core Projects dealing with the ocean. These project elements share a common interest in the open continental shelf. The primary interest of LOICZ in this context is the role of the coastal zone in processing the nutrient elements carbon, nitrogen, and phosphorus; while the primary JGOFS interest is in the delivery of these materials - especially carbon - from the shelf to the open ocean. The joint JGOFS/LOICZ Continental Margins Task Team (CMTT) was formed to co-ordinate research of common interest in this portion of the earth system. The primary question to be addressed by this task team is: **What is the role of the continental margins as a source or sink for the nutrient elements carbon, nitrogen, and phosphorus?**

An early activity within the LOICZ project has been the development of the *LOICZ Biogeochemical Modelling Guidelines* (Gordon *et al.* 1996). The CMTT decided that an initial effort to further the joint interest of JGOFS and LOICZ would be to test the utility of those guidelines - which were primarily developed from the perspective of inshore systems such as bays and estuaries - as a general tool for evaluating systems as sources or sinks for dissolved carbon, nitrogen and phosphorus (C, N, and P) in the open continental shelf. The guidelines provide procedures to develop simple water and salt budgets to estimate water exchange; estimation of net system uptake or release of these materials in the preferred order P, N and C; use of stoichiometric simplifications to approximate the biogeochemical pathways by which these materials are processed.

The CMTT recognised that, in order to gain a global view of shelf function over the duration of the JGOFS and LOICZ Projects, a great deal of the effort will need to be based on existing data. It was also recognised that it would be necessary to work with a broad variety of shelf-sea types as well as a range of data availability. Four areas were chosen as case studies: East China Sea, North Sea, Peru-Chile coast, Gulf of Guinea Shelf. These areas were chosen to give some sense of the range of these criteria, and a workshop was convened in order to evaluate the *LOICZ Biogeochemical Modelling Guidelines* (Gordon *et al*. 1996)in this context.

The workshop was convened in Lagos, Nigeria, October 14-18th, 1996, with participants from each region and “resource people” to facilitate the effort. Preliminary overviews and budgets were presented for each region. This was followed by a three day workshop for each regional group to prepare a consensus budget for their region. These revised budgets were presented in a plenary session on the final day of the workshop.

It was the consensus of the participants that:

- the budgeting approach is a diagnostic tool which is useful for comparing systems; and,
- this tool can yield insight into the performance of very well studied systems.

The budgeting approach should ultimately lead to more sophisticated biogeochemical or ecological modelling procedures which give potential to move from diagnostic to prognostic analysis. Good budgets require good data; budgets from data-poor regions based on “best guesses” may yield calculated fluxes which are unreasonable. In this context, the budgeting procedure assists in the identifying the gaps in knowledge which need to be filled in order to understand the role of continental margins as sources or sinks for C, N, and P.

2. INTRODUCTION AND SCIENTIFIC OVERVIEW

What is the role of the continental margins as a source or sink for the nutrient elements carbon, nitrogen, and phosphorus?

This workshop was convened by the joint JGOFS/LOICZ Continental Margins Task Team (CMTT), to examine the potential to develop biogeochemical budgets for nonconservative fluxes of carbon, nitrogen, and phosphorus (C, N, P) for the continental shelf using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.*, 1996) for the open continental shelf. Four areas were chosen as case studies: A) East China Sea, B) North Sea, C) Peru-Chile coast and D) Gulf of Guinea Shelf (Figure 1). These areas were chosen to span a variety of shelf-sea types within a small sample population, and further, to span a wide range in data availability. It had been a decision of the CMTT that techniques to characterise the continental margins of the global oceans within the context of IGBP and on the time frame of a few years need to meet both of these criteria. The ultimate goal of the exercise, variously expressed in JGOFS and LOICZ documents including the first report of the CMTT (Hall and Smith, 1996), is to understand the role of the continental margins as a source or sink for C, N, and P.

The LOICZ budgeting procedure is to develop coupled water and salt budgets to estimate water exchange. In cases without salinity gradients, salt budgets may not be possible; in such cases some alternative procedure (e.g., numerical modelling) will be required to estimate water exchange. After water exchange is estimated, nutrient budgets are calculated in order to describe the uptake or release of carbon, nitrogen, and phosphorus (C, N, and P), and then to use the uptake or release of these nutrients and simple stoichiometric reasoning surrounding composition of organic matter produced in the systems (i.e., the “local Redfield Ratio”) to calculate net production minus respiration (*p-r*) for the system. In general, the Guidelines recommend that the nonconservative flux of dissolved inorganic phosphorus (DIP), scaled by the local Redfield Ratio, is likely to be the best estimator in many coastal systems for estimating (*p-r*). This value is an estimate of organic carbon produced (and exported or buried) or consumed (supplied from outside the system). Further stoichiometric considerations allow estimates of nitrogen fixation - denitrification (*nfix-denit*) and, in some cases, CO_2 gas flux, calcium carbonate reactions, and sulfate reduction.

Participants familiar with each region plus resource/support persons were identified, furnished with background materials, and met at the Nigerian Institute for Oceanography and Marine Research (NIOMR) in Lagos, Nigeria. The planned procedures and desired products were outlined in an initial plenary session, and overviews of each region and preliminary budgets or budget-related discussions were presented by the workshop participants. It was recognised that somewhat different products were expected from each region, reflecting the heterogeneity of both regional hydrography and information. After some discussion of the kinds of efforts which might work in each system, the session broke into the regional groups to pursue their respective assignments. The results are briefly outlined below:

A) East China Sea - This region is one of the largest continental margin seas in the world and also receives water from two of the largest rivers in the world. Budgets of material exchange for this region can be built on the basis of water and salt budgets. Water residence time is estimated to be approximately 2.6 years. When these budgets are developed to include nutrients, they yield net DIP uptake, stoichiometrically interpreted to indicate net organic production (*p-r*) of about 0.5 mol C m^{-2} yr^{-1}. This rate (about 3% of primary production) suggests that the system is a slight net sink for CO_2. A carbon budget based on the hydrographic budgets and estimates of gas flux across the air-sea interface yields a substantially higher rate of net production, but that rate is poorly constrained by very uncertain estimates of gas exchange across the air-sea interface. Stoichiometric calculation of the quantity (*nfix-denit*) indicates that this region is one of slight net denitrification (approximately 50 mmol N m^{-2} yr^{-1}).

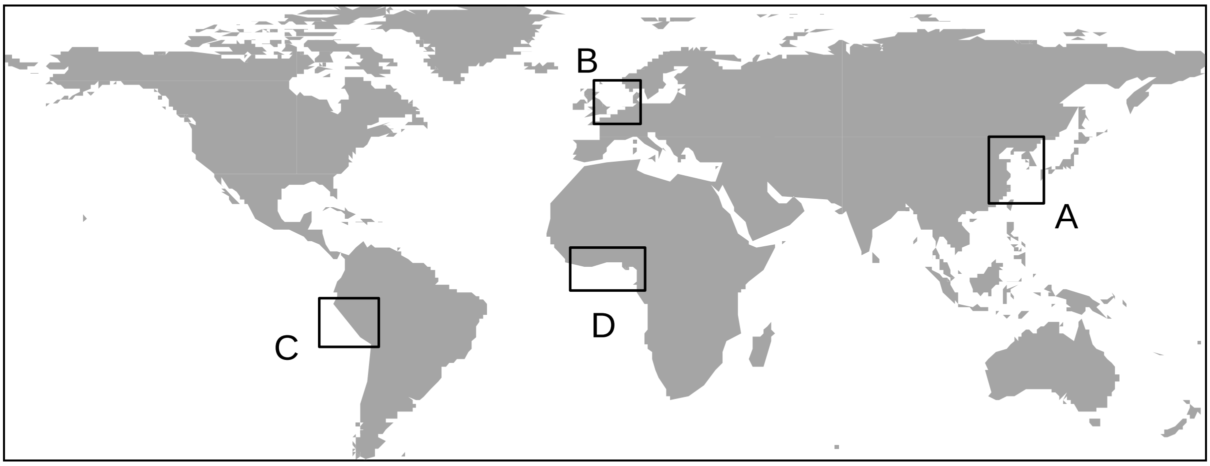

Figure 1. World map showing location of four continental shelf areas chosen for analysis : A) East China Sea, B) North Sea, C) Peru-Chile coast and D) Gulf of Guinea Shelf.

B) North Sea - this large coastal sea is one of the most intensively studied coastal regions. Because there are several oceanic in and outflow water masses, a salt budget is not a practical method to establish water exchange. Therefore exchange in this system is estimated according to a 3-dimensional numerical circulation model. This model indicates a water exchange time of approximately a month. When the exchange data are used in conjunction with observed nutrient data, the North Sea as a whole appears to be approximately neutral with respect to the nonconservative uptake or release of DIP, and hence, carbon. If the Skagerrak, a region which reaches a water depth of 600 m and which is recognised as the major repository of sediments entering and produced in the North Sea, is excluded from the calculations, the shallow portion of the North Sea appears to be a net sink for DIP - stoichiometrically equivalent to net organic carbon production (*p-r*) of about +1.5 mol C m^{-2} yr^{-1} (about 9% of primary production). The near balance of the whole North Sea versus the net production of the shallow North Sea implies that the Skagerrak may be a major site of remineralisation for the entire (shallow + deep) North Sea system. Denitrification is estimated to occur in excess of nitrogen fixation (i.e., [*nfix-denit*] is negative), according to the stoichiometric calculations, at a rate of approximately 150 mmol N m^{-2} yr^{-1} averaged across the entire North Sea.

C) Peru-Chile Coast - this region was chosen as a region of intensive upwelling associated with an eastern boundary current and one for which there exist a moderate (but not intensive) data set. The budgeted region (6°- 40° S) presents a particular challenge, because the “shelf” region (<200 m) is extremely narrow, often less than 1 km wide. Further, the budgeted region is one of the driest regions on earth and receives no runoff to allow construction of a water budget. Water exchange across the narrow shelf is too fast to allow development of an evaporative salinity signal. As a budgetary exercise for this workshop, the “coastal” region is constrained here to be the upper 20 m of the water column (i.e., the mixed layer) within what is called the “Rossby deformation radius” of the coast. This parameter approximately defines the upwelling region and allows budgetary calculations of water entering the mixed layer via upwelling. It is assumed that the water flows out laterally; the current speeds calculated according to this simple budgetary procedure are 10 cm sec^{-1}, close to direct field measurements. Because of the paucity of DIP data, it is difficult to constrain the DIP budget adequately to follow the guidelines exactly. However, bounding calculations and rough stoichiometric conversions suggest organic carbon export from the mixed layer of approximately 50 mol C m^{-2} yr^{-1}. This can be compared with direct measurements of approximately 70 mol C m^{-2} yr^{-1}. The data are insufficient to estimate denitrification by the stoichiometric budgeting model.

D) Gulf of Guinea shelf—There is relatively little information which can be directly used to develop biogeochemical budgets for this complex coastline. The shelf is relatively narrow; it is known to be the site of major river delivery to the sea; and it is a region of upwelling. Budgeting in this region was undertaken as a "scoping exercise". Water and salt budgets for three sections along the coast suggest water residence times ranging from about 0.3 to 3 years. Data are not available to develop nutrient budgets. Coastal lagoons are common along much of this coast and tend to be sites of large urban centres which deliver common along much of this coast and tend to be sites of large urban centres which deliver largely untreated waste discharge. Thus, the composition of river inflow is greatly modified in these lagoons. It was decided to attempt nutrient budgets for some of these lagoons. Preliminary water, salt, and nutrient budgets for one of these systems (Ebrie Lagoon, Cote d'Ivoire) suggests that the site is a strong DIP sink, with a calculated (*p-r*) of about +2.6 mol C m^{-2} yr^{-1}. The budget also suggests that the lagoon is the site of relatively high net nitrogen fixation (*nfix-denit* ~ +6 mol m^{-2} yr^{-1}). Until some further checking of specific data, these results should be regarded as preliminary. A budget for Lagos Lagoon, Nigeria, was incomplete but nevertheless proved useful in identifying information required to complete that budget. A budget for Korle Lagoon, Ghana, proved to be totally unreliable. We think that the average flow rate estimates used did not well represent the period during which the salinity and nutrient data were collected.

At the closing plenary session, the following overall consensus points were agreed:

- the budgeting approach is a useful diagnostic tool for comparing systems, and this tool can even yield insight into the performance of very well studied systems such as the East China Sea and the North Sea;
- as discussed in the Biogeochemical Modelling Guidelines, in many instances some method other than water and salt budgets may be required to establish water exchange;
- a caution was raised that the procedure should ultimately lead to more sophisticated biogeochemical or ecological modelling procedures which give potential to move from diagnostic to prognostic analysis;
- a further caution was that good budgets require good data;
- regions with large data sets allow the development of relatively robust estimates of material fluxes, but budgets from data-poor regions based on "best guesses" may yield calculated fluxes which are clearly unreasonable;
- the Modelling Guidelines should be viewed as suggested, rather than proscriptive, approaches for systems analysis. The analysis of the Peru-Chile coast provides an excellent example of the use of the Guidelines in this fashion; and

the Guidelines were seen to be particularly useful in the various analyses of the Gulf of Guinea in identifying the gaps in knowledge which need to be filled in order to understand the role of this region as sources or sinks for C, N and P.

3. REGIONAL BUDGETS

3.1 East China Sea *Prepared by C.-T. A. Chen** *, D. Hu, K.-K. Liu and T. Yanagi*

Introduction

The continental shelves of the East China Sea, the Yellow Sea and the Bohai Sea in the western North Pacific represent one of the largest continental marginal zones in the world (Figure 2). For this study, the region of interest includes the contiguous shelves extending from the Liaodong Bay to the Taiwan Strait with the isobath of 150 m as the outer boundary. The total area is 1.24×10^{12} m^2. The Kuroshio, a strong western boundary current, flows along the east coast of Taiwan before entering the Okinawa Trough where it borders the shelf break of the East China Sea. A branch of the Kuroshio feeds water from the Pacific to the Taiwan Strait where it combines with the South China Sea warm current and flows northward. Just northeast of Taiwan, the Kuroshio intrudes onto the shelf of the East China Sea forming a cyclonic eddy that provides additional nutrients to the shelf by upwelling (Wong *et al.*, 1991; Liu *et al.*, 1992b; Gong *et al.*, 1996; Chen 1996). In the shelf break region west of Kyushu, there exists another cyclonic eddy (Chen *et al.*, 1992), which also provides nutrients to the shelf water (Ito *et al.*, 1994), while a cold eddy south of Cheju Island pumps the nutrient-laden cold water to the euphotic zone (Hu, 1980; 1984).

Two of the largest rivers in the world, the Changjiang (Yangtze River) and the Huanghe (Yellow River), empty into this study region. These two and several other smaller rivers discharge large amount of runoff (1×10^{12} m^3/yr), dissolved nutrients and sediments (between 1 and 2×10^{15} g /yr) to

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* C.-T. A. Chen did not attend the workshop, contributions were provided in advance.

the shelf sea (Shen *et al.*, 1983; Qin and Li, 1983; Milliman *et al.*, 1985; Milliman, 1991). In this light, this study region enjoys a rich supply of nutrients from both marine and terrigenous sources. The Changjiang runoff has a strong influence on the shelf circulation. In summer, the Changjiang runoff flows predominantly to the northeast as it enters the shelf sea (Beardsley *et al.*, 1985; Chao, 1991). In winter, the Changjiang Diluted Water forms a coastal jet flowing southward and turns cyclonically in the northern Taiwan Strait due to the blocking by a topographic high as well the northward Kuroshio branching current (Chao, 1991; Jan, 1995).

The primary production in the East China Sea shows strong seasonal and spatial variation (Guo, 1991). For coastal waters, primary production shows extreme variability, ranging from 2 - 83 mol C m^{-2} yr^{-1}. (Shiah *et al.*, 1995; Hama, 1995; Wang, 1995). Near the perimeter of the Changjiang river plume, high primary productivity is induced by the high nutrient concentration in summer (Hama, 1995; Gong *et al.*, 1996). In winter, the strong wind mixing may reduce light transmission due to sediment resuspension and causes very low productivity in the coastal waters. For mid-shelf waters, the recent measurements showed primary production values between 15-49 mol C m^{-2} yr^{-1} for spring and summer (Shiah *et al.*, 1995; Hama, 1995) and 6-18 mol C m^{-2} yr^{-1} in winter (Hama, 1995; Wen, 1995). The primary production in the Kuroshio is in the range of 6-17 mol C m^{-2} yr^{-1} throughout the year (Shiah *et al.*, 1995; Hama, 1995).

Based on the areal integration of the atlas of primary productivity in the East China Sea published by Fei *et al.* (1987), one obtains a mean primary production of 46 mol C m^{-2} yr^{-1} for winter and 28 mol C m^{-2} yr^{-1} for summer. An annual value of 15 mol C m^{-2} yr^{-1} is adopted here for this study. Although the values of Fei *et al.* (1987) are lower than more recent observations, the adopted mean value may be a reasonable estimate for the whole study region because the Yellow Sea and the Bohai Sea may be less productive than the East China Sea due to higher turbidity. It should be cautioned that the spatial and temporal variability of primary productivity in the study region causes large uncertainty in the estimation of annual mean.

The long open boundary of the study region and the strong seasonality makes the biogeochemical budgeting by steady state box models difficult. However, the strong riverine discharge and the relatively impenetrable Kuroshio front makes the study region resemble an estuarine system in some sense. Therefore, budgeting by the box model is an interesting exercise to reveal the first order characteristics of biogeochemical cycles in this continental margin. Such an exercise has drawn heavily from data obtained during recent field programs in this region, namely, the Kuroshio Edge Exchange Processes (KEEP), the Marginal Flux in the East China Sea (MFLEAST CHINA SEA), and the Marginal Sea Flux Experiment (MASFLEX).

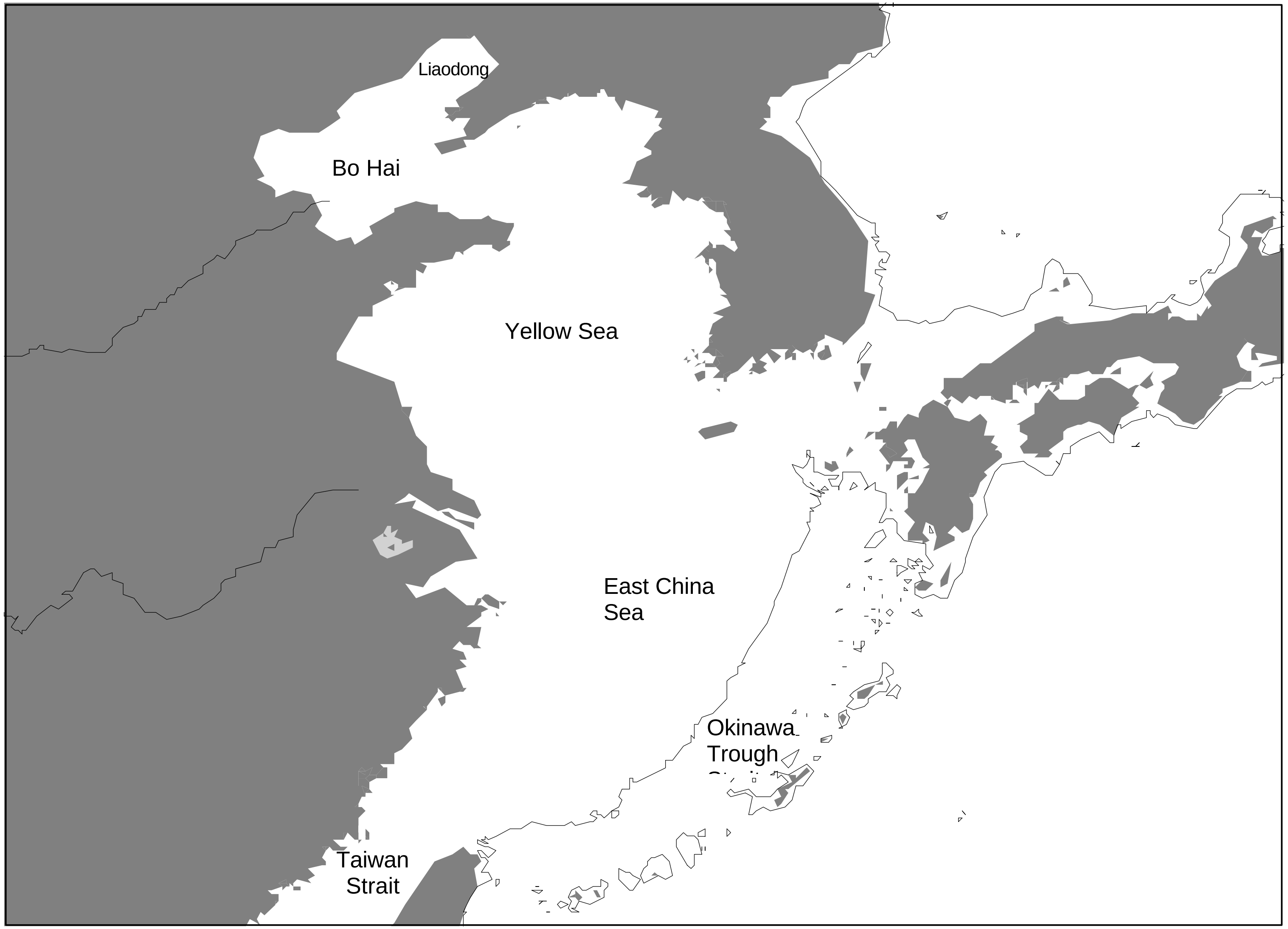


Figure 2. Map of the East China Sea area.

Budgeting - Procedure

We took budgets of water, salt, DIP, DIN and DIC in the East China Sea including the Yellow Sea and the Bohai Sea, which is surrounded by Taiwan Strait, Tsushima Strait and the 150 m isobath as shown in (Figure 2), on the basis of LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.*, 1996) and existing references. The surface area of this region is 1.24 x 10^{12} m^2 and the volume 4.5 x 10^{13} m^3

Results

The result of the water budget is shown in Figure 3. The river discharges V_Q are based on Gao *et al.* (1992) and a personal communication of D. Hu. The fresh water discharge through the ground water may affect the water budget in this region but we do not have a quantitative data for V_G and we assume it to be zero. Precipitation is a little larger than the evaporation and the net inflow of fresh water of 140x10^9 m^3/yr is supplied through the sea surface (Ishii and Kondo, 1987). The residual water flux to the open ocean V_R is 1,250x10^9 m^3/yr from (Figure 3). The salt budget is shown in Figure 3. The average salinity in this region and that in the open sea are based on the observed data by Kim *et al.* (1971). Mixing salt flux from the open sea $V_x(S_2-S_1)$ has to be balanced to the residual salt flux V_RS_1 and the mixing volume per unit time V_x is estimated to be 16 x 10^{12} m^3/yr. In this calculation, we do not use $V_R(S_1+S_2)/2$, which is indicated by Gordon *et al.* (1996), but use V_RS_1 as the residual salt flux because it is correct to adopt an upwind scheme for the advective flux. The DIP budget is shown in Figure 4. The riverine input of DIP of 0.6 x 10^9 mol/yr (Zhang, 1996) is much smaller than the atmospheric input by precipitation and dry fall out of 0.7 x 10^9 mol/yr (Chen and Wang, 1996; Tsunogai, pers. Comm.) although it must be remembered that this number is not well estimated. The average concentration of DIP of 0.1 mmol/m^3 in this region is much smaller than that of 0.34 mmol/m^3 in the open ocean (Chen *et al.*, 1995). DIP is mainly supplied from the open sea into this region. From the balance shown in Figure 4, the net internal sink of DIP in this region ΔY_P is estimated to be 5.8 x 10^9 mol/year. The DIN budget is shown in Figure 4. The riverine DIN load of 65 x 10^9 mol/yr (Zhang, 1996) is larger than the atmospheric input of 30 x 10^9 mol/yr (Chen and Wang, 1996) and is nearly the same as the DIN inflow from the open sea of 50 x 10^9 mol/yr. The difference of DIN concentration between the East China Sea and the open ocean of 3.1 mmol/m^3 (Chen *et al.*, 1995) is larger than that of DIP of 0.24 mmol/m^3. The internal sink of DIN in this region ΔY_N is 93 x 10^9 mol/year from ΔDIP with use of a Redfield ratio and the estimated denitrification (*nfix-denit*) becomes 50 x 10^9 mol/yr. The DIC budget is shown in Figure 5. The riverine input of DIC is 1800 x 10^9 mol/yr (Chen *et al.*, 1996) and the DIC input by precipitation or dry fall out of 11 x 10^9 mol/yr (Chen and Wang, 1996; Buat-Menard *et al.*, 1989) is much smaller than the riverine input. The DIC input through the sea surface by the air-sea exchange is estimated to be 1,750 x 10^9 mol/year by averaging several observed values (Chen and Wang, 1996; Tsunogai, pers. comm.; Huang, pers. comm.; Ma, pers. comm.). The difference of DIC concentration between the East China Sea and the open sea is small (Chen *et al.*, 1995, 1996) and the DIC inflow by the water exchange across the shelf edge is also small. The internal sink of DIC, ΔY_C, is estimated to be 1678 x 10^9 mol/yr from the balance shown in Figure 5.

Discussion

Water volume exchange V_x along the open boundary of 16 x 10^{12} m^3/yr is about ten times larger than the fresh water discharge from rivers of 1.11 x 10^{12} m^3/yr (V_Q, Figure 3) but much smaller than the Kuroshio volume transport of 690 x 10^{12} m^3/yr. This suggests that the active water and material exchange occurs between the shelf water and the Kuroshio water across the shelf edge of the East China Sea. Precipitation (V_P) and evaporation (V_E) are each large in comparison to V_Q but approximately balance out so that V_Q dominates the freshwater balance for the region.

The net internal sink of DIP (ΔDIP, Figure 4) totals 5 x 10^9 mol/yr across the region and shows that this amount of DIP is converted to particulate P and either buried or transported to the open ocean - in either case, probably as organic particles with an approximately Redfield C:N:P composition ratio of 106:16:1. Note that ΔDIP is largely determined by the mixing of DIP from the ocean onto the shelf, not by either terrigenous or atmospheric inputs. This calculated value for ΔDIP is equivalent to -4 mmol m^{-2} yr^{-1} averaged across the shelf. If this uptake is entering organic matter of Redfield composition, it implies ΔDIC entering organic matter (i.e., ΔDIC_{org}) of 106 X -5.0 ♉ -530 x 10^9 mol/yr (-0.4 mol m^{-2} yr^{-1}) and ΔDIN entering organic matter (i.e., ΔDIN_{org}) of about -80 x 10^9 mol/yr (-0.06 mol m^{-2} yr^{-1}).

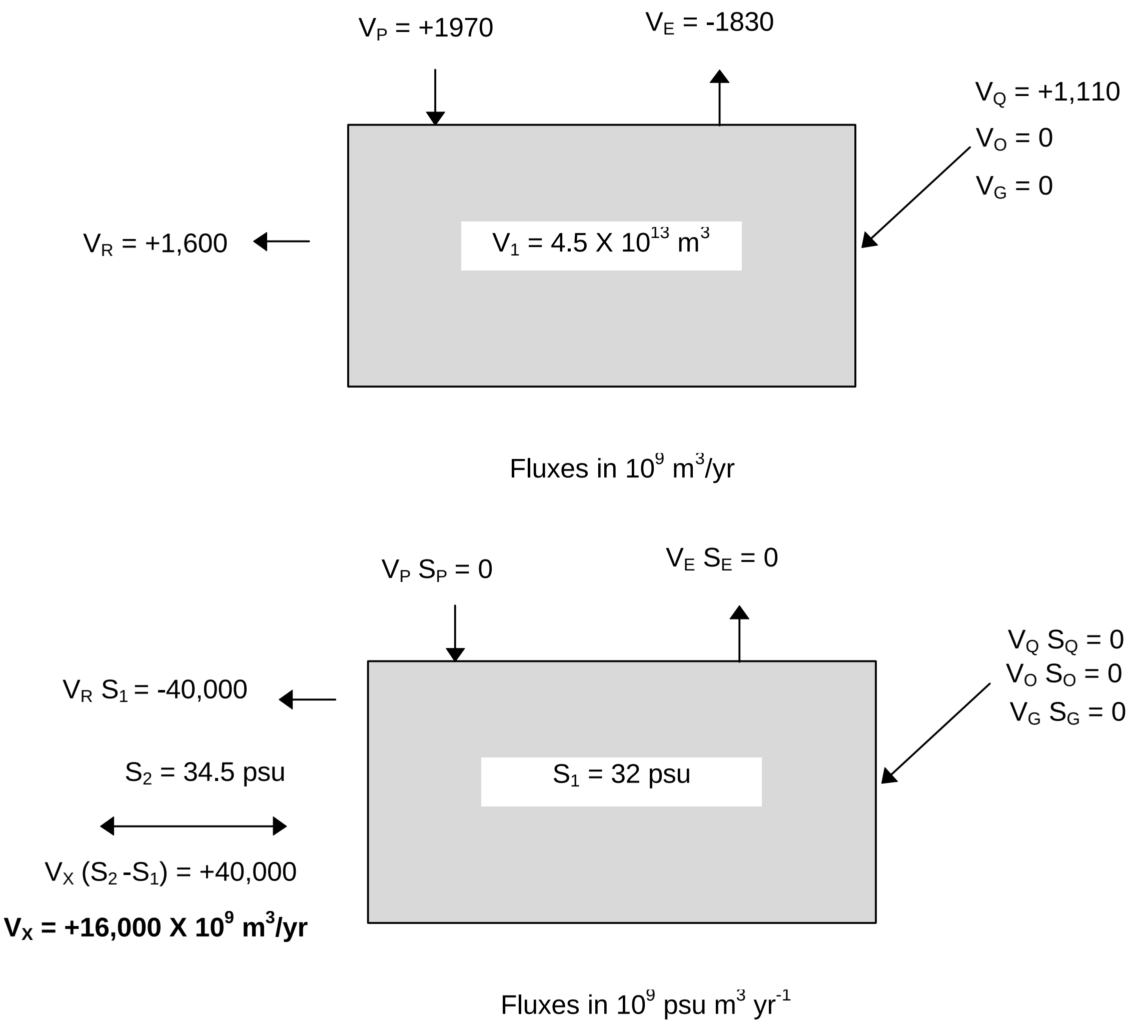


Figure 3. Box model of water (top) and salt fluxes (bottom) for the East China Sea. V_X in the bottom figure is the water exchange flux calculated to balance the net water flux in the top figure and the residual salt flux in the bottom figure.

The observed internal sink of DIN, ΔDIN_{obs}, in -143 x 10^9 mol/yr in order to balance the river and atmospheric influxes, the small residual flux off the shelf, and the exchange flux from the ocean onto the shelf. Note that in this case the sum of river and atmospheric fluxes is substantially larger than the exchange flux. But ΔDIN entering organic matter is only -80 mol/yr, an internal sink which is substantially smaller than implied by the budget. According to the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.*, 1996), the difference between the observed and expected values for ΔDIN (i.e. -63 x 10^9 mol/yr) is interpreted to represent the difference between nitrogen fixation and denitrification (*nfix-denit*). The net denitrification (*nfix-denit)* is equivalent to -0.05 mol m^{-2} yr^{-1} and this figure is small compared to those estimated in the shallow coastal area of the North Sea of 0.2 - 0.7 mol m^{-2} yr^{-1} (Nedwell *et al.*, 1993; Lohse *et al.*, 1995). This may be due to using an estimated value that is averaged, not only in the nearshore coastal area but also in the offshore shelf area.

It can be assumed that rainfall delivers an insignificant amount of DIC to the East China Sea, so V_PY_P for DIC is 0. The net internal sink of DIC (ΔDIC_{obs}) calculated to balance the river influx, residual flux from the shelf, and exchange flux is -83 x 10^9 mol/yr. But ΔDIC_{org} required to balance the value for ΔDIP is -530 x 10^9 mol/yr. We infer from the LOICZ Biogeochemical Modelling Guidelines that the discrepancy between ΔDIC_{obs} and ΔDIC_{org} represents gas exchange (ΔDIC_{gas}) of +447 x 10^9 mol/yr. This value may be compared with direct gas exchange estimates (based on CO_2 partial pressure differences and estimated gas exchange rate coefficients) averaging about 1,800. There are two plausible explanations for the discrepancy of 1,300 x 10^9 mol/yr between ΔDIP-based calculations and "direct" estimates. The calculation based on ΔDIP describes ΔDIC_{gas} which might be expected to balance physical fluxes of DIC with biotic uptake, without taking any gas fluxes associated with $CaCO_3$ reactions into account. Alternatively, either the organic C production inferred from ΔDIP or the gas exchange inferred from a relatively modest collection of pCO_2 data and no direct measurements of the exchange rate coefficient could be in error."

The net internal sink of DIC associated with organic production (ΔDIC_{org}) is -530 x 10^9 mol/yr, as inferred from ΔDIP and the Redfield ratio. This sink is about 3 % of the primary production in the East China Sea. We can understand from this calculation that about 4% of the organic carbon produced in the East China Sea is either buried or transported to the Pacific Ocean, and that that organic metabolism in the East China Sea is thus a sink for atmospheric CO_2.

Uncertainties

Changes in riverine input

Riverine input changes rapidly due to human activities, especially by dam construction and fertilisation. For example, the water and sediment discharges from the Huanghe decreased by about 40% from 1950-1969 mean to 1969-1992 mean, which must influence input of carbon and nutrients. In addition, in the last two years, the Huanghe dried up approximately 650 km from the mouth for more than 130 days. For the Changjiang, the flux of dissolved nitrogen increased from about 1 x10^{10} mol/yr around 1960 to more than 4 x10^{10} mol/yr in the early 1980s due to fertilisation practice along the Changjiang basin, which was increased by approximately 11 times during this period and was doubled again from 1980 to 1993.

Groundwater discharge and seawater infiltration

We are not aware of any data on groundwater discharge and the associated nutrient fluxes in the coastal zone. On the other hand, infiltration of seawater to the land is a serious problem in the areas near the Changjiang and Huanghe deltas. The impact of such intrusion of seawater to the land on nutrient fluxes is unknown but is likely to be small at the scale of the whole region.

Open boundary problem

Processes along the open boundary of the study region are poorly understood. The Kuroshio is an important influence on the circulation in the study region, which governs transport of materials (water, carbon, nutrients, etc.). The exchange of materials between the Kuroshio and the East China Sea shelf is also poorly understood.

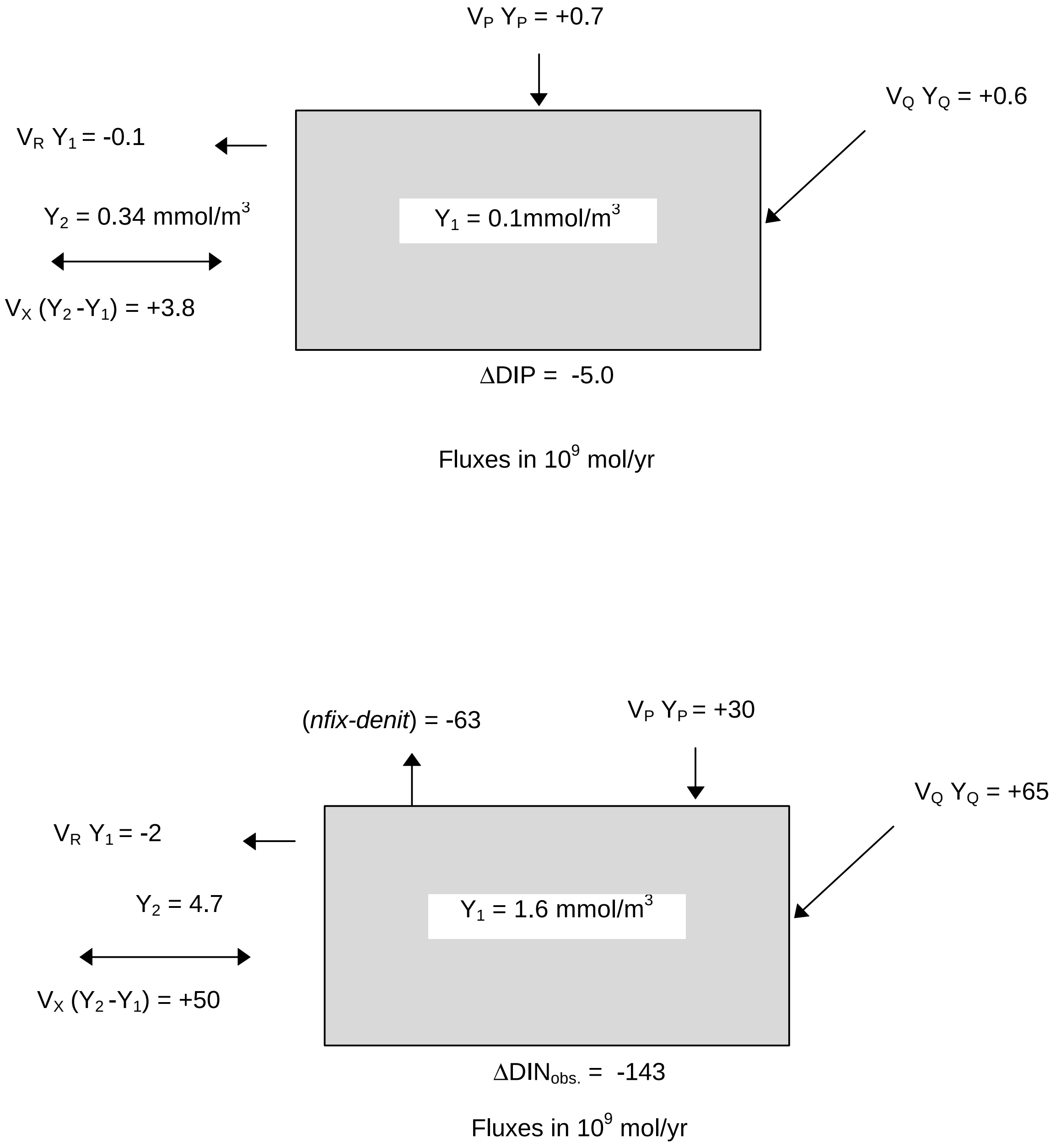


Figure 4. Box model of DIP and DIN fluxes for the East China Sea.

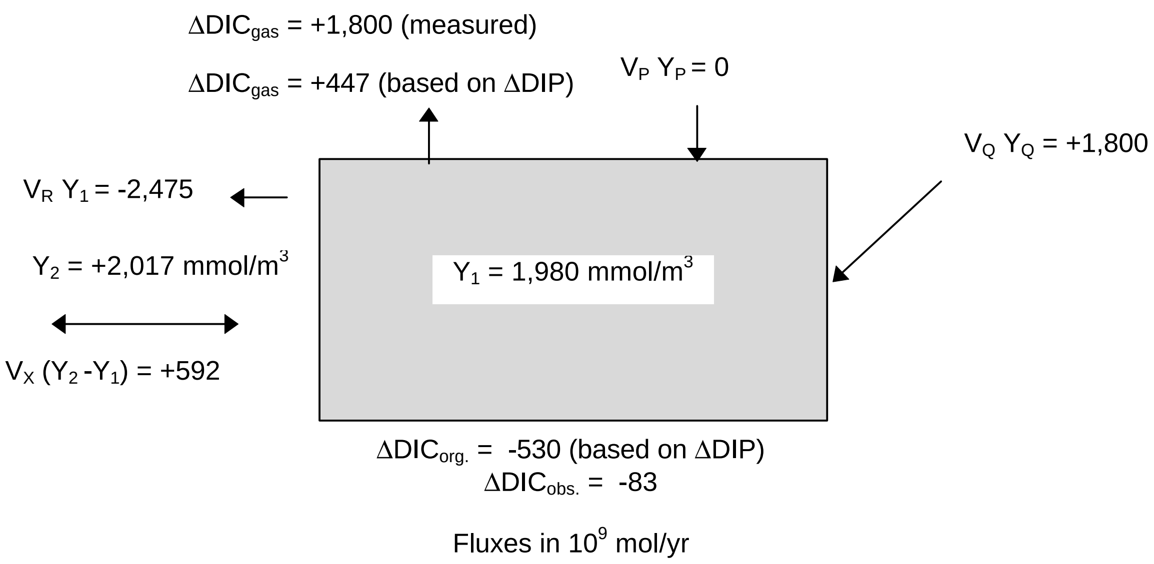


Figure 5. Box model of DIC fluxes for the East China Sea.

Seasonality

Wind is another controller of the circulation in the East China Sea, which is monsoonal. Seasonal changes in the East China Sea are dominant over those of monthly and interannual time scales. The coverage of the seasonality of the data available is poor. Data are available for spring and fall, with less data for the summer and especially the winter. With those data currently available, we extrapolate to get the “annual mean”, and the uncertainties in these numbers are high.

Phosphorus sources

The data available suggests that phosphate input to this region by dry and wet precipitation is more important than riverine input. This seems to be rather unusual. For nitrogen the situation is reversed even though the dissolved N occupies only 55% of the total N input from the Chiangjing. (The atmospheric input of phosphate represents more than 25% of the DIP export). The rather large atmospheric phosphate input is conceivable in view of the strong eolian transport in the northern China, but it is prudent to reassess the strength of this influx. The low phosphate flux in the riverine discharge is due to the high percentage of phosphorus in the particulate form, which occupies 98% of total P input from the Changjiang, and however, which is neglected in this budgeting exercise. If remobilisation of the particulate phosphorus is efficient, the DIP input to this region would be considerably higher. A further consideration is as follows: if the phosphate is particulate, rather than dissolved (aerosol), it should not be counted. Discounting this source would lower ΔDIP and estimated net production and raise estimated denitrification. Despite these various uncertainties, the unequivocal point seems to be that water exchange between the East China Sea and the open Pacific dominates the delivery of DIP to this region.

Air-sea exchange of CO_2

The DIC export directly obtained from the budgeting exercise is critically dependent on the atmospheric influx of CO_2, which is as important as the riverine input and more important than the water exchange. However, the air-sea exchange flux is extremely variable according to the available estimates (0.6-3.0x10^{12} mol/yr). This demonstrates the large uncertainty associated with the carbon budget. This is an advantage if estimating net organic metabolism via ΔDIP.

Suggestions for future study

For improved budgets of carbon, nutrients, etc. in this study region, we need good models of physical, biogeochemical and coupled process with fine spatial resolution (less than 1/8 degree to 10 km) and good data to verify the model. To do this, we need (a) to compare and improve available models, and to develop improved models with physical as well as biogeochemical processes, (b) to identify key sections in certain areas, for instance, river mouths, upwelling areas on the shelf, Kuroshio intrusion areas, cross-shelf sections, and to design a field experiments to cover all seasons in order to verify the models.

For this budgeting exercise, the study region is shown to be a sink of dissolved inorganic biophiles, namely, phosphorus, nitrogen and carbon. The fate of the removed biophiles, which is not elucidated in the budgeting, could be buried in shelf sediments or exported off the shelf. In order to verify the estimated removal fluxes, deposition rates on the shelf need to be measured and the export fluxes quantified. These measurements have been or will be done in the regional field programs. Better constraint of the budgeting is expected from the outcome of these measurements.

The estimation of the mean primary productivity in this region also needs improvement. Satellite remote sensing of the ocean colour is a potential tool for better coverage of the spatial and temporal variation. The Japanese OCTS and the American SeaWiFS may provide such data in the future.

In summary, better organisation and co-ordination are required to establish a joint program on material fluxes in the study region as a core project of LOICZ and JGOFS with focus on both field experiment and model development. With this program, a more complete, up-to-date and reliable data base can be built up for future budgeting exercises.

3.2 North Sea Budget

Prepared by W. Helder, C. Schrum, G. Shimmield

Compared to some of the other target areas addressed during this workshop, a wealth of data sets on physical, chemical, and biological parameters is available for the North Sea system. The collection of these data has been triggered in the last few decades especially by the potential harmful effects associated with fishing, shipping, eutrophication, and riverborne and atmospheric contaminants. Some of the most important characteristics of the North Sea can be summarised as follows:

It is a shallow coastal sea (20 - 600 m) with exchanges with the Northern Atlantic through the narrow English Channel in the south and a large northern boundary. The North Sea is connected to the Baltic Sea through the Skagerrak between Denmark and Norway, with inflow along the southern margin and an outflow to the north. In addition to the fresh water inputs from the Baltic, the continental and British rivers provide inputs (Figure 6).

Figure 6. Map of the North Sea.

The residual current pattern in the North Sea is dominated by inflow from the North Atlantic through the Fair Island Channel (between the Orkneys and Shetland) and by a confined outflow through the relatively deep Norwegian Channel. Another residual current pattern moves northward from the Channel in the south along the French, Belgian, Dutch, and Danish coast into the Skagerrak, from where an outflow along the Norwegian coast into the Norwegian Channel is present. In the southern shallow part, the water column is permanently well mixed, while to the north summer stratification occurs.

Due to the strong tidal currents (up to 1 m/s), permanent sedimentation of fine grained particulates is nearly absent from the North Sea apart from the area of the German Bight. Most of the particulates settle in the Skagerrak and the nearby Norwegian coast. Recent estimates of sediment accumulation within these areas indicate that the amount of settling particulate matter is significantly higher than given here based on previous estimates from water transport and suspended matter concentrations.

Figure only available in hard copy

Figure 7. ICES Boxes for the North Sea - The boxes with two numbers , e.g., 1/11, are divided into surface (1) and deep (11) portions.

Due to its restricted depth there is a tight benthic-pelagic coupling and a large part of the primary production (about 200 g C m^{-2} yr^{-1}) is remineralised at the sediment surface and within the sediment. Thus the Sediment Oxygen Demand (SOD) values can be up to 37 mol m^{-2} yr^{-1}, which leads locally, in the German Bight, to oxygen depletion within the water column in the summer months. Given the high inputs of organic matter to the sediments, apart from oxygen consumption, denitrification and sulphate reduction are important in sedimentary carbon recycling

Methodology

Budgets for DIN and DIP were made for the North Sea using the volumes as defined by the 10 International Commission for the Exploration of the Seas (ICES) boxes (Figure 7). A water volume budget was made based on precipitation/evaporation and river runoff data for the North Sea (Damm, pers. comm.) and for the Baltic Sea (Bergstroem and Carlson, 1995; Omstedt *et al.,* 1996) (Figure 8). A detailed differentiation of the residual circulation by developing a salt budget was impossible because the North Sea inflow consists of two different water masses (English Channel water and North Atlantic water) and two different outflow water masses (Norwegian Coastal Current upper and lower layer). Thus, modelled transport values (Lenhart *et al.*, 1995, Pohlmann, 1996) were used to carry out the budget calculations for phosphorus and nitrogen. The modelled transports overestimated the Baltic Sea outflow by a factor of five. This is caused by boundary problems in the North Sea model, at the Baltic Sea boundary. The modelled volume transport from the Baltic Sea to the North Sea was therefore corrected. Instead of modelled Baltic Sea inflow we used the data based on budget considerations (precipitation/evaporation and river runoff to the Baltic Sea). Consequently, the modelled Norwegian Coastal Current outflow had to be reduced by the difference between modelled Baltic Sea outflow and budget estimated Baltic Sea outflow, to fulfil the water budget. The fluxes of phosphorus and nitrogen (Figure 9 and 10) for the Baltic inflow are represented by the subscript “in”. Annual mean nutrient concentrations in the ICES boxes were derived from Radach *et al*. (1996). In those boxes (Norwegian Coastal current, Atlantic Inflow) where stratification is manifest, transport weighted averages between upper and lower layers were used (Figure 8). An additional budget for the DIP was carried out without considering the stratified nature of the in- and outflows.

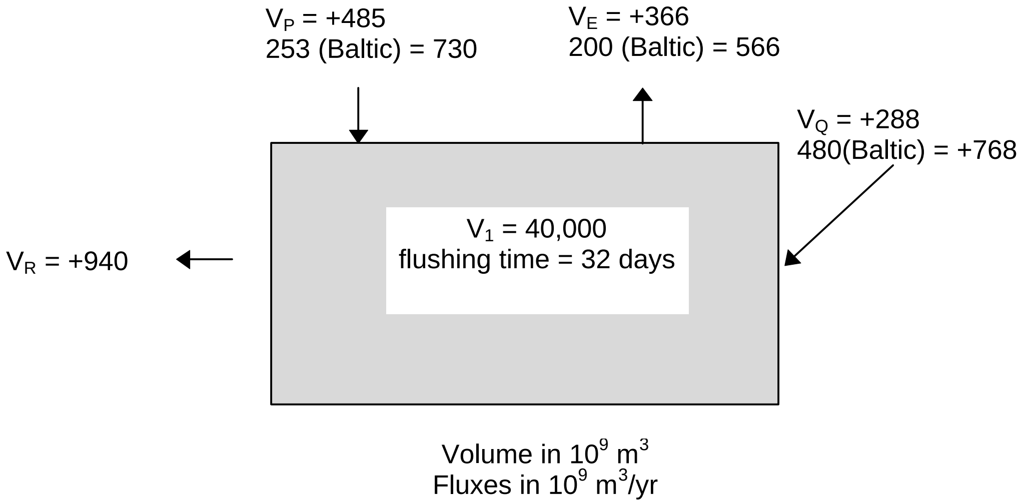
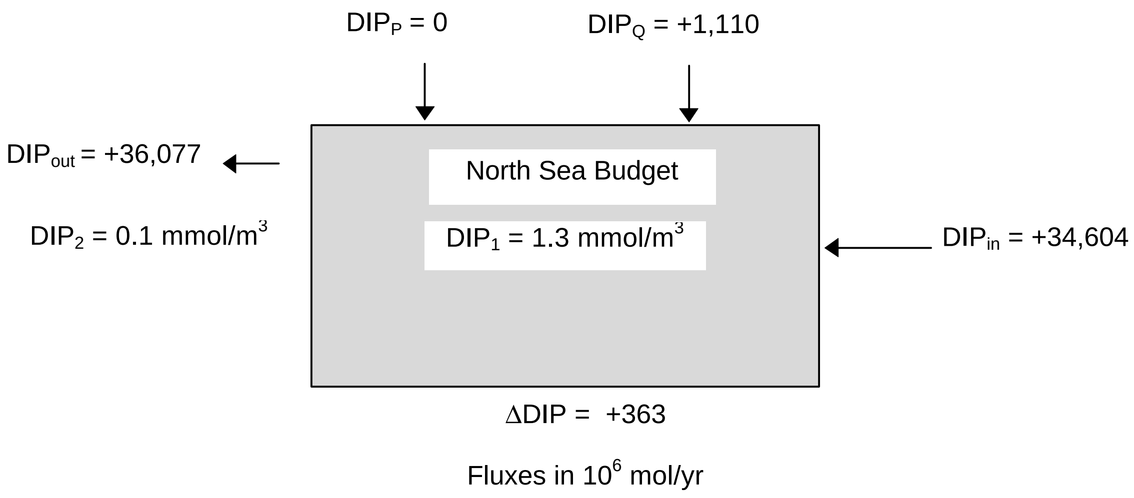


Figure 8. North Sea Water budget. Fluxes determined from 3-d numerical model, except for inflow from the Baltic. This is determined from a water budget for the region.

The DIP budgets for the whole North Sea (Figure 9) were compared to a DIP budget for the shallow North Sea, excluding the ICES boxes number 1, 2 and 3, i.e. excluding the Skagerrak. DIN-Budgets (Figure 10) were made for the whole North Sea, both for nitrate and ammonium. Further the LOICZ-modelling guidelines were followed to estimate ΔDIC, i.e. (p-r), and (Nfix-denit).



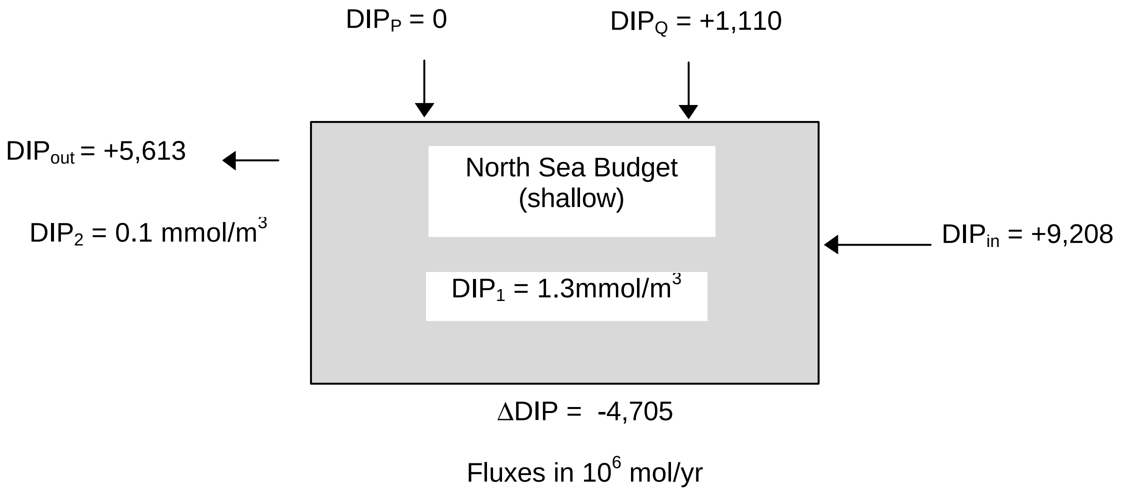


Figure 9. DIP budget for the whole North Sea (top) and for the North Sea excluding the Skagerrak (bottom).

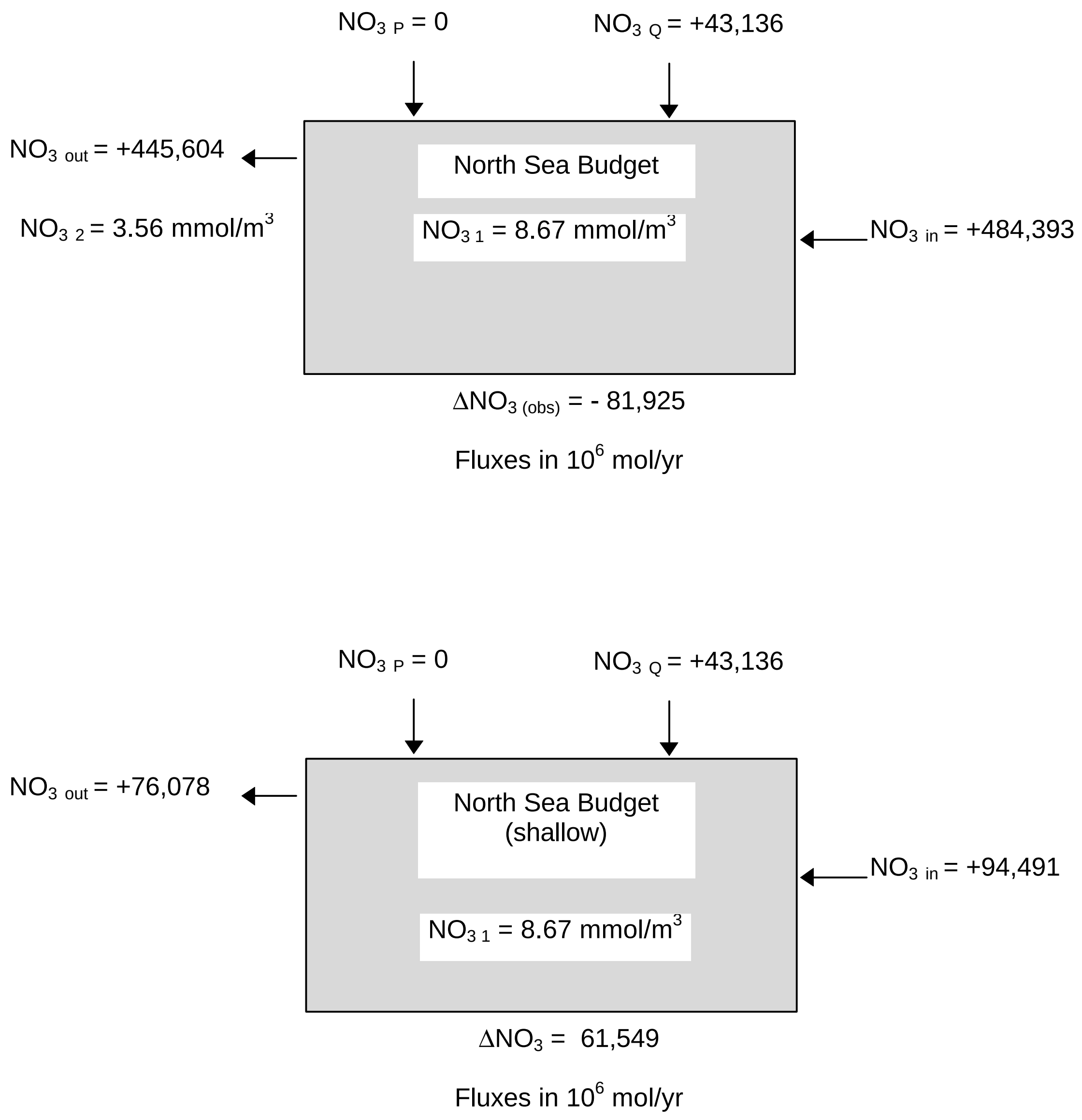
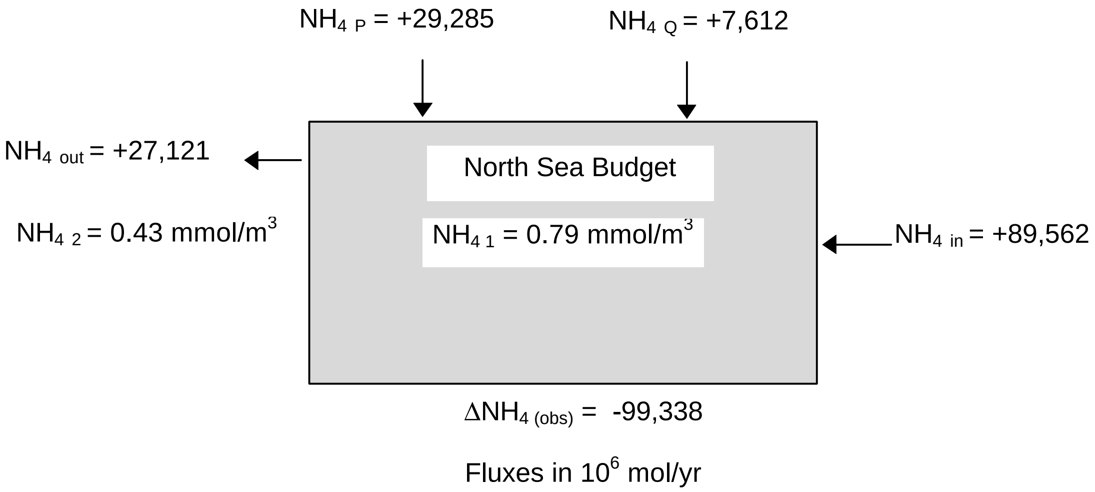


Figure 10. NO_3 budget for the whole North Sea (top) and for the shallow North Sea excluding the Skagerrak (bottom).



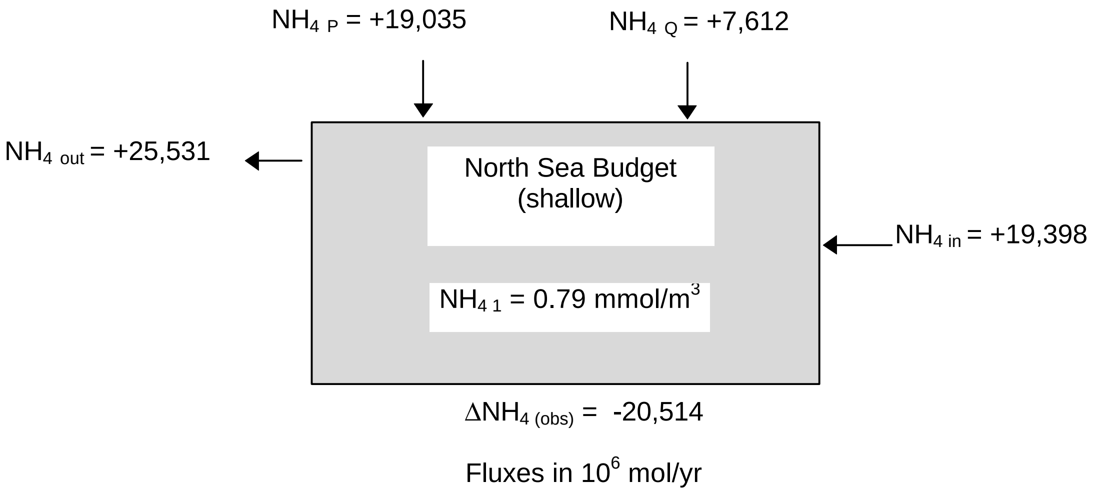


Figure 11. NH_4 budget for the whole North Sea (top) and for the shallow North Sea excluding the Skagerrak (bottom).

Results

When we compare the different ΔDIP, as calculated in the budgets presented above, with the one based on the results of Radach and Lenhart (1995) and Brockmann *et al*. (1990) we find that the estimated ΔDIP values, and consequently also the ΔDIC_o values, are significantly different, even in sign:

Table 1. Various measures for North Sea Fluxes.

	ΔDIP (mol/yr)	Area (km^2)	ΔDIC_{org} (mol m^{-2} yr^{-1})
1. Radach and Lenhart:	$+273 \times 10^6$	513,000	+0.05
2. Brockmann *et al.*:	$+4{,}162 \times 10^6$	513,000	+0.9
3. North Sea ICES-10	$+363 \times 10^6$	513,000	+0.08
4. unstratified North Sea	$-6{,}258 \times 10^6$	513,000	-1.3
5. shallow North Sea	$-4{,}705 \times 10^6$	336,176	-1.5

In the case 3, which is the most advanced budget for the whole North Sea, the calculated export of DIP shows that production and respiration are about in balance. However, the difference between respiration and production for the whole North Sea area is small, in the order of 0.5 % of the primary production in the North Sea. Considering the uncertainties in the budget calculations (seasonal variations are not considered, model based transports are used), the North Sea is seen to behave neutrally with respect to the uptake or release of DIP. By comparing the budgets for the whole North Sea with that for only the shallow portions, two regions with significantly different levels of processing can be distinguished. In the shallow North Sea area, that is without boxes 2 and 3 (Figure 7), the production exceeds respiration considerably, whereas in the Norwegian Trench which is known to be the main area for sedimentation in the North Sea, there is a net source for DIP.

By comparison between the nitrate and ammonium budgets, it could be concluded, that the ammonium contribution to a total DIN budget is in the same order as the nitrate contribution, due to the significant small ammonium outflow. Neglecting to include ammonium in the budget calculation of DIN leads therefore to a considerable underestimation of the ΔDIN. Thus ΔDIN_{obs} for the whole of the North Sea, from Figures 10 and 11, is $-181{,}262 \times 10^6$ mol/yr; for the shallow North Sea it is $-82{,}063 \times 10^6$ mol/yr. From ΔDIP for the whole North Sea, there is a predicted ΔDIN of $16 \times 363 \times 10^6$ mol/yr, or $+5{,}808 \times 10^6$ mol/yr. The discrepancy between the observed and expected is $-187{,}071 \times 10^6$ mol/yr. This discrepancy is attributed to (*nfix-denit)* equivalent to -0.4 mol m^{-2} yr^{-1}, or net denitrification of this amount across the whole North Sea. A similar calculation for the shallow North Sea gives a value of -0.02 mol m^{-2} yr^{-1}, that is near 0. It is well established that denitrification does occur in the shallow North Sea, so the calculations imply that nitrogen fixation and denitrification in this region are about in balance.

3.3 Peru-Chile coast - *Prepared by R.A. Olivieri and F.P. Chavez*[*]

Introduction

The purpose of this report is to summarise our understanding of the fluxes of carbon, nitrogen and phosphorus (C:N:P) in the Peru-Chile coastal zone. For this report we defined the Peru-Chile system as the area of Western South America (Figure 12) where coastal upwelling is the dominant physical mechanism controlling biogeochemical fluxes of C:N:P. The North-South boundaries of the system are ~4° S and 40° S latitudes. The presence of upwelling favourable winds and the pattern of coastal ocean circulation define these boundaries (Parrish *et al.*, 1983; Thomas *et al*., 1994, Strub *et al*., 1995, Strub *et al*., in press).

Upwelling brings water rich in nutrients to the surface, where it fuels an increase in phytoplankton biomass and primary production (Barber and Smith, 1981) that sustain one of the more important fisheries in the world (Ryther, 1969). The surface phytoplankton biomass frequently exceeds 10 mg Chl m^{-3} (Chavez, 1995) with an annual average primary production of 833 g C m^{-2} yr^{-1} (Chavez and Barber, 1987). The increase in planktonic metabolic activity should accelerate biogeochemical fluxes: however our understanding of these fluxes and their consequence for the Peru-Chile coastal system, as well as other coastal areas, is still very limited (Walsh, 1991). Our focus will be on developing a preliminary budget of nitrogen starting from nitrate, and from there use Redfield ratios to approximate the C and P budgets for the Peru-Chile system.

Environmental Setting

The Peru-Chile coastline is a straight coastline without major indentations or bays (Figure 12). The Peru coast is aligned in a Northwest to Southeast direction, while the Chile region is primarily North-South. The continental shelf is very narrow, in some areas practically non-existent, therefore we decided that the 200 m isobath did not adequately define the offshore boundary of the coastal system as suggested by Gordon *et al.* (1995). Instead we used the scale of the Rossby radius of deformation to define the offshore boundary of the coastal upwelling process, and therefore of the coastal system (Barber and Smith, 1981, Chavez and Barber, 1987). The Rossby radius depends on coriolis, and therefore on latitude, thus it changes from about 270 km at 4° S, to 46 Km at 24° S (Chavez and Barber, 1987). From then on, the rate of change of the Rossby radius is slower, decreasing to about 29 km at 40° S

Upwelling favourable winds are seasonal, but occur throughout most of the year from about the 4° S latitude to about 40° S (Thomas *et al.* 1994, Strub *et al.,* in press). The amount of nutrient upwelled depends not only on the South Pacific high that drives the long-shore winds, (Strub *et al*., in press) but also in remote atmospheric-oceanographic forcing mechanisms (Chavez and Brusca, 1991). The Peru coastline has the strongest upwelling of the system, with higher intensity during the austral winter (Bakun 1987, Thomas *et al*., 1994, Strub *et al*., in press). The seasonal upwelling cycle changes with latitude. The strongest upwelling favourable winds are found during July-August (austral winter) off Peru and during December - January (austral spring and summer) off Chile (Thomas *et al*., 1994, Strub *et al*., in press)

Budget Development:

The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al*., 1995) were used, with some variations, for preliminary development of C:N:P budgets for the coastal system of Peru-Chile. The budgets were developed around nitrate instead of phosphate, as nitrate was assumed to be the major limiting nutrient in the system because of the active denitrification found in the region (Codispoti and Christensen, 1985; Codispoti *et al.*, 1986; Ward *et al.*, 1989). The lack of significant runoff, due to the low precipitation and exchange which is rapid relative to evaporation, prevented the development of salt budgets that could be used to trace the water masses. Instead movement of waters was calculated from the rates of upwelling for the area (Wyrtki, 1963; Bakun and Mendelssohn, 1989). Emphasis was given to the area between 6° to 24° S, as this area was the one with the largest amounts of information available. A budget was not fully developed for the lower third of the system (latitude 24° to 40° S), because of the paucity of information, although in many aspects this section may be similar to the central and Northern California upwelling system (Strub *et al.,* in press). This section of the Chilean coastline is also influenced by significant runoff that enters the system through the fjords of Southern Chile.

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[*] F.P. Chavez did not attend the workshop, contributions were made before and after the workshop.

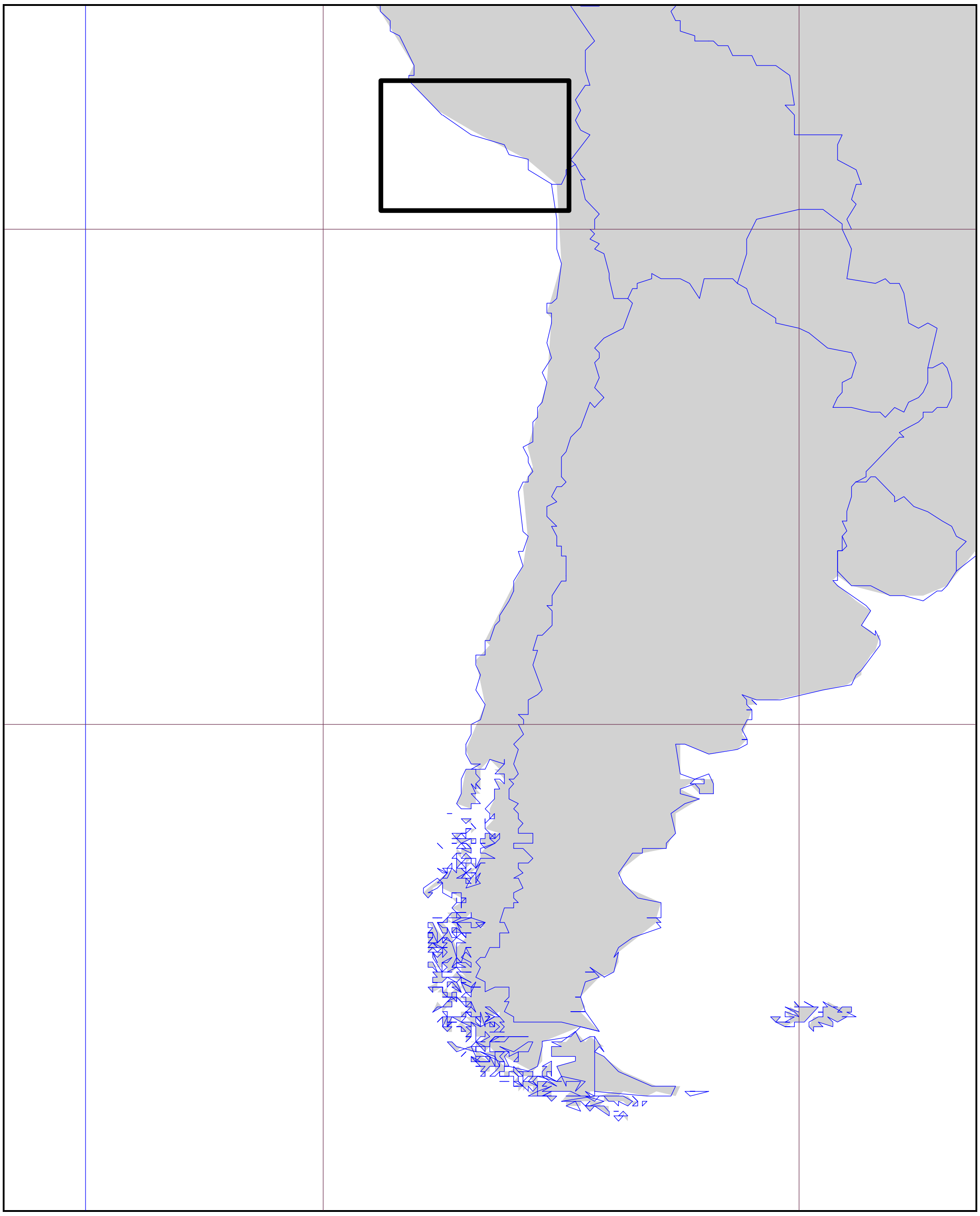

Figure 12. Map of Chile-Peru Coastline with box around area of interest - approximately 6^o to 16^o S.

The assumptions, dimension, and some estimates of upwelling processes will be presented and used to develop a simple preliminary budget of nitrate. Secondly N:P budgets will be developed for different scenarios in which the concentration of nutrients in the surface water are used in conjunction with estimated inputs from below the mixed layer to calculate new, as export, production. These values will be compared with the published rates for primary production for the system.

For the calculation of budgets of water and nutrient fluxes, the Peru Chile coastal upwelling system was divided conceptually into two layers. The upper (surface) layer representing the shallow mixed layer with high primary production, lower nutrients, and offshore flow; and the lower (source) layer with high nutrients, low oxygen levels and high denitrification (Barber and Smith, 1981). The volume of water that upwells into surface waters across the 100 m level between 6 ^{o}S to 24 ^{o}S was assumed to be equal to 1 x 10^{14} m^3 yr^{-1} (Wyrtki, 1963, in Chavez and Barber, 1987). By estimating a coastline length of 1,300 km between latitudes 6^{o} S to 16^{o} S, and a mean upwelling index of 1.883 m^3 sec^{-1} m^{-1} of coastal length (from wind stress values in Bakun and Mendelssohn, 1989) an upwelling volume of 7.92 x 10^{13} m^3 yr^{-1} was calculated. Thus, 79% of the water that upwells between 6 ^{o}S to 24 ^{o}S, reaches the surface mixed layer between 6^{o} S and 16^{o} S. The uneven distribution along the coast suggests that most of the nutrient supply to the upper mixed layer should occurs north of 16^{o} S, and therefore the northern area should have higher primary production. Indeed, the November 1978 to June 1986 phytoplankton pigment composite image from the Nimbus-7 Coastal Zone Colour Scanner (CZCS) (http://seawifs.gsfc.nasa.gov/seawifs_scripts/czcs_subreg.pl) for the Peru-Chile system suggests that the coastal waters between 6^{o} S to 16^{o} S have a wider zone of high pigment concentration, while the area from 16^{o} S to 24^{o} S had a narrower distribution. The 7.9 x 10^{13} m^3 yr^{-1} volume of upwelled water divided by the corresponding area of the Rossby radius of deformation, (calculated by trapezoidal integration) gives an upwelling velocity of 666 m yr^{-1} or 2 x 10^{-3} m sec^{-1}, which is identical to the value described by Codispoti and Christensen (1985) as "reasonable average upwelling velocity for this region." Using a mixed layer depth of 20 m, (Brink *et al.,* 1980, in Mann and Lazier, 1991) and the assumption that the upwelled water is advected offshore (Barber and Smith, 1981), a residence time of 11 days was calculated for water in the upper layer of the coastal system. The residence time, in conjunction with an average Rossby radius of deformation of 90 Km gives an average offshore velocity of 10 cm sec^{-1}, which is similar to the offshore surface flow of 15 cm sec^{-1} reported by Brink *et al.,* (1980, in Mann & Lazier, 1991) for the coast of Peru.

Assuming a NO_3 concentration of 20 mmol m^{-3} for the source of upwelling water below the mixed layer (Chavez and Toggweiler, 1995), and the upwelling volume calculated above for 6^{o} S to 16^{O} S segment results in a potential new production of 1,580 x 10^{12} mol NO_3 (Figure 13). The primary productivity from C^{14} measurements (Chavez and Barber 1987) for the same area was estimated to be 8.3 x 10^{12} mol C yr^{-1} that converted to nitrogen via Redfield ratios gives 1.25 x 10^{12} mol N yr^{-l}. A f-ratio of 0.7 for coastal nutrient rich water gives a new production of 8.75 x 10^{11} mol N yr^{-1}. The difference between the potential new production and the estimated new production results in a surplus of 705 x 10^{9} mol NO_3, or 45% of the input NO_3, that is exported out of the Rossby radius before being consumed by phytoplankton. This excess of nitrate would then be advected offshore to fuel open ocean communities at a concentration of about 9 mmol NO_3 m^{-3}. This concentration is about twice the mean of 4.6 mmol m^{-3}, but within range of reported values for the coast of Peru by Harrison *et al.* (1981).

A similar calculation can be made for the section between 16^{o} S and 24^{o} S using an upwelling volume of 2.08 x 10^{13} m^3 yr^{-1} (from the difference of the volume by Wyrtki (1963) for 6^{o} S to 24^{o} S, and the above calculated volume for the 6^{o} S to 16^{o} S segment). The calculation results in a potential new production of 4.16 x 10^{11} mol NO_3 and estimated new production of 3.65 x 10^{11} mol NO_3. The nitrate not used and potentially available for offshore export is about 12% of the input, at a concentration of 2.4 mmol NO_3 m^{-3} . The estimated average upwelling index for this region was 0.58 m^3 (sec m coast)$^{-1}$, which was similar to the average of 0.68 m^3 (sec m coast)$^{-1}$ calculated for the California coast at 37^{o} N (From values in Mason and Bakun, 1986). If we assume the same upwelling rate for the 24^{o} S to 40^{o} S segment, then potential new production (from upwelling only) in that region would be 6.5 x 10^{11} mol NO_3 yr^{-1}. Thus, the total potential new production for the Peru-Chile area from 6^{o} S to 40^{o} S would be 2.65 x 10^{12} mol NO_3 or via Redfield ratio, 1.8 x 10^{13} mol C yr^{-1} or 0.2 gt C yr^{-1}. This potential new production is almost 3% of the global total, and 25% of all coastal upwelling regions (Chavez and Toggweiler, 1995).

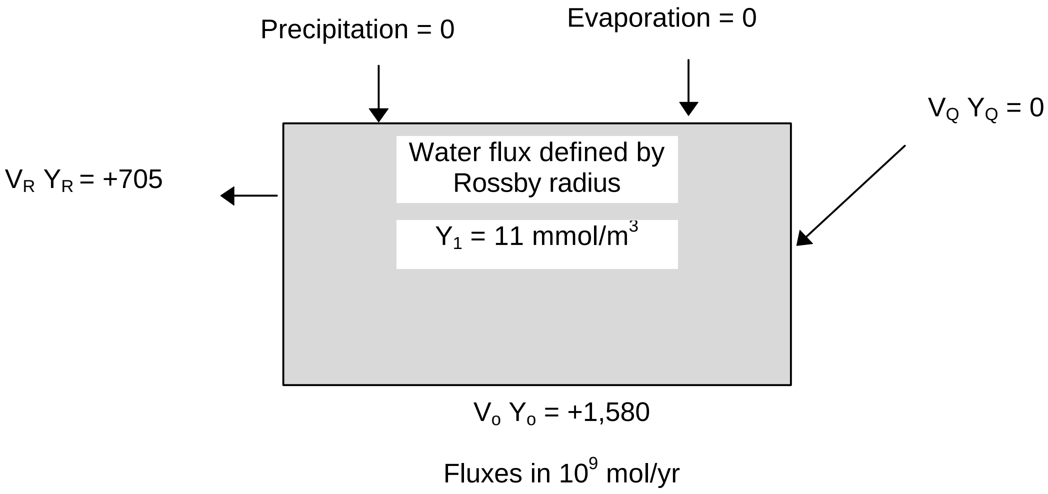

Figure 13. NO_3 budget for Peru coast between 6° S and 16° S.

A mass balance budget for N and P in the surface layer was first built for the section of 6° S to 24° S using a NO_3 concentration of 20 mmol m^{-3} at the source (Chavez and Toggweiler, 1995) and a surface concentration of 4.6 mmol NO_3 m^{-3} and a 1.1 mmol PO_4 m^{-3} (Harrison *et al.,* 1981). The nutrient concentration in surface waters was assumed to be the balance between input from the sources below and phytoplankton uptake, and was expected to be the one available for offshore advection. An f ratio of 0.7 was used, characteristic of nutrient-rich waters. Nutrient inputs from runoff were assumed to be negligible, because of the very low precipitation.

Uptake of NO_3 = (source concentration - surface concentration) (upwelling velocity)
= (20 mmol m^{-3} - 4.6 mmol m^{-3}) (1.73 m d^{-1})

Uptake of NO_3 = 26.6 mmol m^{-2} d^{-1}

$$\text{f-ratio} = \frac{\text{uptake } NO_3}{\text{uptake } NO_3 + \text{uptake } NH_4}$$

$$\text{Uptake } NH_4 = \frac{\text{uptake } NO_3 - [(\text{f ratio})(\text{uptake } NO_3)]}{\text{f-ratio}}$$

$$= \frac{26.6 \text{ mmol m}^{-2} \text{ d}^{-1} - [(0.7)(26.6 \text{ mmol m}^{-2} \text{ d}^{-1})]}{0.7}$$

Uptake NH_4 = 11.4 mmol m^{-2} d^{-1}

Total DIN uptake= NO_3 uptake + NH4 uptake
= 26.6 mmol m^{-2} d^{-1}+11.4 mmol m^{-2} d^{-1}
= 38 mmol N m^{-2} d^{-1}

Total Prim. Prod.= (38 mmol N m^{-2} d^{-1}) (6.625 mmol C / mmol N) (12 g C / mmol C)
= 3021 mg C m^{-2} d^{-1}
= 92 mol C m^{-2} yr^{-1}

Which is about 31% more of what is reported by Chavez & Barber (1987) as annual mean for the area.

Assuming a Redfield uptake of nutrients then:

$$\text{PO}_4\text{ uptake} = \frac{\text{NO}_3\text{ uptake}}{\text{N:P Redfield ratio}}$$

$$= \frac{26.6\text{ mmol m}^{-2}\text{ d}^{-1}}{16\text{ mmol N /mmol P}}$$

$$\text{PO}_4\text{ uptake} = 1.66\text{ mmol m}^{-2}\text{ d}^{-1}$$

$$\text{PO}_4\text{ at source} = \frac{(\text{uptake PO}_4)}{\text{Upwelling velocity}} + \text{surface PO}_4$$

$$= \frac{1.66\text{ mmol PO}_4\text{ m}^{-2}\text{ d}^{-1}}{1.73\text{ m d}^{-1}} + 1.1\text{ mmol PO}_4\text{ m}^{-3}$$

$$\text{PO}_4\text{ at source} = 2.06\text{ mmol PO}_4\text{ m}^{-3}$$

Therefore N:P ratio at source is

$$= \frac{20\text{ mmol NO}_3\text{ m}^{-3}}{2.06\text{ mmol PO}_4\text{ m}^{-3}}$$

$$= 9.7$$

This ratio is lower than the 16:1 Redfield ratio, and is likely the result of denitrification.

Another approach is to use the values of Harrison *et al.* (1981) and assume a PO_4 at source of 3 mmol m^{-3}.

$$\text{PO}_4\text{ uptake} = (\text{source concentration - surface concentration})\ (\text{Upwelling velocity})$$

$$= (3.0 - 1.1\text{ mmol m}^{-3})\ (1.73\text{ m d}^{-1})$$

$$= 3.3\text{ mmol m}^{-2}\text{ d}^{-1}$$

Then if the nitrate uptake follows the Redfield ratio, it would be equal to

$$\text{NO}_3\text{ uptake} = (3.3\text{ mmol m}^{-2}\text{ d}^{-1})\ (16)$$

$$= 52.8\text{ mmol NO}_3\text{ m}^{-2}\text{ d}^{-1}$$

and with an f - ratio of 0. 7

$$\text{NH4 uptake} = 22.6\text{ mmol NH}_4\text{ m}^{-2}\text{ d}^{-1}$$

$$\text{Total DIN uptake} = 52.8\text{ mmol NO}_3\text{ m}^{-2}\text{ d}^{-1} + 22.6\text{ mmol NH}_4\text{ m}^{-2}\text{ d}^{-1}$$

$$= 75.4\text{ mmol N m}^{-2}\text{ d}^{-1}$$

which yield via Redfield ratios 5972 mg C $\text{m}^{-2}\text{ d}^{-1}$, or 182 mol C $\text{m}^{-2}\text{ yr}^{-1}$; more than twice the mean values measured by Chavez and Barber (1987), but within the range reported by Barber and Smith (1981, in Chavez and Barber, 1987).

$$\text{The nitrate at source} = \frac{\text{Nitrate uptake}}{\text{upwelling velocity}} + \text{nitrate at surface}$$

$$= \frac{52.8\text{ mmol N m}^{-2}\text{ d}^{-1}}{1.73\text{ m d}^{-1}} + 4.6\text{ mmol N m}^{-3}$$

$$\text{The nitrate at source} = 35\text{ mmol m}^{-3}$$

$$\text{The N:P at source is} = \frac{\text{NO}_3\text{ concentration at source}}{\text{PO}_4\text{ concentration at source}}$$

$$= \frac{35\text{ mmol NO}_3\text{ m}^{-3}}{3\text{ mmol PO}_4\text{ m}^{-3}}$$

$$= 12$$

The N:P ratio of 12 is higher than in the previous example, but it is still lower than Redfield ratios. However the nitrate concentration at the source is higher than the values reported for the area , especially with the strong denitrification that is known to occurred below the mixed layer (Codispoti and Christensen, 1985; Codispoti *et al.*, 1986; Ward *et al.*, 1989)

A third scenario is one in which Harrison *et al.* (1981) surface nutrient concentration were used in conjunction with a NO_3 concentration of 20 mmol m^{-3} below the mixed layer and a N:P ratio of 8 (typical of water with high denitrification)

if N:P ratio at upwelling source is equal to 8, then:

$$PO_4 \text{ at source} = \frac{\text{concentration } NO_3}{8}$$

$$= 2.5 \text{ mmol } PO_4 \text{ m}^{-3}$$

$$PO_4 \text{ uptake} = (\text{source concentration - surface concentration})(\text{upwelling velocity})$$

$$= (2.5 \text{ mmol } PO_4 \text{ m}^{-3} - 1.1 \text{ mmol } PO_4 \text{ m}^{-3})\ (1.73 \text{ m d}^{-1})$$

$$= 2.4 \text{ mmol m}^{-2} \text{ d}^{-1}$$

$$NO_3 \text{ uptake} = (\text{uptake Of } PO_4) * (16 \text{ Redfield})$$

$$= 38.4 \text{ mmol } NO_3 \text{ m}^{-2} \text{ d}^{-1}$$

Then expected NO_3 concentration at source

$$\text{expected } NO_3 \text{ at source} = NO_3 \text{ concentration at surface} + \frac{NO_3 \text{ uptake}}{\text{upwelling velocities}}$$

$$= 4.6 \text{ mmol } NO_3 \text{ m}^{-3} + \frac{38.4 \text{ mmol } NO_3 \text{ m}^{-2} \text{ d}^{-1}}{1.73 \text{ m d}^{-1}}$$

$$\text{expected } NO_3 \text{ at source} = 27 \text{ mmol } NO_3 \text{ m}^{-3}$$

which results in a deficit of 7 mmol m^{-3} of NO_3, when the expected NO_3 concentration of the source is compared to the 20 mmol m^{-3} assumed initially.

These calculations highlight the importance of denitrification for the 6 to 16°S region. It will be interesting to complete the same calculations for the Southern regions. A priori one would expect that the effects of denitrification to be less evident. It was also encouraging to see that the distribution of chlorophyll from CZCS for the area along the coast of Peru and Northern Chile was consistent with our calculations of primary productivity from water transport and nitrate concentration. Finally the predicted annual productivity for the coast of Peru was only about 31% higher than the one calculated from more than 75 measurements for the area by Chavez and Barber (1987). The calculations showed how sensitive the budget calculations are to the initial values and assumptions used. The next step should be to increase the accuracy and confidence in the initial values by compiling historical measurements and making new ones. Then one could begin to increase the spatial and temporal scales of the budgets. The southern coast of Chile requires additional focus since biochemical fluxes in this region are affected not only by upwelling, but also by land runoff and the presence of an expanded continental shelf.

3.4 Gulf of Guinea

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Introduction

The Gulf of Guinea shelf lies on the west coast of Africa in the Equatorial region between latitudes 7°S-7° N and longitudes 12° E-8° W (Figure 14). To the west of 8°E, the coastline trend is eastwest; to the east, the trend is NNW-SSE. Eleven countries (Angola, Benin, Cameroon, Congo, Cote d'Ivoire, Equatorial Guinea, Gabon, Ghana, Nigeria, Togo, Zaire) abut the coast. The total coastline length is about 4,000 km, with a narrow shelf averaging approximately 40 km. The average shelf break is approximately 100 m depth, with a mean depth across the shelf of approximately 50 m. Two very large rivers (Congo [Zaire], Niger), several other large rivers, and many smaller rivers discharge approximately 2.4 X 10^{12} m^3/yr from a total catchment area of 5 x 10^6 km^2.

Data are sparse for this region, and not collected into any central repository. As a result, budgeting according to the biogeochemical guidelines in this region is difficult and budgetary calculations must be regarded as highly preliminary. Nevertheless, the budgetary exercise was pursued in two ways, as a general "scoping exercise":

First, a knowledge of littoral sediment circulation cells along the coast was used to divide the coast into three main regions each of which seemed likely to have internally homogeneous circulation; very preliminary water salt budget calculations are used to calculate water residence time within these regions. Data were insufficient to develop budgets for dissolved C, N or P for the shelf. The results of these water/salt budget calculations are presented.

Second, it was recognised that much of the river inflow to this coast enters the open shelf via lagoons. Because much of the population of these 11 nations lives along the coast and discharge much of their waste products into the lagoons, river composition is severely modified before it reaches the open shelf. It was felt that there might be enough data available to build preliminary water, salt, and nutrient budgets for several lagoonal systems. Three lagoonal systems were chosen for analysis as samples of what might be possible, with the recognition that data may also exist for other systems. It was also recognised, from examination of maps of the region, that many features (especially in the Niger River delta) have the morphology more classically associated with estuaries and that future efforts might include budgeting some of these systems.

Open Shelf Water and Salt Budgets

It was recognised that the open shelf circulation could best be characterised as "quasi-estuarine," with a surface outflow layer of relatively low salinity water due to river dilution of the open coastal waters and deep inflow of somewhat more saline oceanic water. The LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.*, 1996) were therefore used to develop a simple conceptual framework. The system (with a volume of V_{syst}) is assumed to be at steady state; that is dV_{syst}/dt, $dS_{syst}/dt = 0$. River inflow (V_Q) is known. Rainfall, evaporation, groundwater, and any other water sources are assumed to be 0 (i.e., small, relative to V_Q). Deep inflow (V_{in}) is not known. Surface outflow (V_{out}) is the sum of V_Q + V_{in}. Salinity of the water flowing out of the system (S_{syst}) and that of the inflowing water (S_{in}) are known. These assumptions are illustrated in Figure 14 and allow us to write the following equations:

$$dV_{syst}/dt = 0 = V_Q + V_{in} - V_{out} \qquad (1)$$

$$d(V_{syst}S_{syst})/dt = 0 = V_{in}S_{in} - V_{out}S_{out} \qquad (2)$$

Further, the water residence time in the system (∴) can be calculated as the system volume (V_{syst}) divided by water outflow (V_{out}):

$$\tau = V_{syst}/V_{out} \qquad (3)$$

The shelf was divided into the following regions (Figure 14): Cape Palmas-NW flank of the Niger delta; combined western and eastern drift cells of the Niger delta; northward drift from the Congo (Zaire) River (Awosika and Ibe, *in press*). The relevant statistics of these cells are reported in Table 2.

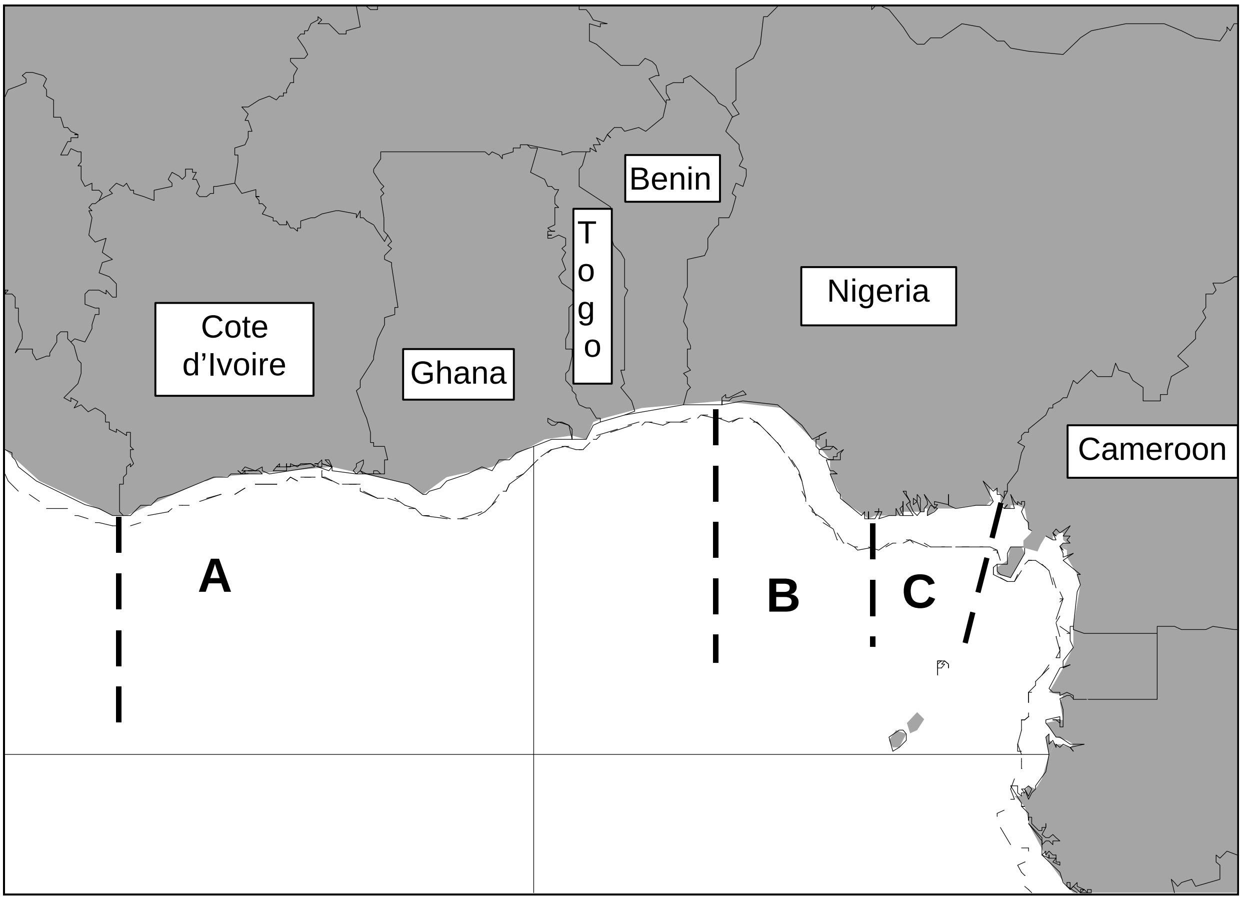

Figure 14. Map of the Gulf of Guinea shelf, showing boundaries between circulation cells used for water and salt budgeting.

Table 2. Calculations of water exchange and residence time for the three circulation cells of the Gulf of Guinea shelf.

SYSTEM	A: Palmas-West Niger	B: Niger - Calabar Estuary	C: Rio del Rey - Congo River
coast length (km)	1,450	660	1,870
coast width (km)	50	50	35
average depth (m)	50	50	50
volume (10^9 m^3)	3,625	1,650	3,273
V_Q(10^9 m^3/yr)	100	1,000	1,260
S_{syst} (psu)	32	28	26
S_{in} (psu)	35	35	35
V_{in} (10^9 m^3/yr)	1,067	4,000	3,640
V_{out} (10^9 m^3/yr)	1,167	5,000	4,900
(τ)	3.1	0.3	0.7

These calculations suggest that water moving westward across the east-west trending arm of the shelf may be held against the shelf for several years. In the region of the Niger delta, flow off the shelf apparently occurs in about four months, while water moving northward from the Congo appears to stay on the shelf for about 8 months. It must be cautioned that these calculations are very preliminary, pending better estimates of both freshwater inflow and salinity, especially on the shelf (where the salinity variation can be large). Nevertheless, the view of the regional participants was that in qualitative terms these sorts of exchange times seemed reasonable. Data were not available at the workshop to develop nutrient budgets, although several workshop participants felt it was likely that some relevant hydrographic data could probably be located in overseas data banks.

Coastal Lagoon Budgets

Because of the likely importance of coastal lagoons in processing riverine material before it reaches the open coast, and because the regional participants felt that there might be sufficient data to budget some of these systems, three lagoons were selected as case studies: Ebrie Lagoon (Cote d'Ivoire), Korle Lagoon (Ghana), and the Lagos-Epe-Lekki Lagoon complex (Nigeria). Each of these is discussed below.

Ebrie Lagoon—This system has been well described by various authors, and a preliminary version of this final budget was presented in the opening plenary session by Kaba . Because that budget was essentially complete and is included here, there is no abstract given in Appendix 1.

This system (area = 5.7×10^8 m^2, depth = 4.8 m volume = 2.7×10^9 m^3) has a watershed area of 9.4×10^{10} m^2. A population of approximately 4,000,000 lives in the city of Abidjan and discharges its wastes into this lagoon. River flow, precipitation, and freshwater discharge in sewage are estimated to be respectively 9.5, 1.2, and 0.015 x 10^9 m^3/yr. Evaporation is estimated at 0.7 x 10^9 m^3/yr. Data on groundwater flow are unavailable, but this input is assumed to be small. Average system salinity is about 25 psu, while local open coastal seawater averages about 35 psu. These data allow the calculation of water and salt budgets, following the Guidelines (Gordon *et al.*, 1996). These numbers lead to an estimated lagoon exchange time of approximately 0.07 yr (about 4 weeks).

Waste discharge is estimated to deliver 2.1x 10^6 mol P/yr and 5.6 x 10^8 mol N/yr. It is assumed for these calculations that this delivery is entirely as organic P and N. This is probably not correct and should be checked further. Nutrient delivery in precipitation is estimated at 4.2 x 10^6 mol P/yr and 4.2 x 10^7 mol N/yr, all as inorganic nutrients. Data also exist for nutrient concentrations in inflowing fresh water, the lagoon, and coastal seawater (Table 3).

Table 3. Nutrient concentrations, Ebrie Lagoon.

NUTRIENT	Seawater ($mmol/m^3$)	System ($mmol/m^3$)	River water ($mmol/m^3$)
DIP	1.1	0.7	14
DOP	0.2	0.7	10
DIN	0.7	10.5	22
DON	8.0	21.2	22

We can use the direct sewage and precipitation loads of nutrients and the river concentrations and flow rates together with the data on residual flow and water exchange to calculate nutrient budgets for Ebrie Lagoon. The system is a net sink of DIP, equivalent to about 0.25 mol m^{-2} yr^{-1}. This result would be only slightly shifted if some (or even all) of the P load from waste discharge were attributed to inorganic P. If we assume the DIP sink is organic matter with an approximately Redfield C:P ratio of 106:1, then organic carbon production (*p-r*) = 27 mol C m^{-2} yr^{-1}. This rate seems high. If further checking of available data supports the calculation, it is likely to indicate that quite a high proportion of the primary production in this system is buried.

The system is an apparent net source of DIN (0.17 mol m^{-2} yr^{-1}) and a net DON sink (0.4 mol m^{-2} yr^{-1}). This partitioning between DIN and DON would shift if as much as 20% of the waste discharge is inorganic. While this is indeed likely to be the case, it would not have an impact on the further calculations.

Net nitrogen fixation - denitrification (*nfix-denit*) is calculated as the difference between observed and expected DIN + DON flux, where the expected flux is calculated from Redfield scaling (i.e., N:P = 16:1) of the DIP + DOP flux. Thus, $\Delta(DIN + DON)_{obs}$ = -0.2 mol m^{-2} yr^{-1}; $\Delta(DIN + DON)_{exp}$ = Δ(DIP + DOP) x 16 = -0.39 x 16 = -6.2. These calculations suggest that (*nfix-denit*) = +6.0 mol m^{-2} yr^{-1}. That is, the preliminary calculations suggest that this system is a substantial net nitrogen fixer.

Lagos-Epe-Lekki Lagoon complex—Data available during this workshop were sketchy for this system, but it appears to be one which is amenable to budgeting and for which it may be possible to identify additional data sources. Like Ebrie Lagoon, this system also is the receiving water body for waste discharge from a large city (Lagos; population = 5,000,000 persons). The total area of this lagoonal complex is approximately 690 km^2, and the volume is 1 x 10^9 m^3. River runoff into the system was estimated to be approximately 4 x 10^9 m^3/yr. Rainfall minus evaporation plus groundwater may contribute an additional 2 x 10^9 m^3/yr. Salinity in the lagoon is about 19 psu, while that in the adjacent open ocean is about 28. These figures lead to a residual flow of about -6 x 10^9 m^3/yr, residual salt flux of -141 x kg/yr and a mixing exchange volume of 16 x m^3/yr. The water residence time is thus about 0.05 yr (about 2 weeks).

It is instructive to reflect briefly on why exchange appears so different in comparing this system with Ebrie Lagoon (above). The two systems are rather similar in size, and Ebrie apparently receives more freshwater inflow. In terms of the calculation, the difference lies in the estimated composition of the seawater exchanging with the lagoon. A salinity approximating oceanic is used for Ebrie, while a much lower value is used for Lagos. One would need to assess both systems more closely, in order to understand whether this calculated difference truly reflects a difference in lagoonal exchange rates or application of different criteria for assigning an oceanic value. The point is important in understanding the exchange characteristics of the system. It would matter somewhat less in budgeting the nonconservative fluxes within the lagoon, as long as the salinity and nutrient data used for the outside water are properly matched with one another.

Constructing P and N budgets for Lagos Lagoon proved at once a useful learning exercise and incomplete in terms of closing the budget. Apparently, sufficient data exist for constraining exchange between the lagoon and coast. However the budgets cannot be closed because of insufficient information available at the workshop on runoff, sewage, and perhaps groundwater nutrient discharge to the system. As a result, the nonconservative fluxes of interest to the workshop cannot be calculated. It is hoped that the data can be located to close this budget.

Korle Lagoon—This system provides another useful lesson in the requirements for successful budgetary calculations. The lagoon is a small system (5×10^5 m^2; 1 m deep) adjacent to the city of Accra, and—like the other two lagoons discussed above—it is heavily polluted with waste discharge. River discharge is approximately 8×10^8 m^3/yr. The immediate environment of the lagoon is relatively dry, with evaporation in excess of rainfall during much of the year. Nevertheless, the average river discharge greatly exceeds local rainfall minus evaporation.

The workshop participants began these calculations with the belief that the data set was adequate for budgeting. However, closer inspection of the data demonstrated that during the period for which salinity data were available, the system was actually hypersaline. Hypersalinity in the face of freshwater discharge in excess of salinity leads to the calculation of a negative value for calculated water exchange—an obvious physical impossibility. There are several possible explanations for this dilemma. The most plausible explanation was that the salinity measurements may have been made during a period of low runoff. The data, as available, were insufficient to match the collection time of the freshwater discharge data against that of the salinity data, so this point could not be reconciled during the workshop.

These calculations were therefore abandoned. Nevertheless the attempt is noted here, because the participants felt that this demonstrates an important lesson: Successful budgets do require attention to this level of detail; if the data which go into a budget are seriously in error, the resultant budgets will also be incorrect.

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Appendix 1

INTERNATIONAL WORKSHOP ON CONTINENTAL SHELF FLUXES OF CARBON, NITROGEN AND PHOSPHORUS

October 14-18, 1996
Nigerian Institute for Oceanography and Marine Research
Lagos, Nigeria

MEETING REPORT

SUMMARY REPORT

A1 OPENING

Dr. Larry Awosika, Nigerian Institute for Oceanography and Marine Research (NIOMR) introduced Dr. Benjamin N. Akpati, Acting Director of NIOMR, as the chairman for the opening session. A number of official representatives were introduced to the participants (Appendix 2). Workshop participants briefly introduced themselves and their research interests (Appendix 2).

Dr. Akpati provided the welcoming address (complete text is included as Appendix 4).

A1.1 Mr. Paul Boudreau, LOICZ Core Project Scientist provided a very brief introduction to the International Geosphere-Biosphere Programme (IGBP), Joint Global Ocean Flux Studies (JGOFS) and the Land-Ocean Interactions in the Coastal Zone (LOICZ). He drew attention to the various thematic foci of the IGBP Programme Elements and their aim to work towards the study of global models and analysis. The common field of interest for JGOFS and LOICZ falls between the shallow waters of the estuarine zone and the open ocean.

A1.2 Dr. Julie Hall, co-chair of the Continental Margins Task Team (CMTT) and JGOFS Scientific Steering Committee (SSC) member presented the objectives of the workshop. She outlined the purpose of the workshop which was to:

1. examine the general knowledge about continental shelf fluxes of carbon, nitrogen and phosphorus for four “regions” chosen both to span a wide range of shelf types and a wide range of general knowledge about shelf function; and,
2. develop this information into budgets of conservative and nonconservative fluxes, to the extent possible following a common conceptual protocol laid out in the LOICZ Biogeochemical Modelling Guidelines (Report & Studies No. 5).

It was also outlined that the workshop would publish a short technical report summarising these budgetary fluxes and consider the development of a possible session on continental shelf fluxes at the LOICZ Open Science Meeting to be held in fall, 1997, to more broadly synthesis knowledge on the fluxes of conservative and non-conservative of nutrients on the shelf.

A1.3 Dr. Dublin-Green, NIOMR, officially thanked the invited guests for their attendance.

A2 INITIAL BUDGET PRESENTATION

Professor Stephen Smith, CMTT co-chair and LOICZ SSC Member, initiated this agenda item by making three main points:

- The continental margins are neither regions which passively transmit land-derived materials to the open ocean without reaction nor regions which act (cumulatively) like the other 93% of the world ocean.
- Biogeochemical reactions on continental margins affect both land-derived and ocean-derived reactants delivered to these regions.
- Net fluxes between the continental margins and adjacent areas, not gross fluxes determine the importance of continental margins in global biogeochemical cycles.

A2.1 Initial East China Sea Budgets

EAST CHINA SEA OVERVIEW

by TETSUO YANAGI

The results of a three-dimensional diagnostic calculation on the seasonal variation of current systems in the East China Sea (Yanagi and Takahashi, 1993) were used to characterise the circulation patterns in the sea. They are used here to show the key role that the current plays in the material transport and its budget. A counterclockwise circulation develops in the surface and middle layers of the Yellow Sea during summer but a clockwise one in the bottom layer. On the other hand, a clockwise circulation develops from the surface to the bottom in the Yellow Sea during winter and a counterclockwise one in the East China Sea. Such calculated results coincide with those observed using altimetric data from TOPEX/POSEIDON (Yanagi *et al*., 1996). Such hydrodynamic models will become a very useful tools for the investigation of material transport from the land to the shelf sea and the material exchange at the shelf edge.

East China Sea Budget

by TETSUO YANAGI

Three-dimensional ecological modelling in the East China Sea was conducted on the basis of the observed data by MFLECS in April 1994. Model results quantitatively reproduced the observed DIP, DIN, chlorophyll *a* and detritus distributions.

The riverine DIN load to the East China Sea is 2400 tons/day and the DIN load from the lower water of the Kuroshio and from Taiwan Strait are 11,000 tons/day and 8,300 tons/day, respectively. Such DIN load mainly balances to the PON exports across the Kuroshio and from Tsushima Strait. The riverine DIP load is 52 tons/day and the DIP load from the lower water of the Kuroshio and from Taiwan Strait are 2,500 tons/day and 740 tons/day, respectively. Such DIP load mainly balances to the POP exports across the Kuroshio and from Tsushima Strait.

Carbon Budget In The East China Sea With Uncertainties

by DUNXIN HU

Based on three cruises carried out in October 1993, April 1994 and October 1994, in the East China Sea with MFLECS program, the following calculations were made

-Primary production ranges from 200-2770 mg C $m^{-2}d^{-1}$
~ 0.55 - 7.56 x 10^{12} mol/y (area of the ECS: 5 .9 x 10^{11} m^2 without the Yellow Sea)
-Downward CO_2 flux based on ΔpCO_2 is calculated:
7.2 x 10^6 ton/y = 0.6 x 10^{12} mol/y for the whole East China Sea.

Note: measurements were made in either October or April and we extend the calculated number to the whole year to get an "annual mean".

*Based on only the cruise in April 1994, with sections in the East China Sea, we get from the box model (modified inverse model):-
water budget:- 0.41 x $10^6 m^3/s$ (outflow)
Heat budget: + 2.4 GW (influx)
Carbon (TCO_2 + DOC) budget - 2 x 10^6 mol/s - 6 x 10^{13} mol/y

*Based on historical hydrographic data, water budget was made as follows:

- inflow: 23.6 x 10^6 m^3/s from east of Taiwan
2.1 x 10^6 m^3/s from Taiwan Strait
-outflow: 24.0 x 10^6 m^3/s from Takara Strait
3.6 x 10^6 m^3/s for Tsushima Current
net inflow of 2.4 x 10^6 m^3/s
exchange of water between shelf and Kuroshio is 0.70 x 10^6 m^3/s

*discharge of DOC from Yangtze R. (Gan *et al*. 1983)
12 x 10^6 ton C/yr = 1 x 10^{12} mol/yr)

discharge of POC from Yangtze R. for 1993 (measurements made monthly for whole year):
2.8 x 10^5 ton C/yr = 0.023 x 10^6 mol/yr.

Budgets for the East China Sea

by ARTHUR CHEN

(based on a recent publications Chen and Wang (1996); presented by K.K. Liu)
The following table summarises some of their results.

	Water ($10^9 m^3/yr$)	P (10^9mol/yr)	N (10^9mol/yr)	DIC (10^9mol/yr)	DOC (10^9mol/yr)	PIC (10^9mol/yr)	POC (10^9mol/yr)
River runoff	1217	0.32	40	1830	170	1670	830
Inflow from Kuroshio	38268	12.86	179.5	75195	3321		211
P-E or Atm input	140	1.5	30			11	
Air-sea exchange			-47 (Denitrif.)	3000	-3 CH_4, -2 DMS		
Outflow from shelf	-39625	-0.79	-4.0	-75763	-4359		-396
Export to sediments		-13.9	-198			-4356	-1385

A2.2 Initial Peru-Chile Shelf Budget

PERU - CHILE COASTAL SYSTEM: OVERVIEW AND PRELIMINARY C:N:P BUDGET

by RAFAEL ARNALDO OLIVIERI

A short overview of the oceanographic characteristics of the Peru-Chile coastal system was presented in conjunction with a preliminary budget of nitrate. The nitrate budget was developed as a proxy of the nitrogen budget, and therefore with Redfield ratios, as a budget for carbon and phosphorus.

Coastal upwelling is the major mechanism for the input of nitrate into the system. The north-south boundaries were set at 4^o to 40^o S based on the presence of upwelling favourable winds and coastal ocean circulation. The lack of shelf along most of the coast of Chile precluded the use of the 200 m isobath as the offshore boundary between the coastal and open ocean system. Nitrate from runoff was considered to be negligible because of the extremely low precipitation. A mean upwelling index of 1,883 m^3 sec^{-1} m^{-1} along the coast was used to calculate the volume of water that upwells between 6^o to 16^o S, which is 79% of the total water that upwells between 6^o to 24^o S. Published primary production rates for the coast of Peru were used to calculate annual primary production of 1.25×10^{15} mmol NO_3 for the coastal area between 6^o to 16^o S. An F-ratio of 0.7 was used to calculate the new production of 8.75×10^{14} mmol NO_3. A potential new production of 1.58×10^{15} mmol NO_3 was calculated from a NO_3 concentration of 20 mmol m^{-3} at the source of the upwell water. This suggests that 45% of the NO_3 upwelled is not used within the coastal system and it may be available for export by advection to offshore waters. Fluxes of DON and losses of PON were not estimated at this time.

A2.3 Initial North Sea Budget Budgets

NORTH SEA OVERVIEW

by WILLEM HELDER

Compared to some of the other target areas addressed during this workshop, a wealth of datasets on physical, chemical, and biological parameters is available for the North Sea system. The collection of these data has been triggered in the last few decades especially by the potential harmful effects associated with fishing, shipping, eutrophication, and riverborne and atmospheric contaminants.

Some of the most important characteristics of the North Sea can be summarised as follows:

It is a shallow coastal sea (20 - 600 m) with marine exchanges with the Northern Atlantic through the narrow English Channel in the south and a large boundary along the line Scotland-Shetlands-Norwegian coast.

The North Sea is connected to the Baltic Sea through the Skagerrak between Denmark and Norway. In addition to the fresh water inputs from the Baltic, the continental and British rivers contribute fresh water to the system.

The residual current pattern in the North Sea is dominated by an inflow from the North Atlantic through the Fair Island Channel (between the Orkneys and Shetland) and by a confined outflow through the relatively deep Norwegian Channel. Another residual current pattern moves northward from the Channel in the south along the French, Belgian, Dutch, and Danish coast into the Skagerrak, from where an outflow along the Norwegian coast into the Norwegian Channel is present.

In the southern, most shallow part, the water column is permanently well mixed, while more northward summer stratification occurs.

Due to the strong tidal currents (up to 1 m/s), permanent sedimentation of fine grained particulates is nearly absent from the North Sea apart from the area of the German Bight. Most of the particulates settle in the Skagerrak and the nearby Norwegian coast. Recent estimates of sediment accumulation within these areas indicate that the amount of settling particulate matter is significantly higher than given before based on water transport and suspended matter concentrations.

Due to its restricted depth there is a tight benthic-pelagic coupling and a large part of the primary production (about 200 g m^{-2} yr^{-1}) is mineralised at the sediment surface and within the sediment. Thus the Sediment Oxygen Demand (SOD) values can be up to 100 mmol m^{-2} d^{-1}, which leads locally, in the German Bight, to oxygen depletion in the summer months. Given the high inputs of organic matter to the sediments, apart from oxygen consumption, denitrification and sulphate reduction are important in sedimentary carbon recycling.

Carbon, Nitrogen And Phosphorus Fluxes in the North Sea

by GRAHAM SHIMMIELD

The North Sea region has been divided into 10 regional areas by the North Sea Task Force for operationally-defined fluxes and inventories of materials and biota. Large variability in water transport (40 -120 days) and flushing times (500 days - 5 years based on anthropogenic radionuclides) characterise a well-mixed shallow sea with primary inputs from the north Atlantic, English Channel and Baltic. Output occurs via the Norwegian Current. Substantial suspended particulate matter (SPM; 23.7 mt y^{-1}) characterise the turbidity of the water.

Sources of carbon to the system include:

- Marine carbon from primary and secondary productivity
- Terrestrial carbon (including rivers and sewage sludge)
- Anthropogenic carbon from incomplete fossil fuel burning and atmosphere deposition
- Oil contamination

Nutrient sources include substantial inputs from the North Atlantic augmented by riverine discharge and atmospheric input (670 kt y^{-1} for NO_3-N and 48 kt y^{-1} for PO_4-P; OSPARCOM (1992). Riverine data suggest that P contents of the Rhine/Meuse have increased by tenfold over 1930-85, with decreases since then. N is decreasing at a slower rate. Britain is the only country discharging sewage sludge at present (5.1-5.7 mt y^{-1}, amounting to 6,300 t N and 570 t P), although this will cease in 1998. Oil discharges amount to 20,000 t y^{-1}. Nutrient ratios vary from Redfield ratios up to N/P ratios of 30 along the Dutch-German coast. Both Si and P limitation can occur with common *Phaeocystis* occurring in early spring blooms. Denitrification rates measured in both the open North Sea and coastal regions show very large ranges from 150 mmol N m^{-2} d^{-1} to 350 mmol N m^{-2} d^{-1} .

Using a comparison between sediment respiration rates and net primary production provides a means of estimating the importance of benthic processes to the North Sea budget. Nedwell *et al.* (1993) measured oxygen uptake rates of 5-10 mmol O_2 $m^{-2}d^{-1}$ in winter and 15-28 mmol O_2 $m^{-2}d^{-1}$ in summer. Furthermore, sulphate reduction accounts for 10-53% of organic matter remineralisation. Using these figures on an annual average indicates that 1.16 x 107 t y^{-1} of carbon is remineralised in the bottom sediments. Using an average net primary production figure of 4.0 x 10^7 t y^{-1} shows that 17-45% of net primary production is degraded in the sediment.

Despite substantial quantities of data on nutrient concentrations and specific C-N-P reactions and transformations, an overall nutrient budget for the North Sea is always governed by uncertainties in the Baltic outflow and inflow contributions, coupled with major source and sink terms associated with the North Atlantic inflow and Norwegian Current outflow.

Draft Budget for the North Sea

by CORINNA SCHRUM

Following the LOICZ modelling guidelines, firstly a water/volume budget was presented. Based on data for river runoff to the North Sea, precipitation and evaporation over the North Sea (Damm, ZMK - Hamburg, in preparation) and river runoff data for the Baltic Sea (Bergstroem & Carlsson, 1995) and precipitation and evaporation data for the Baltic Sea (Omstedt *et al.*, submitted to Tellus) the difference between inflow (V_{in}) and outflow (V_{out}) was estimated as $V_{in} - V_{out} = 29848\ m^3\ s^{-1}$.

The second step was to investigate how modelled transport fitted this water budget. Therefore modelled transports (Pohlmann, 1996; Lenhart *et al*., 1995) where used. It was found that the modelled transports lead to a net outflow of

$$V_{in} - V_{out} = 102{,}000 \text{ m}^3 \text{ s}^{-1}$$

One reason is the overestimated modelled transports from the Baltic Sea. However, a phosphate budget for the North Sea, based on these transports and calculated with the ERSEM model (Radach and Lenhart, 1995) was presented.

By evaluating the phosphate balance, a net transport of dissolved inorganic phosphorus out of the North Sea of 26 kt/yr = 838 x 10^6 mol/yr was estimated. This corresponds to a net change of dissolved organic carbon of $\Delta DIC_o = \Delta DIP \ (C:P)_{part}$ = with $(C:P)_{part} = 106$ => $DIC_o = 88{,}828 \times 10^6$ mol/yr. The sign is positive, i.e., respiration is bigger than production.

An estimate of the gaseous exchange between North Sea and the atmosphere was given by Kempe and Pegler (1991). They estimated for $\Delta DIC_o = 2 \times 4.3 \times 10^3$ ton C/yr = 8.6×10^3 ton C/yr

$\Delta DIC_o = 716\ 666\ 10^6$ mol/yr, which is one order of magnitude higher than the net production - respiration term ΔDIC_o .

An estimate of the term ΔDIC_C (precipitation or dissolution of $CaCO_3$) could not be given.

A2.4 Initial Gulf of Guinea Budgets

THE GULF OF GUINEA: AN OVERVIEW OF OCEANOGRAPHIC AND FLUX CHARACTERISTICS

by AYITE-LO N. AJAVON

The continental shelf is narrow and shallow with width ranging from 10 km off Tema (Ghana) to a maximum of 85 km off Calabar (Nigeria). The widest part exists east of Cape Three Points and Secondi (Ghana) averaging 50 km. The shelf break occurs at 120 - 129m water depth but infrequently at 160m. The bathymetric configuration run parallel with the coastline and often punctuated by sandbars and sand-ridges off river mouths and promontories in the eastern Gulf. The middle to outer shelf (45 - 85m) is incised by four canyons namely the Avon, Mahin and Calabar in Nigeria and Trou sans Fond in Cote d'Ivoire. Bands of dead Holocene coral banks parallel to the coastline occur at 40 - 45m and 85 - 100m in the middle - inner shelf.

The entire Gulf is highly stratified with a thin superficial layer of warm fresh tropical water (25 - 29^o C, 33 - 34 psu) overlying high salinity subtropical water (19 - 28^o C, 35 - 36.5 psu) referred to as South Atlantic Central Water (SACW). The low salinity surface water reflects the excess of precipitation over evaporation. Surface water becomes much influenced by river discharges as a general estuarisation of the shelf or through the existence of a discrete plume of river discharge water. During upwelling, the competing effects of saline upwelled water and freshwater discharges produces a distribution that highlights the major freshwater sources and generates quasi-permanent salinity fronts on the shelf. The sharpest gradients in physical characteristics occur in this tropical area. The upper limit of the thermocline is 20 - 35m but shallower (12 - 14m) in Senegal - Liberia, Bight of Biafra and south of the equator. Major part of the shelf area is below the thermocline and exposed to 13 - 16^o C.

The circulation along the northern coast is characterised by a superficial eastward warm freshwater flow that weakens to the east over a westward cold saline flow below the thermocline that weakens to the west. Seasonal upwelling is the most important oceanographic feature in equatorial West Africa. On the northern coast (1^o E - 7^o W) and eastern coast south of 2^o S upwelling persists for about 2 - 3 months. A secondary upwelling event occurs in Dec. - Jan. possibly due to a seasonal minimum in solar radiation. The coincidence in time with equatorial upwelling and lack of a correlation with local wind forcing on the northern coast have motivated hypothesis of remote forcing by equatorially trapped waves generated in the western Atlantic.

Twelve major rivers account largely for sediment input into the shelf with a total catchment area of 3.497 x 10^6 km^2 and 92.6 x 10^6 t/yr. Sediment distribution is by longshore, tidal and rip currents. Four main littoral drift cells are recognised. These are: (a) a west-east drift cell between Cape Palmas and the North western flank of the Niger Delta in Nigeria, (b) a north-western drift cell of the western Niger delta between Akassa Point and the Benin River, (c) a west-east drift cell of the eastern Niger delta and the Strand coast of Nigeria between Akassa Point and the Calabar estuary and (d) a north ward drift cell between the Congo river and the Calabar estuary, (Awosika and Ibe, In press).

The common features are canyons and gullies which act as chutes for sediment loss and changes in drift direction. The Congo River alone discharges 3 - 7 mm^3 of sand annually. Man-made harbour protection structures and damming of major rivers interrupt sediment supply and drift. Onshore offshore transport are not very important in the Guinea Gulf.

Primary and secondary production measurements are scanty but major area of production are the upwelling regions. Recorded peak production off Dakar is 0.014 gC m^{-2} yr^{-1} and 7.39x10^{-3} gC m^{-2} yr^{-1} off Takoradi (Ghana). Interannual variations are related to changes in the extent and duration of upwelling. In non-upwelling area production is as low as 0.27 - 0.41 mg C m^{-2} yr^{-1}. However, local nutrient enrichment enhances production during the rainy season by stormwater run-off into coastal waters. Benthic - pelagic coupling shows that production of phytoplankton greatly exceeds the demand by all herbivores except during the wet season. Production and consumption are otherwise in balance and between 72 - 90% (c.f. Gulf of Mexico) is exported to a sink on the shelf or deep ocean.

The Gulf of Guinea: an Overview of Oceanographic and Flux Characteristics

by NASSERE KABA

The budget for the Ebrie lagoon is described in some detail in Section 3.4.

Factors Influencing Continental Fluxes of Carbon, Nitrogen and Phosphorus in the Gulf of Guinea

by AYITE-LO N. AJAVON

The tropospheric concentrations of most reactive chemical species have been found to vary in space and in time all over the tropical Africa. Two categories of chemical species play a major role and are most involved in Africa tropospheric chemistry: Aerosols and trace gases.

Aerosols originate from biomass burning, harmattan, dusts, open-air house solid waste incineration and vehicular traffic of unpaved as well as unswept paved roads and are composed of TPM, POC, SO.

More than 60% of active population live in the coastal zone of the Gulf of Guinea where most of industries are concentrated. In this area Lagoon, Rivers and water surfaces are used as sources and deposits for everyday needs by inhabitants and industry activities.

These anthropogenic activities yield increasing amounts of nutrients. Estimates for emission from African savannah fires, all biomass burning and all anthropogenic sources show more than 2 x 10^{10} g/yr Nitrogen compounds, 30 x 10^{10} g/yr particulate matters, 15.6 x 10^{10} g/yr carbon and other species like S, P, K which can be washed out by rainwater during wet season and increase nutrient budgets in the coastal zone.

Field measurements and observations have showed that during full activity the smokes from the phosphate rock factory in Kpeme contain a large amount of phosphate which is deposit on tree leaves. We observed between 1 and 2 mm deposit per day. In addition, the waste water from this factory flow directly into the ocean expanding to Cotonou in Benin Republic and increasing phosphate budget in the Benin region.

We need more data to understand the chemical behaviour involved by the nutrient fluxes of Carbon, Nitrogen and Phosphorus from anthropogenic sources in the continental shelf of Gulf of Guinea.

A2.5 Summary of Budgets Presented

In summarising the presentation of the initial draft budgets, Prof. Smith made some recommendations regarding the continued development of budgets. He pointed out that the methods to be generated should be simple and easily generalised to other areas to facilitate the development of budgets in other areas of the continental margins. The models should express values in annual rates, water in m^3; moles/yr and where no contrary data exists, use the Redfield ration of C:N:P: as 106:16:1.

A3 PLENARY AND BREAKOUT GROUP SESSIONS

Following the presentation of the initial budgets for the regions it was decided that participants should work in four groups, one for each region. The work in the breakout groups comprised most of the meeting with one plenary session held to review progress, inform the other participants on the work for the regions, and in many cases, allow the groups to get feedback and suggestions from the workshop participants.

A4 PRESENTATION OF FINAL RESULTS

On the final morning the results of the budgeting for each region was presented. In summary, the majority of participants came to the meeting somewhat sceptical about the methodologies. In the final session, all participants were very positive about the results of the budgeting exercise and the use of the LOICZ *Biogeochemical Modelling Guidelines* (Gordon et al. 1996) to compare different regions.

A5 CONCLUSIONS & RECOMMENDATIONS

There were a number of general points made during the presentation and discussions of the regional budgets that relate more to the general CMTT modelling initiative.

One important point for the Gulf of Guinea was data access. There were several indications throughout the meeting that data existed elsewhere but was not well known or easily accessible to the researchers in the region. A suggestion was made to ask the LOICZ CPO to help in this regard. Mr. Boudreau suggested that the researchers in the region consider working together to identify specific ways that they require help as the CPO cannot respond to individual request for information, except on a very limited bases.

In addition to this general comment there was a discussion concerning the development of a CMTT session to be held at the LOICZ Open Science Meeting, October 10-13, 1997 in The Netherlands. It was recommended that:

1) a one day tutorial on LOICZ budgeting methods to present the completed work and to promote additional work from new and interested researchers. The tutorial could be held prior to the OSM so as to provide the participants with the days of the OSM to consult with SSC members and other that could provide guidance. This would also allow researchers newly familiar with the methods to get maximum benefits out of a possible OSM session on CMTT work. This tutorial would have a relatively small number of participants. START might possibly support such a tutorial if sufficient capacity building could be achieved.
2) a half day session be included in the LOICZ Open Science Meeting with invited speakers, presentations and intercomparisons of budgets for various classes of marine coastal areas: upwelling, shelves with large rivers, semi-enclosed sea, etc. The focus on this session would be to further promote the extrapolation of information from to poorly studied sites and the scaling up from regional to global based on the outcome of the Lagos workshop.
3) a CMTT workshop to be held in conjunction with the LOICZ OSM to initiate the development of budget fluxes for C, N and P in the continental margins at a global scale.

It was agreed by all participants to promptly review and respond to the LOICZ CPO with comments and corrections concerning the draft Workshop report so that the final report could be produced and circulated in November. The CPO agreed to attempt to provide participants with draft copies by Oct. 20 and would like comments by November 1. The report will be produced by the LOICZ CPO in hard copy and distributed by the WWW Home Page through the CMTT site. All participants were encouraged to make use of the meeting report material to generate newspaper articles to advertise the CMTT approach and this work. Additional it may be possible to publish some of the budgets in referred scientific journal. For all such publications, proper acknowledgement for support should be made to JGOFS, LOICZ, SCOR and IOC.

A6 GULF OF GUINEA CRUISE PLANNING

By holding the workshop in Nigeria, scientists from the Gulf of Guinea (several of whom were directly supported by IOC) were able to benefit from the experience of participants from other regions and scientists from outside the Gulf were made much more familiar with the research questions, data availability and scientific expertise in the region.

Larry Awosika presented an outline of the previous IOCEA cruise conducted in the Gulf of Guinea region in October 1989. The objectives of this cruise, conducted on the NIOMR research vessel R.V. Sarkin Baka in the region between Lagos and Cote d'Ivoire, were to collect oceanographic data necessary for understanding the forces responsible for coastal erosion and sediment fluxes on the continental shelf.

The initial objectives for the proposed second IOCEA cruise were also outlined. These were based on the need to fill gaps in the information collected on the first IOCEA cruise as well as to address additional LOICZ research questions where appropriate. Variables initially discussed were:

- Sediment fluxes; and,
- River discharge rates and transport of sediments on the shelf.

The workshop participants were then requested to discuss what data would be required to enable budgets of C, N and P fluxes to be calculated to the Continental Margins in the Gulf of Guinea. The key issue identified was the need for detailed knowledge of the distribution of sediment and nutrient loads coming from the freshwater input into the Gulf of Guinea. It was recommended that the following measurements and analysis should be undertaken.

- vertical and horizontal mapping of salinity, temperature, dissolved C, N and P, total suspended solids, and chlorophyll a and dissolved oxygen. It was recommended that these measurements be conducted from the coastal zone to the edge of the salinity gradient in the continental margin.
- using the sediment grain size data, collected on the first IOCEA cruise, areas of varying sedimentation rate should be identified and cores be taken in a variety of areas to determine both sedimentation rates and carbon, nitrogen and phosphorus content of the sediments.
- temperature and chlorophyll a data collected on the cruise be used in conjunction with remote sensing information from the ADEOS satellite to extend the knowledge of oceanic processes in the region.

Brief consideration was then given to the capacity building required to conduct this work in the region in terms of both knowledge and equipment. The following equipment was considered to be necessary:

- CTD; with rosette and cable;
- equipment for analysis of particulate carbon, nitrogen, phosphorus and chlorophyll;
- box corer.

It was acknowledged that training in use of this equipment and analysis of the data collected would be required for scientists in the region.

It was strongly supported that a copy of the data collected be maintained within the region. It was recommended that laboratories specialising in dating of cores be approached to analyse the core material.

A7 CLOSING OF THE WORKSHOP

In closing the meeting Dr. Hall, recognised the past support of the CMTT activities of Dr. John C. Pernetta. She thanked NIOMR for hosting the meeting in Lagos with special thanks to the local organising committee of Dr. Larry Awosika, Dr. Dublin-Green, Mr. Oyewo, Mr. Adegbie, Ms Catherine Isebor, Ms Regina Folorunsho, Mr. Uko, Mr. Agbakobo, Ms. Koronwo and the secretarial staff lead by Ms. Seliat Fakan. The LOICZ CPO staff of Paul Boudreau and Cynthia Pattiruhu were thanked for arranging the travel for all of the participants and Stephen Smith was thanked for his scientific input into the workshop.

Appendix 2

INTERNATIONAL WORKSHOP ON CONTINENTAL SHELF FLUXES OF CARBON, NITROGEN AND PHOSPHORUS

October 14-18, 1996
Nigerian Institute for Oceanography and Marine Research
Lagos, Nigeria

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In addition to the participants of the workshop there were a number of who attended some sessions :

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Jarikre, (Mrs) Betty E.
Okpanefe, Moses O.
Olukosi, J. O.
Omage, T. R.
Oresegun, Dr. A.
Pepple, P. C. (Mrs)
Solarin, B. B.
Udolisa, Mr. R. E. K.
Ugbodu, Mr. Vincent
Williams, A. Bamikole

Appendix 3

INTERNATIONAL WORKSHOP ON CONTINENTAL SHELF FLUXES OF CARBON, NITROGEN AND PHOSPHORUS

October 14-18, 1996
Nigerian Institute for Oceanography and Marine Research
Lagos, Nigeria

PROGRAMME OF THE WORKSHOP

International Workshop on Continental Shelf Fluxes of Carbon, Nitrogen & Phosphorus
Nigerian Institute for Oceanography and Marine Research
October 14 - 18, 1996

Monday - 14th October
Opening Plenary Session

08.45 - 08.55	All invitees seated
08.55 - 09.00	Arrival of the Honourable Minister of Agriculture
09.00 - 09.15	Introduction of Chairman, other Dignitaries and International Workshop Participants - Dr. Larry Awosika
09.15 - 09.25	Welcome address by the Acting Director of NIOMR - Prof. B. N. Akpati
09.25 - 09.35	Address by the Honourable Minister of Agriculture and declaration of the opening of the Workshop
09.35 - 09.50	Introduction of IGBP, JGOFS & LOICZ: Mr. Paul Boudreau
09.50 - 10.00	Aims and Goals of the Workshop: Dr. Julie Hall
10.00 -10.05	Vote of Thanks: Dr. Dublin-Green
10.05 -1 0.30	Mini Cocktail
10.30 - 10.45	Overview of Budgeting: Dr. Steve Smith
10.45 - 11.00	Overview East China Sea: Dr. Tetsuo Yanagi
11.00 - 11.15	Budget 1: Dr. Dunxin Hu
11.15 - 11.30	Budget 2: Dr. Tetsuo Yanagi
11.30 - 11.45	Budget 3: prepared Dr. Arthur Chen - presented Dr. KK Liu
11.45 - 12.00	Discussion of budgets for East China Sea
12.00 - 12.15	Overview Chile/Peru Region: Dr. Rafael Olivieri
12.15 - 12.30	Budget: Dr. Rafael Olivieri
12.30 - 12.45	Discussion of budgets for Chile/Peru Region
12.45 - 13.45	Lunch NIOMR
13.45 - 14.00	Overview North Sea: Dr. Wim Helder
14.00 - 14.15	Budget 1: Dr. Corinna Schrum
14.15 - 14.30	Budget 2: Dr. Graham Shimmield
14.30 - 14.45	Budget 3: Dr. Wim Helder
14.45 - 15.00	Discussion of budgets for North Sea
15.00 - 15.30	Afternoon Tea
15.30 - 15.45	Overview Gulf of Guinea Region: Dr. E. A. Ajao
15.45 - 16.00	Budget 1: Madame Nassere Kaba
16.00 - 16.15	Budget 2: Dr. Ayite-Lo Ajavon
16.15 - 16.45	Discussion of budgets for Gulf of Guinea
16.45 - 17.00	Summary of the budgets presented: Dr. Steve Smith
19.00	Drinks and dinner with NIOMR staff and invited guests

Tuesday - 15th October

Workshop Sessions

08.30 - 10.00	Workshop plenary
10.00 - 10.30	Morning Tea
10.30 - 12.30	Break out sessions (Regional)
12.30 - 13.30	Lunch
13.30 - 17.00	Break out sessions (Regional)

Wednesday - 16th October

Workshop Sessions

08.30 - 10.00	Workshop plenary
10.00 - 10.30	Morning Tea
10.30 - 12.30	Break out sessions (Regional)
12.30 - 13.30	Lunch
13.30 - 17.00	Break out sessions (Regional)
19.00	Dinner Hosted by NIOMR

Thursday - 17th October

Workshop Sessions

08.00 - 10.00	Preparation of documentation and presentations
10.00 - 18.00	Field Trip to National Museum, Botanical Garden, Lekki Peninsula, Lekki Beach

Friday - 18th October

Closing Plenary Session

08.30 - 09.00	Presentation of East China Sea Budgets
09.00 - 09.15	Discussion
09.15 - 09.40	Presentation of Chile/Peru Budgets
09.40 - 10.00	Discussion
10.00 - 10.30	Morning Tea
10.30 - 11.00	Presentation North Sea Budgets
11.00 - 11.15	Discussion
11.15 - 11.45	Presentation Gulf of Guinea Budgets
11.45 - 12.00	Plenary Discussion “ Where to from here with regional budgets”
12.00 - 13.00	Lunch
13.00 - 13.30	Presentation of Gulf of Guinea Cruise Proposal - Larry Awosika
13.30 - 15.00	Discussion of Gulf of Guinea Cruise Proposal
15.00 - 15.30	Afternoon Tea
16.30 - 17.00	Closing addresses

Appendix 4

INTERNATIONAL WORKSHOP ON CONTINENTAL SHELF FLUXES OF CARBON, NITROGEN AND PHOSPHORUS

October 14-18, 1996
Nigerian Institute for Oceanography and Marine Research
Lagos, Nigeria

WELCOME ADDRESS BY THE ACTING DIRECTOR OF NIOMR

PROF. B. N. AKPATI

The Honourable Minister of Agriculture,
State commissioners,
Representative of the Federal Environmental Protection Agency,
Distinguished scientists,
Ladies and Gentlemen.

It is my pleasure to welcome you all to the official opening ceremony of the JGOFS/LOICZ Workshop on continental shelf fluxes of carbon, nitrogen and phosphorous.

We are particularly honoured to have here today world renowned scientists from 15 countries spread all over the world to work with regional scientists from the Gulf of Guinea.

The choice of NIOMR to host this important and highly technical workshop cannot be over emphasised. The Nigerian Institute for Oceanography and Marine Research is a multidisciplinary Institute with mandate to collect and analyse both oceanographic and fisheries data and information on the Nigerian marine environment. This Institute has played very important roles in both regional and International oceanographic and fisheries research in the past. In 1989, NIOMR made available its vessel R.V. SARKIM BAKA and research scientists for a regional cruise in the Gulf of Guinea to collect oceanographic data and information with regards to the sediment flux programme of the Intergovernmental Oceanographic Commission, of the Central Eastern Atlantic (IOCEA) region of IOC UNESCO. The Institute’s research officers are also playing very active roles in many international oceanographic and fisheries programmes. We believe that our hosting of this workshop is a recognition of our capability to participate effectively in global oceanographic research. We are glad to offer you all our facilities and assistance to ensure the success of the workshop.

The IOCEA and LOICZ programmes in this sub region are very well laid out. We see this as a positive step towards successful implementation of the IOCEA regional programmes especially the sediment budget programme. We hope that Nigeria as well as the West African scientists will benefit from the JGOFS, LOICZ and IOC programmes through capacity and infrastructural enhancement.

We hope that this workshop will come out with strategies that will assist coastal nations particularly those in the Gulf of Guinea to understand the processes associated with continental shelf fluxes.

For some of you, this may be your first visit to Nigeria and in fact to the African Continent. I say Welcome to Nigeria to all of you. We also invite you to see and enjoy the beauties of our traditional settings.

Have a successful workshop.

Prof. B. N. Akpati