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JOINT GLOBAL OCEAN FLUX STUDY (JGOFS)

LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)

Core Projects of the
International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)

REPORT OF THE

JGOFS/LOICZ WORKSHOP ON NON-CONSERVATIVE FLUXES IN THE CONTINENTAL MARGINS

Edited and Compiled by J. Hall and S. V. Smith

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LOICZ International Project Office
Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59, 1790 AB Den Burg
Texel, The Netherlands

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1. EXECUTIVE SUMMARY

The Joint Global Ocean Flux Study (JGOFS) and the Land Oceans Interactions in the Coastal Zone (LOICZ) Programme Elements of the IGBP jointly sponsor the Continental Margins Task Team (CMTT) to study the fluxes of water and materials from the land to the open ocean. The two Programme Elements co-sponsored a workshop October 6-9th, 1997 to bring together experts from around the world to review the present status of knowledge, synthesise this knowledge and prepare plans for future activities in this field of research.

The results of the workshop are reported here. The researchers presented data, information and research for a large number of areas in the world. This information was then used to identify data availability and gaps, devise a preliminary classification of continental margins, and to begin work on a scientifically refereed publication of this synthesis.

2. OVERVIEW

The objectives of the workshop were to:

- Identify on a global scale differences between inputs to the coastal ocean from land (and atmosphere) and exchanges between coastal and open ocean.
- Understand why these differences occur, and in particular the roles of:
    1) inputs from land;
    2) exchange and isolation; and,
    3) biogeochemcial processes.

The workshop was organised into three parts. The first was the presentation of four keynote addresses. These were followed by the presentation of submitted carbon, nitrogen and phosphorus (C,N, P) budgets or general descriptions of C, N and P dynamics for specific continental margin regions by workshop participants. The keynote addresses and the participant presentations laid the foundation for the third part of the workshop which was small group discussions focused around the following topics:

- Characterisation of terrigenous inputs;
- Cross-shelf exchanges of materials and regionalization;
- Budgets and biogeochemical process measurements;
- Terrigenous-dominated coastal margins;
- Land-Ocean interaction on Arctic shelves; and
- Assimilation and evaluation of existing databases.

These discussions were held over three days with workshop participants moving between groups where appropriate.

3. KEYNOTE ADDRESSES

The four keynote presentation to the workshop were:

3.1. Input of materials from land into the coastal zone - Dr Nina Caraco

Dr Nina Caraco presented results on river inputs to the coastal zone. A major point is that a simplistic model was used to account for a significant portion of the variation in the nutrient data. Different nutrients showed different patterns, some were related to human impacts and some to the natural environment.

3.2. Physical transport between the continental margins and the open ocean- Dr Larry Atkinson

Physical transport between the ocean margins and the open ocean can be divided into three conceptual areas:

- the geographic constraints of the region;
- the forcing of winds, freshwater flow, heating and cooling, and ocean currents; and,
- the resultant oceanographic processes that are observed.

The key geographic constraints are the shelf depth, shelf width, roughness of the bottom and coastline, and presence of canyons and reefs.

Forcing over the inner shelf is controlled by runoff and winds while farther offshore winds predominate. Near the ocean boundary the currents of the open ocean may dominate.

The complex interplay of the forces and the geography create the processes we see. Those processes include coastal currents, upwelling and downwelling in a classical sense and the more local upwelling and downwelling and the effect of coastal currents, shelf edge processes and effects of ocean currents especially western boundary currents.

3.3. Interactions between the water, sediments and organisms - Dr Peter Herman

In the context of studies of land-ocean interactions, the establishment of global budgets for the production, transport, decay and deposition of organic matter along the land-river-estuary-coastal sea-ocean continuum is a major objective. Associated with the fluxes of organic matter are fluxes of nutrients, principally N and P. Along the transport routes, the sediments and their associated biota may be important sites of modification of organic matter and nutrients. Although in shallow systems benthic primary production may be important, the general role of the sediments is highly heterotrophic: they are sites of deposition, mineralisation and burial of organic matter. For nutrients, they are sites of regeneration, burial and final removal from the system.

The role of sediments in biogeochemical cycling cannot be disassociated from the activity of the biota. Sediments host a variety of living organisms, conventionally grouped in a number of size classes. They range from a high (and yet badly described) diversity of prokaryotes (bacteria, cyanobacteria), microbenthos (unicellular organisms such as flagellates and ciliates), meiobenthos (defined formally as organisms in the 38 um - 1 mm range) and macrobenthos (>1 mm).

When considering the role of benthic biota in the biogeochemical cycling on a global scale, several aspects of the problem need to be considered. A generalisation of the flux of organic matter to the sediment is made for different habitats ranging from estuaries to the deep-sea. The depth of the water column is an important master variable in this generalisation, although local topographic factors may play an important modifying role. The overall fate of the deposited matter (mineralisation or burial) depends on several factors, among which the benthic fauna may be important. The mineralisation pathways are important, especially with reference to denitrification, since this has an impact on the overall nitrogen budget in the world's ocean. The role of animals in determining the relative importance of the different mineralisation pathways is highlighted.

3.4. A global perspective - Dr Fred Mackenzie

The coastal ocean is a region of the ocean that interacts strongly and in a complex manner with the land, adjacent atmosphere, and open ocean. It is a region of important commercial fisheries, a spawning ground for many marine organisms, a haven for coral reefs, and a major site of tourism activities. With an area on the order of one-tenth of that of the open ocean, approximately 25% of oceanic primary production occurs in coastal waters, obviously representing significantly higher specific rates of organic productivity in this region than in the open ocean. Also, 8 to 30 times more organic carbon and 4 to 15 times more calcium carbonate per unit area accumulate in the coastal ocean than in the open ocean. In addition, specific area gas exchange fluxes of carbon, nitrogen and sulphur in coastal waters are considerably higher than in the open ocean. Furthermore, 60% of the world's current human population lives within 100 kilometres of the coast, and the numbers are increasing every year as people move from continental interiors to urbanised centres on the coast or to immediately adjacent riverine watersheds.

Humans are strongly interfering in the global biogeochemical cycles of carbon, nitrogen, phosphorus and sulphur. This interference has led to substantially increased loadings of the land and atmosphere with chemicals from these activities. Horizontal fluxes of these elements to the coastal ocean via rivers, groundwaters, and the atmosphere play a strong role in the biogeochemical dynamics, cycling, and metabolism of coastal waters--witness the world-wide events of pollution and eutrophication of coastal water ecosystems because of excess nutrients and other materials delivered to these systems from point and non-point sources on land.

Under the anthropogenic forcings of the past several centuries, how has the coastal zone changed during this period of time and what is its future in the early part of the 21st century? If global warming continues and the thermohaline circulation of the ocean slows as predicted, what will be the response of the coastal zone? Using a new process-driven Earth system model (TOTEM, Terrestrial Ocean atmosphere Ecosystem Model) of the coupled global biogeochemical cycles of C, N, P, and S in the land-ocean-atmosphere system, we show: (1) despite growth In anthropogenic atmospheric carbon dioxide concentrations throughout the 19th and 20th centuries, the global coastal zone remained principally a net source of CO_2 to the atmosphere because of organic carbon metabolism and the deposition of calcium carbonate. This state was largely due to horizontal fluxes of reactive materials from land; (2) Because of the growing human perturbation on the environment, the future coastal zone will become a stronger sink for atmospheric CO_2; and (3) any change in the thermohaline circulation of the open ocean because of global warming may lead to an increase in the sink strength of the coastal ocean, principally because of the slow-down in upwelling carbon fluxes.

4. PARTICIPANTS PRESENTATIONS

These presentations were prepared for specific continental margin regions (Figure 1) by participants prior to the workshop. A summary of key features of each of these systems are presented in Appendices II and III.

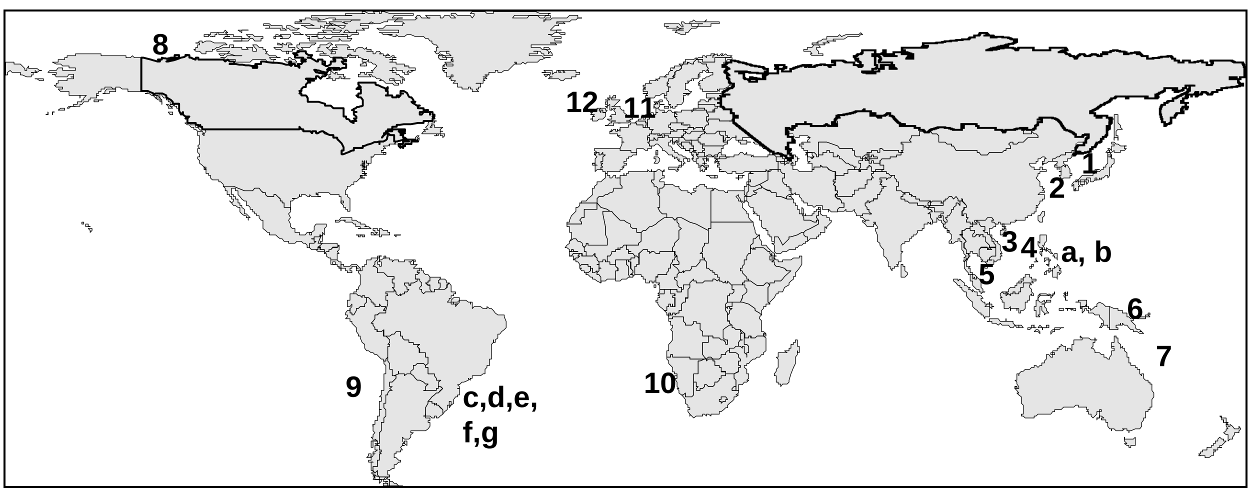

Figure 1. General location of sites for which data and information was presented. Sites **1** to **12** represent Continental Margin regions and **a** to **g** represent estuarine and lagoonal systems.

1. Sea of Japan - Dr Arthur Chen

This deep silled basin is characterised by the pattern of progressive eutrophication apparently as a consequence of reduced water exchange.

2. East China Sea - Dr Arthur Chen

An updated detailed budget including pCO_2 and alkalinity was presented for this region which has strong influences from both large rivers and the open ocean. This budget will be available on the LOICZ WWW Homepage. An earlier version prepared at the 1996 CMTT Lagos workshop is currently on this Homepage (http://www.nioz.nl/loicz/projects/core/biogeochem.htm).

3. South China Sea - Dr Arthur Chen

This is a large shallow shelf region influenced by large riverine inputs, monsoon winds and a boundary upwelling current. The data available for this region are insufficient for a complete budget.

4. Lingayen Gulf - Dr Marilou McGlone

This is a relatively small area that opens into the South China Sea with a strong human influence on the inputs into the area. This area is strongly influenced by the monsoon winds.

5. Gulf of Thailand - Dr Anond Snidvongs

This is a shallow semi-enclosed sea in which the circulation is strongly influenced by the monsoons. In the upper regions there is a strong riverine influence and on the ocean side the inflow is influenced by underflows into the area, and by the Mekong River.

6. North coast, Papua New Guinea - Dr Denis Mackie

This region is subject to high river flow, strong stratification of both freshwater and contained materials, and relatively deep water immediately adjacent to the coast. Preliminary data were presented.

7. Great Barrier Reef - Dr Stephen Smith

This is a region silled by shelf-edge coral reefs which impede cross-shelf transport and strongly influenced by episodic upwelling events. A budget is available on the LOICZ WWW Homepage.

8. Mackenzie River Delta - Dr Rob MacDonald

In this region the Mackenzie River flows into the Arctic Ocean. This area has a large active delta with very significant sediment input from the river. The seasonal ice formation can play a significant role in the water, salt, and sediment budgets of the system.

9. Chile coast - Dr Renato Quiñones

This region has a very narrow shelf over several hundred kilometres. The fluxes in this region are primarily driven by coastal upwelling and possibly influenced by coastally trapped waves. Upwelling events and ecosystem responses are both highly episodic and spatially heterogeneous.

10. Benguela - Dr Mike Lucas

This is a classic upwelling region with strongly seasonal upwelling and downwelling events. Several models of the fluxes have been developed for the region.

11. North Sea - Dr Stephen Smith

This broad shallow shelf sea is influenced by both riverine inflows and the inflow from the English Channel. This budget is on the LOICZ WWW Homepage.

12. Irish Sea - Dr John Simpson

This region is a relatively enclosed system with a small amount of flow through. The primary forcing factors are tides, seasonal heating and cooling and wind stress.

There were several presentations on a number of more coastal and smaller regions.

a. Manila Bay, Philippines - Dr Marilou McGlone

This bay which opens into the South China Sea is heavily influenced by human wastes. The primary driving force for the bay is the monsoon winds.

b. San Miguel Bay, Philippines - Dr Marilou McGlone

This bay which receives a high sediment load and has a low residence time opens into the Pacific Ocean.

c. Patos Lagoon, Brazil - Dr Eduardo Marone, F. Niencheski (Niencheski *et al.*, 1994)

This is a large lagoon in southern Brazil for which a budget is currently being prepared. Most of the lagoon area is fresh water, with a narrow estuarine inlet to the open sea

d. Paranaguá Bay, Brazil - Dr Eduardo Marone, R.M. Lopes, E.C. Machado & E.T da Silva

This bay is dominated by mangroves and salt marshes with significant riverine inputs during the wet season.

e. Cananéia-Iguape/Santos Bay, Brazil - Dr Eduardo Marone, E. Braga

This bay is dominated by mangroves and salt marshes and has significant seasonal pulsed of primary production.

f. Guanabara Bay, Brazil - Dr Eduardo Marone; B. Knoppers (Kjerfve *et al.*, 1996)

This is a hypersaline mangrove lagoon which is significantly impacted by the local population.

g. Paraíba do Sul River - Carneiro, M.E.R. *et al*., 1997.

Mangrove with reactive organic sediments and recycled to the continental slope with refractory organic sediments.

As budgets are completed for the areas listed above they will be added to the LOICZ WWW Homepage (http://www.nioz.nl/loicz/projects/core/biogeochem.htm) and be linked to the CMTT WWW Homepage (http://keep.oc.ntu.edu.tw/cmtt)

There were also presentation by workshop participants on general issues related to continental margins:

1. Data Availability - Dr Toby Tyrell
2. Global models and time scales of the coastal zone - Dr Abe Lerman
3. Typology: a method for globalisation - Mr Paul Boudreau

4.1 Plenary discussion of presentations

In the plenary discussion a number of issues raised in the presentation of budgets were highlighted. These included:

- need to put confidence limits on budget estimates;
- need to address spatial and temporal trends in the data;
- need to use caution with data and need to screen for errors;
- need to have validation procedures for comparison with budget estimates; and,
- need to include process studies in CMTT work.

5. REPORTS FROM THE DISCUSSION GROUPS

Several short plenary sessions were held at intervals to allow for the presentation and discussion of the work being carried out by the small groups. These plenary sessions provided useful comments, suggestions and refocusing of the individual group activities towards the overall CMTT goals.

5.1 Characterisation of Terrigenous Inputs

a. Delivery Pathways of C, N and P

Carbon, nitrogen and phosphorus inputs to the coast are delivered via rivers and freshwater runoff, atmospheric deposition, and point source discharges (particularly of sewage). On a global scale, the total discharge of river water and the fluxes of nitrate, phosphate, dissolved inorganic carbon, and particulate organic carbon are well known (Berner and Berner 1996; Meybeck 1982,1993; Wollast *et al*. 1993). Also known, but perhaps not as well as the preceding, are the fluxes of dissolved organic nitrogen, particulate phosphorus in its different chemical forms, and particulate organic carbon (Milliman *et al.* 1995; Meybeck and Ragu, in press)

Total groundwater discharge and associated chemical fluxes to the coast are uncertain, especially over substantial periods of time and areas. The total groundwater discharge is probably about 5 to 10% of the total surface discharge (36,000 to 38,000 $km^3\ yr^{-1}$) reaching the oceans. However, the total flux of dissolved solids in groundwaters may be a higher proportion of the riverine flux, approaching as much as 50% of the latter. Nitrate loading of groundwaters may lead to substantial inputs of DIN to the coastal zone. The input of DIP via groundwaters, however, is not expected to be higher than in surface waters because of the poor solubility of mineral phosphates and the tendency of dissolved phosphorus to be adsorbed on solid particles. DIC concentrations in groundwaters are elevated owing to dissolution of limestone in the subsurface and bacterial oxidation of organic matter. Thus the DIC flux via groundwaters to the coastal oceans may amount to as much as 25% of its riverine flux. Dissolved organic fluxes of carbon, nitrogen and phosphorus associated with groundwater discharge to the coast are poorly known, but they are probably not substantial fractions of the surficial inputs.

The hydrologic cycle involving the atmospheric and other surface reservoirs of water is well constrained on a global scale. The balance between precipitation and evapo-transpiration is known over the globe, include the land and ocean areas. The global depositional fluxes of nitrogen (NO_y) and reduced nitrogen (NH_3) are known over the large areas of the world and, to a first approximation, over certain regions of the ocean. Less well constrained are the depositional fluxes of organic carbon, nitrogen and phosphorus.

The sources of atmospheric inputs to the oceans have recently been reviewed for a number of minor and trace species and shown to be significant, particularly in coastal regions and adjacent open waters of the North Atlantic, western North Pacific and Indian Oceans, and the inland seas. These regions are subjected to large atmospheric inputs because of their proximity to both natural dusts (deserts) and industrial and agricultural sources. Atmospheric delivery of major nutrients (N, P and Si) plus some trace nutrients (e.g., Fe) is hypothesised to affect coastal and ocean biological production, and in some cases, to limit production. For example, inputs of nitrogen via atmospheric deposition to coastal areas may locally constitute as much as 50% of the total river plus atmospheric input. In the North Atlantic, atmospheric delivery of elemental carbon comprises about one third of the total tropospheric anthropogenic carbon flux to the sea surface, a result of biomass burning and fossil fuel combustion. Atmospheric deposition of both organic carbon and nitrogen is substantial, and world-wide the atmospheric deposition of organic nitrogen is about the same as inorganic nitrogen.

b. Patterns and Controls of Inputs

Global estimates of point-source inputs of C, N and P from sewage and industrial outflows to the coast have been made, and such estimates are available for certain regions, such as the North Sea. However, sewage and industrial-waste inputs to the coastal regions of developing countries are poorly known, but they may be substantial along some of the coastlines, such as those of India, South-eastern Asia, etc.

The various agents of material input to the coast have a varying degree of potential influence on the biogeochemical dynamics and cycling of C, N and P in the coastal margin. It is likely that groundwater and point-source inputs and their fluxes have most impact near-shore, whereas the impact of the big rivers, such as the Amazon, Mississippi or Mackenzie, extends over greater distances offshore, through dispersal of their inflow across the shelves. Thus, the input fluxes of the bigger rivers can be a part of the exchange at the boundaries between the continental margins and the open ocean.

There are several reasonably well known global patterns and controls of terrestrial fluxes to the coastal ocean. High river loads of nitrate and phosphate are associated with regions of substantial inputs of these substances to the Earth's surface from deposition related to combustion of nitrogen and application of chemical fertilisers to croplands. These inputs have increased rapidly sine the middle of the 20th century. Regions, such as the Eastern U.S., Europe and Eastern China are good examples of this.

Another well documented example of pattern and control in rivers is that of POC. POC fluxes are strongly correlated with water discharge and, therefore, atmospheric precipitation. Hence export of POC to the coast is highest in the wet regions, such as the wet tropics.

Another well documented example of pattern and control in rivers is that of organic carbon. Area specific annual DOC fluxes are significantly correlated with water runoff (e.g., Spitzy and Ittekkot, 1991) and, therefore, with atmospheric rainfall patterns. Thus, for DOC, South American rivers dominate the global export. POC fluxes are strongly correlated with total suspended solids, hence the largest amounts of POC are being transported by rivers of Asia.

A final example of pattern and control related to rivers is that of sediment discharge. In general, the slope and watershed size are important controls on sediment export to the coastal region. Rivers on high islands, such as those in the Western Pacific and the West Indies, export large quantities of sediment, whereas export is relatively low for rivers draining bog watersheds of small slope.

As mentioned previously, there are well documented patterns for the atmospheric deposition of reduced and oxidised nitrogen. NO_y is associated with regions of strong fossil fuel combustion which has increased substantially during the past 50 years. High atmospheric inputs of ammonia (NH_3) to the land and coastal ocean surface are associated with regions of high agricultural livestock populations and attendant manure production, and subsequent volatilisation of ammonia.

For groundwaters, regional patterns of high nitrate concentrations are related to agriculture and domestic wastes. Production of both the nitrogen fertilisers and domestic wastes has increased dramatically during the last 50 years. Leaching of nitrogen from these sources has led to high concentrations of nitrate in the groundwaters of certain regions, such as the Middle West of the U.S.

Finally, point-source inputs to the coast are strongly correlated with human population growth and distribution. Approximately 60% of the world population lives within 100 km of the coastline, principally in urban centres and watershed areas where drainage reaches the coast. It has been projected that the coastal population density of the world will continue to increase into the 21st century, and so will undoubtedly increase the point-source inputs, particularly in developing countries.

c. Understanding and Predicting Changes

Relevant to prediction of change in the C, N and P fluxes from land to the coastal ocean is the following table that provides a first-order assessment of the state-of-the-art of our knowledge. In order to predict changes in these fluxes in the future, there will have to be developed models of the processes and there will be needed data to validate the models. In some cases, the links between the models and data have already been made; in others, they have not. Table 1 summarises the current state of existence of the models, data and links between them for some of the chemical species of C, N and P, and for some attributes of suspended sediment.

Table 1. Qualitative Summary of State of Knowledge of C, N, and P Inputs to Coastal Zone.
+ Model or data exist and linkage has been demonstrated.
- Model or data do not exist, no linkage demonstrated

INPUT	MODEL	DATA	LINK
Rivers			
NO_3, PO_4	+	+	+
DOC	+	+	(?)
Suspended Sediment			
Transport	+	+	(?)
Characteristics (grain size, mineralogy, form)	+	-	-
DIC	+	+	+
Groundwater			
NO_3	+	+	-
PO_4	+	+	+
DOC	-	-	-
DIC	+	+	+
Atmosphere			
NH_3	+	+	+
NO_y	+	+	+

5.2 Cross-shelf Exchanges and Regionalization

a. Overview

The first effort was to differentiate between systems where we have budgets, or at least are close to completion, for N, P, C and water. Table 2 summarises these. Note that some of these systems fall at least partially outside the definition of "continental margins."

Table 2. Summary of information available and desired for budgeting continental margin systems. Note that this list excludes the many smaller systems at the inner portion of the continental margin. Budgets available on the LOICZ Modelling Homepage - indicated by *.

COMPLETE OR NEARLY SO	SEEK DATA AND/OR LIKELY SITES
Sea of Japan	Upwelling areas (NW Africa, Somalia, Oregon, California, etc.)
East China Sea*	Large river deltas (Amazon, Mississippi, Yellow, etc.)
South China Sea	Oceanic (Mid-Atlantic, South Atlantic Bights)
Gulf of Thailand	Nova Scotia, Gulf of Maine, Georges Bank
Lingayen Gulf*	Galicia
Great Barrier Reef*	Arabian Sea shelf
Spencer Gulf*	East Australia
North Sea*	Japan Pacific coast
Irish Sea	Sea of Okhostk
Baltic Sea*	Arctic/Antarctic shelves (Bering Sea)
Mackenzie River delta	Patagonia
Benguela	Venezuela
Rio de la Plata*	Mediterranean shelves
Chile/Peru	Bahamas Banks (salt/water budgets available)
Gulf of California	East Africa, Gulf of Guinea
	Enclosed Seas - Red Sea, Black Sea

The CMTT needs to identify persons who might be able to retrieve data sets & construct first step budget models for the systems in column two, Table 2 and encourage their movement into column 1!

b. Regionalization and System Characteristics

The group recognised that the ambition of obtaining budgets for all the systems identified column 2, Table 2, was unlikely. To overcome this, key shelf characteristics were identified and systems were allocated into two broad groups, based on defining characteristics (Table 3). It was recognised there is some sort of continuum between the two extremes for a number of regions.

Table 3. Comparisons between systems dominated by recycling and systems dominated by material export.

RECYCLING SYSTEMS	EXPORT SYSTEMS
Biologically mediated Tidal, geostrophic circulation Benthic bioturbation	Physically forced Ekman shelf-edge baroclinic upwelling Boundary currents Can be forced by high river input--especially rivers with shelf-edge deltas.
Broad shelves (> 50 km)	Narrow shelves (< 50 km)
Forcing, responses on seasonal time scales	Forcing, responses episodic
Long water exchange time (> to >> 1 month)	Short water exchange time (< to << 1 month)
May have (*p-r*) + (autotrophic) or - (heterotrophic), but generally near 1.0	If upwelling dominated or dominated by rivers with high inorganic nutrients, (*p-r*) > 0 (autotrophic); if dominated by sediment-laden rivers, (*p-r*) < 0 (heterotrophic).
EXAMPLES	**EXAMPLES**
North Sea, Baltic, Sea of Japan, Okhostk, South China Sea, NW Atlantic, Great Barrier Reef, Barents Sea	Western Boundary Currents of the Americas and Africa, Amazon, Mackenzie, Mississippi Rivers

Some important systems (notably the East China Sea) may function like recycling systems towards their landward side and export systems towards their seaward side.

Water exchange time is perhaps the single defining difference between "export" and "recycling" systems with respect to CNP budgets.. We therefore considered some of the features that control exchange time:

- Shelf width, depth and shelf-edge depth and profile: i.e., aspect ratio; high = short exchange time.
- Long-shore relative to cross-shelf scales; where long-shore >> cross-shelf encourages retention.
- River input - large rivers discharge beyond the shelf-break; small rivers discharge onto the shelf - influence of fresh-water buoyancy control. (If river flow is >10% of shelf volume, effect is significant).
- Winds and orientation to coast to drive entrainment, circulation, upwelling/downwelling cycles.
- Insolation & heat balance - stratification, one/two layered system.
- Retention time of less than or greater than one month seems to be significant in the balance between "recycling" or "export" system processes.

c. Sample Systems

Three systems were summarised to exemplify similarities and differences in terms of the general typology characteristics explored. These included allocating systems on the basis of positive or negative estimates for a number of processes and fluxes, where the sign is taken as gains (+) or losses (-) with respect to the shelf box. Key processes were (*p-r*), (*nfix-denit*), air↔sea transfer of C, shelf↔ocean particle transfers and burial fluxes. Workshop participants were asked to designate signs for these variables for budgets presented during the workshop. A separate listing of these is given as Appendices II and III.

Examples

- <u>East China Sea--</u>A broad, shallow shelf where the Kuroshio injects nutrients at the outer shelf edge. Monsoon winds drive coastal (low salinity, river discharge) water across the shelf seasonally. Overall: (*p-r*) is +, (*nfix-denit*) is -, and for C, the air↔sea flux is + (sink); shelf↔sediment flux is - (burial); and net shelf↔ocean transport is - (export off shelf).
- <u>Benguela Current--</u>Classic summer Ekman upwelling system (Oct. - March) and winter downwelling. South Benguela highly pulsed; North Benguela dominates overall upwelling water flux. Little or no river input. Narrow shelf characterised by six major upwelling centres and discrete deposition centres. Equatorward surface flow and poleward shelf and off-shelf boundary current. Strong insolation. Overall: (*p-r*) is +, (*nfix-denit*) is -. For C, net air↔sea flux is 0 or + (sink); shelf↔sediment flux is - (burial); and net shelf↔ocean transport is 0 or - (export).
- <u>Gulf of Thailand--</u>Large semi-enclosed shallow sea forced by several large rivers to the north and west and by ocean-estuarine exchanges to the south. System is strongly stratified by freshwater buoyancy and insolation. Net precipitation-evaporation is strongly positive, reinforcing freshwater buoyancy. Surface mixed layer 40-60 m of 28 °C water. Overall: (*p-r*) is -, (*nfix-denit)* is probably -. For C, air↔sea flux is near zero; shelf↔sediment flux is -; and shelf↔ocean transport is -.

d. Concerns and Recommendations

A concern growing out of this consideration of cross-shelf exchange and regionalization in the construction of some of the models for the various budgets is constraining the boundary conditions, particularly in the complexity of the physical oceanography. Another is the common use of C and N as currencies of metabolism when P exhibits less speciation and essentially behaves as a more nearly conservative tracer with respect to system-level metabolic processes--except where sediment loading and riverine input may cause inorganic reactions to dominate P cycling processes. Denitrification is clearly an important process in the continental margins, where N:P flux ratios offer the opportunity of exploring DIN deficits due to denitrification.

5.3 Budgets and Processes

a. Overview

A basic problem is to define clearly the objectives of the whole budgeting exercise. Points needing emphasis are:

- with respect to primary production - respiration (*p-r*), there is no point in globally integrating the budgets in perspective of improving the global estimate. We know from global budgets of 1) the organic load of rivers brought into the ocean and 2) the organic matter buried in marine sediments, that the global ocean must be slightly heterotrophic: (*p/r*) ~ 0.995.
- Nonetheless, extrapolation of the budgets and global integration will be a very useful validation check. Any significant deviations of the established global *p/r* value will indicate systematic errors in the budgets and/or in the extrapolation procedures.
- The main focus, however, is on determining the regional distribution of (*p-r*), and on identifying the principal environmental controls on (*p-r*) (e.g. controls by latitude, proximity to river outlets, depth, upwelling, eutrophication, etc.)
- With respect to nitrogen fixation - denitrification (*nfix-denit*), both the regionalization and the global integration are important. Large uncertainty remains on global denitrification and nitrogen fixation budgets. These uncertainties exist between different experimental/observational determinations (including the effects of changing methodology), between modelling and observational estimates, and between different modelling approaches. It is expected that compilation of the budgets will reveal the importance of different environmental factors on nitrogen fixation and denitrification, as well as providing global integration.

The main concern of our group discussion was to consider the optimal exploitation of the existing budgets, and their relation to process studies derived rates. We also examined how process studies, either from published studies or planned in specific areas, can contribute to the quality control of the budget studies. We went on to develop a proposed strategy for future developments

b. Strategy for Quality Control and Incorporation of Process Studies**.**

We identified different potential problems with the assembled budget studies, several of which may be cured by adoption of a consistent procedure for post-treatment. The basic outline of this procedure is shown in Table 4.

Table 4. Procedures for validating budgeting data.

INTERNAL VALIDATION
Application of standard uniform modelling methodology - LOICZ Biogeochemical Budget Modelling (Gordon *et al.*, 1996).
Where possible calculate error bars and confidence limits.
Sensitivity analysis - how are the model outputs affected by changes in the inputs.
EXTERNAL VALIDATION
Describe and audit necessary differences in the model applications with the standard.
Comparisons among budget for similar types of areas.

The first step in the treatment of budget should be the selection of the most promising budgets on the basis of criteria such as:

- A well-defined morphology with either restricted open boundaries or appropriate information on open-boundary exchanges from other sources such as dynamical models or direct field observations. We feel that the box modelling approach alone is likely to fail in systems with extensive open boundaries. However, exclusion of these systems from the collection of budgets would bias the global sampling, since some types of systems, e.g. coastal upwelling systems, systematically fall into this category and are important for the processes studied. The existing data base on hydrography in several of these systems may allow to improve the estimates of exchange, using approaches other than the box modelling alone.
- well-monitored for salinity, nutrients, input and output. Seasonal variations in net freshwater input and in concentrations of salt and nutrients are necessary.
- in the presence of horizontal gradients in concentration of salt or nutrients, care should be taken to multiply the incoming and outgoing water fluxes with the appropriate concentrations, which are not necessarily then the average concentrations in the box. Property-property plots (e.g. salinity - nitrate plots) can be useful to assess the potential importance of gradients. The use of a multi-box approach in the case of strong gradients should be encouraged. In the case of strongly stratified systems, the use of different vertical layers cannot be avoided.

As far as possible, a uniform approach to the budgeting should be adopted. However, in specific cases, modifications should be allowed for. As an example, the fixed Redfield stoichiometry, which is a basic assumption of the budgeting method, may need to be modified in the case of strong deviations from Redfield stoichiometry in the inflowing organic matter (e.g. in the case of mangrove systems). It is proposed that all budgets should be subjected to a sensitivity analysis in which the input parameters are varied within realistic limits, ideally set by observations. This sensitivity analysis should be part of the presentation of the budgets. We suggest that statistically sound techniques **[*see TEXT BOX*]** should be applied to each of the models, to test their robustness and the uncertainty of their output (i.e. the model parameters).

The finalised budgets will then need validation, as far as possible against independent results of biogeochemical process studies. It is acknowledged that the degree of heterotrophy (*p-r*) cannot be evaluated significantly from direct measurements of *p* and *r*, as it is a usually small (usually less than 10%) difference between two large numbers (*p* and *r*), with considerable uncertainty (in the order of tens of %) in each number taken individually. For a few systems, a direct evaluation of (*p -r*), based on inorganic carbon dynamics, is available and should be used for validation. In many other systems, direct evaluations of *p* and *r* exist, and the possibility of using this information in the validation should be explored. For the nitrogen cycling, validation against independent measurements of denitrification and nitrogen fixation rates should be feasible in a number of areas. System scale estimations of benthic vs. pelagic mineralisation rates can also constrain the range of possible denitrification in the system. Physico-chemical estimates of phosphorus adsorption-desorption processes in sediments and suspended matter should be evaluated to validate the assumption of equalling delta-p to biological phosphorus incorporation. Property-property plots can be used to identify net sources or sinks, and compared to the budget rates.

The validated budget results will be of value in the development of time-dependent global models, in that they will help to constrain the regional distribution of (*p-r*) and (*nfix-denit*). The establishment of good correlations with known forcing variables is a condition for such developments. They will also have a limited use in assessing the impact of local changes in the forcing, e.g. reduction of runoff inputs.

A number of points were raised concerning the need to validate and carry out sensitivity analysis on the budgets produced. Budget results should be compared with process results wherever possible A promising recent development in the measurement of denitrification with respect to biogeochemical process is the use of Nitrogen to Argon flux ratios. However these methods are just coming into use, are not yet readily available, and certainly have not yet accumulated a widespread data base.

Text Box 1

Assuming steady state of the system, i.e. unchanging volume and concentrations in time, the box modelling equations can be summarized as follows (for the simple case where one considers salt, dissolved inorganic nitrogen and dissolved inorganic phosphorus):

Water balance:

$$V_R = V_{in} - V_{out}$$

Salt balance:

$$-V_X (S_2 - S_1) = V_R S_R$$

Phosphorus balance:

$$-V_X (P_2 - P_1) = V_R P_R + P_{in} + \Delta P$$

Nitrogen balance:

$$-V_X (N_2 - N_1) = V_R N_R + N_{in} + \Delta P * 16 + (N_{fix} - N_{denit})$$

With:
V_R: residual flow of water
V_X: exchange flow
S_i: salinity of compartment i (1: inside system, 2: sea, R: at the sea-estuary boundary)
P_i: DIP concentration of compartment i
N_i: DIN concentration of compartment i
P_{in}, N_{in}: inflow of DIP, resp DIN (from groundwater, freshwater, atmosphere)
ΔP: net reaction term of DIP inside the system
$N_{fix} - N_{denit}$: net balance of nitrogen fixation and denitrification inside the system

Text Box 1, continued

These equations can be summarised in the following matrix form:

$$\begin{bmatrix} S_2 - S_1 & 0 & 0 \\ P_2 - P_1 & 1 & 0 \\ N_2 - N_1 & 16 & 1 \end{bmatrix} . \begin{bmatrix} V_X \\ \Delta P \\ N_{fix} - N_{denit} \end{bmatrix} = \begin{bmatrix} -V_R S_R \\ -V_R P_R - P_{in} \\ -V_R N_R - N_{in} \end{bmatrix}$$

which is of the form **X·β=Y**, with the vector **β** containing the relevant unknowns (exchange flow, mineralisation flux and net denitrification flux).

In cases where there are only single observations of salinity, DIN and DIP concentrations, and water and nutrient inflows, the system is solved as a linear system of equations. It yields single estimates of the unknowns, and no information concerning the uncertainty.

In cases where there are several coherent and complete sets of observed variables, the similarity of the above design with a regression problem could be used to obtain a least-squares estimate of the parameter vector **β**. This approach is generally not warranted, however, because the 'dependent' and 'independent' variables in this case are not truly independent of each other. The concentration S_R (and similar for P_R and N_R) is calculated from the sum of the concentrations S_1 and S_2, while the difference between these two concentrations appears in the 'independent' variables. This induces correlation between the two columns, jeopardising the interpretation of the standard errors of the estimates of the parameters.

If the data come as a consistently collected time series (e.g. once per season - see example of Tomales Bay in Gordon et al., 1996; and Smith and Hollibaugh, 1997) with one data point for every variable per season, the best strategy is to solve the set of equations for every point in time, and construct a time series of the non-conservative fluxes. The non-conservative fluxes can then be characterised as an average with (essentially seasonal) standard deviation, but the resolution of the seasonal trends is most meaningful in interpreting the realism of the results. If in fact the underlying data structure of these time series is a number of samples for every season, combined to produce an average figure, the uncertainty of the estimates based on the within-season averages is underestimated by neglecting the variation in the underlying data. A randomisation procedure within every season could be used for that purpose.

With access to the original measurements, one can bootstrap the data set to estimate the distribution of the parameter estimates. In bootstrapping, one samples with replacement from the data set a number of samples equal to the total sample size. However, due to the replacement, some samples may be represented twice or more, and others may be un-represented. By repeating this process many times, and every time solving the linear equation for the parameters, one obtains the distribution of the parameters, which can then be represented by their mean, variance and covariance. Care should be taken in the present case for the correlation between the observations. It is likely that salinity, DIN and DIP will be determined in the same water sample. It is more logical in that case to resample from the set of water samples, taking or rejecting a particular sample with its salinity, DIN and DIP together. A similar situation may exist for the estimates of precipitation, evaporation and freshwater runoff, if these are determined for a limited number of short periods. The physical and chemical variables may also be correlated when all have been determined for a number of irregularly spaced short periods. In the latter case, bootstrapping by re-sampling coherent sets from the total set of measurement periods seems the most appropriate approach.

Without access to the original measurements, a Monte Carlo sampling from the (reconstructed) distributions of the variables may provide some estimate of uncertainty. It will not always be possible, however, to have due consideration of the covariance of the different chemical concentrations and of the physical (flow) variables. If this information is provided, one can sample from the representative distribution of the variables a large number of 'data sets', and calculate the parameters from these. In the absence of that information, a more conservative approach is to refrain from any uncertainty analysis and consider the whole estuary/bay with its reconstructed data set as a single observation in the world's population of such systems.

5.4 Terrigenous Dominated Shelves

a. Overview

It is recognised that these systems pose some unique characteristics which require further evaluation. In particular, systems with large river deltas extending out onto the open shelf pose severe problems in terms of closing budgets at the oceanic boundary. Further, nonconservative DIP flux may not be an adequate measure of (*p-r*) under strongly sediment-dominated regimes in which inorganic reactions may dominate. It is felt that explicit budgets of sediment burial and of the burial of specific forms of P (organic, sorbed, precipitated, detrital, etc.) should be considered

b. System Characteristics

It was felt that there are several system characteristics which merit consideration in the context of ongoing and future studies of terrigenous-dominated shelves.

- <u>Ratio of inorganic nutrient flux to organic carbon flux</u>. This will tend to control the degree to which river inputs push a continental margin system towards autotrophy [(*p-r*) > 0] or heterotrophy [(*p-r*) < 0]. This is also sometimes expressed in terms of *p/r* ratios [(*p/r*) >1 or <1, respectively].
- <u>Sizes of rivers</u>. Small rivers trap sediments in bays and estuaries, and organic matter associated with these sediments tend to push the estuarine systems towards heterotrophy. Nutrients both released from the net heterotrophy and directly associated with the river discharge are transported out of the estuarine systems and tend to increase the autotrophy of shelf waters. Large rivers entering coastal margins tend to transport much of their sediment load and accompanying organic carbon further offshore (often to the shelf edge and even beyond). This has a tendency to increase the heterotrophy of shelf waters. For either small or large rivers many forms of pollution (either from upstream [diffuse-source] transport or many forms of direct [point-source] discharge) tends to force the system towards autotrophy because it leads to an increase in the ratio of the flux of inorganic nutrients to organic carbon. A complicating factor in terrigenous dominated systems is that large inputs of sediment-laden freshwater may limit light penetration. In such cases, and even with excess N and P inputs, biological production is displaced offshore. Buoyancy effects due to input of freshwater in combination with tidal mixing and wind stress control the extent and time scales of stratification of coastal waters, and the development of density front which may affect the productivity.

c. Comparison among Systems

The following question was posed: How similar or different are the areas of the North Sea, Irish Sea, the Baltic, and the Mackenzie River delta? It was recognised that each of these systems represented an example of a system with strong terrigenous influence, but each with potentially different characteristics.

- The Mackenzie is a heterotrophic big river loaded with sediments that get far out onto the shelf. Other examples would be the Mississippi and the Amazon. A further point about the Mackenzie is the strong influence of ice as a transport mechanism.
- The Baltic is very isolated, stratified and autotrophic. It has many small rivers flowing into it but is clearly not a sediment-dominated system.
- The Irish and North Seas are reasonably similar, with much sediment transported in the proximal zone. The nutrients by-pass this zone to some extent, feeding the production on the shelves. The systems are apparently overall autotrophic.

5.5 Arctic Shelves

An important point which was emphasised at this workshop was the areal importance of boreal continental margins, especially in the Arctic, and the considerable potential for change in response to changing global climate. Further, the amount of information about this region was recognised to be limited. Consequently, this short section has been added to discuss unique characteristics of this continental margin region.

The Arctic Ocean contains the largest relative proportion of shelves in the world (30% by area, 20% of the world shelf area) onto which rivers discharge a total of about 3,000 km^3 yr^{-1} of fresh water (Aagaard and Carmack, 1989). On the one hand, buoyancy supplied by river inflow to shelves produces stratification while on the other hand, ice formation and export tends to produce mixing or convection. The interaction between these two opposing processes occurs around the margin and it is this competition that makes the Arctic and its shelves unique (Macdonald *et al*., 1995).

In addition to fresh water, rivers supply the Arctic Ocean with sediments which are either trapped on the shelves or escape to the basin interior. Ice can be an effective agent to move sediments over long distances, to be deposited when the ice melts (Colony and Thorndike, 1985; Pfirman *et al*., 1989; Reimnitz *et al*., 1993). A compelling argument for attempting to construct material budgets for arctic shelves is that, according to models, these locations will probably be the most sensitive to projected change (e.g., see Walsh, 1989). With warmer temperatures, we can anticipate a different ice climate and an altered productivity cycle - with sea level rise we can anticipate accelerated erosion of coast in low-lying regions that contain poorly-consolidated, relict sediments. Indeed, with the lower sea-level stands that occurred during the last glacial period (Hequette *et al*., 1995), much of the shelf in the Arctic must have been "dry." Clearly, extremely large changes have occurred on the arctic shelves within the past several thousand years. Palaeo-oceanographic studies should therefore provide an opportunity to determine the effect of drastically altering the Arctic.

In the Beaufort Sea the Mackenzie River provides an important model estuary - it is a large, seasonally ice-covered, particle-rich river that impinges directly onto a broad, shallow, seasonally ice-covered arctic shelf. A large, historic data set provides probably the best opportunity within the Arctic to calculate of budgets for freshwater, sediments and organic carbon (Macdonald *et al*., 1997). Because the Mackenzie River delivers a such a large quantity of sediment (127×10^6 t yr^{-1}), it is not possible to construct an accurate budget for carbon (or any other particle-reactive element) without first constructing a sediment budget for the region. The river particulates are important because they carry a large fraction of the total C (and P) flux to the estuary, but it must not be forgotten that they also provide the means to bury material in the delta and on the shelf.

The Mackenzie Estuary is characterised by a large, active delta. The organic carbon budget for the Mackenzie shelf shows the region to be net heterotrophic, a situation that is probably typical for any shelf receiving a large sediment and carbon supply from land (e.g., see Smith and Holibaugh, 1993). This situation arises because the amount of terrestrial carbon metabolised on the way to final burial in sediments is larger than the amount of marine-produced carbon sequestered by the same sediments. Indeed, this statement may well be extended to include the Arctic Ocean basin sediments which appear to be influenced much more by terrestrial carbon than marine carbon (Schubert and Stein, 1996). Despite the observed heterotrophy, coastal regions like the Mackenzie Delta and shelf remain important sites for ultimate burial of terrestrial carbon (see, for example Hedges, 1992; Smith and Hollibaugh, 1993) and within the Arctic they are especially vulnerable to the projected climate changes.

5.6 Data availability

This group effectively completed their task of identifying some example CMTT databases after the first session. The participants agreed to add to the list of databases after the completion of the workshop. Table 4 summarises examples of such data sets. Many others, of course exist and can be found by searching the World Wide Web. The JGOFS and LOICZ Homepages are useful starting points.

Table 4. Examples of available data bases.

DATABASE	WHAT FOR?	HOW TO OBTAIN
LOICZ-GLORI	Water, sediment fluxes	LOICZ
GEMS-GLORI	Water, CNP fluxes	GEMS
ETOPO5	Bathymetry	http://www.qpsf.edu/au/mirrors/csep/etopo5-doc/node1.html
COADS	Wind speed, SST	http://ferret.wrc.noaa.gov/fbin/climate_server
Global Sea Level	Global tides	http://www.nbi.ac.uk/psmsl/gb.html
WOA94	Temperature, salinity, nutrients	http://ingrid.ldgo.columbia.edu/SOURCES/.LEVITUS94/.ANNUAL/?help+datasetdatafiles

6. FUTURE ACTIONS

In the final session there was a review of the expected outputs from the meeting and an agreement on how to proceed after the workshop to finish the tasks:

6.1 List of available data

A number of participants agreed to finalise the list of available CMTT data for inclusion on the CMTT WWW home page. It was agreed that links be made between the LOICZ WWW Home Page (http://www.nioz.nl/loicz) and the CMTT WWW Home Page (http://keep.oc.ntw.edu.tw/ctt).

6.2 Budgets for presentation on the Web Site

It was agreed that all budgets produced from the workshop would be published on the WWW. LOICZ related budgets would be added to the LOICZ budgeting home page (http://www.nioz.nl/loicz/modelnod.htm) and CMTT budgets should be placed and/or linked to the CMTT home page.

Budgets would be reviewed for quality and content as is the policy of the LOICZ home page. Only budgets on the home page would be considered for use in the synthesis paper to be developed from this workshop.

6.3 Workshop publication

It was agreed that the participants of the workshop prepare a series of papers for publication in a scientifically referred and indexed publication. It was agreed that this publication would include at a minimum:

- the three introductory talks (Caraco, Atkinson and Herman);
- Mackenzie global overview paper; and,
- a synthesis paper authored by all of the workshop participants.

The CMTT would be responsible for identifying a suitable journal and working with the publisher to ensure the timely production of the document.

7. WORKSHOP SUMMARY

Smith provided a brief summary statement. He pointed to the success at having a wide variety of systems presented and discussed.

Key general points:

- We have looked, in various levels of detail, at continental margins, and in some cases, estuaries, from a wide variety of locations around the world (Figure 1). Complete and or partial budgets are available for several of these sites.
- It was found to be convenient to classify the systems into terrigenous and ocean dominated
- With respect to the ocean dominated, an important feature influencing the budgets is upwelling which is characteristically episodic in nature. Physical forcing was identified as an important influence on the retention and exchange along the shelf.
- With respect to terrigenous dominated systems, it is convenient to classify them into a class that is strongly dominated by large rivers that deliver sediment directly to the shelf and those dominated by smaller inputs and sediments largely trapped in the estuaries. The amount of freshwater flow may also be important through its impact on buoyancy flux.

Biogeochemical points:

- Regions that receive river sediment discharge directly appear to be heterotrophic. In the smaller systems this heterotrophy seems likely to be confined to the estuaries. With large rivers the heterotrophy may be pushed well out onto the sheloves.
- Most of the shelves and estuaries examined appear likely to show denitrification as a consistent and important feature
- Exchange times are an important feature of these continental margin systems and that in general the export of inorganic nutrients will decrease as a function of residence time. This has been previously reported in the Block Island workshop on the North Atlantic (Howarth *et al.* 1996). This phenomenon was not fully explored in this workshop.

A number of additional points were raised in the subsequent discussion:

- There is a need to attempt to check, validate and carry out sensitivity analyses on the available budgets. Not all budgets are equal - some budgets have more precise input data and so have more precise output. This must be identified in their descriptions;
- There is a need to compare budget results with process studies in as many situations as possible. One possibly useful comparison is with direct measurements of p-r and denitrification.
- Efforts should be made to explore the finer categorisation of different shelf systems based on other globally available parameters such as shelf width and human impacts;
- Work on regional scales shows the greatest potential for the use of budget analysis in understanding the discrepancies of inputs and exports of inorganic nutrients.

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JGOFS/LOICZ WORKSHOP ON NON-CONSERVATIVE FLUXES IN THE CONTINENTAL MARGINS

LOICZ International Project Office
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LIST OF PARTICIPANTS

Dr Larry Atkinson
CCPO, Crittenton Hall
Old Dominion University
768 W 52nd Street
Norfolk, VA 23529
UNITED STATES
Phone: 757-683-4923
Fax: 757-683-5550
E-Mail: atkinson@ccpo.odu.edu

Mr Paul Boudreau
LOICZ International Project Office
Netherlands Institute for Sea Research
P.O. Box 59
1790 AB Den Burg, Texel
THE NETHERLANDS
Phone: 31-222 369404
Fax: 31-222 369430
E-mail: loicz@nioz.nl

Dr Nina Caraco
Institute of Ecosystems Studies
Millbrook New York 12545
UNITED STATES
Phone: 914-677-8343
E-Mail: ncaraco@aol.com

Prof Chen-Tung ARTHUR Chen
Institute Marine Geology and Chemistry
National Sun Yat-Sen University
Room 3054
Kaohsiung, 80424
TAIWAN ROC
Phone: 886-7-525 5146
Fax: 886-7-525 5346
E-Mail: ctchen@mail.nsysu.edu.tw

Dr Maria Lourdes San Diego-McGlone
The Marine Science Institute
University of the Philippines - Diliman
UP PO Box 1
Diliman, Quezon City, 1101
PHILIPPINES
Phone: 63-2-922-39-44
Fax: 63-2-924 76-78
E-Mail: mcglonem@msi01.cs.upd.edu.ph

Dr Julie Hall
National Institute of Water & Atmospheric Research
P O Box 11-115
100 Aurora Terrace
Hamilton
NEW ZEALAND
Phone: 64-7-856 1709
Fax: 64-7-856 0151
E-Mail: j.hall@niwa.cri.nz

Dr Wim Helder
Netherlands Institute for Sea Research (NIOZ)
P.O. Box 59
1790 AB Den Burg - Texel
NETHERLANDS
Phone: 31 222 369443
Fax: 31 2223 19674
E-Mail: helder@nioz.nl

Dr Peter Herman
Centre for Estuarine and Coastal Ecology
Netherlands Institute of Ecology
P.O. Box 140
4400 AC Yerseke
NETHERLANDS
Phone: 31-113-577475
Fax: 31-113-573616
E-Mail: herman@cemo.nioo.knaw.nl

Prof Dunxin Hu
Institute of Oceanology
Chinese Academy of Sciences
7 Nan-Hai Road
Qingdao, 266071
P.R. OF CHINA
Phone: 86-532-286 0099
Fax: 86-532-2860099
E-Mail: dxhu@ms.qdio.ac.cn

Dr Abraham Lerman
Dept. of Geological Sciences
1847 Sheridan Road
Northwestern University
Evanston, IL 60208
UNITED STATES
Phone: 1-847 491 3238
Fax: 1-847 491 8060
E-Mail: abe@earth.nwu.edu

Dr Mike Lucas
Southampton Oceanography Centre
European Way
Southampton, SO14 3ZH
UNITED KINGDOM
Phone:
Fax:
E-Mail: mike.i.lucas@soc.soton.ac.uk

Dr Rob Macdonald
Institute of Ocean Sciences
P O Box 6000
9860 W. Saanich Road
Sidney, British Columbia, V8L 4B2
CANADA
Phone: 1-604-363 6409
Fax: 1-604-363 6807
E-Mail: robie@ios.bc.ca

Dr Fred T. Mackenzie
School of Ocean and Earth Science and Technology
University of Hawaii
1000 Pope Road
Honolulu, Hawaii, 96822
UNITED STATES
Phone: 1-808-9566344
Fax: 1-808-9567112
E-Mail: fredm@soest.hawaii.edu

Dr Denis Mackey
CSIRO
Division of Marine Research
PO Box 1538
Hobart 7001
AUSTRALIA
Phone: 61-3-6232-528
Fax: 61-3-6232-5123
E-Mail: denis.mackey@marine.csiro.au

Prof Dr Eduardo Marone
Centro de Estudos do Mar
Universidade Federal do Parana
Av. Beira Mar s/n
83255-000- Pontal do Sul PR
BRAZIL
Phone: 55-41-455-1333
Fax: 55-41-455-1105
E-Mail: maroneed@aica.cem.ufpr.br

Dr Renato Quiñones
Departamento de Oceanografia
Universidad de Concepcion
Casilla 2407
Concepcion
CHILE
Phone: 56-41-203861
Fax: 56-41-225400
E-Mail: rquinone@buho.dpi.udec.cl

Prof John H. Simpson
Marine Science Laboratory
University College of North Wales
Menai Bridge
Anglesey, LL59 5EY
UNITED KINGDOM
Phone: 44-1-248 382844
Fax: 44-1-248 382612
E-Mail: jhs@sos.bangor.ac.uk

Dr Stephen V. Smith
School of Ocean and Earth Science and Technology
University of Hawaii
1000 Pope Rd.
Honolulu, Hawaii, 96822
UNITED STATES
Phone: 1-808-956 8693
Fax: 1-808-956 7112
E-Mail: svsmith@soest.hawaii.edu

Dr Anond Snidvongs
Department of Marine Science
Faculty of Science
Chulalongkorn University
Phya Thai Road
Bangkok, 10330
THAILAND
Phone: 66-2-2188126
Fax: 66-2-2554967
E-Mail: anond@start.or.th

Dr Toby Tyrrell
Department of Oceanography
Southampton Oceanography Centre
European Way
Southampton SO14 3ZH
UNITED KINGDOM
E-Mail: toby.tyrrell@soc.soton.ac.uk

JGOFS/LOICZ WORKSHOP ON NON-CONSERVATIVE FLUXES IN THE CONTINENTAL MARGINS

LOICZ International Project Office
Texel, The Netherlands
6-9th October 1997

CONTINENTAL MARGINS SITE DESCRIPTION

Name[1]	Region[1]	Description	References (*presenter of budgets)
Benguela Current	49	A classic wind forced upwelling system.	Lucas*
East China Sea	72	A large, wide, shallow shelf influenced from the shore by large rivers, from the ocean by the Kuroshio and by seasonal monsoon winds. See LOICZ WWW Homepage	Chen*
North Chile Coast	14	A narrow to medium width trending north south hundreds of km driven by seasonal upwelling and possibly coastal trapped waves.	Quiñones*
Gulf of Thailand	71	A narrow to medium width trending north south hundreds of km driven by seasonal upwelling and possibly coastal trapped waves. Water exchange time about 1 year. Flushing time with respect to freshwater input ~ 25yr.	Snidvongs*
Great Barrier Reef	67	A narrow to medium width trending north south hundreds of km driven by seasonal upwelling and possibly coastal trapped waves. See LOICZ WWW Homepage	Smith*
North Sea	38	A large shelf sea with a dominantly anticlockwise circulation driven by a combination of wind and buoyancy flux from freshwater input along the European coast. See LOICZ WWW Homepage	Smith*
Irish Sea	40	Largely enclosed system with through flow.	Simpson*
Mackenzie Estuary	2	Broad shallow shelf dominated by the Mackenzie River that freezes annually. Exchange time < 1 yr and as short as 2-4 months depending on season. Seasonally ice covered ocean. The continental shelf is a platform of ~60,000 km^2 into which the Mackenzie River puts 330 km^3 yr^{-1} + 127X 10^6 tonnes sediment. The river clearly dominates the shelf in sediment and freshwater supply and sediment biomarkers.	Macdonald*
Southeast US Shelf	26	Broad shallow shelf narrowing to north and shelf with northward flowing Gulf Stream at shelf break. Outer shelf controlled by Gulf Stream with inner shelf controlled by buoyancy and wind.	Lee, Yoder et al., Atkinson*
Lingayen Gulf, Philippines	70	Embayment opening to the south to the South China Sea. Affected by solid, sanitary, municipal and agricultural waste. Exchange time = 2.8 months.	San Diego-McGlone*

[1] Region number and name as listed in LOICZ 1995 Typology report.

Name[1]	Region[1]	Description	References
Manila Bay, Philippines	70	Embayment opening to the south to the South China Sea. Highly polluted by domestic and industrial activities. Exchange time = 2.9 months.	San Diego-McGlone*
San Miguel Bay, Philippines	70	Embayment opening to the Pacific Ocean. Very shallow (7m) and receiving large amount of sediment load from the river. Exchange time = 0.2 months.	San Diego-McGlone*
South China Sea	71	A large, wide, shallow shelf influenced from the shore by large rivers, from the South China Sea basin by the eddies and by seasonal monsoon winds. Exchange time < 6 months.	Chen*
Upper Gulf of Thailand	71	Flushing time with respect to freshwater (R+P-E) ~ 7 years.	Snidvongs*
Paranaguá Bay, Brazil	18	400 km^2 . Subtropical bay environment with mangroves and salt marches	Marone*, Lopes, Machado & Silvia
Bering Sea, Summer		A large, wide shallow shelf area influenced from shore by large rivers and cyclonic eddies in the Bering Sea, Exchange time < 6 months	Chen*
Bering Sea, Winter		A large, wide shallow shelf area influenced from shore by large rivers and cyclonic eddies in the Bering Sea. Exchange time < 6 months.	Chen*

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CONTINENTAL MARGINS SUMMARY

Name	*(p-r)*	(*nfix-denit*)	C air↔ water	water↔ sed.	shelf↔ ocean	Forcing
Benguela Current	+	-	+	-	0	Wind forced upwelling
East China Sea	+	-	+	-	-	Boundary current upwelling (Kuroshio), monsoon winds, river buoyancy forced coastal current
North Chile Coast	+	-	?	?	-	Wind forced upwelling
Gulf of Thailand	-	-	~0	-	-	Monsoon, coastal buoyancy, entrainment, deep thermocline
Great Barrier Reef	+	~0	-	-	?	Assumed dominated by upwelling forced exchange
North Sea	+	-	+.	~0	-	Counterclockwise flow; buoyancy flux from river inflow; injection from English Channel; mixing
Irish Sea	small +	-	small +	?	?	tides, seasonal heating, cooling and windstress
Mackenzie Estuary	-	-	-	-	+	Coastal current, thermohaline from brine.
Southeast US Shelf	?	-	?	?	?	Forced by Gulf Stream with meanders, eddies and wind important.
Lingayen Gulf, Philippines	-	+	-	-	?	Monsoon winds
Manila Bay, Philippines	-	-	-	-	?	Monsoon Winds
San Miguel Bay, Philippines	-	-	-	-	-	tides, seasonal heating, cooling and windstress
South China Sea	+	-	?	-	?	Boundary current upwelling, monsoon winds, river buoyancy forced coastal current
Upper Gulf of Thailand	+	-	-	-	0	Tidal mixing, buoyancy and winds
Paranaguá Bay	+	?	?	+	-	Tidal mixing with freshwater inputs in rainy season
Bering Sea, Summer	+	+	+	?	-	Boundary current upwelling
Bering Sea, Winter	?	?	0	?	-	Boundary current upwelling