THE ROLE OF THE COASTAL OCEAN IN THE DISTURBED AND UNDISTURBED NUTRIENT AND CARBON CYCLES

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Cover: The cover shows a GTP030 image of the world, with the estuaries budgeted using the LOICZ methodologies shown in red.

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1. Introduction

1.1 The Global Coastal Zone

The world's coastal zone is under extraordinary and increasing pressure from human use and habitation and from changes in the global climate regime. A recent evaluation of the impacts of marine pollution from land-based sources found that marine environmental degradation has continued and in many places intensified (GESAMP 2001). The Intergovernmental Panel on Climate Change in 2001, while revising earlier assessment values, noted and projected increased global temperatures and allied CO_2 concentrations which will dramatically influence the coastal zone differentially across regions. Global assessments of the environment (OECD 2001), of world resources (WRI 2000), of oceans and coastal seas (IOC in press), and of global change (IGBP 2001) describe a tapestry of pressures, impacts and predictions. These paint a picture of trends towards further degradation in the coastal zone (e.g., overfishing, direct and indirect effects of land use and greenhouse gas emissions) despite some local and regional successes in coastal management that are arresting processes such as pollution, eutrophication, and urban waste impacts on water quality (e.g., the Rhine River and the Baltic Sea).

The coastal zone encompasses river basins and catchments, estuaries and coastal seas, and extends to the continental shelf – the domain surrounding the land-sea interface extending to the landward and seaward limits of marine and terrestrial influences (Figure 1.1). There is no single definition for the coastal zone. However, there is general adoption of the OECD Environment Directorate's approach which suggests that the definition of the coastal zone needs to vary according to the type of problem being addressed and the objectives of management (see, for example, Commonwealth of Australia 1993).

A common rule-of-thumb is to include the landward area to 100 km from the coast (WRI 2000). In LOICZ, while setting spatial dimensions to address key issues of land-ocean interaction, the coastal zone is nominally considered to extend from 200 m elevation to 200 m depth (Pernetta and Milliman 1995).

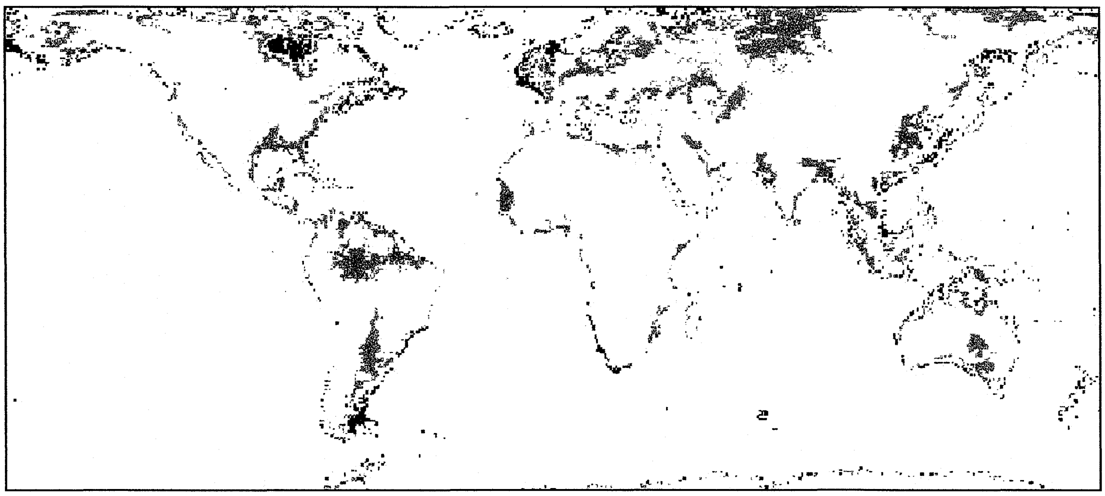


Figure 1.1. The LOICZ global coastal zone. (Terrestrial areas; yellow 100-200 m elevation and green <100 m elevation: marine areas; light blue <100 m depth, dark blue 100-200 m depth).

This coastal region is viewed as encapsulating the material fluxes and processes of transformation, storage and interaction of coastal materials, including human dimensions. In the LOICZ typology approach to integrating processes and interactions in the global coastal zone, the coastal domain is described by 49,000 pixels of half-degree resolution, generally to about 100 km inland and to the continental shelf edge (www.kgs.ukans.edu/Hexacoral/Envirodata/cell_structure.htm).

Table 1.1. Characteristics of the global coastal zone

The coastal zone:

- comprises <20% of the Earth's surface
- contains >50% of the human population
- is the location of 70% of cities with >1.6 million inhabitants
- yields 90% of the global fisheries
- produces about 25% of global biological productivity
- is a major sink for sediments
- is a major site of nutrient-sediment biogeochemical processes
- is a heterogeneous domain, dynamic in space and time

The coastal zone is a relatively small but dynamic area of the Earth's surface. It is home to more than half of the human population, providing wide societal benefits, containing an extensive matrix of natural ecosystems and habitats, and functioning as a significant and complex region for biogeochemical transformation (Table 1.1). Its heterogeneity in physical, chemical, biological and human dimensions is a challenge to measure, model and manage. Biogeochemically, it can be considered as a region of dominant horizontal gradients, exchanges and fluxes, but the vertical interactions with atmosphere, soil and groundwater sustain and influence vital processes. Temporal dimensions and variability are crucial to coastal zone dynamics and natural function. It is not in a steady state, but changes across time in response to a multitude of forcings – from daily (e.g., tides and precipitation-river flow), seasonal (e.g., climatic patterns), annual (e.g., fisheries yield), and decadal (e.g., ENSO) to glacial-interglacial scales (e.g., sea level was about 100 m lower 8000 years ago in many parts of the world and in Scandinavia considerably higher than present).

A multiplicity of human uses and benefits are derived from the coastal zone. Resources, products and amenities are as heterogeneously dispersed at local and regional scales as the natural settings and processes, and subject to changing patterns of availability, quality, limitations and pressures. The human dimension is crucial in modifying, directly and indirectly, the entire fabric of the coastal zone through exploitation of living and non-living resources. Urbanisation and intensified land uses are resulting in degraded water and soil quality, pollution and contamination, eutrophication, overfishing, alienation of wetlands, habitat destruction and species extinction.

The natural systems of the coastal zone and examples of changes in their state, at least at local levels, are recognised in the scientific arena and across much of the wider community. The entire spectrum of coastal habitats – coral reefs, mangroves and tropical wetlands, seagrass systems, rocky shores and estuaries, salt marshes and sand dune communities, coastal forests and woodlands, estuarine and deeper shelf communities – are subject to pressures from humans and natural changes.

The impact and influence of human populations in the coastal zone is well-recognised but poorly documented. Indeed, estimates of population in the coastal zone are diverse and range from 37% to 80% and the variability is dependent not only on the spatial units used for the estimate (Robert Bowen pers. comm.) but is also a function of methodologies. Burke *et al.* (2001) cite census estimates of 2.075×10^9 (in 1990) and 2.213×10^9 (in 1995, representing 39% of global population) people living within 100 km of the coastline. LOICZ estimates from Landscan data include 2.7×10^9 (in 1998, or 52% of global population) people within the coastal typology-delimited global database (i.e., within about 100 km from the coastline). Importantly, the proportion of national population totals in the coastal zone is far from being uniformly distributed (for example, ranging from near-zero in polar regions to around 90% in most island states, Australia and some European nations) and elevated densities coincide with urban conurbations and "altered" landscapes (Burke *et al.* 2001).

Croplands and managed pastures are associated with much of the coastal zone and the major river basins that discharge into the coastal seas, supporting local and global societies and economies. Use of fertilisers continues to grow from levels of about 150×10^6 tonnes per year in 1990 to projected use in excess of 200×10^6 tonnes per year by 2020 (Bumb and Baanante 1996, cited in GESAMP 2001). A recent assessment by UNEP considers that global nitrogen overload is one of four major emerging environmental issues (Munn *et al.* 2000) as does GESAMP (2001), because of effects on eutrophication, human health and general water quality of fresh and marine coastal waters and allied ecosystems. In immediate coastal lands, alienation of wetlands (mangroves, saltmarshes, dune systems) continues as sugarcane, rice and mariculture facilities are expanded. Freshwater used for irrigation accounts for significant changes in flows affecting, *inter alia,* coastal sedimentation processes and delta maintenance. For example, in the Yellow and Nile rivers, flows have been reduced by more than 90%, with concomitant coastal erosion and changes in trophic systems of the coastal receiving waters. Significant tracts of forest continue to be lost in river basins in many parts of the world, diminishing watershed protection, increasing erosion that influences river transport and water quality, and impacting on coastal ecosystems through increased sedimentation rates and elevated nutrient inputs (Scialabba 1998).

The effects of damming and irrigation on water transport are obvious and manifested in multiple examples of coastal erosion through all regions of the world in response to reduction in sediment flows (Milliman 1997). Such effects impact coastal ecosystems, increase saline intrusions, diminish coastal groundwater discharge and reduce biodiversity. More subtle pressures through changes in water quality are coming to light through recent research, notably the effects of damming on reducing silicate loads to coastal waters (Conley *et al.* 1993) with a resultant shift in phytoplanktonic communities from dominantly diatoms to flagellates (e.g., Black Sea: Humborg *et al.* 2000). This has ramifications for coastal biogeochemical cycles including sequestration of carbon and elevation of eutrophication, as well as trophic structures in estuaries and coastal seas (e.g., the Bay of Bengal and areas of major river plumes such as the Amazon) dependent on land-derived nutrient inputs (Ittekkot *et al.* 2000).

Historically, humankind has been closely associated with the coast, reflecting the evolution of trade and commerce and resource access. However, there is a trend for coastal migration from rural to urban environments in many countries, and most of the world's megacities are coastal. Patterns of tourism and global trade exacerbate these densities; for example, the northern Mediterranean coastal zone population swells from 130 million to 230 million for most of summer (Han Lindeboom, pers. comm). The challenges for management and planning are obvious, and the pressures imposed by people are geographically highly variable in nature and intensity, and are often inter-regionally connected. It is now considered that "human activities are influencing or even dominating many aspects of the Earth's environment and functioning" leading to the suggestion we are now in "another geological epoch, the Anthropocene era" (IGBP 2001).

Our awareness and scientific understanding of the dynamics in coastal ecosystems (the scales of variability and forcing) has markedly increased over the last few decades. Observations and measurements of elements of human forcing leading to changes and loss of ecosystems have been increasingly documented. However, we are limited in our ability to scientifically and objectively measure, assess and predict the natural and human dimensions of these changes and the effects of different pressures. Differentiating human-induced changes from naturally forced changes remains a challenge. These problems derive from the complexity of endogenous natural functions and biogeochemical interactions, the inherent complexity of the human dimension, and the synergies, feedbacks and disjuncts in scales between natural and socio-economic interactions in the heterogeneous landscape of the coastal zone.

1.2 The Global Synthesis Expert Workshop on Coastal Biogeochemistry and Scaling

The workshop (11-14 November 2001) brought together participants from all regions of the world to evaluate the biogeochemical performance of estuarine and coastal ecosystems and the changes in human and natural pressures that influence the C, N and P transformations in the ecosystems. A variety of databases and analytical tools had been developed and assembled through earlier regional workshops (Buddemeier *et al.* 2002) and these formed the basis for the synthesis work carried out during the workshop. Subsequent research by participants and a widely developed network of scientists is extending this global analysis and synthesis; some of the additional results are included in the conclusions of this report. The full and wider global synthesis of the biogeochemical pressures and resultant changes in coastal ecosystem metabolic and ecological responses will be contained in the LOICZ Global Change publication to be published in early 2003. This report, in addressing key objectives of an associated UNEP GEF-funded project, represents a major part of a challenging journey of global assessment, analysis, training and synthesis of knowledge into information about the biogeochemistry of the global coastal zone.

1.2.1 Background

The key objectives of the Land-Ocean Interactions in the Coastal Zone (LOICZ) core project of the International Biosphere-Geosphere Programme (IGBP) are to:

- gain a better understanding of the global cycles of the key nutrient elements carbon (C), nitrogen (N) and phosphorus (P);
- understand how the coastal zone affects material fluxes through biogeochemical processes; and
- characterise the relationship of these fluxes to environmental change, including human intervention (Pernetta and Milliman 1995).

To achieve these objectives, the LOICZ programme of activities has two major thrusts. The first is the development of horizontal and, to a lesser extent, vertical material flux models and their dynamics from continental basins through regional seas to continental oceanic margins, based on our understanding of biogeochemical processes and data for coastal ecosystems and habitats and the human dimension. The second is the scaling of the material flux models to evaluate coastal changes at spatial scales to global levels and, eventually, across temporal scales.

It is recognised that there is a large amount of existing and recorded data and work in progress around the world on coastal habitats at a variety of scales. LOICZ is developing the scientific networks to integrate the expertise and information at these levels in order to deliver science knowledge that addresses regional and global goals.

The United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF) have similar interests through the sub-programme: "Sustainable Management and Use of Natural Resources". LOICZ and UNEP, with GEF funding support, established the project: "The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles" to address these mutual interests.

The UNEP GEF project provides a means to address the consequences of changes in nutrient flux from land to ocean for coastal ecosystems functioning, including estimates of changes in carbon cycling and flux of CO_2 from the coastal ocean to the atmosphere. From general observations and research on relatively few estuarine and coastal seas sites, it is clear that external loading from land (or land and atmosphere) to coastal systems is being widely influenced by human activities in river basins. Some assessments of loading of N and P to coastal systems are available but there is very limited number coherence among the databases that can underpin global measurements and the relationship between changing nutrient cascades in the river basin-to-coastal water continuum of river and groundwater flows to the estuarine and marine environments. Of particular interest is establishment of estimates for the changes of CO_2 flux from the coastal ocean in terms of enhanced nutrient loads for different locations and regions of the world, and the uncertainty surrounding the regional and global scale estimates. An issue of equal importance is estimation of the transformation of land (or atmosphere)-derived nitrogen within the coastal zone.

1.2.2 Objectives and Purpose

The overall purpose of this final workshop in the series of local/regional assessments was:

> "to use teams of expert researchers and resource persons dealing with coastal fluxes and biogeochemistry to relate C-N-P biogeochemical budgetary information at global and major regional scales to a coastal system classification that will be developed primarily by cluster analysis of suites of environmental and human-dimension variables."

To develop this assessment, the project has aimed to assemble:

a) estimates of inputs of nutrients (N and P) to coastal waters and, where possible, to relate the observed nutrient loads to the environmental and anthropogenic forcing that exists especially in the river catchments delivering to the coast;
b) estimates of biogeochemical fluxes of C, N and P from coastal and shelf seas to the atmosphere, and analyse these for trends and patterns that could be geo-spatially related to loads and ecosystem settings; and
c) tools and methodologies allowing up-scaling of local site information to regional and global scales, in particular identifying suites of variables and proxies that represent settings, drivers and forcings for ecosystem performance.

The LOICZ biogeochemical budgeting approach (Gordon *et al.* 1996) provided a common methodology for delivering regionally comparable data on coastal ecosystem loads and net metabolic performance of coastal systems. About 160 site budgets have been contributed from a series of nine regional workshops supported by the UNEP GEF project, adding to 40 site-specific budgets previously contributed to LOICZ. The project has also provided new assessment tools and proxies for horizontal nutrient flux modelling, and provided training for more than 180 scientists around the world in use of biogeochemical modelling and assessment techniques.

A typological system (LOICZView: Maxwell and Buddemeier 2002, Buddemeier *et al.* 2002) was developed as part of this project (in conjunction with US NSF support) to address the challenges of scaling and classification of coastal ecosystems and their environmental/anthropogenic "settings" in order to elucidate patterns and trends in ecosystem performance. Three regional workshops in 2001 have provided training and opportunities for additional development of the LOICZView typology tool.

This workshop aimed to synthesise the site-specific coastal system C-N-P biogeochemical information (loading and system flux measures) and relate these to regional and global patterns and typologies of systems settings, forcing (especially resulting from human-induced pressures) and ecosystem net metabolism. Thus, the outcomes provide a description and an understanding of the spatial patterns of habitats and fluxes of C, N and P in coastal ecosystems through the marriage of biogeochemical assessment with geo-spatial assessments.

1.2.3 Contributing Information

1.2.3.1. Biogeochemical Budget Sites

The wider LOICZ project, and in particular the UNEP GEF project, has delivered more than 200 site-project specific C-N-P budgets of estuarine and coast sea locations, ranging from several km^2 to 10^6 km^2 and covering all climate zones from tropical to polar regions.

The LOICZ approach is based on one of the most fundamental concepts of the physical sciences: conservation of mass. Details of the approach are given in Gordon *et al.* (1995) and on the LOICZ Modelling web page (http://data.ecology.su.se/MNODE); nutrient budgets rely largely on secondary data. Steady-state conditions are assumed, in which water volume and salt content in the estuarine or coastal sea system remain constant over time, as water flows through the system and mixes with adjacent systems. The net flow of water can be described by a water budget. Information about mixing can be deduced from a budget of non-reactive materials, usually salt. The data to establish at least first-order water and salt budgets can be found for many sites around the globe.

Nutrients not only move with the water but also undergo reactions within the system. Nutrient data (especially data on the dissolved inorganic forms of phosphorus and nitrogen, here termed DIP and DIN) can be found for many of these same sites and used to establish nutrient budgets. These nutrient budgets include water flow and mixing, as defined by the water and salt budgets, and an additional term that describes net uptake or release of these nutrients within the system. In the jargon of oceanography, these are termed "non-conservative fluxes," because the nutrients do not follow exactly the flux pathways of water and salt.

The non-conservative flux of DIP (ΔDIP) can be used as an approximation of net uptake of phosphorus into organic matter during primary production, or release from organic matter by respiration. While it would be desirable to have direct measurement of carbon uptake into organic matter, such data are not available for most locations. Therefore the flux of DIP becomes a proxy for net carbon flux. In the open ocean, DIN is often scaled in exactly this manner to carbon. That scaling in general does not work well in the coastal ocean, for a reason that contains a great deal of information itself. Nitrogen fixation and denitrification are important metabolic processes in bottom-dominated systems and can account for most of the observed non-conservative flux of DIN (ΔDIN). Therefore calculations are derived from the budgets:

1) using DIP flux as a proxy to calculate how much net carbon uptake or release has occurred;
2) scaling DIP flux to estimate the expected nitrogen (DIN) flux (typically using the Redfield N:P ratio of 16:1); and
3) using the deviation between the observed DIN flux and the expected DIN flux to estimate the net of nitrogen fixation and denitrification.

The global synthesis workshop had available about 160 site-specific biogeochemical budgets (see Figure 1.2) – polar sites and a number of additional sites from Africa and Latin America were in the final stage of completion. For some sites data quality and quantity are high; other sites suffer in the quality and quantity of information available. The site diversity and data quality pose significant challenges when attempting comparison. While the full set of budget data was made available, in general the workshop participants worked with an abridged but robust set of system budgets – in all about 80 systems. Systems for which the basic data sets are incomplete, open shelf systems, and systems with average depths >100 m were set aside. Subsequent work has extended the budget set and makes use of the elements contained in the larger budget data set (e.g., nutrient loads or water-salt budgets) even where the total site budget is incomplete.

The array of estuarine and coastal sea budget sites is being continually added to and data are made publicly available through the LOICZ Biogeochemical Budgets and Modelling website (http://data.ecology.su.se/MNODE). Hard-copy reports from workshops are widely distributed by the LOICZ IPO, including:

Region	Report
Shelf Seas	LOICZ Reports and Studies No. 9, 1996
Mexican coastal lagoon systems	LOICZ Reports and Studies No.10, 1997
Australasian estuarine systems	LOICZ Reports and Studies No.12, 1999
Central American lagoon systems	LOICZ Reports and Studies No.13, 1999
South China Sea estuarine systems*	LOICZ Reports and Studies No.14, 2000
South American estuarine systems*	LOICZ Reports and Studies No.15, 2000
East Asian estuarine systems*	LOICZ Reports and Studies No.16, 2000
Sub-Saharan African estuarine systems*	LOICZ Reports and Studies No.18, 2001
Mediterranean and Black Sea estuarine systems*	LOICZ Reports and Studies No.19, 2001
African estuarine and coastal systems*	LOICZ Reports and Studies No.20, 2002
Polar and Central American estuarine systems*	LOICZ Reports and Studies No.22, 2002

(* supported by UNEP GEF; a workshop in South Asia (2000) showed a dearth of site data required for budgets development and a project funded by the Asia Pacific Network for Global Change is contributing to filling this information gap)

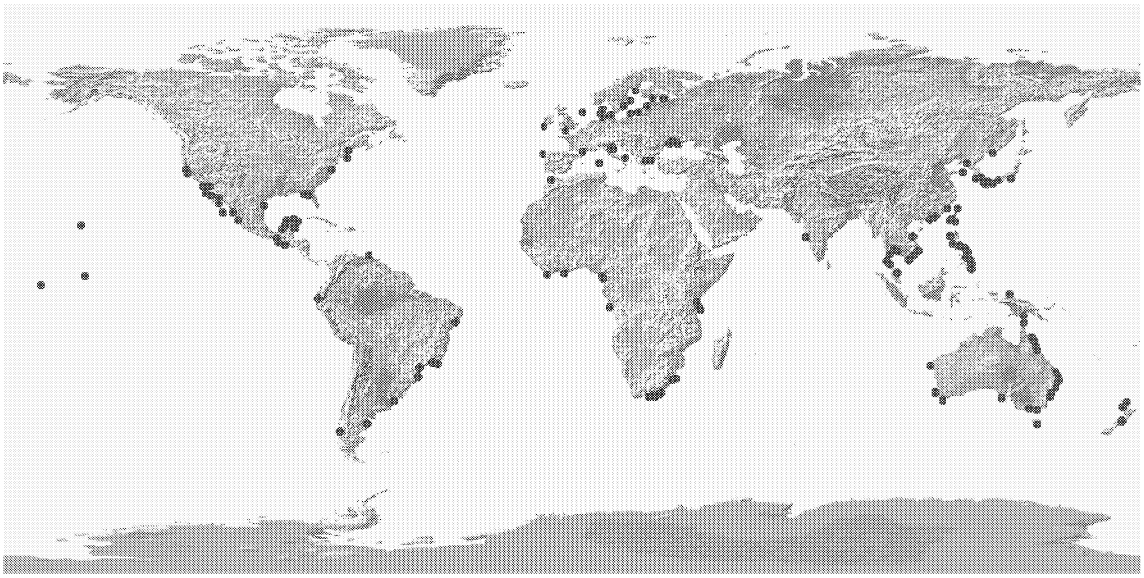


Figure 1.2. Map of LOICZ budget sites, November 2001.

1.2.3.2. LOICZView Typology System

The LOICZView typology system was developed during an early phase of the UNEP GEF project in parallel with the biogeochemical workshops, and has been constantly upgraded with new tools, databases and tutorials. The typology system is made up of two parts, viz., the typology database and a set of geo-spatial clustering tools (Web-LOICZView, WLV).

The database is located at Kansas Geological Survey, University of Kansas and is served to users on the World-Wide-Web. It is founded on 47,057 cells of a half-degree resolution representing the global coastal zone (Buddemeier *et al.* 2002). An array of parameters and variables (with descriptive metadata) describe atmospheric, geomorphic, human dimensions, oceanic, terrestrial and river basin conditions, and biogeochemical sites (www.kgs.ukans.edu/Hexacoral/Environdata/environdata.html).

The WLV clustering and visualisation tool is located at Swarthmore College, Pennsylvania (www.palantir.swarthmore.edu/loicz). It is a web-based graphical user interface to a set of data analysis tools intended to facilitate analysis and understanding of trends and groupings that exist in a spatially indexed data set. It is tightly integrated with the "LOICZ Hexacoral database" and includes clustering routines, ways to visualise data, data management tools and statistical assessment techniques, such as principal component analyses (Maxwell and Buddemeier 2000). The tutorial web pages for WLV are included on the CD-ROM version of this report, and may be referred to as supporting documentation for the results and experiments described in the working group reports.

Three regional workshops in 2001 (Australasia-Asia, the Americas, Africa-Europe; Buddemeier *et al.* 2002) had provided familiarity in use of the LOICZView system to about 90 participants, globally, and its use is being applied to address research and environmental management questions more widely.

The data sets and variables available to workshop participants are listed in Buddemeier *et al.* 2002. The workshop activities identified the need for several additional data sets that have subsequently been added or developed. The LOICZView databases are being continuously developed as project needs and relevant geo-spatial data sets become available. Collaborative interests on loading and land runoff estimates and spatial modelling, for example with researchers at the University of New Hampshire, are yielding refinements to a number of key data sets, and new derivative data are being built for river basin analyses.

Participants at the workshop had familiarity with the LOICZ programme and the UNEP GEF project activities, and with the LOICZ biogeochemical modelling approach and the LOICZView typology methods. Most participants had previously attended a workshop for their region and contributed to site-specific biogeochemical budget development, and/or a regional typology workshop.

1.2.4 Workshop Structure and Approach

Three working groups were established to address the key elements through a mixture of plenary and group discussions including:

1. Typology and global settings – to evaluate key variables and proxies for the coastal zone and river catchments for use as a typological background for up-scaling of individual budgets, and to make regional and global estimates of estuarine function related to ΔDIP and ΔDIN.
2. Functional processes – to develop a conceptual model at the process level to determine what drives budgets and to link these with the environment, especially in relation to land and oceanic loads and linkage to ΔDIP and ΔDIN.
3. Systems performance – to evaluate relationships between biogeochemical function parameters and to develop derivative models and insights that integrate the internal parameters of the site budgets.

Working group membership varied from time to time to encapsulate different skills and experiences of participants in response to new or changing questions developed in plenary sessions. A mix of expert judgement and experimental approaches was taken within the working groups to address issues and to develop and test hypotheses using the LOICZView typology system and an array of statistical approaches.

Group activities and outputs are described in the chapters of this report. A concluding chapter draws together an overview of findings relating to the UNEP GEF project objectives. Information contained in the concluding chapter incorporates results from subsequent work being done by the participants to further the integration and up-scaling of the coastal systems information to global scale assessment.

1.2.5 Acknowledgements
The data and information brought into this synthesis workshop are the result of work by a large number of scientists who have been involved as regional participants, as innovators and contributors to methodological and tools development, and as providers of data and data sets. We are particularly indebted to the LOICZ resource team members identified in the participant lists for their dedication and sustained support in the contributing workshops and to the overall project.

Many institutions have provided venues for workshops and support for the developmental science involved, and for operational platforms that underpin the budgets data base, and the typology tools and allied databases. Workshop venues are listed in the contributing reports, above. Our thanks to all concerned in co-ordinating workshops and providing support.

Core funding for this synthesis workshop, the contributing workshops and much of the developmental work has been provided by the LOICZ core project of IGBP and by United Nations Environment Programme, supported by the Global Environment Facility. The OBIS project, through US NSF grant OCE 00-03970, has provided additional support to the development of the typology tool and data base in meeting complementing goals for global scaling and assessment of organismal biogeography.

1.2.6 Appendices: Print Summary and CD-ROM

Organisational and administrative information about the workshop (e.g., participants, agenda) are contained in Appendix I of this report.

An electronic CD-ROM is provided with this report. Much of the detailed work of the Working Groups described in the chapters of the report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. A brief text and table description of each Group information is provided in the relevant Appendix section of the report; the full data and images from the can be accessed on the CD-ROM along with a complete electronic version of the printed report.

2. Geo-spatial and Typology Working Group

Executive Summary: The Geo-spatial and Typology Working Group considered issues of up-scaling the biogeochemical budget information, starting from the perspective of coastal zone process identification and classification. The Group used consensus-based expert judgement to select and evaluate variables from the LOICZ/Hexacoral database, and to make recommendations for its improvement. Initial data subdivisions were into anthropogenic and biophysical variables, with a secondary division of the biophysical into terrestrial and marine. Preliminary global-scale experiments demonstrated a need for more highly resolved studies, so the world was divided into polar, temperate and tropical areas based on sea-surface temperature, and a further series of clustering experiments was conducted with those zones and the data type subdivision. Finally, the distribution of budgets classified by the sign of ΔDIP and ΔDIN was considered in relation to the zones and clusters identified. The Group found good agreement between most of the clusters and expert knowledge, and recommended that future analyses concentrate on relating the signs of the ΔDIP and ΔDIN variables to subsets of clusters within the climatic zones, rather than working initially at a global scale. Further exploration of relations between variable type, geographic zone, and cluster numbers was carried out in the immediate post-workshop period.

2.1 Introduction

2.1.1 Objective
Identify and test key variables in the global coastal zone and associated river basin catchments to make a typology for the up-scaling of individual budget site data, and to make global estimates of coastal water body (estuarine) function in terms of estuarine processes, for example, the non-conservative fluxes of dissolved inorganic phosphorus and nitrogen (ΔDIP and ΔDIN).

2.1.2 Background
The LOICZ programme addresses issues of land-water interactions and focuses on the environments of coastal seas and estuaries. Figure 2.1 provides a global-scale overview of the coastal marine and estuarine environments. The term *estuary* is used in the most general sense to describe coastal water bodies. The LOICZ typology maps coastal features in LOICZ pixels (one half degree, or ~50x50 km). The mapped area captures many coastal features including long straight shores, river mouths, lagoons, embayments and large bays. ΔDIP and ΔDIN were chosen as a starting point for the Group evaluation of budget sites. The ΔDIP and ΔDIN metrics are meaningful in terms of community respiration, net ecosystem metabolism, and broadly representative of ecological processes.

2.1.3 Approach – sequential development
Expert knowledge was used to identify and assess appropriate variables (and some derived variables) in the LOICZ-Hexacoral Typology database (http://www.kgs.ukans.edu/Hexacoral) that captured coastal processes (e.g., upwelling, forcing by tides, river inputs) at broad landscape scales. Variables were examined and their suitability evaluated.

Cluster analysis using LOICZView (http://palantir.swarthmore.edu/loicz) was applied to look for environmentally significant patterns in the selected variables at the global scale.

The major environmental properties and drivers of the coastal systems and contributing catchments of the globe were discussed and assessed by the Group members, and an expert judgment summary was developed.

The data were aggregated in different ways to produce clusters/patterns through a process of stratifying the global data set:

(i) the variables were combined into biogeophysical and anthropogenic data sets, and
(ii) a broad geographic zonation of the globe was constructed, including polar, temperate and tropical belts, on the basis of sea surface temperature (SST – see Figure 2.1).

Based on conceptual understanding of biophysical and anthropogenic processes, the Group selected those variables from the various categories developed by the division into biogeophysical and anthropogenic data sets that could provide insight into coastal nutrient loading and processing capacity. These were then evaluated in terms of the zonal divisions (polar, temperate and tropical belts). Classifications developed from this stratified approach ('cluster busting') were compared with expert knowledge and maps of the global coastal environment.

Global maps of ΔDIN and ΔDIP from the biogeochemical site budgets were constructed and related to:
(i) the zonal division of the globe based on SST, and
(ii) the clusters of various biophysical and anthropogenic factors.

2.2 Variable selection

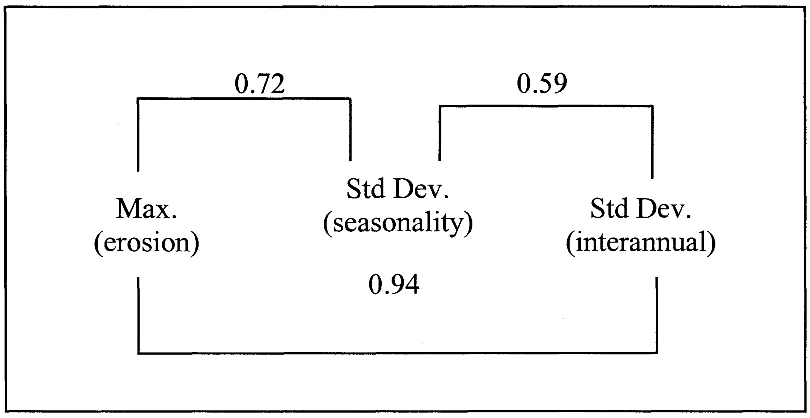
Expert knowledge of coastal processes (i.e., the way that materials processing in coastal basins is driven by catchment and oceanic forcing) was used to identify variables in the LOICZ-Hexacoral Typology database that captured key coastal processes and forcings (e.g., upwelling, forcing by tides, river inputs, effluent inputs) at broad landscape scales.

Two guiding principles in variable choice were that:
- Only variables considered environmentally meaningful were chosen, and
- The number of descriptive variables for clustering should be minimal.

Variables were examined closely and their suitability evaluated and improved by statistical testing, construction of derived variables, transformations and expert knowledge. For example, the following precipitation variables were chosen as being representative of processes:

Precipitation variable	**Environmental significance**
Log Ppt 12 month average	wet/dry areas
Log Ppt SD of average annual	seasonality
Log Ppt SD of 12 month average	interannual variation
Log Ppt maximum	erosion of soils in catchment

Further checking by correlation analyses showed some precipitation variables to be strongly associated.



As a consequence, the variable "precipitation maximum" was deleted from the data set because of its high correlation with interannual precipitation (0.94) and seasonal precipitation (0.72). The variables relating to seasonal and interannual precipitation were retained due to their lower correlation (0.59).

Variables were rationalized as follows:

- mean sea surface temperature versus air temperature (0.95) - eliminate mean sea surface temperature.
- minimum air temperature versus mean air temperature (0.95) - eliminate minimum air temperature.
- precipitation, average maximum versus standard deviation, precipitation and standard deviation, precipitation/mean.
- basin runoff (cubic meters) was the best runoff parameter for our purposes.

The final list of variables and their environmental significance (i.e., processes to be captured in the variables) is summarised in Appendix II, Table II.1, with details in Table II.2.

For some purposes, it was necessary to 'double up' on variables. For example, the two variables, basin population (total) and basin population (density) could be combined to capture total loading of nutrients and nutrient loading intensity. However, this created concerns about double counting or double weighting in the cluster analysis. Another example was the possible use of SST (mean) and SST (variability) to capture perennial and seasonal upwelling.

Most (17 out of the original 25) variables were log-normally distributed and these were generally transformed by log10; although the variable, basin (road density), was best transformed using a square root function. This transformation did cause some minor interpretation problems, since when the variables are log-transformed, the raw numbers do not make obvious sense in the correlation matrices.

The inclusion of graphic and correlation tools in the LOICZ-Hexacoral database and in LOICZView proved very useful in variable testing, and in the assessment and selection of relevant correlated variables and transformations. However, the lack of units on the axes of the histograms and scatter plots was sometimes frustrating.

2.3 Results

2.3.1 Results of early cluster analyses

The first clustering runs mapped the variables for the whole globe using the LOICZView cluster analysis, and deriving 10 clusters (See Appendix II for notes, observations, descriptions and links to the summaries of these first 6 cluster runs.). The Group then addressed the question: *"are the clusters useful in terms of our objective?"* The general findings were that the results:

- provided a strong latitudinal signal;
- identified the land areas adjacent to coastal upwelling regions;
- displayed the warm Gulf Stream and colder shelf seas;
- poorly clustered Australia, New Zealand and the Mediterranean region;
- effectively grouped coastal South America;
- gave emphasis to areas of high population;
- were difficult to interpret with so many (10) clusters; and
- appeared to be driven by large variations in the data sets, hiding known important processes. For example, the lengthy coastline (numerous shallow coastal cells) of the Indonesian region skewed the clustering results.

2.3.2 Tuning the cluster analysis (cluster busting)

2.3.2.1 Global-scale refinements: In an attempt to reduce some of the variance, the Arctic and Antarctic regions were removed from some cluster runs. [At the time of the workshop, there were no biogeochemical budget sites described in these regions; additional sites were added to the database in December 2001]. Additional runs at this 'adjusted global' level showed minor improvements.

The eigenvector analysis in Web-LOICZView, which provides a factor weighting of the variables, is a possible tool for cluster refinement. However, it was not practical to apply in this instance, given the time schedule and lack of experience within the Group.

The 10-cluster maps provided images that were difficult to interpret. For preliminary global-scale classification, it was decided that the information in 5-cluster analyses was adequate and more readily understood, even when the minimum description length LOICZView tool (MDL analysis) recommended 20 clusters as the optimal number.

2.3.2.2 Subdivision of data and regions:
A two-pronged approach was applied to the problem of minimising variance. First, reduced variance and greater explanatory power was sought by running the biophysical (indicative of the dynamics) and anthropogenic (strong influence on the catchment basin signal) variables separately in the clustering runs. Second, the global data were split into climatic zones corresponding to tropical, temperate and polar regions. Here, one option was to divide the globe on the basis of latitude, but the Group considered this too generic as a discriminator in light of the relatively sophisticated database available. Sea temperature is known to play a major role in structuring ecological patterns in the ocean, influencing the distribution of habitats (coral reefs, salt marshes and mangroves, seagrasses, and kelp beds) and major coastal upwelling.

On this reasoning, and to avoid climate strongly skewing some of the plots, the globe was divided on the basis of sea surface temperature (SST) into tropical (>24° C), temperate (4-24° C) and polar (<4° C) regions (Figure 2.1).

The conceptual understanding of the properties and functioning of the coastal systems in the broad zonation bands also was captured in diagrams (conceptual models) for tropical coasts (Figure 2.2), temperate coasts (Figure 2.3) and polar coasts (Figure 2.4).

2.3.3 Cluster analysis in the tropical, temperate, and polar zones

Slightly different variable combinations were selected for clustering of the tropical, temperate and polar zones, recognising that different processes dominate in each of those groups (see Appendix II, and conceptual models). Following the zone delineation, it was possible to remove SST from the list of variables. Further consideration of the variables led to weighting the chlorophyll variable by a factor of 2. For the climate region analysis, an output setting requiring five clusters was applied, and a total of six cluster runs were made – using biophysical and anthropogenic variable sets in each of the three climate regions (see Appendix II, for images and a discussion of each of the clustering classifications).

Overall, classifications using this stratified approach (cluster busting) were very encouraging for the biophysical typologies. The clusters mapped well against expert knowledge and the maps of the global coastal environment. Patterns in the clusters could be readily interpreted in terms of key environmental properties at the global scale.

The anthropogenic typologies showed little more than would be expected from population distribution maps.

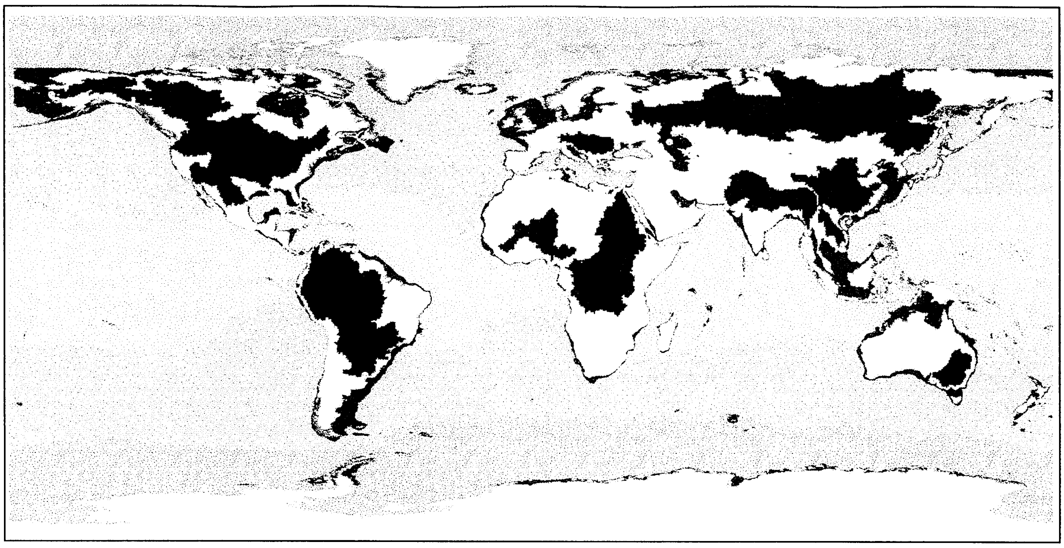


Figure 2.1 The LOICZ domain. (Represented as the region landward from the 200m isobath (dark blue). The pink, light blue, and medium blue shades represent the tropical, temperate, and polar regions, defined by SST. The green regions are major land drainage basins (green) with associated biogeochemical budget sites shown as yellow points.

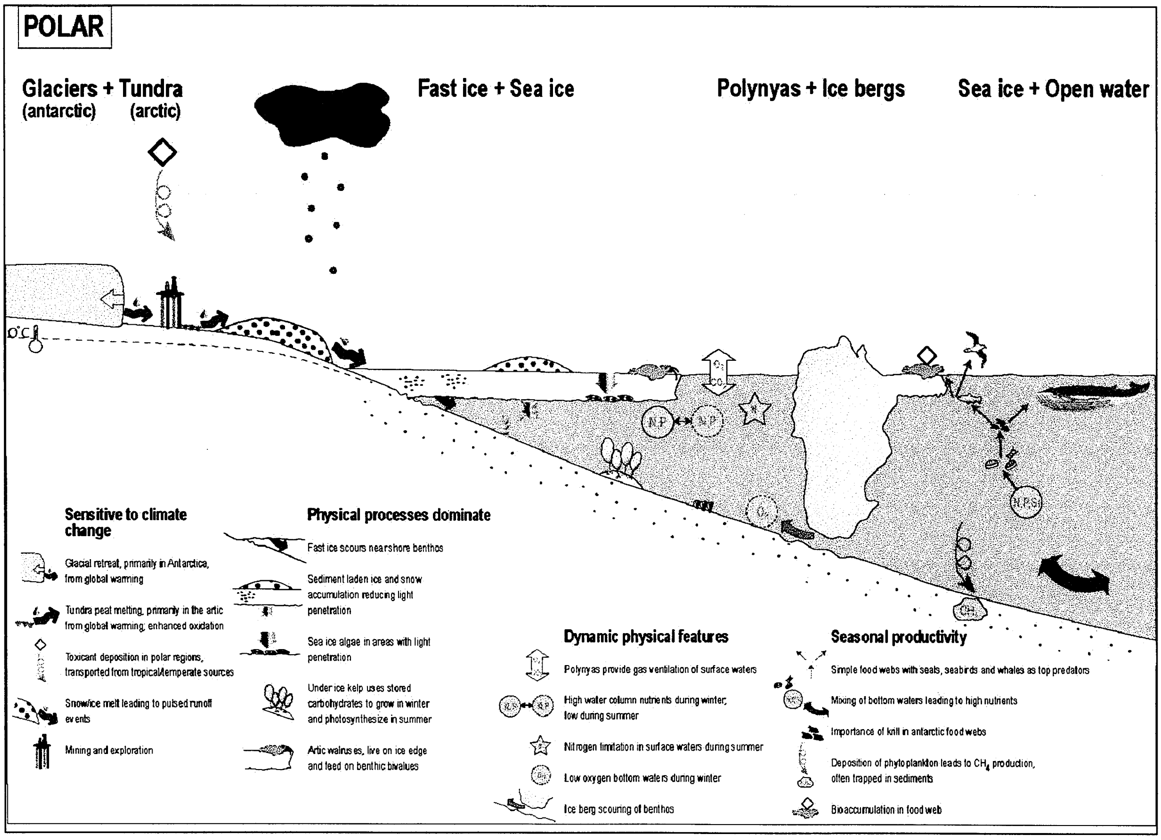


Figure 2.2 Conceptual model of processes and conditions affecting biogeochemical fluxes and budgets in polar coastal environments.

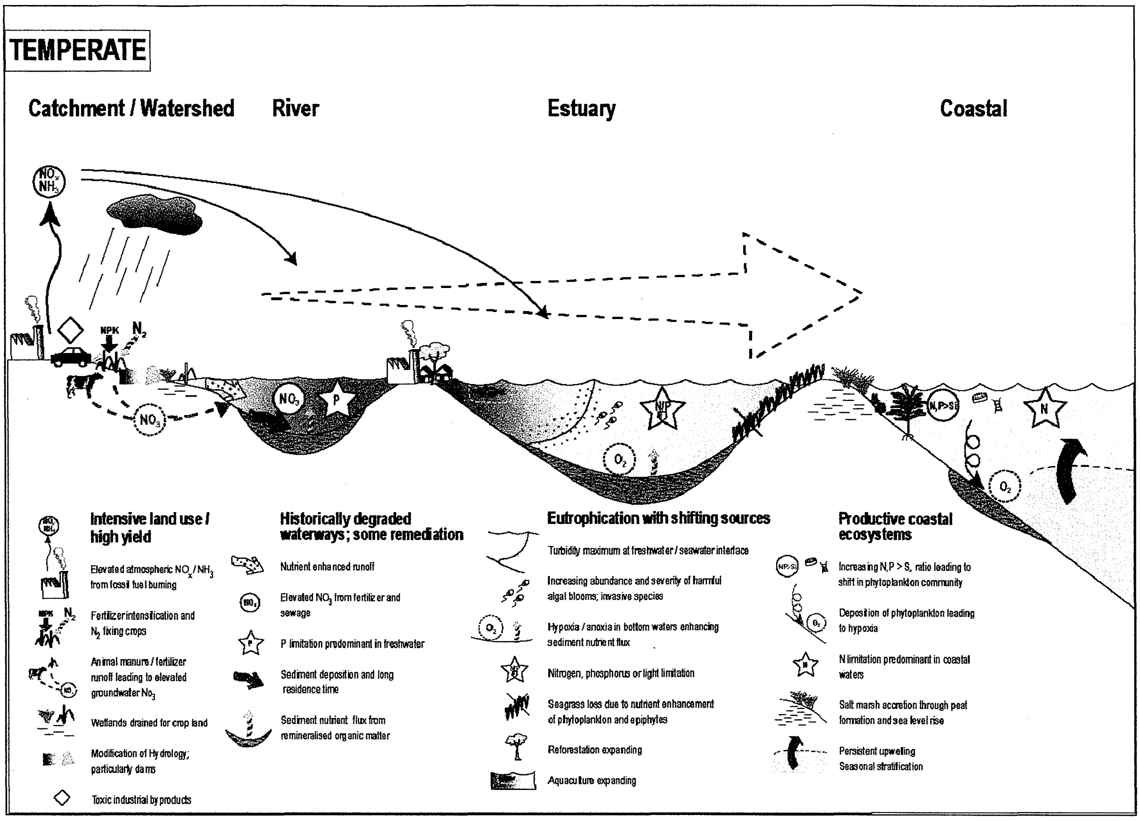


Figure 2.3 Conceptual model of processes and conditions affecting biogeochemical fluxes and budgets in temperate coastal environments.

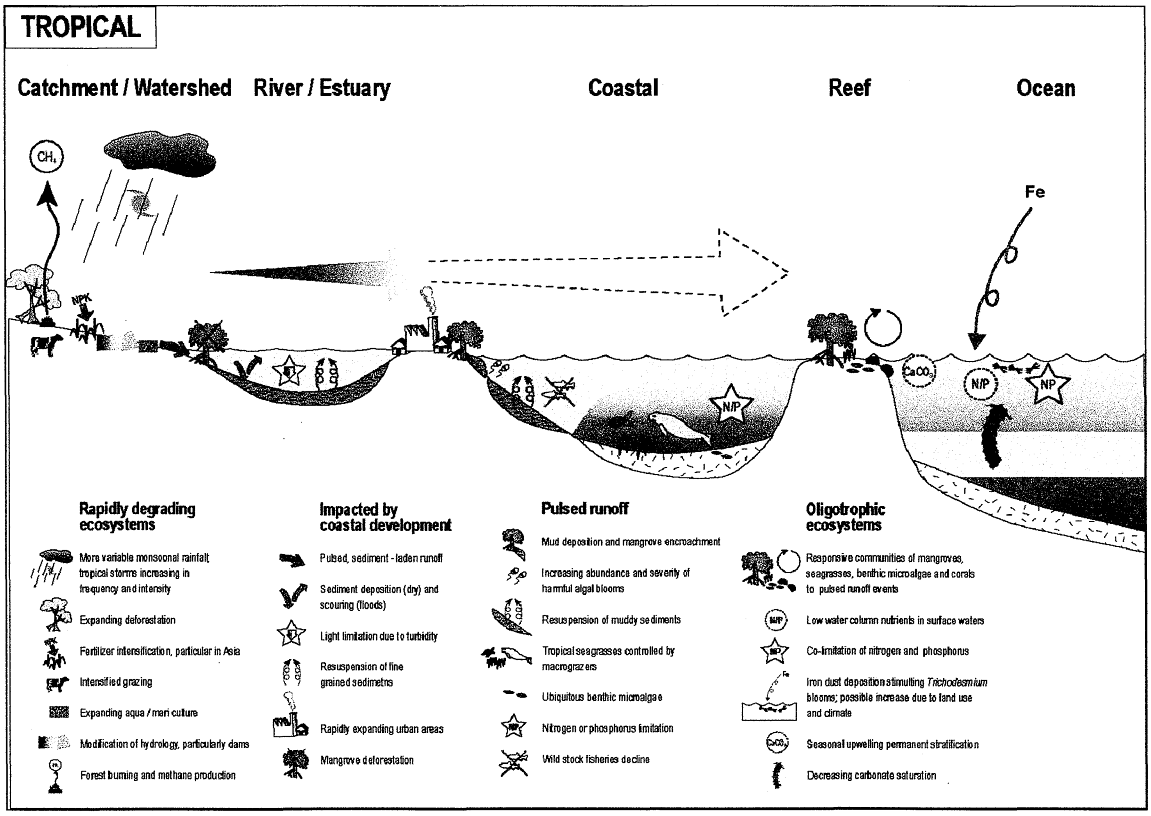


Figure 2.4 Conceptual model of processes and conditions affecting biogeochemical fluxes and budgets in tropical coastal environments.

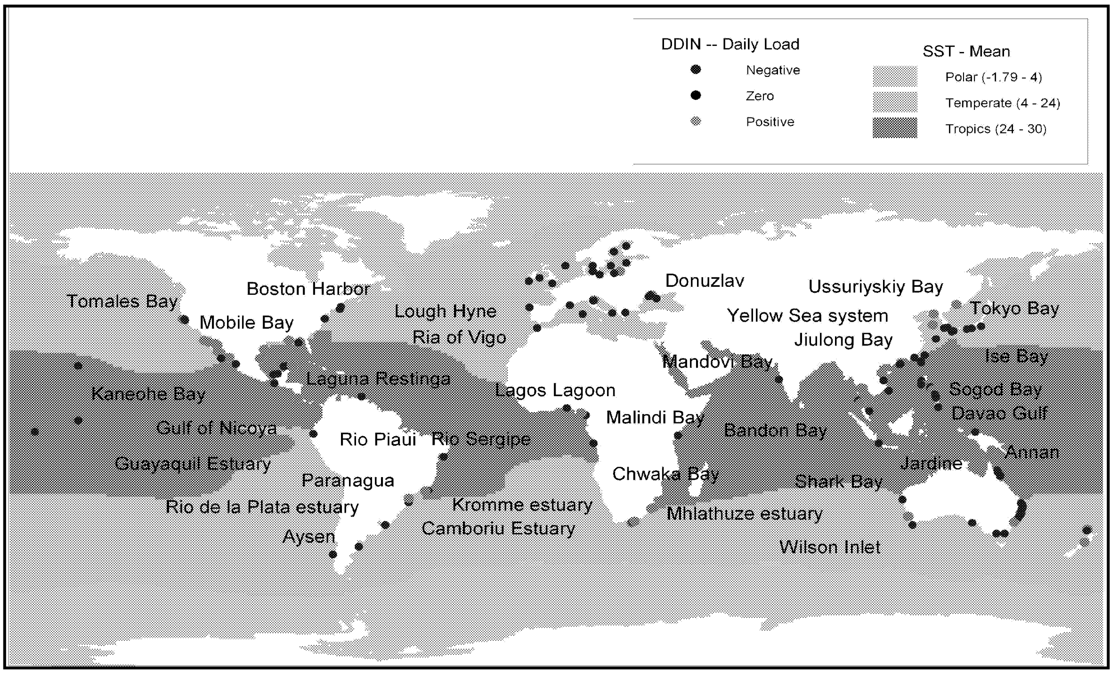


Figure 2.5 The ΔDIN load classes for various budget sites, superimposed the tropical-temperate-polar classification of the world coastline.

2.3.4 Comparing typology to budgets for the up-scaling and to make global estimates of coastal (estuarine) function, in terms of ΔDIP and ΔDIN

Global maps were constructed in ArcView based on the SST-defined tropical and temperate zones (polar budgets were not available). Budget parameters, ΔDIN and ΔDIP, from all the sites were overlaid on these maps; Figure 2.5 shows the classes of ΔDIN superimposed on the SST-derived climate classification.

There was not time to develop a Group interpretation, but on the basis of initial review it is recommended that future analyses should not try to look for a relationship between the +/-ΔDIP and +/-ΔDIN and the broad-scale zonation. Instead, it should look for relationships between +/-ΔDIP and +/-ΔDIN and selected tropical and temperate cluster summaries.

2.4 Summary and Conclusions

2.4.1 Observations and suggestions concerning the LOICZ-Hexacoral Database

In terms of the suitability for the task of the Hexacoral database:

1. additional variables for geology and catchment basin steepness would allow better parameterisation of soil runoff. This is important, given that some nutrients adsorb on silts and clays and are transported bound to sediments;
2. depth data was of limited quality and insufficient to estimate basin volume for flushing estimates;
3. data layers for tides and particularly waves are inadequate, given that there are ocean models to hindcast these parameters;
4. present variables provide no easy way to parameterise/capture the effects of: i) animal inputs, ii) atmospheric inputs, iii) aquaculture (freshwater and marine) inputs, iv) rates of change of land use/population, v) groundwater inputs, vi) engineering works and particularly the effects of dams in catchments, vii) regions of "rich vs poor" human communities, and viii) tectonically active vs tectonically passive regions;
5. advantage may be gained from incorporation of the new SeaWiFS layers for turbidity, chlorophyll, and colour distinction;

6. plain language descriptions of how the variables are derived would improve utility; display of the codes for each variable identified in the correlations would aid interpretation; and
7. the basin urban density variable is limited, containing many incomplete data cells.

(See note, below, in responses to database recommendations)

2.4.2 Summary of methodologies and findings

- Expert knowledge of coastal processes was used to identify variables in the LOICZ-Hexacoral Typology database that captured key coastal processes and forcings across broad landscape scales.
- Variables were examined closely and their suitability evaluated and improved.
- Cluster analysis using LOICZView tools was used to look for environmentally significant patterns.
- Major environmental properties and drivers of the coastal waters and contributing catchments of the globe were discussed and are summarised in base maps and other graphics.
- The global dataset was subdivided to produce more environmentally meaningful clusters/patterns by: (i) splitting variables into biogeophysical and anthropogenic data sets, and (ii) stratifying into broad geographic zonations of the globe (polar/temperate/tropical belts) based on SST.
- Conceptual models were developed as cartoons to capture the key processes in the polar, temperate and tropical zones.
- The information content in five clusters is sufficient and manageable even when MDL recommends 20; using too many clusters provided images that were difficult to interpret.
- Classifications using the stratified approach (cluster busting) mapped well against expert knowledge and maps of the global coastal environment.
- Maps of ΔDIN and ΔDIP from the site budgets were developed on the global scale, including: (i) the zonal division of the globe based on SST, and (ii) clusters of various biophysical and anthropogenic factors. (See CD-ROM appendices)
- It is recommended that further analyses should look for relationships between +/-ΔDIP and +/-ΔDIN and selected tropical/temperate cluster summaries (rather than for a relationship between the +/-ΔDIP and +/-ΔDIN and the broad-scale zonation).

2.5 Further activities

During a post-workshop meeting, further systematic investigation of clustering results was obtained with various combinations of class of variable, geographic region and number of clusters. These results are presented in Appendix II.

Actions taken in response to the Hexacoral database:

1. Topographic index data (one km resolution) have been acquired and aggregated into all terrestrial cells and the basins studied.
2. Regrettably, the depth data in use are the most highly resolved available on a global basis.
3. A much improved windspeed data set has been acquired; the square of windspeed can proxy for wave height. A tide model will be run when time and personnel are available.
4. Global datasets covering sub-items (see numbering in section 2.4.1, above): 1-3 are not available; 4 will be addressed by adding the LUCC historical land use/population data; 5 is an area of active research, but no consistent data set is yet available; 6 is possible but labor intensive; 7 will be addressed by adding country level GDP data; and 8 is possible but of low priority.

2.6 Appendices: Print summary and CD-ROM

Appendices to the Working Group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. This information is included on the electronic CD-ROM version of the report; a list of appendix materials, brief descriptive summaries, and items that are primarily text are printed in Appendix II in the Appendix section of this report.

3. Functional Processes Working Group

Executive Summary

The Functional Processes Working Group developed a conceptual model of the processes and forcing functions that drive estuarine biogeochemical budgets from both landward and seaward directions. Analyses and exercises were designed and conducted to explore the potential of the typology data set to characterize the processes, and to identify problem areas and further needs. Linear and non-linear regressions were used to identify relationships between budget and basin variables, and to explore potential scaling or normalization relationships.

Population, basin area, crop area and runoff variables were shown to relate to DIP and DIN loads, with "population" providing the most consistently strong signals. Total suspended solid (TSS) loads could be adequately approximated from the typology data set, but had no point of comparison in the budget data. Upwelling zone classifications (developed jointly with the Geo-spatial and Typology Working Group; see Section 2) were used to identify marine DIP and DIN inputs. However, problems were identified involving analysis of connectivity between different types of cells, the TSS issue, and lack of a coastal-oceanic mixing term. Estuarine process experiments also identified the need for exchange or mixing time estimators, and resulted in recommendations for further development to meet these needs.

3.1 Objective and Approach

The main objective of this Group was to develop a conceptual model at the process level as a means of identifying key factors that drive estuarine biogeochemical budgets. On land, catchment processes and anthropogenic influences that determine DIP, DIN, organic carbon and TSS loads were identified (Figure 3.1).

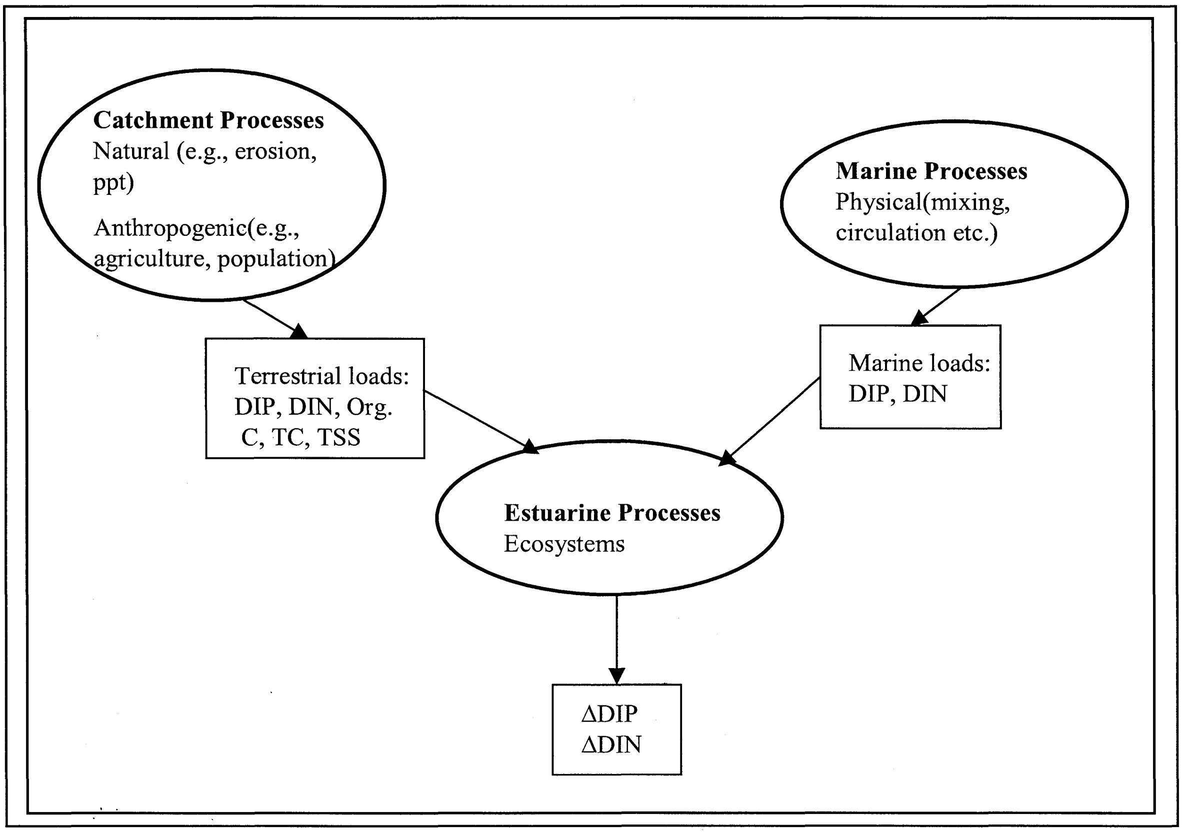


Figure 3.1 Conceptual model of coastal zone biogeochemical processes and function.

In the coastal ocean, the occurrence of upwelling was considered a major means of providing new N and P nutrients to the coastal zone. Within the estuarine basins, the roles of physically-forced variables (e.g., water residence time) and of biologically-mediated material recycling were assessed to be key determinants of the non-conservative fluxes of nutrients and carbon.

The key forcing variables identified in the catchments, oceanic system and estuarine basins were used as guides in choosing main and proxy variables from the global typology dataset. These typology variables were then used to derive predicted values (where quantified empirical relationships were accessible to the Group) or cluster-based types, against which to assess parameters estimated for budgeted sites.

The exercises discussed below describe processes that represent N, P and C loads into coastal cells from river catchments and the marine environment, and describe biogeochemical processes within coastal cells which further affect DIN and DIP. The analytical tools used and outputs of the Group are presented. In implementing these, constraints in the data sets and tools were identified. Future steps were suggested to improve on both so that the ultimate goal of upscaling what is known of the dynamics and fluxes in budgeted estuarine sites unto the global coastal zone may be achieved.

3.2 Exercises

3.2.1 Catchment

The "Catchment" exercises identified conceptual contributors to the total terrestrially-derived load from a basin, and experimented with potential representative or proxy variables.

Concept: TOTAL LOAD = $load_{BG} + load_{crops} + load_{population} + load_{atmosphere}$

where

$load_{BG}$ = flow x C_{BG} set to measured nutrient levels from pristine catchments,

$load_{crops}$ = f {(fertilizer use per unit crop area, crop area, transfer efficiency, CNP ratio) (livestock units, load per unit, transfer efficiency, CNP ratio)},

$load_{population}$ = f {population, load per person, transfer efficiency, CNP ratio}

$load_{atmosphere}$ = f {precipitation, basin area, precipitation CNP concentrations, precipitation CNP ratios}.

Experimental approach: Basin-scale crop area, runoff and population were used as independent variables to explain DIN and DIP loads in budgeted sites (n = 58). Basin area and independent variables were also used to normalize loads.

Actions taken and progress:

3.2.1.1 Non-linear fitting of DIN and DIP against independent variables runoff, crop area and population. Exploratory analysis consisted of multiple regression for 64 budget sites (omitting Rio de la Plata):

Dependent variables (D): DIN & DIP (annual raw data)
Independent variables (I): Crop area, runoff & population (raw data)

Linear regression produced no significant fits. Non-linear regression ($D = aI + bI^2 + cI^3 + dI^4 + eI^5 + \ldots$) of raw data produced only one significant regression:

DIP load = f {$(population)^2$}

When variables were standardized by (value-mean)/standard deviation, almost all non-linear regressions were significant (see Appendix III.1 for plots):

DIP load = f {$(population)^1$}

DIP load = f {$(runoff)^{2,3,4}$}DIN load = f {$(population)^{1,2}$}

DIN load = f {$(runoff)^2$}

DIN load = f {(crop area)[1,2,3,4]}

Pairwise linear regression plots and equations of the following budget and environmental variable combinations are shown in Appendix III.2.

Variable		Plotted against Variable(s)_
Basin area		DIP load, DIN load, DIP load/area, DIP:DIN
Population		DIP load, DIN load, DIP load/area, DIP:DIN
Crop area		DIP load, DIN load, DIP load/area, DIP:DIN
Runoff		DIP load, DIN load, DIP load/area, DIP:DIN
DIP load		DIN load, DIP:DIN
DIP load/area		DIN load/area

These results suggest that in catchments:

(i) DIN and DIP behave in similar but not identical ways;

(ii) raw data are relatively uninformative but that a variety of normalizations (by variance or by basin characteristics) show promise of revealing relationships; and

(iii) "population" shows the most consistent signal relative to DIN and DIP, but "runoff", "basin area" and "crop area" may be correlated with load for some formulations of the variables.

3.2.1.2 Predicted and observed concentrations of total suspended solids (TSS) using the GEMS-GLORI Database (observed values) and Syvitsky and Moorehead (2000) (predicted values). This component of the catchment experiment (referred to as the TSS hybrid approach) compared observed TSS values tabulated in the GEMS/GLORI database (basins illustrated in Figure 3.2) with predicted loads calculated according to the relationship given in Syvitski and Moorehead (2000):

$Q(s) = 0.00004\ R^{3/2}\ A^{1/2}\ 10^{\ 0.00578T}$

where

Q(s)= river's sediment load

R = basin relief (m) (maximum elevation data were provided by Pamela Green,. UNH)

A = basin area (km^2)

T = mean temperature (^oC) (data provided by Pamela Green, UNH)

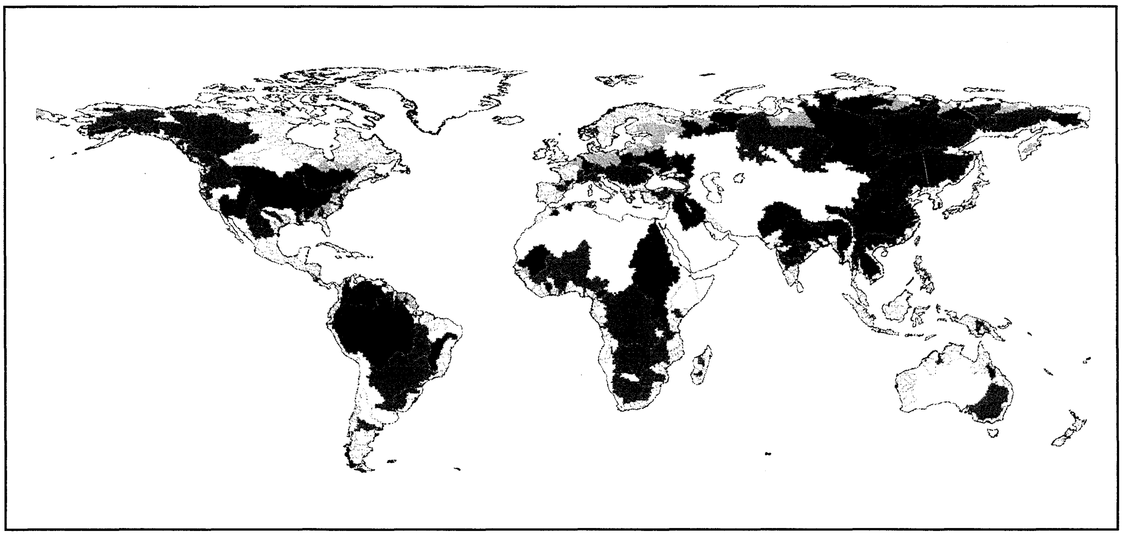


Figure 3.2 Global extent of GEMS/GLORI TSS observations.

Initial progress was impeded by the lack of basin scale data in the LOICZ-Hexacoral Typology database for the variables, "relief" and "temperature"; Pamela Green provided data sets for "maximum elevation" and "mean temperature" in the basins, from IGBP BAHC. TSS was calculated for the 191 (BAHC) basins (Figure 3.2) using the Syvitski and Moorehead relationship. Results were tested against the GEMS/GLORI data base of stream sediment discharge:

- For $\log_{10}$ transformed total data log(Q(s)), the r^2 correlation was ~0.5 (Figure 3.3).
- For $\log_{10}$ transformed area-averaged data [log(Q(s)/basin area)], the r^2 correlation was ~0.5 (Figure 3.4).

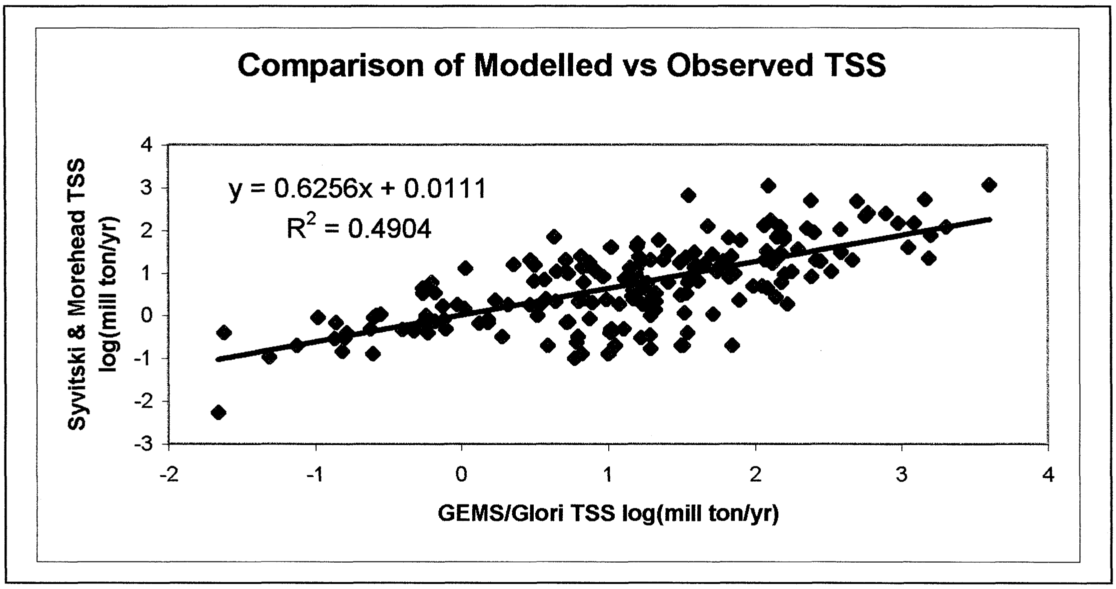


Figure 3.3 Total load.

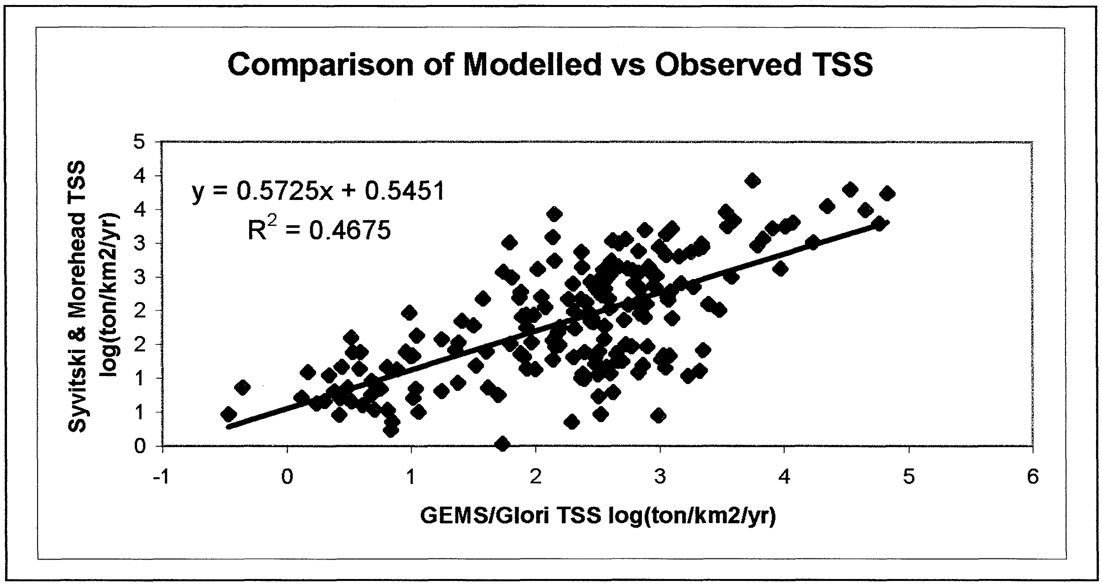


Figure 3.4 Basin area-normalized load.

The observations from this experiment indicate that modelled and observed loads of TSS correspond reasonably well, and that the relationship looks qualitatively tighter at the more extreme values for TSS. While there is no appropriate parameter available in biogeochemical budget data set with which to test these outcomes, the implications for the budgets interpretation and upscaling is that similar results may be useful for assessing nutrient loads, with the likelihood that P and C may behave more like the TSS than N because of relative contributions of particulate and dissolved constituents.

3.2.2 Oceanic influence

The oceanic influence was assessed in terms of potential sources of C-N-P by using the upwelling typology cluster ($SST_{cell} - SST_{zoneavg}$) developed by the Geo-spatial and Typology Working Group to indicate oceanic influence on DIP and DIN loading

Marine inputs and their possible representative variables or proxies were identified as:
Loads: DIP, DIN Levitus climatology? (not in database at present)
Upwelling? (index variable developed by Typology Group)

Organic C	SeaWiFS chloro_a
TSS	resuspended sediments (tides, wave height, Windspeed^2, depth, ecosystem

<u>DIN/DIP experiments</u>: "upwelling" ($SST_{cell} - SST_{zoneavg}$: Figure 3.5) was used as a proxy for marine DIN/DIP, and tested by examining the relationship with budgets. The upwelling index was based on annual average values for SST, and on the coastal cells within the climate zone defined by SST range (see Geo-spatial and Typology Working Group report). There was decent agreement between upwelling and sites where marine DIN/DIP was significant.

Problems identified include the lack of analytical connectivity between coastal and marine cells (equivalent to basin-coastal cells), and the desirability of a convenient method for performing latitude/longitude-supervised clustering.

No experiments were performed for Organic C or TSS.

General observations from this experiment include the positive suggestion of a relationship between upwelling/offshore nutrient levels and the marine input to coastal budgets. Satellite data may be useful for validating resuspended sediments as well as for the carbon proxies, and there is a real need for a variable reflecting the mixing term between coastal/oceanic waters.

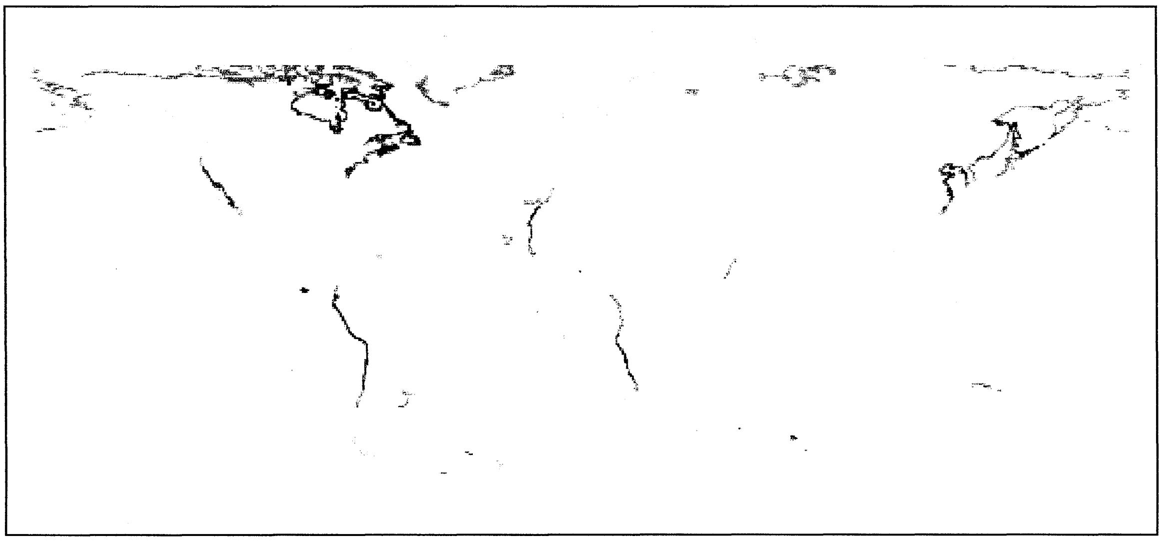


Figure 3.5 SST anomalies for coastal cells. (Negative anomalies, shown as dark lines in the coastal cell outlines, should relate to upwelling. Mapped temperature differences are: light blue, -3.4 to -1.1 °C, dark blue -8.6 to -3.4 °C).

3.2.3 Estuarine processes

3.2.3.1 Residence time was addressed using mean elevation, wave height, tidal range and runoff as cluster variables. Experiments were preliminary and discussional, and started by identifying the need for knowledge of estuary volume, discharge rate and mixing rate.

Developing estimates of estuary volume directly from the typology database is problematic unless estuary boundaries coincide with cell boundaries or the system contains many cells. River discharge (minimum, maximum and mean values) is appropriate, and can be supplemented with runoff values where specific river discharge values are not available. For the mixing term, hydrodynamic variables are required, such as tidal range, wave height, windspeed[2] (for which the database needs augmentation). Discerning or classifying variables of interest would include: salinity (standard deviation), wave height (especially for closed versus open systems), and coastline rugosity (not presently available, but highly desirable).

The proposed approach is to use typology to identify coastal cells with similar exchange rates. An initial design is to determine residence time by developing a ternary classification to discern whether the system is fluvial-, wave-, or tide-dominated and to combine this with some measure of "cell slope" (as an exposure proxy). Depending on the dominant influence, the systems might then be classified in a typology using various combinations of, for example, mean land elevation, tidal range, wave height, and/or river discharge. A final test would be to compare the proxy V_X with V_X from budget sites.

3.2.3.2 Estuarine processes were discussed by the Group for the purpose of experimental design. A primary objective is development of functional relationships for p, r, DIN, DIP, ΔDIN, ΔDIP, nfix and ndenit; as a secondary objective turbidity could be considered. The budget data immediately available in the LOICZ/Hexacoral data base are: DIN, DIP, and (if available) CNP_{org}, and TSS loads.

Desired parameters are residence time and measures of ecosystems processes (to be defined and developed). To determine estuarine processes, V_Q, and Vx could be used to predict ΔDIN, ΔDIP.
Focusing on ΔDIP as an example, the relationship to be solved would be:

$$\Delta DIP = -DIPcatchment + DIPsys\ VQ + (DIPsys - DIPocn)\ V_X$$

Since ΔDIP = [p-r], there is a ready relationship to community metabolism. These predictive classifications could then be overlaid with some community-dependent bio-uptake terms, using community classification overlays.

3.3 Appendices: Print summary and CD-ROM

Appendices to the working group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. This information is included on the electronic CD-ROM version of the report; a list of appendix materials, brief descriptive summaries, and items that are primarily text are printed in Appendix III in the Appendix section of this report.

4. Systems Performance Working Group

Executive Summary.
LOICZView cluster analysis of the 8 budget variables used to derive ΔDIP, ΔDIN and the other non-conservative flux terms, using the selected budget sites, was overlaid with the ΔDIP values. The percentage of the variance of ΔDIP explained through this exercise is only ~30%, with no significant differences in ΔDIP among the 8 clusters. The most obvious feature of the spatial distributions of both the untransformed and the log-normal transformed values of ΔDIP and ΔDIN is that, although some spatial trends may be observed, there are regions where highly negative or highly positive ΔDIP or ΔDIN values can be observed in neighboring systems. Further analyses were undertaken to resolve the lack of obvious statistical or spatial relationships.

Correlation analysis shows that when the analysis includes ΔDIP and ΔDIN values for all of the preferred sites (79 sites), ΔDIP was significantly correlated with only 5 variables, whereas ΔDIN was correlated with only 4 variables. In contrast, after splitting the ΔDIP into two sets and using the ln transformation, the number of significant correlations for each subset was increased. The ln positive ΔDIP values (lnΔDIP(+)) showed significant correlations with 12 budget variables, and the ln negative ΔDIP values (lnΔDIP(-)) with 11 budget variables. The ln negative ΔDIN values (lnΔDIN(-)) showed significant correlations with 12 budget variables, whereas the ln positive ΔDIN values (lnΔDIN(+)) showed no significant correlations.

A series of clustering experiments were carried out using various combinations of the correlated budget-system variables to explore the possibility of explaining and up-scaling ΔDIP and ΔDIN. Simple clustering, the use of variable weighting, and the use of categorized lnΔDIP values did not result in significant improvements in initial experiments. However, it was found that limiting the number of independent budget-system variables and using a larger number of clusters resulted in a modest improvement in the percentage of variance explained in lnΔDIP. Eigenvector analysis was explored and was considered to show promise as a means of identifying the variables that dominate the principal components.

A similar set of experiments was carried out with the lnΔDIN categories (+ and - values) and for the nitrogen fixation and denitrification variables. These produced yielded somewhat more encouraging results, with 30-50% of the variance explained with fewer modifications and iterations than had been the case with lnΔDIP.

Based on its findings, the Working Group produced a number of recommendations for future activities, expanding on the following points:

1. Divide data and geographic regions into smaller, more coherent subsets for analysis.
2. Find an objective way to reduce variables, and merge significant typology variables (developed by the other Group analyses) with significant budget.
3. Add more preferred budgets and more system-specific driving variables (e.g., drainage basin characteristics, proxies for pollution) to the database.

4.1 Objectives and tasks

The Systems Performance Working Group had as its broad objective the scaling of ΔDIP and ΔDIN information from the biogeochemical budgets for individual sites to a global scale – an objective reflected by the Group's informal workshop designation as the "Budgets-to-World" Working Group. Although several of the closely related variables from the LOICZ budgets database may be up-scaled for typological purposes, given the time constraints the Group agreed to focus on the up-scaling of the ΔDIP and ΔDIN values. As other Working Groups were analyzing in more detail the LOICZ Hexacoral typology database, it was decided that the analysis of the proxies for budget variables would be pursued as time allowed.

The workshop objectives defined by the Group were:

1. Determine the variables that control the observed ΔDIN and ΔDIP values contained in the LOICZ budgets database; and
2. Try to up-scale ΔDIN and ΔDIP using typology variables.

This objective complemented that of the Functional Process Working Group (Chapter 3), which addressed the issue of flux controls and up-scaling on a "first-principles" basis, while the Systems Performance Working Group took a data-oriented approach to the same task.

To define the experiments (subtasks) to be conducted, a simple analysis of the factors controlling the magnitude of the ΔDIN and ΔDIP values contained in the database was performed (Table 4.1). The relevant variables available in the LOICZ budgets database are listed in Table 4.2. The experiments were performed using the 'selected' or 'preferred' budget sites, a subset of about 80 locations judged to provide a particularly robust and reliable set of results (see Chapter 1.2.3 for discussion). Taking into consideration the processes and variables available in the LOICZ budgets database, the exercise sequence was defined.

Table 4.1. What controls ΔDIN and ΔDIP?

Underlying processes	**Controlling parameters**	**Proxies in LOICZ Database**
Primary production Respiration N-fixation N-denitrification	Water temperature Oxygen concentration N and P loading Light Organic matter quality Salinity Residence time (flushing rate) Water depth [DIP], [DIN]	SST Population, cropland, runoff, ocean color (SeaWiFS) as proxy for turbidity.

Table 4.2 LOICZ budget variables from which ΔDIP, ΔDIN, [*p-r*] and [*nfix-denit*] are derived.

Biogeochemical attributes:	**Physical attributes:**
DIPsys	System area
DIPocn	System depth
DINsys	System volume
DINocn	Texchange
Ssys	Total fresh water
Socn	Drainage basin area
DIPload	Freshwater discharge (Vq)
DINload	Residual flow (Vr)
	Exchange flow (Vx)

4.2 Exercises and experiments

4.2.1 Exercise 1: Perform a LOICZView cluster analysis of the 8 variables (Table 4.2) using the selected budget sites, and overlay the ΔDIP values.

Results: After an MDL analysis the selected variables (DIPsys, DINsys, Ssys, DIPload, DINload, Area, Depth and Texchange) were classified into 8 clusters, and for the overlay exercise the ΔDIP observations were split into five classes. The output from this exercise is given in Tables 4.3-4.6 and Figure 4.1.

Table 4.3. Statistics for the overlay of ΔDIP_ANNUAL

Class	Range of ΔDIP	# Points
Class 0	value < -31.5023	17
Class 1	-31.5023 <= value < -4.71815	18
Class 2	-4.71815 <= value < 0.228876	14
Class 3	0.228876 <= value < 5.96625	8
Class 4	5.96625 <= value	22

Table 4.4. Percent of each variable class that appears in each cluster.

	Class #0	Class #1	Class #2	Class #3	Class #4
Cluster #0	47.1(8)	22.2(4)	7.1(1)	12.5(1)	22.7(5)
Cluster #1	11.8(2)	5.6(1)	7.1(1)	0.0(0)	13.6(3)
Cluster #2	5.9(1)	0.0(0)	0.0(0)	0.0(0)	9.1(2)
Cluster #3	11.8(2)	5.6(1)	0.0(0)	0.0(0)	4.5(1)
Cluster #4	5.9(1)	5.6(1)	21.4(3)	25.0(2)	13.6(3)
Cluster #5	0.0(0)	33.3(6)	21.4(3)	12.5(1)	27.3(6)
Cluster #6	0.0(0)	16.7(3)	42.9(6)	50.0(4)	9.1(2)
Cluster #7	17.6(3)	11.1(2)	0.0(0)	0.0(0)	0.0(0)

Table 4.5. Percent of data points in each cluster belonging to each variable class.

	Class #0	Class #1	Class #2	Class #3	Class #4
Cluster #0	42.1(8)	21.1(4)	5.3(1)	5.3(1)	26.3(5)
Cluster #1	28.6(2)	14.3(1)	14.3(1)	0.0(0)	42.9(3)
Cluster #2	33.3(1)	0.0(0)	0.0(0)	0.0(0)	66.7(2)
Cluster #3	50.0(2)	25.0(1)	0.0(0)	0.0(0)	25.0(1)
Cluster #4	10.0(1)	10.0(1)	30.0(3)	20.0(2)	30.0(3)
Cluster #5	0.0(0)	37.5(6)	18.8(3)	6.2(1)	37.5(6)
Cluster #6	0.0(0)	20.0(3)	40.0(6)	26.7(4)	13.3(2)
Cluster #7	60.0(3)	40.0(2)	0.0(0)	0.0(0)	0.0(0)

Table 4.6. Averages, Standard Deviations, Minimum, and Maximum Values.

Cluster	Number Points	Average value	Std Dev.	Std error (95%)	Min.	Max.	% Populated	% Total Error
Cluster #0	19	-23.23	54.39	24.45	-114.61	109.5	100	28.8
Cluster #1	7	3.971	61.90	45.86	-87.6	73	100	12.4
Cluster #2	3	60.16	99.89	113.0	-36.5	163	100	10.8
Cluster #3	4	-59.46	103.3	101.3	-182.5	54.75	100	17.3
Cluster #4	10	5.496	27.80	17.23	-54.75	39	100	3.76
Cluster #5	16	2.042	15.10	7.40	-20	33.81	100	1.85
Cluster #6	15	3.950	25.38	12.84	-17	93	100	4.88
Cluster #7	5	-96.34	96.36	84.46	-219	-21.83	100	20.1

% of total variance explained by clustering: 28.6

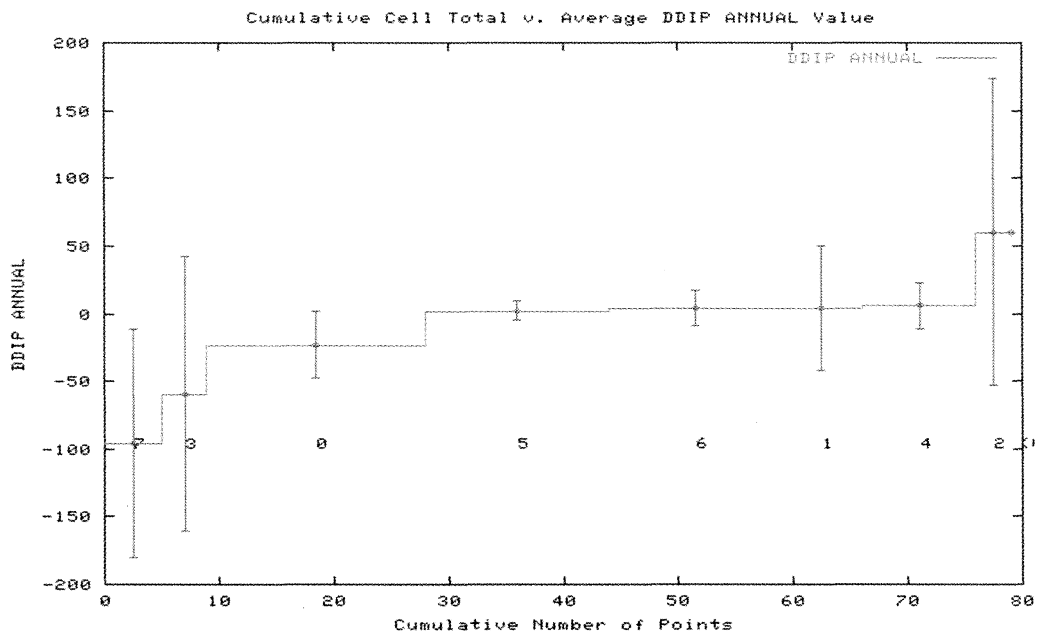


Figure 4.1 Percent of total variance explained as a function of cumulative clusters.

Conclusions

The percentage of the variance of ΔDIP explained through this exercise is only ~30%, and there seem to be no significant differences in ΔDIP among the 8 clusters. From an initial examination, it was considered that it was difficult to explain that a single cluster (i.e., clusters 0, 1, 2, 3 and 4) contained both highly positive and highly negative ΔDIP values. Consequently, it was decided that a closer look into the database was necessary, including more detailed analysis of the relationship between ΔDIP, ΔDIN and the other budget variables.

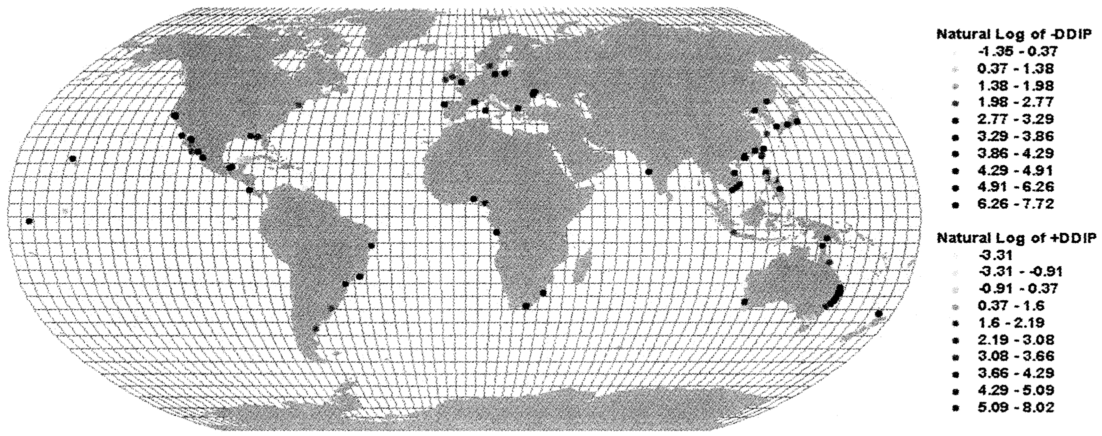


Figure 4.2a. Map of the positive and negative lnΔDIP values for the selected budgets data set.

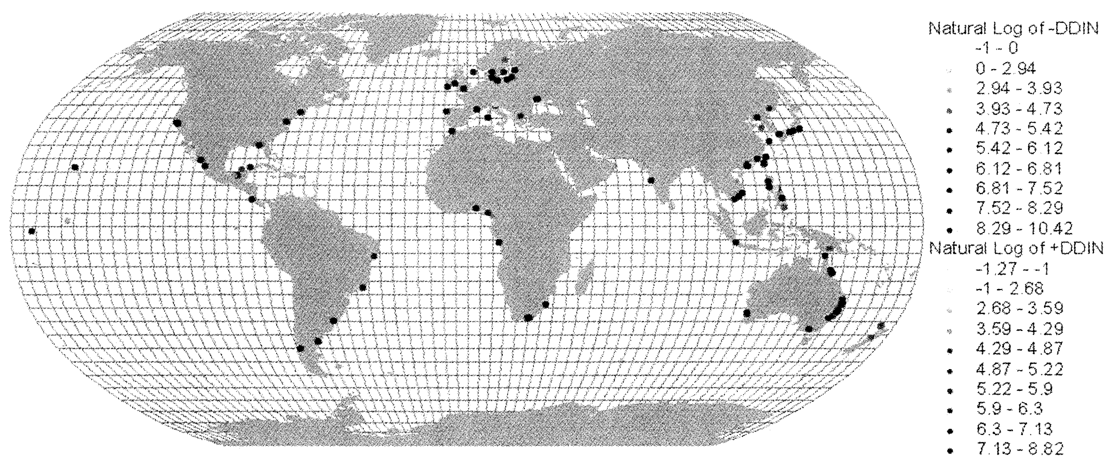


Figure 4.2b. Map of the positive and negative lnΔDIN values for the selected budgets data set.

4.2.2 Exercise 2: Mapping ΔDIP and ΔDIN distributions.

The geographic distribution of budget sites displayed with ΔDIP and ΔDIN show a wide range of ΔDIP and ΔDIN values (+163 to -219 mmol m^{-2} y^{-1} and +3,358 to -14,782 mmol m^{-2} y^{-1}, respectively). In order to get more homogeneous classes it was decided to work with the log-normal transformed ΔDIP and ΔDIN values. From this point onwards, there are 2 log-normal transformed data sets per variable; the ln values for the positive rates and the ln values for the negative rates (which were multiplied by -1 to be able to perform the ln transformation).

(+) ΔDIP, 45 sites; (-) ΔDIP, 33 sites; and ΔDIP = zero 1 site

(+) ΔDIN, 61 sites; (-) ΔDIN 17 sites; and ΔDIN = zero 1 site

Mapping results are shown in Figure 4.2 (see also Appendix IV.1a and the slide show of results in Appendix IV.1b on the CD-ROM).

Conclusions

The most obvious feature of the spatial distributions of both the untransformed and the log-normal transformed values of ΔDIP and ΔDIN is that, although some spatial trends may be observed, there are regions where highly negative or highly positive ΔDIP or ΔDIN values can be observed in neighboring systems.

4.2.3 Exercise 3: Correlation analysis for log-normal transformed ΔDIP and ΔDIN

A simple correlation analysis was performed to determine which of the variables contained within the LOICZ database are more "related" to the ΔDIP and ΔDIN magnitudes. In doing so, and in considering the results, it is important to keep in mind the equation used in the estimation of the non-conservative fluxes of DIP (and DIN) through the LOICZ budgeting procedure (see Gordon *et al.* 1996), viz.:

$$\Delta DIP = -\underbrace{(VqDIPq+VoDIPo+VgDIPg)}_{\{Terrestrial\ loading\}} - \underbrace{(VrDIPr + Vx\,(DIPocn-DIPsys))}_{\{Exchange\ with\ ocean\}} \quad \ldots\ldots\ (Eq.\ 1)$$

In general terms, this equation indicates that the LOICZ model estimates ΔDIP and ΔDIN from the imbalance between the observed inputs of phosphorus and nitrogen from land (DIP and DIN loading) and the exports (or imports) of DIN and DIP with the ocean. Also, it is important to note that most of the DIN and DIP nutrient budgets contained in the LOICZ database were estimated on the basis of inorganic nutrients and therefore, discussions refer to terrestrial loading in terms of DIP and DIN loadings (dissolved and inorganic loadings). However, it is recognized that the ideal budget should contain the total (inorganic plus organic, including particulate) nitrogen and total phosphorus loading, as in some of the sites ΔDIP and/or ΔDIN may largely reflect the respiration of terrestrial organic carbon.

Conclusions

The correlation tables (Tables 4.7 and 4.8) show that when the analysis includes ΔDIP and ΔDIN values for all of the sites (79 sites), few significant correlations are observed between these dependent variables and variables in the database. For example, ΔDIP (without ln transformation) was only significantly correlated with 5 variables, while ΔDIN was only correlated with 4 variables.

In contrast, after splitting the ΔDIP into two sets and using the ln transformation, the number of significant correlations for each subset was increased. The ln positive ΔDIP values (lnΔDIP(+)) showed significant correlations with 12 budget variables, and the ln negative ΔDIP values (lnΔDIP(-)) showed significant correlations with 11 budget variables. Remarkably, whereas the ln negative ΔDIN values (lnΔDIN(-)) showed significant correlations with 12 budget variables, the ln positive ΔDIN values (lnΔDIN(+)) showed no significant correlations.

Table 4.7. Correlation table between ΔDIP, ΔDIN and several budget variables. (Values are significant at 95% level).

Variable	ΔDIP annual	ΔDIN annual
Texchange		
DIPsys		
DINsys	-0.47	-0.55
DIPsys-DIPocn		
DINsys-DINocn	-0.41	-0.60
lnDINsys/DIPsys	-0.38	
lnDINocn/DIPocn		
lnDIP load per area	-0.33	-0.37
lnDIN load per area	-0.40	-0.43
lnTexchange		
lnVr (annual)		
lnVx (annual)		

Table 4.8. Correlations between some budget variables and log-normal transformed ΔDIP (Values are significant at the 95% level).

Budget Variable	lnΔDIP(-)	lnΔDIP(+)	lnΔDIN(-)	lnΔDIN(+)
T exchange	-0.33	-0.36	-0.27	
DIPsys		0.45		
DIP ocn		0.42		
DIN sys	0.46		0.48	
DIN ocn	0.50			
DIP gradient (DIPsys-DIPocn)		0.38		
DIN gradient (DINsys-DINocn)	0.37		0.45	
DIN sys/DIP sys		-0.41	0.27	
DIN ocn/DIP ocn	0.35			
lnDIN sys		-0.46	0.27	
lnDIN ocn	0.33	-0.38		
DIPload/sys area (normalized)	0.47		0.49	
DIN load/sys area (normalized)	0.41		0.45	
lnDIP load/sys area (normalized)	0.37	0.66	0.45	
lnDIN load/sys area (normalized)	0.35	0.59	0.61	
lnTau x	-0.47	-0.46	-0.37	
lnVx		0.46	0.39	
lnVr		0.49	0.40	
Number of cases	**45**	**33**	**61**	**17**

The most important observation from this exercise is that the wide range of ΔDIP and ΔDIN values associated with the high spatial heterogeneity in physical and biogeochemical processes in coastal environments, makes it necessary to look at small sections of the database to search for potential relationships among variables within the database. Further examples related to this subject are presented in Appendix IV.1. A further issue to remember is that in this exercise only linear correlations were explored. However, the potential for nonlinear relationships between ΔDIP and ΔDIN (or their ln transforms) is recognized. The differences between the untransformed and log transformed corellations reported here closely parallel the differences between linear and non-linear correlations observed by the Functional Process Working Group (see report in Chapter 3).

Correlations (scatter plots) between ΔDIP and ΔDIN (and ln transforms) were further explored (see Appendix IV.1b on the CD-ROM for detailed results).

4.2.4 Exercise 4 (multipart): LOICZView trials

A series of clustering and cluster analysis trials were conducted for the joint purposes of exploring relationships among the selected variables and exploring and demonstrating the capabilities of LOICZView for these applications. Brief summaries of the experiments and outcomes are provided below (additional results for some sections may be found in Appendix IV.2 on the CD-ROM).

4.2.4.1 Independent variable clusters with ΔDIP overlay analysis

Independent variables were selected as in 4.2.3. MDL analysis was used to determine cluster numbers, and eigenanalysis was used to confirm that the number of variables was appropriate. After clustering the independent variables, the number of clusters was merged from 14 to 6, and ΔDIP was overlayed. Results showed both positive and negative ΔDIP values in the same clusters, which was not desirable for classification purposes. The experiment was performed again, with weighting of DIPsys and DINsys by 2 and using six original clusters. No significant improvement was seen.

4.2.4.2 Clustering 9 "correlated" budget variables and overlaying ln-ΔDIP(-) and ln-ΔDIP(+)

Nine budget variables (DIPsys, DINsys, DIPsys-ocn, DINsys-ocn, ln(DIN/DIP)sys, ln(DIN/DIP)ocn, ln(DIP)load/area, ln(DIN)load/area and lnTexchange) were clustered into six clusters for this test. The major finding was that if the variables are weighted equally, the variable most commonly appearing as characteristic of clusters is (DIPsys-DIPocn) among all six clusters

4.2.4.3 Clustering selectively weighted variables, with overlay

As a follow-on to the preceding experiment, the predictive (genetic algorithm) clustering module in LOICZView was used to generate 'optimum' weights for the variables:

Variable	*Weight*	*Variable*	*Weight*
DIPsys	0.75	lnDINsys/DIPsys	3.70
DINsys	2.07	lnDINocn/DIPocn	3.88
DIPs-DIPo	1.44	ln normDIPload-d	6.94
DINs-DINo	0.44	ln normDINload-d	3.88
lnTexchange	5.38		

When experiment 4.2.4.2 was repeated using these weightings, it did not improve clustering, and in fact described less of total variation than did the unweighted variables. The Group considered the possible reasons as to why weighting of budget variables was less effective, and identified several potential issues:

- there was a low weight assigned to DINsys-DINocn although its correlation was significant;
- there was a high weight for ln(DIN/DIP)load although that correlation was not significant;
- the experiment assigned six clusters, while MDL give 11-17 clusters for these weights; and
- it is possible that five classes for lnΔDIP is not the best value.

4.2.4.4 Clustering 11 "correlated" budget variables & overlaying lnΔDIP(-) and lnΔDIP(+)

Six clusters were created with 11 budget variables (lnTexchange, DIPsys, DINsys, DINocn-DINsys, DIPocn-DIPsys, ln(DIN/DIP)sys, ln(DIN/DIP)ocn, lnDIPload(norm), lnDINload(norm), lnVx, lnVr) and overlayed with lnDDIP(+) and lnDDIP(-). The percentage of total variance explained by the clustering was 40%. Detailed results may be viewed in Appendix IV.2 on the CD-ROM.

4.2.4.5 Staged trials of overlaying categorized ln-ΔDIP to merge ln-ΔDIP(+) and ln-ΔDIP(-)

LnΔDIP was categorized into 9 classes. The clustering of exercise 4.2.4.4 was repeated using nine variables (excluding lnVx and lnVr), and overlayed with categorized lnΔDIP. Only 9% of the total variance was explained by the clustering. However, resolution of lnΔDIP classes was improved by increasing the number of clusters from 9 to 15, which explained 13% of the total variance. When the number of clusters was further expanded to 60, only 14% of the total variance was explained. This result is thought to reflect control of ΔDIP by different factors in different ranges of value magnitude and sign, so that subsets of the data are resolved better by a finer subdivision of the range of possible conditions.

4.2.4.6 Multiple regression analyses

Since using categorized ΔDIP was not effective, regressions were tried with nine budget variables. Linear regression explained 30% of variance. The use of breakpoint regression may be a better option. This is to be further investigated after the workshop.

4.2.4.7 Effect of Reducting Number of Budget Variables.

The experiment was re-run while limiting the budget variables to four (DIPsys, DIPocn-DIPsys, lnDIPload(norm), and depth). When the results were overlayed with lnΔDIP(-), the separation of clusters was improved and the percentage of total variance explained by clustering was 34% - a value slightly better than that obtained in the initial experiment (section 4.2.1).

4.2.4.8 "Objectively" reducing the number of variables by eigenanalysis

There is some degree of correlation or covariance among the 11 budget variables significantly correlated with either lnΔDIP(+) or lnΔDIP(-). By performing an eigenanalysis it should be possible to determine a smaller set of variables for the clustering procedure without significantly reducing the variance of lnΔDIP(+/-) explained by the clustering of 11 variables.

Results showed that first three components explained 70% of total variance, while addition of the next two components brought the total variance encapsulated to 86%. Correlations were done to determine which among the variables with high factor loadings are significant.

Table 4.9. Variable weighting for the eigenvectors with 11 variables. (See last row of table for order of eigenvector coefficients.)

Weight		Vector
30.93		(-0.198036, -0.46763, -0.192033, -0.447763, -0.219204, -0.0761817, -0.356264, -0.410213, 0.274063, -0.258127, -0.118076)
23.36		(0.519496, -0.0333536, 0.499651, -0.0269053, -0.468004, -0.349848, 0.183242, -0.0274059, 0.041599, -0.224734, -0.225056)
16.43		(0.011665, 0.285951, 0.0206457, 0.261186, 0.271966, 0.280652, -0.184496, -0.13715, 0.0326538, -0.524587, -0.606312)
8.8		(-0.209277, -0.190203, -0.22797, -0.170619, -0.173007, -0.0559924, 0.225851, 0.242408, -0.76028, -0.277001, -0.203354)
8.68		(0.321982, -0.206273, 0.379709, -0.345617, 0.145156, 0.675359, -0.0943007, -0.0906336, -0.268246, 0.0424997, 0.148659)
5.15		(-0.0347761, -0.242166, -0.0338023, -0.295274, 0.213974, 0.151118, 0.511163, 0.463936, 0.474386, -0.0328521, -0.283813)
2.52		(-0.138192, 0.201383, -0.168845, 0.0974279, -0.411251, 0.39566, 0.57428, -0.45147, 0.104849, -0.10114, 0.147742)
2.01		(0.0257563, -0.0930209, 0.0102929, -0.0567741, 0.221721, -0.149015, 0.214991, -0.467877, -0.176071, 0.592377, -0.518601)
1.08		(-0.632144, -0.184033, 0.565111, 0.260854, -0.269372, 0.159277, -0.102075, 0.130495, 0.0335636, 0.167876, -0.156344)
0.89		(0.225968, 0.150834, -0.353203, -0.0211351, -0.520431, 0.308408, -0.309993, 0.299749, 0.0622925, 0.371256, -0.327669)
0.1		(0.267698, -0.674718, -0.207454, 0.643126, 0.0217323, 0.108251, 0.0416743, -0.0184311, 0.00824207, -0.0300787, 0.03473)
Variable order:		(DIPSYS, DINSYS, DIPSYSMINUSDIPOCEAN, DINSYSMINUSDINOCEAN, LNDINSYSOVRDIPSYS, LNDINOCNOVRDIPOCN, LNNORMDIPLOAD_DAILY, LNNORMDINLOAD_DAILY, LNTAUX, LN_VRA, LN_VXA)

Appendix IV.2 (CD-ROM) contains detailed information on the cluster summaries and overlay results.

4.2.4.9 Overlaying lnΔDIN

Clustering and overlay experiments similar to the ones outlined for ΔDIP were performed on ΔDIN. Initially, 11 budget variables were used, with five classes and six clusters. For ΔDIN(+), 32% of the total variance explained by the clustering, and for ΔDIN(-), 38%of the total variance. When seven budget variables were used with five classes and six clusters, the results were:

for ΔDIN(+): %total variance explained by clustering = 34%
for ΔDIN(-): %total variance explained by clustering = 38%
for [nfix-denit(-)]: %total variance explained by clustering = 38%
for [nfix-denit(+)]: %total variance explained by clustering = 48%

4.3 Future activities: assessments and recommendations

A number of generic and specific approaches were identified that might improve fitting, correlations and predictive abilities. Among these are:

- Divide data into smaller subsets; subdivide and analyze them piece by piece.
- Find an objective way to reduce variables.
- Merge significant typology variables (developed by the other Group analyses) with significant budget variables (e.g., establish relationship to the LOICZ Hexacoral Typology data set).
- Identify regions where different categories (ΔDIP, [nfix-denit], ΔDIN) are nested.
- Add more preferred budgets to the database.
- Add more system-specific driving variables (e.g., drainage basin characteristics, proxies for pollution).
- Regionalize the Typology exercise.

4.4 Appendices: Print summary and CD-ROM

Appendices to the Working Group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. This information is included on the electronic CD-ROM version of the report; a list of appendix materials, brief descriptive summaries, and items that are primarily text are printed in Appendix IV in the Appendix section of this report.

5. Synthesis and Conclusions

5.1 Overview

This final report of the UNEP GEF project presents the project outcomes and findings, based on assembly and integration of the global synthesis workshop working group reports (Chapters 2-4), results obtained at other project workshops (see listing in Chapter1, section 1.2.3), and on follow-up analyses and developments initiated at the synthesis workshop.

The UNEP GEF project has resulted in major steps forward in our understanding of the drivers of coastal zone biogeochemistry. In particular, the evidence marshaled below for the extent and ubiquity of the dependence of terrestrial nutrient loading to the coastal zone on human population and population density is the first global-scale empirical demonstration of its sort – and one that has profound implications for our understanding of both present and future environmental conditions. One of the other patterns emerging from the study is that of a strong but complex and multi-faceted relationship between large terrestrial loads and the strength of the non-conservative budgetary fluxes within and through the coastal systems.

Complementing the generality of these findings is the recognition of the need for region-, environment-, and process-specific analyses to fully develop predictive understanding of budget characteristics and controls. This finding echoes throughout the Working Group reports (Chapters 2-4), and emphasizes the fact that although this final report on the specific project yields important and exciting insights, it is a major milestone but still not the end of the LOICZ journey of coastal biogeochemical flux characterization.

The overall LOICZ approach to characterizing global biogeochemical fluxes involving the coastal zone is composed of three elements: estimation and modelling of loads (from land); estimation and modelling of exchanges (between the coastal marine/estuarine environment and the offshore ocean); and interpretation of internal reactions.

In the UNEP GEF project, we have built within this framework an inventory of measures and biogeochemical models of coastal ecosystem performance in response to C-N-P nutrient conditions that can fit across a gradient of undisturbed to disturbed coastal systems. The approach has been structured to:

a) build patterns and understanding of loads (land, ocean, atmospheric) to coastal ecosystems;
b) model coastal system performance in terms of relative C-N-P nutrient sink/source relationships of the receiving systems, using a common methodology;
c) infer system net metabolic responses to various forcings as a basis for subsequent typological assessment of regions for which data or coastal estuarine metabolic performance models are absent; and
d) develop databases and tools for evaluation of variables that will allow construction and hierarchical development of typologies in order to relate loads and forcings to system performance – such as, climate, then population distribution.

The complexity of the model results and the array of different loads and other forcings, overlaid on the inherent heterogeneity of the coastal zone (a narrow, 500,000 km ribbon twisting through all of the environmental regions of the globe), creates major challenges in formulating patterns and trends at regional to global scale in the metabolic performance of coastal ecosystems. The development of proxy variables to serve as key spatial or temporal parameters to describe functional relationships with ecosystem metabolic performance is equally challenging. This report documents the findings to date, and reports some important milestones in this journey of assessment. The network of global scientists developed through LOICZ and by the UNEP GEF project is continuing to analyse and synthesise the data. Additional results will be published in scientific journals and websites, and within the LOICZ Synthesis text on global change in the coastal zone to be published in early 2003.

5.2 Key findings on coastal ecosystem metabolism

5.2.1. Estuarine and coastal site characteristics

As of April 2002, an inventory of 200 biogeochemical budgets has been developed, the collective effort of 175 researchers from institutions in 37 countries (Figure 5.1), and data coverage of nutrient fluxes in much of the global coastal zone continues to accumulate. About 80 sites are represented by full budgets with high reliability in the elements comprising each budget, viz., water-salt budget component, the nutrient and non-conservative flux estimates, and the stoichiometric interpretation of net carbon metabolism [p-r] and net nitrogen metabolism [nfix-denit], according to the LOICZ budget approach (Gordon *et al.* 1996). Some 90+ sites have useable but less complete budgets, wherein the data quality of one of the components is limited and/or seasonality estimates are not fully described. Around 30 sites are considered to have less reliable budgets in that more than one component is not fully resolved and assumptions have been made to make a preliminary estimate of metabolic performance. The principle behind the biogeochemical budgeting approach used here is the very fundamental concept of mass balance. While the principle itself is unassailable, its practice has some operational limitations. Three of the specific problems that arise with the budgets (besides simple limitation on data) are:

(i) Systems with very short water exchange times (a few days or less) simply do not "incubate" the water long enough to accumulate a robust non-conservative signal;
(ii) In some systems, particularly those with very high sediment loads, the "stoichiometric assumptions" are undoubtedly compromised by inorganic (sediment)-based reactions; and
(iii) In systems with extreme nutrient loads, even proportionally small uncertainties in the loads can introduce error into the non-conservative flux calculations.

All of these problem areas can be characterized as representing the large and potentially dominating dynamic range of external variables forcing the budgets in comparison to the relatively much smaller dynamical range in the internal system biogeochemical reactions. This has been taken into account during the current and on-going analyses and assessments. The full suite of biogeochemical budgets is contained within the database describing the suite of budgets (http://data.ecology.su.se/MNODE) and is also contained in the biogeochemical budget modules of the LOICZ/Hexacoral environmental database (http://www.kgs.ukans.edu/Hexacoral/ Envirodata/envirodata.htm). In some cases the full 200 budget sites have contributed to the establishment of trends and patterns of system performance, loading or environmental setting conditions; and expert judgment has been applied to site selection for metabolic performance assessments. Typically, specific analyses have relied on 130-150 of the budget sites.

The range in quality of data for the site budgets reflects the diversity of available, relevant data across the globe and has resulted in a geo-spatial spectrum of budgets for coastal estuarine and shelf sea locations (Figure 5.2). We have a relatively good coverage for Europe, East Asia, Southeast Asia and Australasia. There is poor representation at high latitudes, north and south, although the recent addition of sites for the Arctic region generally represents estuaries and shelf seas associated with the major river basins of Russia. Africa and South America are represented by a less than ideal coverage; the addition of further sites is improving the representation of environmental settings for different types of river basins and estuaries and provides an initial representation of the coastal systems of the regions. In South Asia, the UNEP GEF project work has stimulated a network of researchers who are currently funded by APN to carry out a program of field measurements in a number of sites, and the resultant budgets are expected later in 2002. Similarly, a project addressing West Africa is being prepared for funding by an international agency. These additions, along with further North American site information, are expected to contribute at a later date to validation of the current assessments of coastal system nutrient metabolism and forcings.

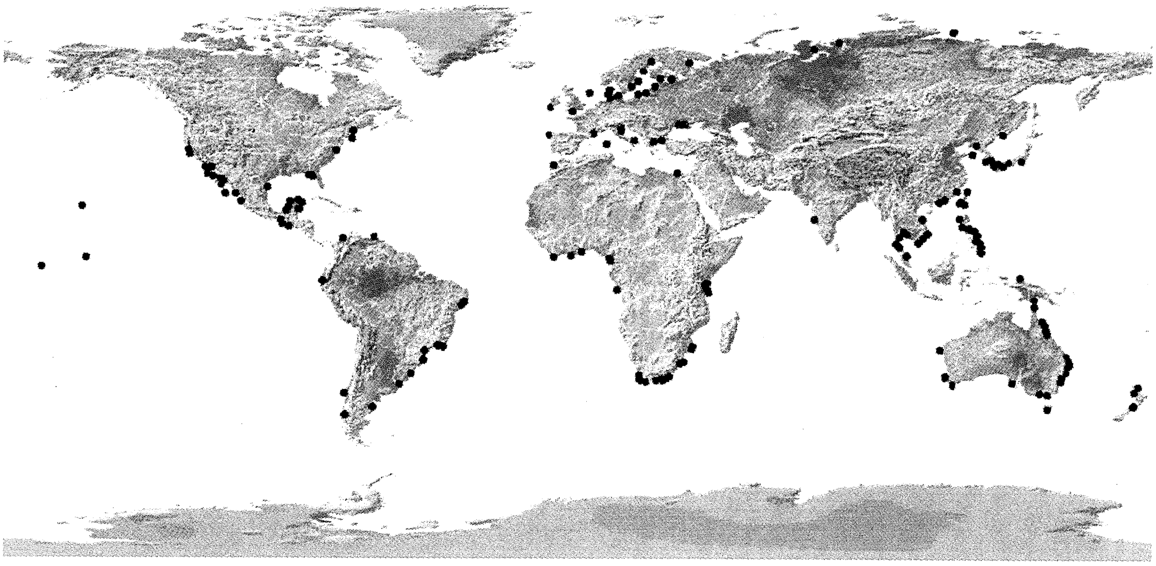


Figure 5.1 Map of LOICZ budget sites, April 2002.

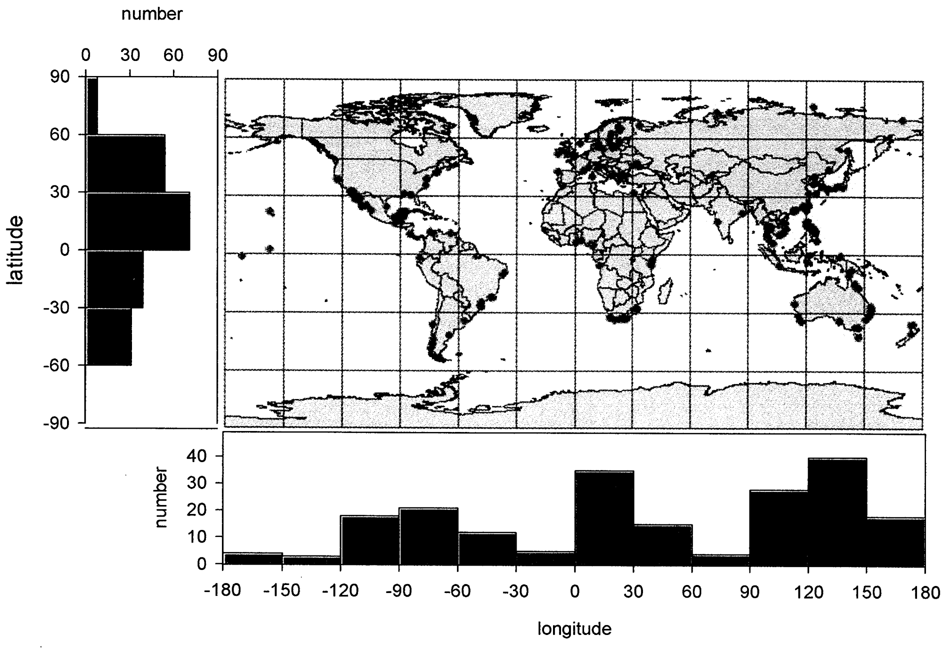
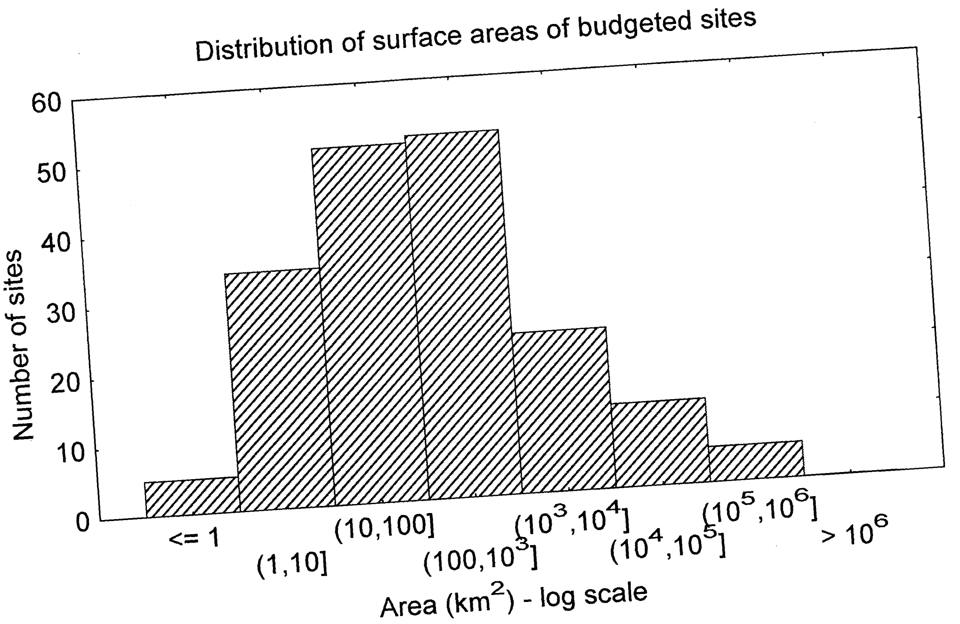


Figure 5.2 Representative coverage of latitude and longitude by biogeochemical budget sites, April 2002.



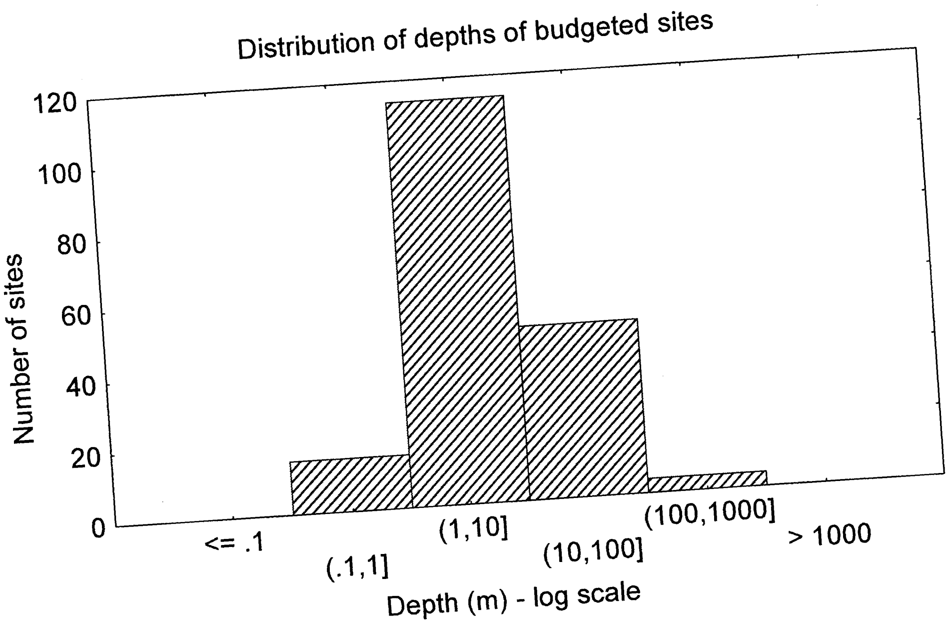
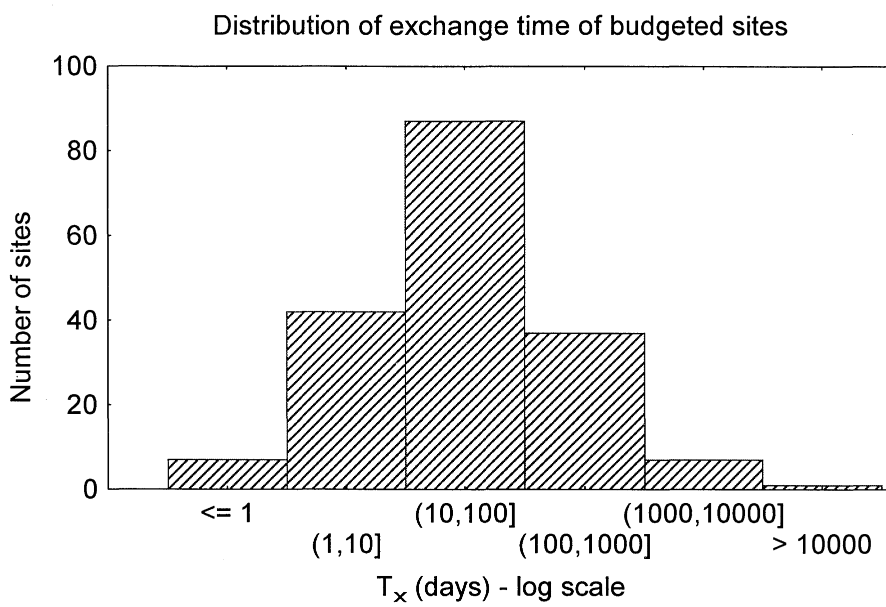


Figure 5.3 Area and depth of biogeochemical budget sites.



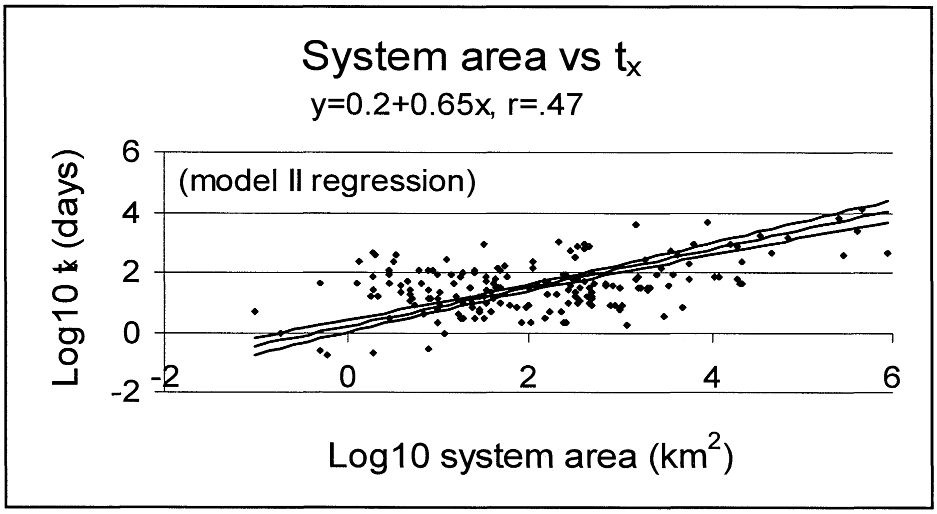


Figure 5.4 Exchange times and relationship to surface area for biogeochemical budget sites.

The characteristics of the biogeochemical budget sites vary dramatically:

- area of the budgeted coastal ecosystems span 6 orders of magnitude, from <1 km^2 to the 10^6 km^2 East China Sea (Figure 5.3);
- depth of sites span 3 orders of magnitude, from decimeters to hundreds of meters deep (Figure 5.3);
- exchange time of the systems spans 4 orders of magnitude, from <1 day to about 35 years (Laptev Sea) (Figure 5.4);
- loading of nutrients to sites ranges from locations that are virtually devoid of nutrient load to those that receive heavy loads of inorganic nutrients derived from human wastes, agriculture and other sources;
- loading and forcing conditions encompass an array of environmental settings, from river-dominated estuaries to ocean-dominated estuaries to hypersaline lagoons; and
- climatic zones extend from Arctic to tropical latitudes, including arid locales, episodically flooded sites and various monsoonal patterns.

The majority of budgeted sites are relatively shallow and have a high surface area to volume ratio providing for close interaction between benthic processes and the water column. The general pattern of exchange times (between weeks and months) for the sites thus provide "incubator" conditions that are favorable for supporting C-N-P transformations and cycling.

5.2.2. Net C-N-P metabolism of coastal sites

Various authors (e.g., Smith and Mackenzie 1987; Smith and Hollibaugh 1993; Sarmiento and Sundquist 1992) have argued that the ocean is net heterotrophic, and Smith and Hollibaugh (1993) have made the case that most of this net heterotrophy probably occurs in the coastal ocean. The fundamental global evidence for this conclusion is the observation that organic carbon delivery to the ocean apparently exceeds organic carbon burial by about a factor of 3. This observation suggests that, regardless of the amount of primary production in the global ocean, more carbon is oxidized there than is produced there. Evidence suggests that human activity can shift (indeed, is shifting) the trophic status of at least parts of the coastal ocean towards increasing net heterotrophy (e.g., Rabouille *et al.* 2001). At the same time, other authors (e.g., Boynton *et al.* 1995, Kemp *et al.* 1997) have argued that some parts of the coastal zone are presently clearly net autotrophic, and arguing that this could represent a shift historically as a result of growing coastal eutrophication. Obviously, addressing this question becomes a major piece in the puzzle of evaluating the role of oceanic biological reactions in the global carbon cycle.

Addressing the question has some particular challenges within the coastal zone. The coastal zone is tremendously difficult to describe in detail. Because it is relatively narrow, the coastal domain is not well represented in gridded global databases. Sites within kilometers of one another (e.g., inside or outside of an embayment) can be dramatically different. Arguments can be made that both the large load of materials from land and the human influence along the seashore cause much of the net reaction of this zone to occur in bays and estuaries along the landward margin of the strip. The region is not well represented as an extension of oceanic processes up onto the shelf and into the bays and estuaries, because the influence of both benthic chemical reactions and terrestrial inputs (including especially those associated with human activities) render this region very different from the open ocean.

The analyses of the budgeted sites developed by UNEP GEF project are providing insights into resolution of the sink-source status of the global coastal zone in terms of C-N-P and the net carbon and nitrogen metabolic poise of the systems. This assessment has focussed on deriving and developing an understanding of the non-conservative fluxes of N and P (ΔDIP and ΔDIN) within coastal estuaries and seas and examining the relationships of the systems characteristics and their inorganic nutrient loading.

The geographical distribution of ΔDIP and ΔDIN shows the uptake and release of phosphorus and nitrogen (based on inorganic nitrogen and phosphorus assessments) across the suite of budgeted sites (Figure 5.5). While there is no clear pattern in the ΔDIP, there is a clear dominance of locations showing ΔDIN uptake over release.

In the LOICZ approach to the biogeochemical site budgeting, the non-conservative fluxes for phosphorus and nitrogen (ΔDIP and ΔDIN values) can be interpreted as an estimate of net carbon and net nitrogen metabolism of the budgeted ecosystem. The DIP flux is scaled to an estimated carbon flux via a scaling ratio (typically a molar C:P ratio of 106:1, representing the so-called "Redfield Ratio"). This is represented as net photosynthesis minus community respiration [p-r].

Similarly, the Redfield N:P molar ratio (16:1) is used to estimate the expected DIN flux corresponding to the DIP uptake/release associated with [p-r], and then the difference between the observed DIN flux (ΔDIN) and the expected flux is interpreted as an estimate for the net nitrogen fixation and denitrification processes for the system. This is represented as [nfix-denit].

Both the [p-r] and [nfix-denit] values are *apparent* measures of net carbon and net nitrogen metabolism for the budgeted systems. For [p-r], negative values are apparent net organic C consumption (respiration), with associated release of DIP and DIN, and positive values are apparent net organic C production by the system, with associated uptake of DIP and DIN. For [nfix-denit], negative values are apparent net denitrification (i.e., a sink of DIN) and positive values are apparent net nitrogen fixation (i.e., a source of DIN).

Applying the stoichiometric relationships to ΔDIP and ΔDIN provides a picture of the relative storage and release rates for carbon and nitrogen across the sites. The frequency distributions of the apparent rates ([p-r] and [nfix-denit]) (Figure 5.6) provide an insight into the role of coastal systems in C-N-P exchange. The [p-r] values are consistent with ΔDIP in showing no clear pattern. While, the modal values a slightly positive (autotrophy) and the rates cluster near zero, there is a large "tail" of negative values (heterotrophy). The [nfix-denit] shows a central tendency towards denitrification.

Simple averaging of metabolic performance for the budget sites is not a legitimate estimate of regional or global performance – the coastal zone is too heterogeneous and sampling is too biased for such averaging – and system size or relative geographic importance is not accounted for in simple averaging. Further detailed analyses are in progress and some additional findings and directions of the current work are described below.

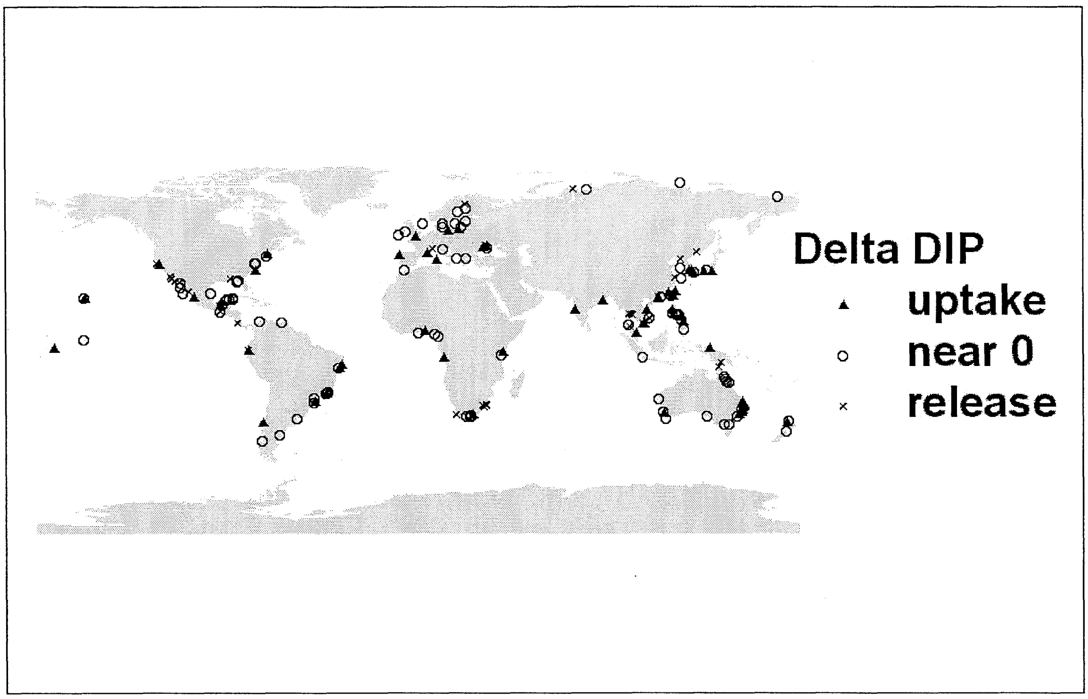
Clearly, the systems will respond to different forcing conditions, such as climate and input loads, and to the different bio-physical characteristics of the systems.

The influence of climate zones is being addressed particularly through the typology approach along with an approach that allows for inclusion of multivariable and multi-scaling elements that are vital to development of regional and global assessments of coastal system performance, status and change. Loads of nutrient materials into the estuarine and coastal seas are a function of the catchments associated with the systems and the characteristics of human activities and natural settings that apply to the catchments.

5.2.3 Nutrient loading to coastal sites

Nutrient loading to the coastal systems can occur from three sources: i) oceanic, through mixing and tidal exchange; ii) terrestrial, through rivers, other surface run-off and submarine groundwater discharges; and iii) atmospheric deposition. Terrestrial and oceanic inputs predominate.

Oceanic inputs are estimated for all budget sites and, with the exception of the few negative estuaries contained in the database, the exchange flux term is largely responsive to the difference between the ocean and terrestrial load concentrations. In the negative estuaries, the residual flux term into the system reflects the oceanic nutrient concentration. As a result, fluxes between ocean and estuary can dominate terrestrial fluxes in either positive or negative estuaries, but generally must be dominant in negative estuaries.



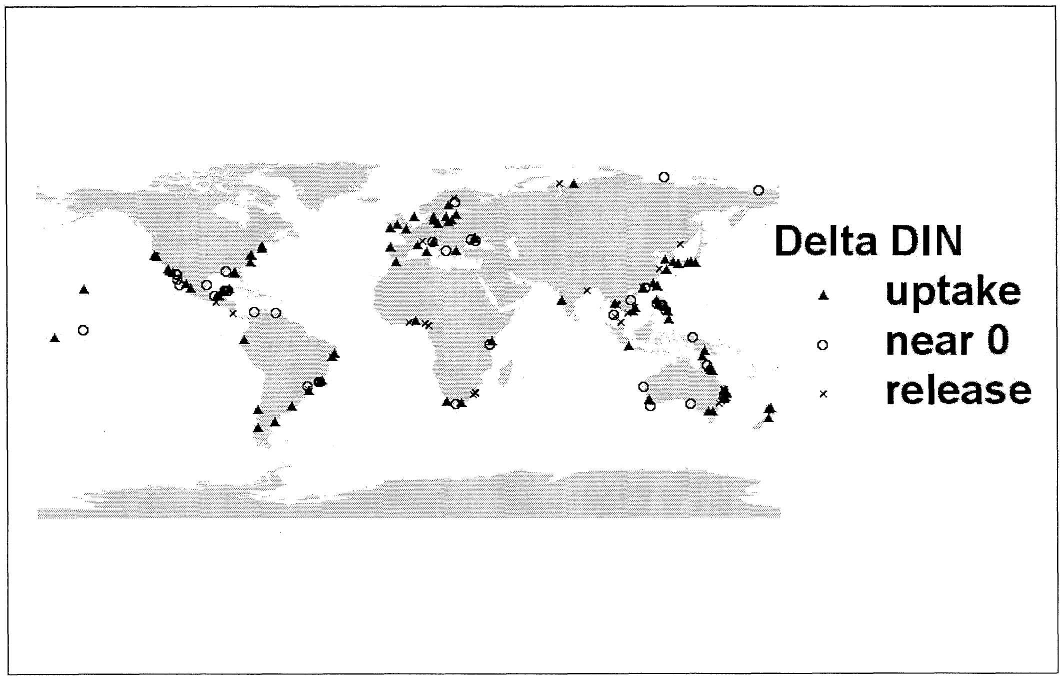


Figure 5.5 The ΔDIP and ΔDIN for global sites.

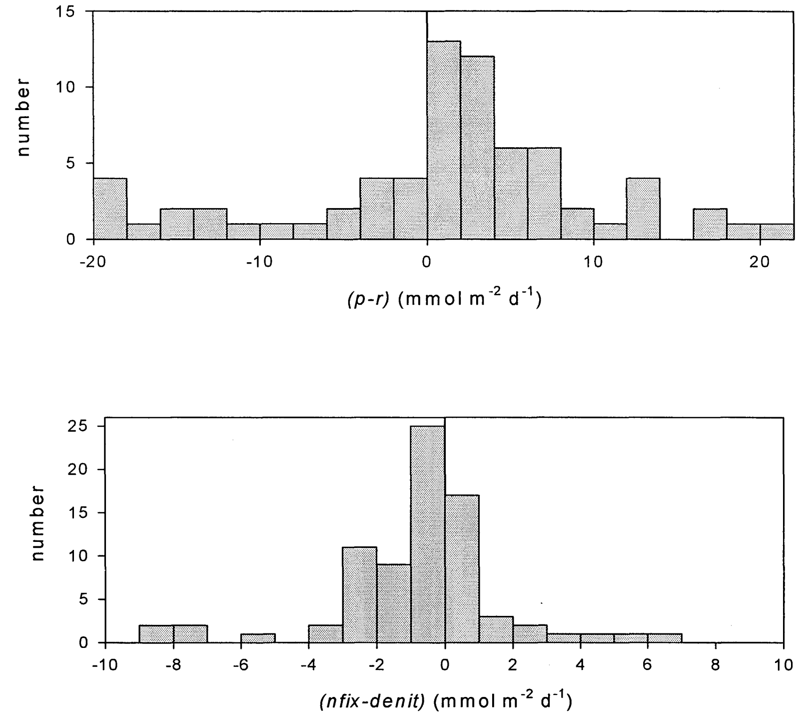


Figure 5.6 Frequency distributions of apparent [p-r] and apparent [nfix-denit] at the budget sites.

Where available, groundwater inputs have been included in the calculations for site budgets. These contributions to nutrient load are particularly influential in the Yucatan region of Mexico; however, the availability of groundwater data is sparse across most sites. Atmospheric sources of nutrient were generally of minor significance. While it is known that some regions of the world are subject to enhanced nutrient deposition, especially of nitrogen, from atmospheric transport (e.g., parts of the eastern US, Europe and the North Sea and Baltic Sea; East Asia and the Yellow Sea and Sea of Japan), existing global databases are incomplete (Valigura *et al.*, 2001). However, atmospheric nutrient deposition to river basins that influence the budget sites will be reflected in the river-borne terrestrial load terms and, where the budgeted system area was large, the site budgets have included a directly calculated atmospheric term using "best estimates' available for the particular region.

The terrestrial nutrient loading (mainly influenced by land use and agricultural practices, and urban sewage discharges) is a major factor contributing to the global gradient of metabolic poise between undisturbed and disturbed coastal systems. The relative magnitude of delivery of terrestrial nutrient loads into the budgeted sites is shown in Figure 5.7.

A key analytical tool to assess the relationship between sources and loads (as well as relationships between other variables) has been linear regression (see Peierls *et al.* 1991; Howarth *et al.* 1996). While the most popular method of fitting a line to a set of data is simple linear regression, in which the slope and y-intercept of the line are determined by minimizing the squared deviations of the y-data from the line, it is important to recognize that this can introduce bias in the slope estimate if the x-data are also subject to measurement error (see Sokal and Rohlf 1995). If both the x and y values (the independent and dependent variables respectively) are subject to the same types of errors, the data are often better analyzed using a "Model II" type regression which uses the deviations of both x and y from the line of best fit, especially if the primary objective is determining the value of the slope of the regression line. Ricker (1973) recommends a specific type of Model II regression, called Geometric Mean (GM) or Reduced Major Axis (RMA) regression, for such cases (Ricker 1973, Sokal and Rohlf

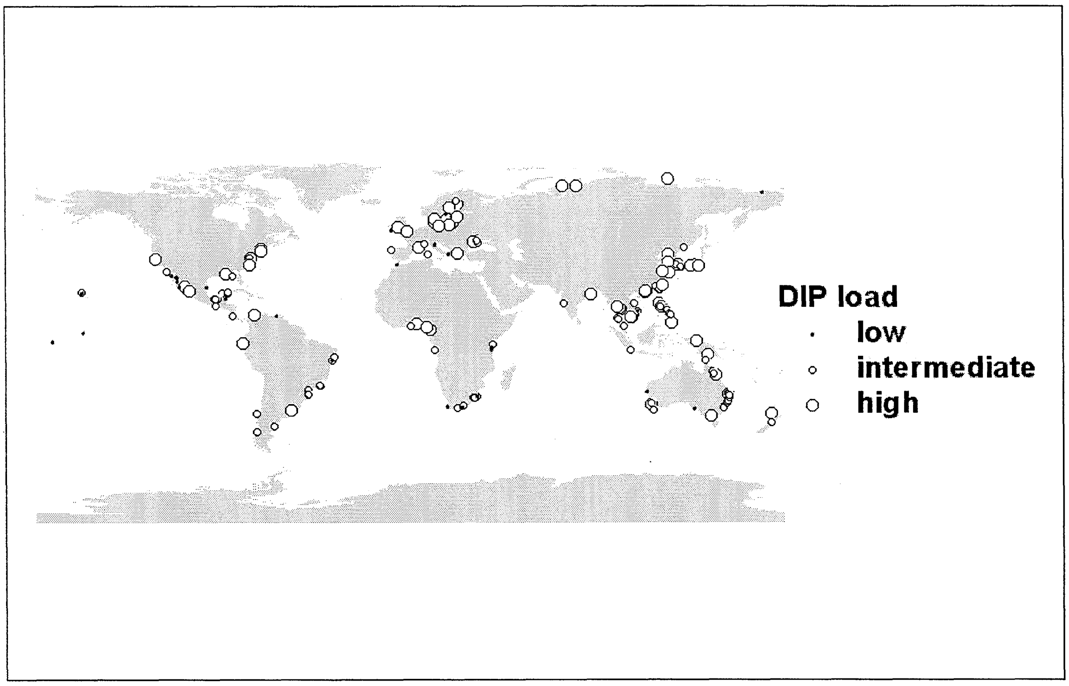
1995, Laws 1997). If the primary aim of the analysis is to predict values of the dependent variable associated with a particular independent variable or variables, then ordinary ("Model I") linear regression is recommended (Legendre and Legendre 1998). The analyses reported here general use simple linear regression, but use the GM regression if interpretation of the slope of the relationship (e.g., deviation from 1) is of special significance.

As observed in earlier studies (Peierls *et al.* 1991, Howarth *et al.* 1996), the terrestrial load per unit catchment area is strongly related to catchment population density (Figures 5.8 and 5.9). Interestingly, both DIN and DIP loading increase as a function of river catchment size, but there is no size-dependent production or assimilation evident in the data. Similarly, while area-normalised catchment loading spans about 4 orders of magnitude, our results to date suggest no significant change in the N:P ratio of the load over this wide range, despite our knowledge that the terrestrially-based chemical pathways of nitrogen and phosphorus reactions are very different – N is strongly affected on land by denitrification and nitrogen fixation, while P is strongly influenced by a variety of mineral-related reactions (Froelich 1988, Schlesinger 1997).

Further analysis of the relationship between population density and dissolved nitrogen loading provides an initial assessment of loading and area relationships on coastal ecosystems (Figure 5.10). Loads increase in proportion to catchment area and load per person shows a decreasing relationship to population, such that systems with low population density show high *per capita* loads, while systems with high population density show low *per capita* loads. We believe that this may represent a transition between landscape-dependent loading and population-dependent loading. The World Health Organisation estimates of total N and P loading *per capita* from domestic waste are shown. We interpret these results as showing that the landscape has considerable capacity to assimilate nutrients, including the increased loads from population – denitrification as the major process in the case of nitrogen, and mineral reactions in the case of phosphorus. However, it is clear that the effects of humans, landscape and runoff on loading can not be clearly separated and that there are further interactions between population density and runoff parameters that influence calculation and prediction of loading of N and P to the coastal systems (see Appendix V.2; Smith *et al.* in preparation). Further evaluation of these interactions is being made to understand these forcings.

Net nutrient reactions in coastal ecosystems clearly respond to nutrient loading. The upper panels of Figure 5.11 demonstrate that in general, as nutrient load goes up, the absolute values of non-conservative fluxes increase. DIP and DIN behave somewhat differently. At low DIP loads non-conservative flux is near zero; at loads in excess of about 0.01 mmol m^{-2} d^{-1}, non-conservative DIP flux may become either positive or negative, reflecting either uptake or release within the system. Non-conservative DIN flux also responds to loading; as DIN loading increases above about 1 mmol m^{-2} d^{-1} systems tend to take up DIN. Appendix V shows the plots of Figure 5.11 compared to regression plots and equations, which illustrate the relationships between load, exchange time and non-conservative fluxes in an alternative, more quantitative presentation.

Coastal ecosystems not only receive inputs from land but also exchange water with the adjacent ocean. The ocean water may have a range of nutrient levels, but these levels typically approximate natural oceanic nutrient concentrations. Usually the water is low in both DIN and DIP relative to the terrigenous load and has an N:P ratio of <10. Indeed, nutrient loading at the low end of the range is roughly equivalent to upward mixing of nutrients from the deep ocean to oligotrophic mid-latitude gyres of the surface ocean. The lower panels of Figure 5.11 demonstrate that water exchange times of <100 days generally promote more rapid non-conservative DIP and DIN fluxes; the area of these systems is usually <1000 km^2 (see Figure 5.4, above). This suggests that on a unit-area basis small systems with short water exchange times dominate non-conservative fluxes in the ocean and that the inner portion of the coastal zone accounts for a relatively high proportion of the net non-conservative flux of P, N and C of the continental shelf ocean. Because there is a great deal of apparent "noise", in the form of both positive and negative non-conservative fluxes and because of the challenge in up-scaling these local budgets to a meaningful global mean, it remains a part of the ongoing effort of the LOICZ synthesis phase to draw this information together. Also, additional work is being done to evaluate relationships between the seemingly bimodal distribution of non-conservative fluxes and the influence of terrestrial/oceanic dominance in nutrient loading.



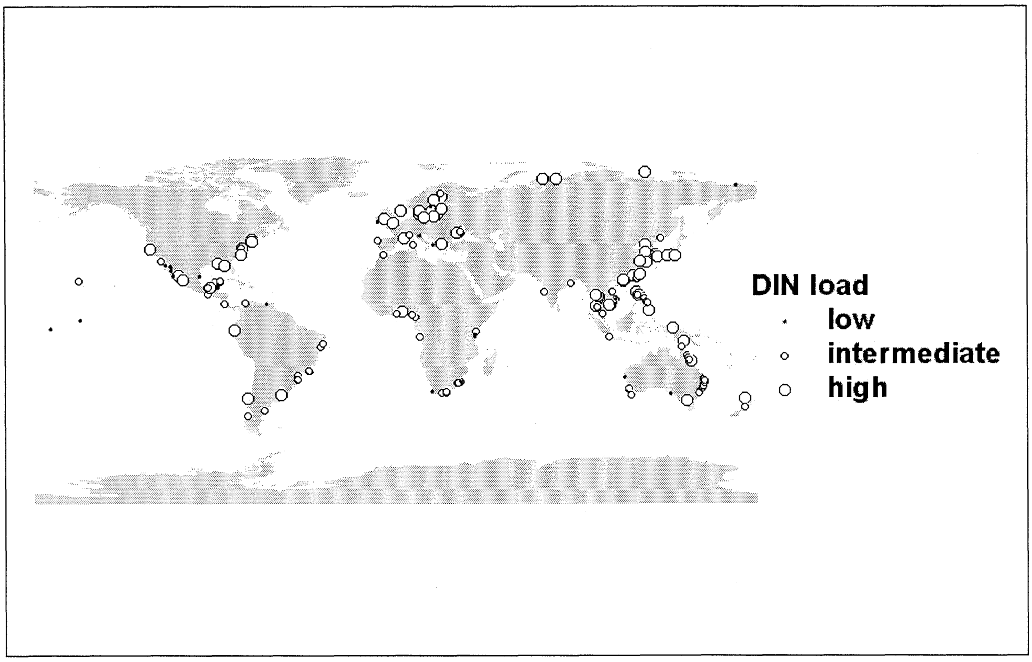
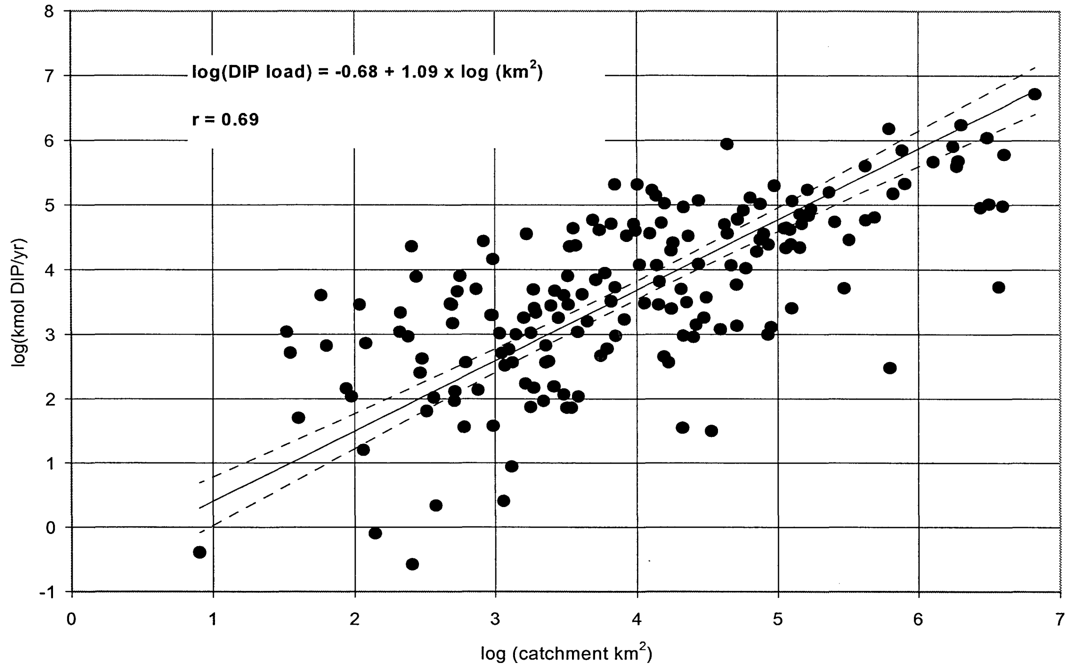


Figure 5.7 DIP and DIN loads for global sites.



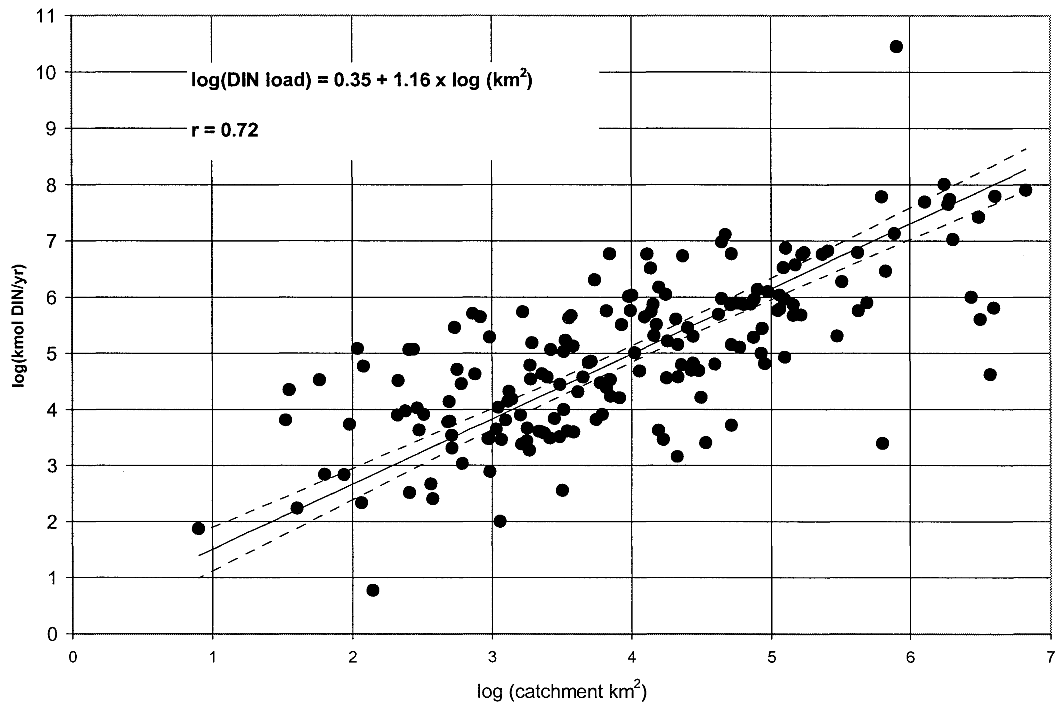
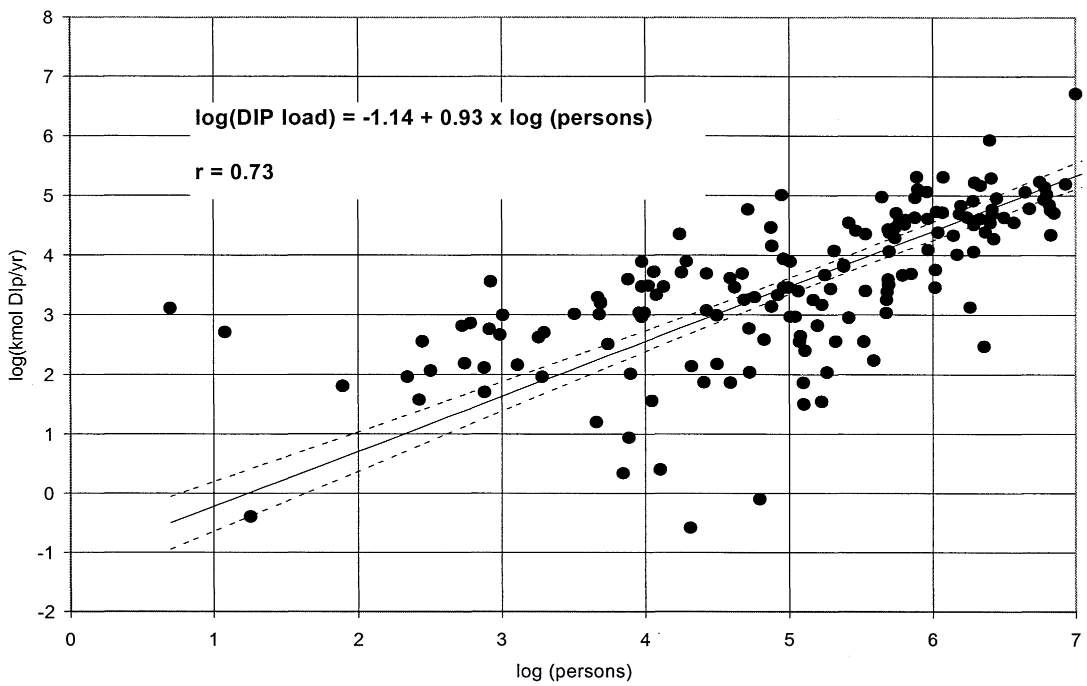


Figure 5.8 Loading to budget sites as a function of catchment area.



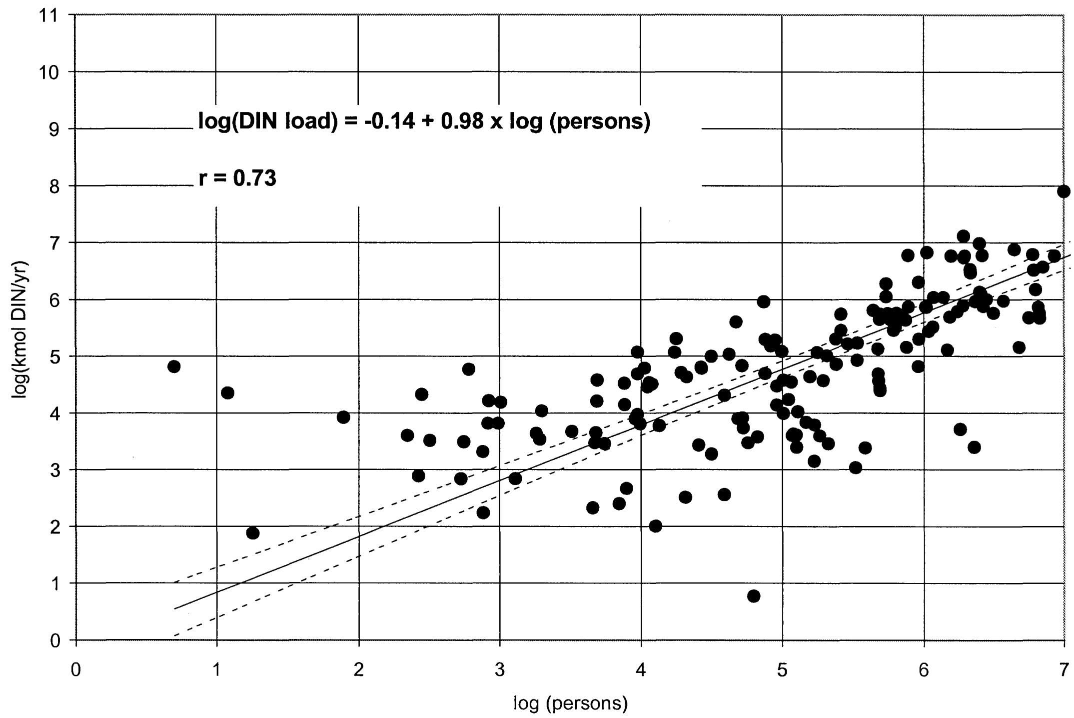
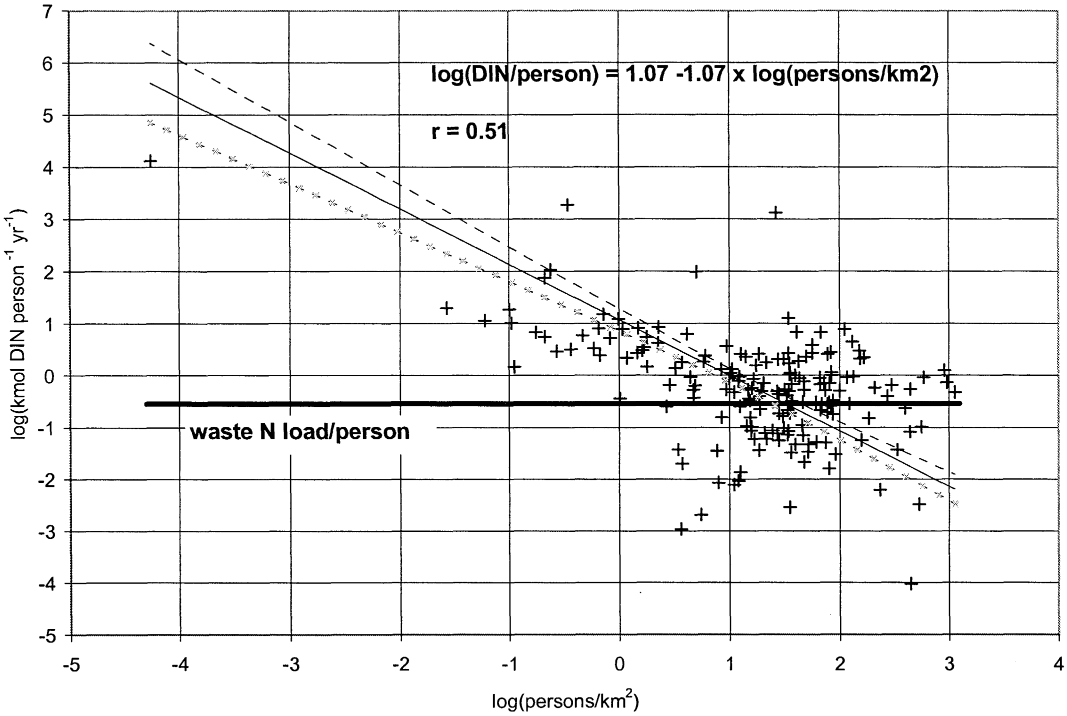


Figure 5.9 Loading to budget sites as a function of catchment population.



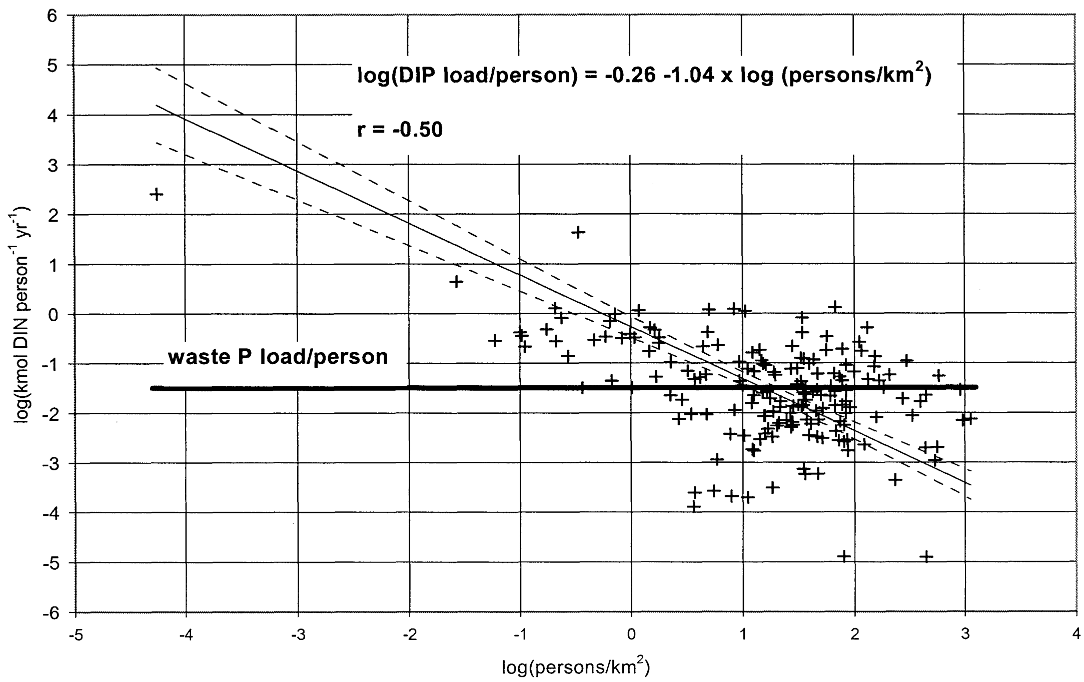
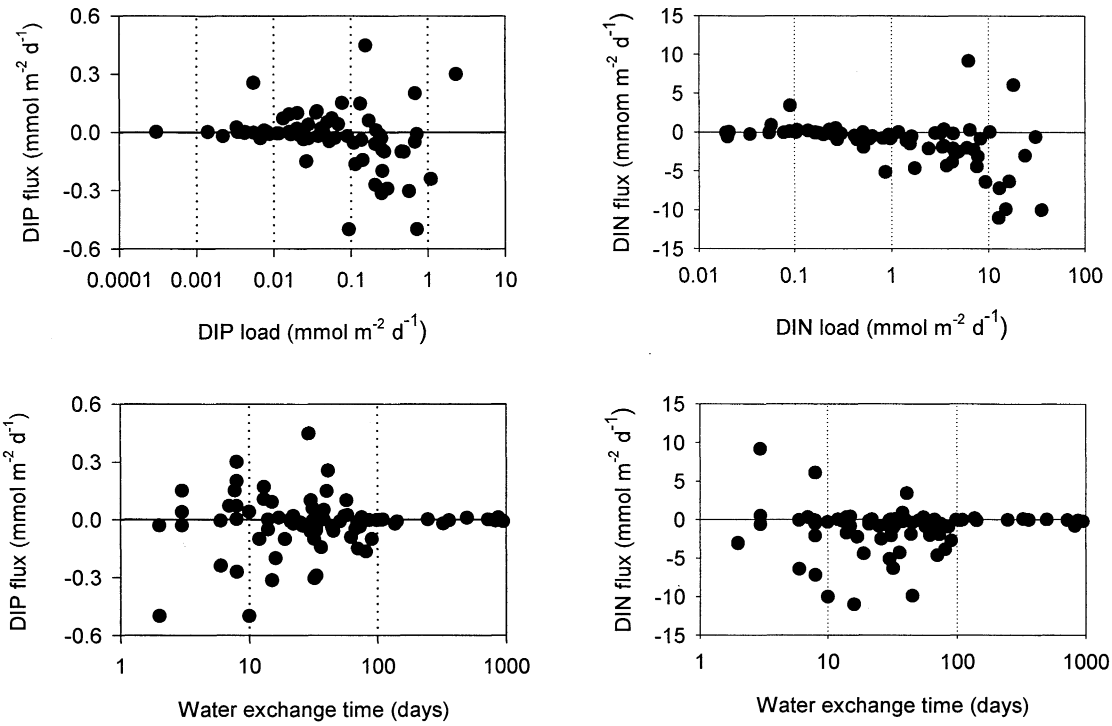


Figure 5.10 ***Per capita*** **nitrogen and phosphorus loading as a function of population density in site-associated catchments.**



5.11 DIP and DIN fluxes as a function of nutrient loads and water exchange times.

5.2.4. Disturbed and undisturbed systems

The response of coastal marine ecosystems to the various forcings that they are receiving world-wide obviously needs a foundation of analyses that capture and integrate the multi-variable and multi-scaled settings of the sites. Our approach of biogeochemical budgeting, statistical evaluation of loads and other forcings (especially from terrestrial sources), and application of a typological methodology is yielding a picture of the coastal metabolic performance.

The typology research within the project has developed both a vital tool (LOICZView) that allows for multi-variate analyses (especially by clustering and principal component analyses) and a geo-spatial array of variables (>130) describing the coastal zone. The biogeochemical data describing the coastal systems has been incorporated into the database (http://www.kgs.ukans.edu/Hexacoral/) that can be applied through LOICZView and used in other statistical assessments. In looking for patterns and trends within the coastal systems, we are following an approach that includes:

a) screening the data for quality and other criteria, such as outliers and trends that can be elucidated by standard regression analyses;
b) merging site budget data with global typology data sets into a common database that is geo-referenced and links the budgeted coastal sites with allied river basin catchments;
c) generating correlation matrices to look for significant relationships between variables or transformed variables;
d) plotting relationships between "likely candidate variables" for further inspection and analyses; and
e) proceeding with multivariate regression, cluster analysis and principal component analysis by use of LOICZView.

The Working Group reports in the preceding chapters provide an outline and examples of these developments; some of the outcomes from subsequent work are described below.

The statistical assessment of correlation matrices has yielded a suite of significant relationships between a number of the typological variables contained in the geo-spatial database and key variables that influence the non-conservative flux values of the budget sites (Table 5.2 and see Chapter 3 - Functional Processes Working Group). Current work is extending this array of correlations, developing additional databases in response to outcomes from statistical correlations (e.g., better attributed basins areas and population density) and providing the framework for a concerted efforts in multivariate typological assessment.

Table 5.2 Significant correlations (95% confidence level) between typology variables and biogeochemical system parameters.

Typology variables	System parameters
% cropland	logΔDIN, logΔDIP, DINload concentration
% urban land	logΔDIN(-), DIN and DIPload concentrations
Population density	DIP and DINload and catchment area
Standard deviation in sea surface temperature	logDIN concentration, DIPout/DIPin
Air temperature	DIN concentration (-)
Soil organic carbon content	DIP load

In these relationships, most of the correlation coefficient (r) values are low (<0.5) even when statistically significant. Transforming the variables (e.g., log) frequently improves the value of r. Indeed, many environmental variables are found to be skewed or otherwise distributed in some non-normal fashion (see Chapter 2 - Geo-spatial and Typology Working Group). For example, fundamental characteristics of the budget sites (such as system area and depth) appear to be log-normally distributed. On a linear scale, the non-conservative fluxes of DIN and DIP appear to be excessively "peaky" (i.e., "leptokurtic").

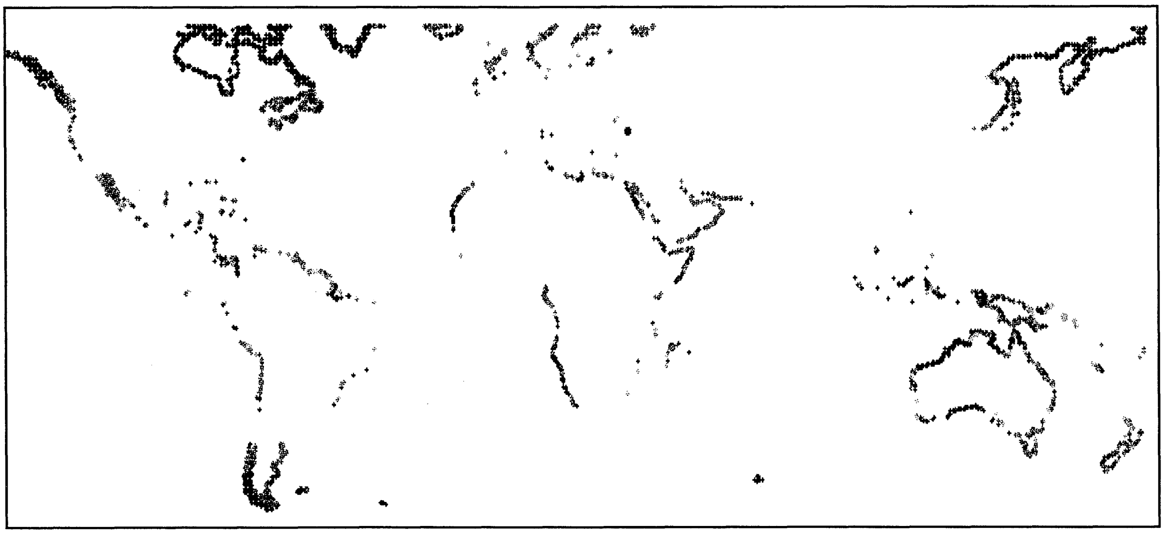


Figure 5.12 Global typology of low population density and low % cropland use. (With polar regions cropped and data filtered for population density <10/km^2, land cover < 5% cropland, the clusters representing areas of probable human impact disappear.

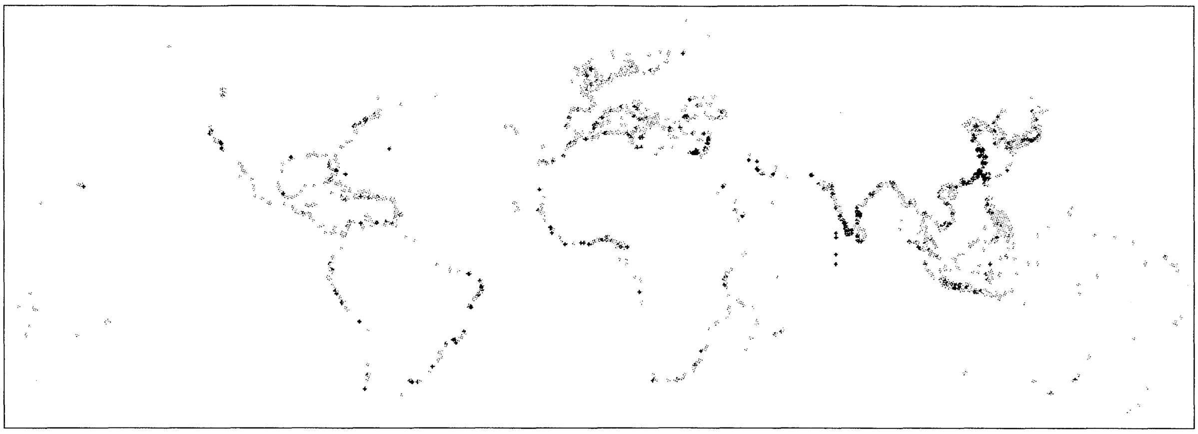


Figure 5.13 Global typology showing estimated regions of highly "disturbed" coastal systems. (Typology of high population density [>60/km^2] and high cropland use [>10%].).

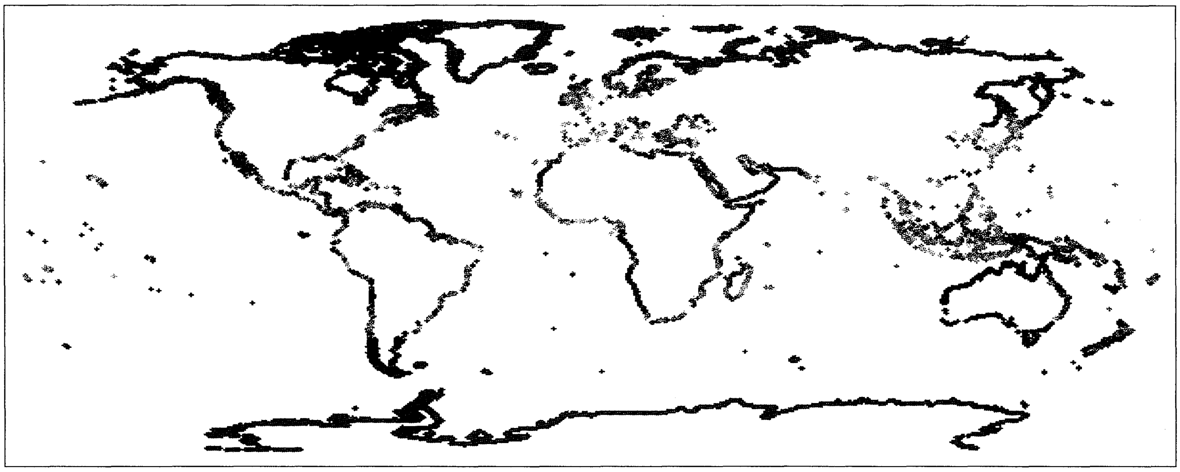


Figure 5.14 Global typology showing estimated localities and gradient of "disturbance" in coastal ecosystems. (Blue, <10 people /km^2; Green, 10-20 people/km^2; yellow, 20-35 people/km^2; red, 35-60 people/km^2).

Breaking the data set into subsets sometimes improves r. For example, plotting the distribution on a log-scale for the positive and negative sides of the real line suggests a separate log-normal (or bimodal) distribution for the positive and negative parts of the non-conservative flux estimates, reflecting the apparent log-normal distribution of the terrestrial and oceanic fluxes which drive them. Whether this is a fundamental characteristic of these fluxes or an artifact of the methodology is currently an active area of study.

The clear relationship between human population distribution and nutrient loads to coastal systems has led to a first geo-spatial assessment of where we can expect to find coastal ecosystems that are undisturbed, from application of the typology approach to key variables of population and cropland in the coastal zone.

Using data filters (deleting the polar region and offsetting the megacities to remove their overwhelming influence on clustering), a typology of human demographic data was developed (Figure 5.12) representing coastal regions with a population density of <10 persons/km^2 and <5% cropland usage. The coastline in this graphic represents those parts of the global coastal zone where we can expect human influence to be small and thus to contain relatively "undisturbed" coastal ecosystems. This suggests that there are likely to be few if any *regions* of the world that can be described as containing "relatively pristine" or undisturbed ecosystems.

Extending this approach with population density and cropland as human pressure proxies, it can be argued that human effects predominate over landscape effects on nutrient loading to the coastal systems (section 5.2.3, above); population densities greater than about 30/km^2 may be considered to represent dominant human influences (Figure 5.10). From this assumption, we have taken a conservative value for population density (60 people/km^2) to make an initial estimate of coastal areas that are likely to contain systems "highly disturbed" by nutrient loading (Figure 5.13). Similarly, and by sub-grouping the population density data, a gradient of loading pressure can be represented (Figure 5.14) and, in combination with global population projections, a space-for-time interpretation could be applied to develop scenarios predicting key areas of change in coastal systems.

These preliminary typologies will be tested and further extended by application of the key variables currently being identified in the biogeochemical site analyses and allied knowledge of causal relationships between coastal system function (ΔDIP and ΔDIN responses) and nutrient loading.

5.3 Where to from here?

Trends are emerging, though they appear to be generally non-linear and often noisy, reflecting the multiple forcings (especially in the nutrient loading data and the related influence by human activities), as well as the quality and completeness of the mostly secondary data used in the work.

Our initial efforts have been founded on conceptual analysis of the ecosystem variables and influences on metabolic performance of the ecosystem sites, based on correlative and linear regression approaches. Recognising the great range in the magnitude of the variables, we have applied a log-transformation to the data to stabilise variance when performing initial investigations by statistical analyses. This approach has frequently been observed to provide insightful linear relationships between log-transformed variables over large scales, to which we can ascribe meaning to the resultant parameters that characterise the relationships. This work is being extended to examination of relationships using other statistical approaches, for example, principle component analyses and cluster analyses, which may be more robust for extracting and interpreting the multi-variable and multi-scaled coastal environments.

Our three-fold approach to obtain information on system-level C-N-P metabolic performance across the global coastal zone (See Figure 3.1 - Chapter 3 Functional Processes Working Group) includes: a) understanding loading particularly from land, b) understanding exchanges with the ocean, and c) understanding the internal processes of the estuaries and coastal seas. Initial findings are reported here and work continues to build further understanding that will provide a coherent regional and global assessment of the relative importance of the coastal zone as a C-N-P sink-source, and how this may be changing.

Concerted efforts are being made to develop a quantitative, predictive understanding of controls on the signs and magnitudes of the ΔDIP and ΔDIN fluxes, to statistically assess the functional relationships between key variables and to examine the interdependence of non-conservative fluxes and the relative terrestrial/oceanic loading of nutrients to the systems. An evaluation of river basins and the significance of small rivers versus big river systems as sources of terrestrial loading and drivers of coastal system change is being pursued. These analyses are identifying the need for, and in some cases providing, additional geo-spatial data sets and techniques (e.g., Geographic Information System analyses and models; higher resolution spatial data) to describe key variables for use in typological assessments. Up-scaling and spatial integration of the information is proceeding through a structured approach that includes, *inter alia*, hierarchical nesting of key variables such as climate, population and ocean-land loading in multi-variate assessments.

It is clear that extrapolation of information from individual site budgets to the "global coastal zone" remains a challenge, and that natural influences and human dimensions affecting system metabolism must be addressed by a combined approach of both the numerical budgets and typology. Thus, we have reported here on progress in our efforts towards regional and global assessment of coastal metabolic performance, presenting our initial findings and the direction and framework of our inquiry, and some key questions being addressed by on-going analyses.

5.4 Appendix

A list of appendix materials and brief descriptive summaries are printed in Appendix V in the Appendix section of this report.

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Appendices

This report has five appendices, presented in two different forms. The table below indicates the contents of both the printed report appendices and those appearing on the accompanying CD-ROM. The CD-ROM contains all of the printed material, and in addition contains slide shows and collections of color illustrations (e.g., cluster output maps) that provide supporting information for the observations in the report sections.

Each chapter of the report has an associated appendix with the same number as the chapter. In the content list below, items in the print appendices are listed in normal type, and the *contents unique to the CD-ROM are in italics*.

Appendix I (Chapter 1 supporting documents)
I.1 Workshop Participant list
I.2 Workshop Agenda
I.3 Workshop TOR

Appendix II (Chapter 2 supporting documents)
II.1 Selected variables, transformations and justification (print and CD-ROM).
Table II.1.1 Variables, transformations and their environmental significance.
Table II.1.2 Variable names and expanded notes on environmental significance.
II.2 Phase 1 Global cluster experiments with notes and informal observations (10 variables, global). See report sections 2.3.1 through 2.3.2.
II.3 Phase 2 Zonal clustering experiment results, with tabular descriptions of clusters and informal notes (5 variables, SST climate zones). See report sections 2.3.2.2-2.3.2.3.
II.4 Post-workshop cluster experiments
Systematic investigation of the interactions of variable classes, regions and cluster numbers. Patterns resulting from splitting the biophysical variables into marine and terrestrial components, the effects of combining terrestrial and anthropogenic variables into a single clustering approach, and comparison of 5-cluster and 10-cluster runs for the various components and combinations.

Appendix III (Chapter 3 supporting documents)
III.1 Non-linear curve fits for budget variables.III.2 Pair-wise plots and linear regressions of budget and environmental variables.

Appendix IV (Chapter 4 supporting documents)
IV.1a Some statistical investigations of the budget datasets – draft report prepared at workshop by Dennis Swaney.
IV.1b Slide-show (from Powerpoint) presentations from workshop:
- *i. Working Group Summary Report*
- *ii. Comparisons and regressions of budget variables and their log transforms*
- *iii. Quadrant Typology – an exploration of the relationships of ΔDIN, ΔDIP, and environment, by Laura David*
- *iv. Environmental vulnerability – preliminary developments by Laura David*

IV.2 Cluster summaries and related information on Working Group 'experiment' results.

Appendix V (Chapter 5 supporting documents)
V.1 Comparison of selective regression results with plots of logΔDIN (+ and -) and logΔDIP (+ and -) against log Texchange.
V.2 Regression equations for the dependence of ΔDIN and ΔDIP on catchment area, runoff and population.

Appendix I Organisational Information

I.1 Workshop Participants

LOICZ/UNEP GLOBAL SYNTHESIS EXPERT WORKSHOP ON COASTAL BIOGEOCHEMISTRY AND SCALING
Kansas Geological Survey
Lawrence, Kansas, USA
11-14 November 2001

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I.2 Workshop Agenda

LOICZ/UNEP GLOBAL SYNTHESIS EXPERT WORKSHOP ON COASTAL BIOGEOCHEMISTRY AND SCALING
Kansas Geological Survey
Lawrence, Kansas, USA
11-14 November 2001

Sunday, November 11:
(8:30-9:30, transport, assemble at KGS Auditorium)

9:30	Welcome, introductions, meeting plans and logistics
10:00	Update on the budget variables, database and interpretations – Dennis Swaney, Steve Smith
11:00	An example of typology application to a budget surrogate: coral reefs and sea anemones – Bob Buddemeier, with Bruce Maxwell
11:45	LOICZView features, capabilities and use for synthesis and upscaling – Bruce Maxwell
12:15	Pulling it together – resource panel and general discussion
12:30	Lunch
13:30	Brief presentation – Jean-Pierre Gattuso on coastal budget initiatives
14:00	Identification of breakout groups, organization and work brief
14:30	Breakout groups
17:30	(approximate) Adjourn

Monday, November 12

09:00-12:30	Continue in breakout groups
12:30	Lunch
13:30	Brief presentation – Joe Salisbury on initiatives to develop an Index of River Influence and classify biogeochemical domains in the surface ocean
14:00	Plenary session – working group reports, assessment of progress, identification of key issues and needs remaining
16:00	Identification of second stage working group membership and working brief. Breakout groups
18:00	(approximate) Adjourn

Tuesday, November 13

09:00-12:30	Continue in breakout groups
12:30	Lunch
13:30	Brief presentation? – open
14:00	Plenary session – working group reports, assessment of progress, identification of key issues and needs remaining
16:00	Identification of third (final) stage working group membership and working brief. Breakout groups
18:00	(approximate) Adjourn

Wednesday, November 14

09:00-11:30	Continue in breakout groups; prepare summary report contributions.
11:30-12:30	Reassemble in Plenary; summary reports
12:30	Lunch
13:30	Final plenary discussion, which may include small, short-term breakout periods to review questions and prepared recommendations and conclusion
16:30	Concluding Plenary session
18:00	Close of workshop

I.3 Terms of Reference

LOICZ/UNEP GLOBAL SYNTHESIS EXPERT WORKSHOP ON COASTAL BIOGEOCHEMISTRY AND SCALING
Kansas Geological Survey
Lawrence, Kansas, USA
11-14 November 2001

Background Information:
A major overall objective of LOICZ (http://www.nioz.nl/loicz/) and the facilitating UNEP GEF project is to provide an assessment of uptake and release of nutrients (nitrogen and phosphorus) in the global coastal zone. The tools being used to meet this objective are biogeochemical budgets of nitrogen and phosphorus for specific sites (primarily bays, estuaries, and lagoons) in the coastal zone, and application of an objective classification ("typology") (http://www.kgs.ukans.edu/ Hexacoral/Workshops) to extrapolate from individual sites to the global coastal zone.

To date, more than 150 site budgets have been developed (http://data.ecology.su.se/MNODE), mostly through the series of workshops sponsored by UNEP GEF. The primary classification tool is the geo-spatial clustering program "LOICZView," which has been developed for this specific application (http://www.palantir.swarthmore.edu/~maxwell/loicz/).

This workshop will synthesise the existing LOICZ biogeochemical budgets and modelling data and information, to build a picture of net metabolic performance of coastal systems at global and appropriate regional scales. External forcing and anthropogenic forcings will be a major ingredient in this synthesis and assessment.

Primary Goals:
To use teams of expert researchers and resource persons dealing with coastal fluxes and biogeochemistry to relate C, N, P biogeochemical budgetary information at global and major regional scales to coastal system classifications that will be developed primarily by cluster analysis of suites of environmental and human-dimension variables.

The workshop provides the opportunity to synthesise and integrate the evolved data and information into an initial global picture. Importantly the outcomes are expected to not only meet the LOICZ-UNEP project requirements, but will contribute significantly to the LOICZ "Synthesis" which is in progress and due for completion in 2002.

Participation:
The number of expert participants will be limited to about 30 persons, to allow the active involvement of all participants and working group arrangements.

Workplan:
Participants will be expected to come prepared to contribute actively to the classification and synthesis process. Preparation should include: reading, examination of the data, tools, and tutorials presented on the LOICZ Typology and Web-LOICZView web pages (see URLs, above). Additional information from recent workshops, budget databases and an enhanced version of LOICZView will be made available in the lead up to the workshop. We ask that you continue to visit the budgets and typology websites to keep abreast of continuing developments, evolving case studies and thematic developments. The provision of further documentation (electronic and hard-copy) will identify themes and provide a basis for expert participants to give thought to, trial evaluations/scenarios, distil questions in preparation for the working group activities.

Further Details:
The workshop will be held in Lawrence, Kansas and hosted by the Kansas Geological Survey (KGS).

LOICZ will arrange travel and make other workshop arrangements in consultation with the KGS, and will pay for all travel, accommodation and support costs for the participants.

Further details will be provided to participants during the lead-up to the workshop.

A small group of resource people will remain in Lawrence for 2-3 days after the workshop to finalise reports and products.

Draft Workshop Schedule:

November 10:	Arrival of participants.
November 11:	(am) General introduction to workshop schedule, plans and goals. Plenary review of pre-workshop tests and outcomes. Refinement of workshop strategy; development of teams and assignments. (pm) Working Group activities
November 12-13:	Working Group activities and workshop discussion.
November 14:	Working Group activities Plenary synthesis overview and compilation of products.
November 15:	Departure.

A detailed program and approach using expert working groups and focal topics or questions is being developed through meetings of resource people. Elements of earlier workshop outcomes (products, databases, comments) are being incorporated into this planning. More detailed information will be disseminated to the participants before the workshop.

Appendix II: Print summary of Geospatial and Typology Working Group

Detailed outcomes to the Working Group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. Most of this information is included on the electronic CD-ROM version of the report; primarily text contents and brief descriptive summaries are printed below.

Appendix II.1 Selected variables, transformations, and justification (print and CD-ROM)

Table II.1.1 Variables, transformations and their environmental significance.

Variable	Transformation	Environmental significance
Biophysical		
Total annual precipitation (12 month total)	Log10	Wet/dry environments
Monthly precipitation variation (Std. Dev. of avg. annual)	Log10	Seasonality
Annual precipitation variation (Std. Dev. of 12 month av)	Log10	Interannual variability
Tidal range	Log10	Dynamics/exchange
Wave height		Dynamics/exchange
Basin runoff (Basin runoff, m^3)	Log10	Riverine influence
Coastal topography (Std. Dev. elevation SS2)	Log10	Residence time/shelf type
Mean ocean colour (mean chloro for 1997-00)	Log10	Surrogate for productivity which regulates the DIP/DIN
Ocean colour variability (Std. Dev. of 4yr mean Chloro 1997-00)	Log10	Upwelling/riverine influence, seasonal influences?
Anthropogenic		
Basin population total	Log10	Total nutrient loading
Basin population density	Log10	Nutrient loading intensity/consequences
Basin land area (SB area km^2)	Log10	Processing of nutrient loading
Coastal population (pop. in 30' cell)	Log10	Direct nutrient inputs, point-source loading
Coastal population density (pop. density per km^2 land area)	Log10	Urbanisation
Basin road density	Square root	Atmospheric loading/vehicle emissions
Basin crop area	Log10	Agriculture fertilizer/animal inputs
Basin crop density	Log10	Agricultural intensity
Soil texture	Log10	Run-off and potential delivery of fine particulates to the coast
Soil organic C (0-1m)	Log10	Run-off and potential delivery of fine enriched particulates to the coast
Variables tried but dropped in the final runs		
Precipitation average monthly		Runoff and potential delivery of fine particulates to the coast

Table II.1.2 Variable names and expanded notes on environmental significance.

Category	Variable – our description	Variable - LOICZ database description	Environmental significance, the process we are trying to capture in the variables
Biophysical variables			
Climate	Mean air temp 12 month average	AIRTEMP_MNTHAVG_TRAD	Polar/temperate/tropical Tropics – not important in estuaries Temperate – not important Polar – not important
	Total annual precipitation, average total annual	PRECIP_AVGANNTOT_SERIES	Wet/dry environments Tropics – important Temperate – important Polar – important
	CV monthly precipitation	Use CV from list	Seasonality of precipitation Tropics – important Temperate – important Polar – important
	CV of annual precipitation (1950-96)	PRECIP_INTRA_ANN_STDV_GAGE	Interannual variability of precipitation Tropics – important Temperate – important Polar – important
Coastal oceanography	mean monthly SST	SST_MEAN_MONTHLY	Upwelling/currents, only the perennial upwelling Tropics – important Temperate – important Polar – important
	Variance in the SST field and anomalies	SD of the SST	Upwelling/currents particularly seasonal upwelling Tropics – important Temperate – important Polar – important
	Tidal range	TIDAL_RANGE	Dynamics/mixing exchange Tropics – important Temperate – important Polar – important
	Wave climate	WAVE_HEIGHT	Dynamics/mixing exchange Tropics – important Temperate – important Polar – dump
Freshwater inputs	Maximum salinity	SALINITY_MAX_MONTH (strange data - 2 degree data?)	Riverine influence Tropics – not important

			Temperate – important Polar – important
	Runoff from entire catchment	BASIN_RUNOFF? (units are m^3)	Riverine influence/mass loadings Tropics – important Temperate – important Polar – important
Coastal topography	Shape of the coastal topography and the adjacent seabed	STDV_ELEV_BATH CZbath/elev, SS2 value	Residence time/shelf type Tropics – important Temperate – important Polar – important
Chlorophyll - this is our 'third layer' test	Ocean colour variability	CHLORA_STD SD of the 4yr mean 1997-2000	Upwelling/riverine influence Temperate – important Tropical –seasonal upwelling using SD of CHL Temperate – important Polar – important
	Ocean colour variability	Mean chlorophyll for the 4 yrs 1997-2000	Surrogate for productivity, which regulates the DIP and DIN Tropical –seasonal upwelling using SD of CHL Temperate – important Polar – important
Anthropogenic variables			
Population	Basin population	SB_POP	Total loading of nutrients Tropics – important Temperate – important Polar – important
	Basin population density	SB_POP_DENSITY	Nutrient loading intensity Tropics – important Temperate – as above Polar – as above
	Basin land area	SB_AREA Km^2	Processing of loading Tropics – important Temperate – important Polar – important
	Coastal population density	POP_DENSITY_CELLNUM Pop density per km^2 land area	Urbanisation Tropics – important Temperate – important Polar – important
	Coastal population	Pop 30' cell	Point source loading Tropics – important Temperate – important

			Polar – important
	Coastal land area	Derived Cell area dived by % land Land % WVS	Coastal loading normalisation NOT USED
Development			
	Basin road density	SB_ROAD_DENSITY_DD	Atmospheric loading/vehicle emissions Tropics – important Temperate – important Polar – important
Agriculture	Basin crop area	SB_CROP_AREA	Fertilizer/animal inputs
	Basin crop density	SB_CROP_DENSITY	Fertilizer/animal loadings Tropics – important Temperate – as above Polar – as above
Sediment erosion	Precipitation average monthly max	~~PRECIP_AVGMAXMNTH_GAGE~~ We took this out	Runoff potential and erodibility and delivery of fine particulates to the coast
	Soil texture	SOIL_TEXTURE	As above Tropics – important Temperate – important Polar – important
	Soil organic C (0-1m)	SOIL_ORGANIC_CARBON_0_1M KgC/m^2 0-1m	As above Tropics – important Temperate – important Polar – important
Biochemical budget variables			
	DeltaDIP DeltaDIN DIPloadann DINloadann Texchange Depth Area		*Nutrient processing*

Appendix II.2 Phase 1 (10 variables, global)

Cluster experiments with notes and informal observations. See report sections 2.3.1 through 2.3.2.1 – CD-ROM only.

Appendix II.3 Phase 2 (5 variables, SST climate zones)
Zonal clustering experiment results, with tabular descriptions of clusters and informal notes. See report sections 2.3.2.2-2.3.2.3 – CD-ROM only.

Appendix II.4 Post-workshop cluster experiments
Systematic investigation of the interactions of variable classes, regions, and cluster numbers. Print summary, linked images viewable on the CD-ROM.

The objectives of the cluster runs identified in the table below were:
1. To explore the patterns resulting from splitting the biophysical variables into marine and terrestrial components;
2. To consider the effects of combining terrestrial and anthropogenic variables into a single clustering approach; and
3. To compare 5-cluster and 10-cluster runs for the various components and combinations.

	tropical		**temperate**		**polar**	
Human (A)	5 clu	10 clu	5 clu	10 clu	5 clu	10 clu
Marine (M)	5 clu	10 clu	5 clu	10 clu	5 clu	10 clu
Terrestrial (T)	5 clu	10 clu	5 clu	10 clu	5 clu	10 clu
Biophysical (B=M+T)	5 clu	10 clu	5 clu	10 clu	5 clu	10 clu
All Land (TA=T+A)	5 clu	10 clu	5 clu	10 clu	5 clu	10 clu

<u>Run 1 - All variables untransformed, whole world</u>
10 CLUSTERS, WHOLE WORLD
Observations:
- Strong latitudinal signal
- Identified the land areas adjacent to coastal upwelling regions
- Displayed the warm Gulf Stream and colder shelf seas
- Australia, and NZ and the Mediterranean were not well clustered
- Good grouping for coastal South America
- Areas of high population apparent

Generate histograms: – checking what is needed to be transformed
- Need to transform log-normally distributed data sets (17 of the 25 variables).
- Generally, $\log_{10}$ was the best transformation.
- Basin urban density has poor global representation – delete

List of data transformations:
- Transform .....precipitation (raw), Std Dev. of the 12 month average.....$\log_{10}$
- Transform .....precipitation, average total annual....$\log_{10}$
- Transform .....precipitation, cv of average annual....$\log_{10}$
- Transform .....basin pop density....$\log_{10}$
- Transform .....basin pop total....$\log_{10}$
- Transform .....basin road density....square root
- Transform .....basin area (km^2)....$\log_{10}$
- Transform .....basin runoff cum....$\log_{10}$
- Transform .....basin crop density....$\log_{10}$
- Land percent WVS
- CZ bathymetry/elevation, Std Dev. of the SS2 value.......$\log_{10}$
- Transform .....pop density/km^2 land area in the coastal cell....$\log_{10}$
- Cell area (km^2)....no transformation
- Population, density/km^2 land area....$\log_{10}$

Run 2 - All variables, transformed, whole world

10 clusters, whole world; with variables transformed, as above, and adding chlorophyll_*a*, avg. spatial (previously, the variable Std Dev. Chlorophyll_*a* was included).

Run 3 – Selected variables, transformed and several not transformed; poles excluded (from 67°N – 60°S)

Run 4 - All variables, untransformed; poles excluded (from 67°N – 60°S)]

10 clusters, basin, urban density, removed.

Run 5 - Biophysical variables, transformed and several untransformed; poles excluded (from 67°N – 60°S)

10 clusters

Run 6 – Anthropogenic variables, transformed several untransformed; poles excluded (from 67°N – 60°S)

10 clusters

Appendix II.5 Zonal clustering experiment results

Polar – biophysical

Cluster	0 Labrador Sea Hudson Bay, Kamchatka, Palmer Peninsula	1 Alaska, Canada, Siberia	2 North Greenland, Ross Sea	3 Antarctic and Canadian islands	4 Newfoundland, east Greenland
	red	green	blue	yellow	purple
Precipitation	395	190	190	416	580
Wave height	1.9	1.0	0.5	0.4	5.4
Tide range	6.2	1.9	2.1	2.0	2.7
Chlorophyll	150	177	137	129	141
	Tidal, steep shores	Northern slopes	Cold, dry	Cold, dry	Wet, waves

Polar – anthropogenic

- Red cluster zero, Alaska, Canada, Siberia; unpopulated and zero agriculture
- Green cluster 1, Antarctica, Greenland, Canadian islands; zero population and, zero agriculture
- Blue cluster, lower Hudson Bay, Iceland, west Finland and Kamchatka; some population

Temperate – biophysical

Cluster	0 Fjords	1 Japan, Black Sea and Spain, SE Australia, NE New Zealand, Aleutians, Oregon	2 East coast USA, Baltic, N Black Sea, N China, Rio del la Plata	3 Mediterranean	4 S Australia, SW USA, NW Africa, SW Africa, Peru, Chile
	red	green	blue	yellow	purple
Precipitation	1120	1110	766	670	168
Wave height	6.4	3.2	3.1	3.1	3.6
Tide range	4.7	3.3	1.7	1.1	3.0
Chlorophyll	151	144	181	98	143
	Tidal, steep shores	Steep coast	Productive coastline	Small tides, low precip, clear water	Arid coast

Temperate – anthropogenic

- two major clusters; high loading and low loading

Tropical – biophysical

Cluster	0 Indonesia	1 Tropical Australia, Bay of Bengal, eastern Arabian Sea, East Africa, Amazon	2 Desert, Arabian Peninsula and SW Australia	3 Island archipelagos of Solomon Islands, New Caledonia and Caribbean	4 Vietnam to China, east India, Guiana coast, central America, Caribbean
	red	green	blue	yellow	purple
Precipitation	2430	1643	174	2158	1633
Wave height	1.2	2.8	2.1	2.8	3.3
Tide range	2.9	5.2	3.3	1.9	2.0
Chlorophyll	131	152	126	85	142
	Indonesia	Wet and turbid	Desert	Oceanic islands	Populated coasts?

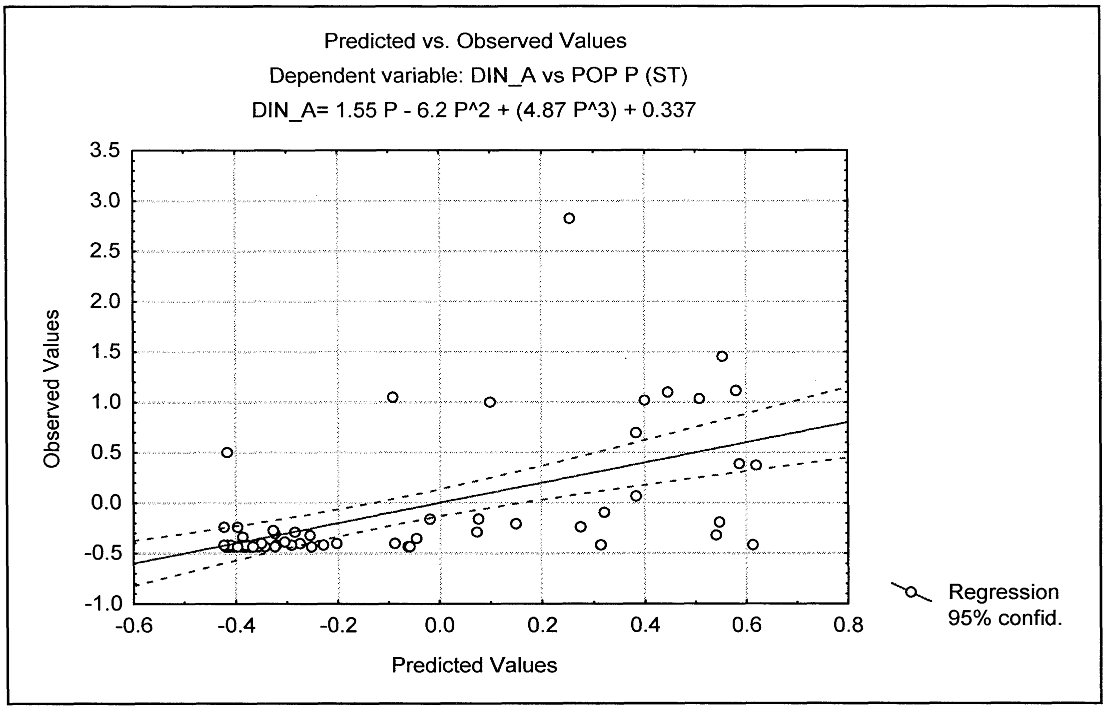
Tropical – anthropogenic

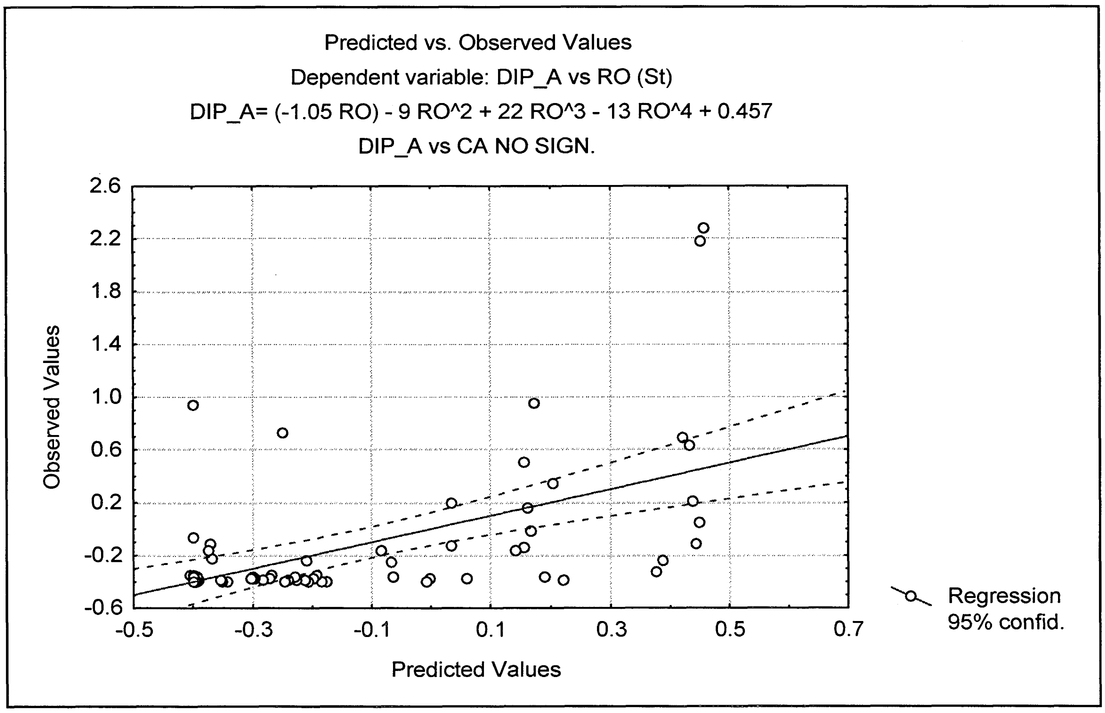
- yellow, low/no population
- green, high population
- red, relatively low population
- blue, outflow of large rivers
- purple, high population

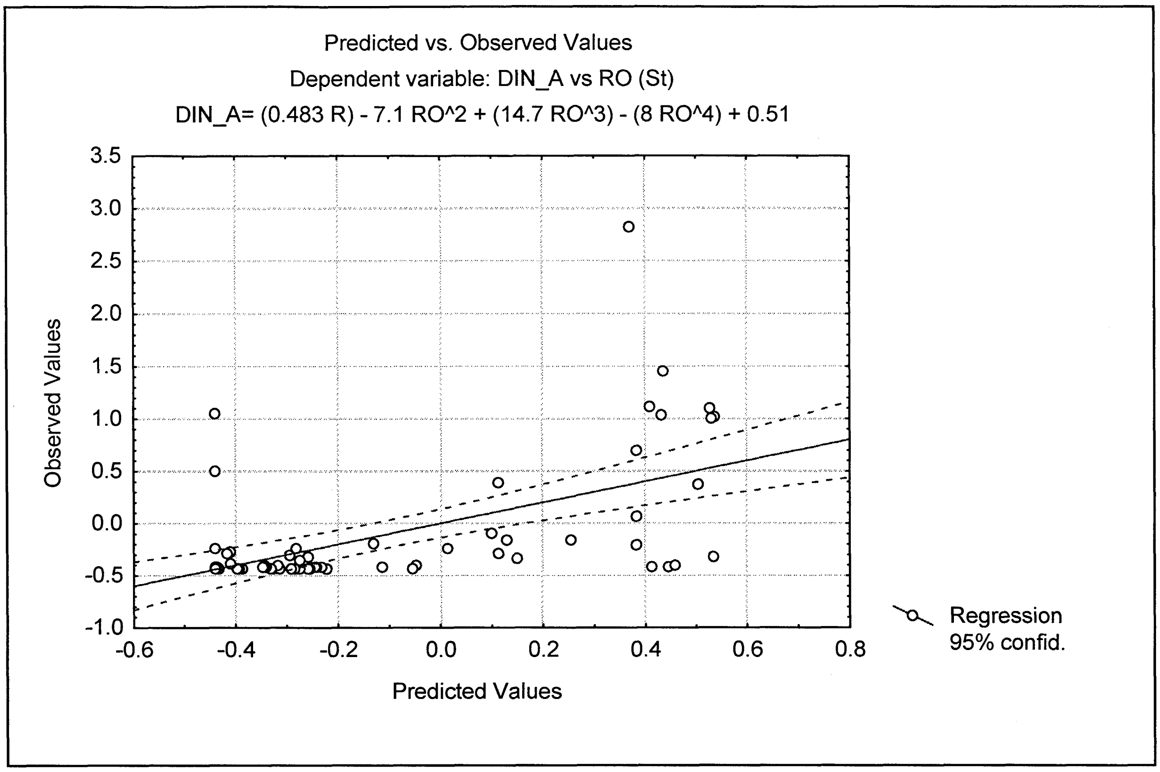
Appendix III: Print summary of Functional Processes Working Group

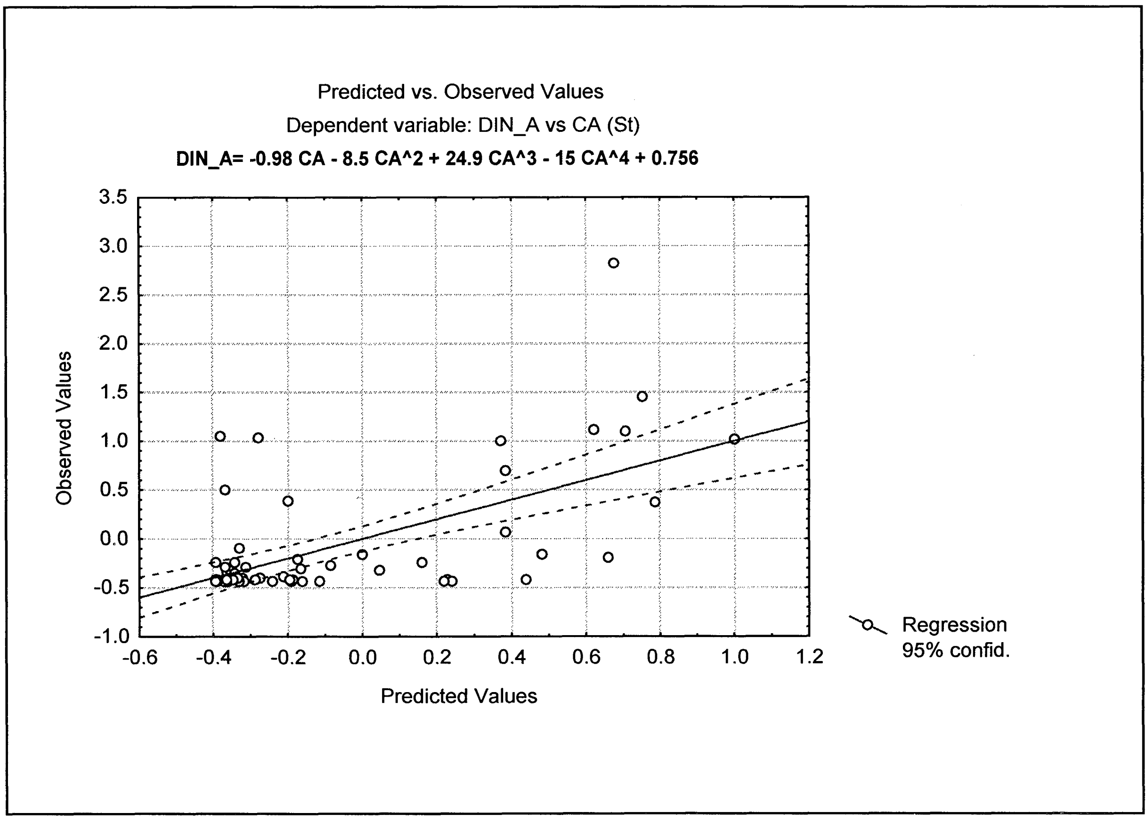
Detailed outcomes to the Working Group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. Most of this information is included on the electronic CD-ROM version of the report; primarily text contents and brief descriptive summaries are printed below.

III.1 Non-linear curve fits for budget variables.



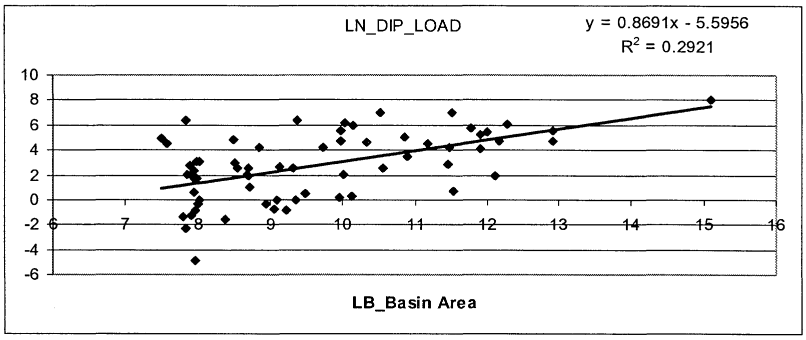



Predicted vs. Observed Values
Dependent variable: DIN_A vs RO (St)
DIN_A= (0.483 R) - 7.1 RO^2 + (14.7 RO^3) - (8 RO^4) + 0.51
Observed Values
Predicted Values
Regression
95% confid.

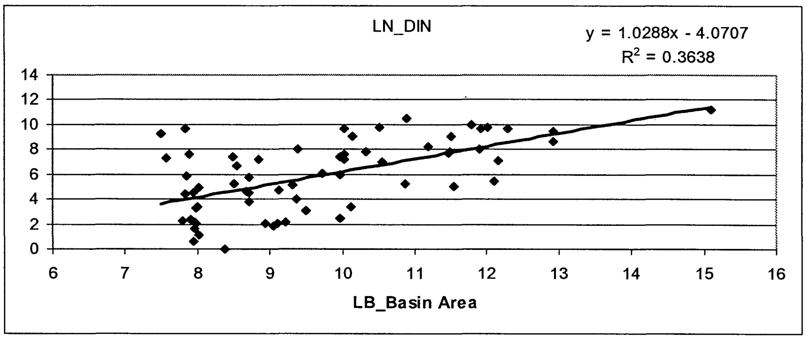

Predicted vs. Observed Values
Dependent variable: DIN_A vs CA (St)
DIN_A= -0.98 CA - 8.5 CA^2 + 24.9 CA^3 - 15 CA^4 + 0.756
Observed Values
Predicted Values
Regression
95% confid.

III.2 Pair-wise plots and linear regressions of budget and environmental variables.

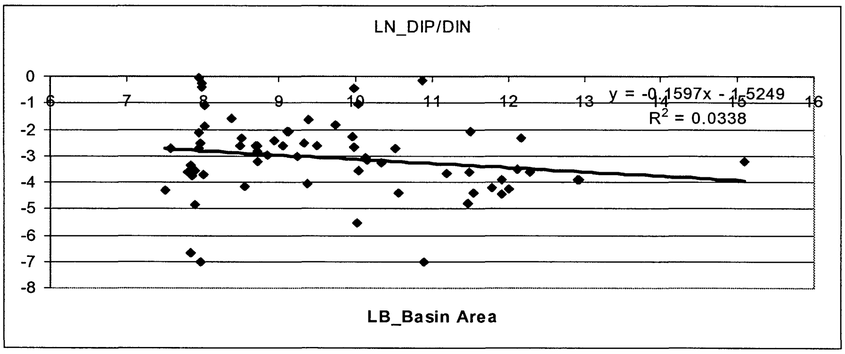
Basin area vs DIP load



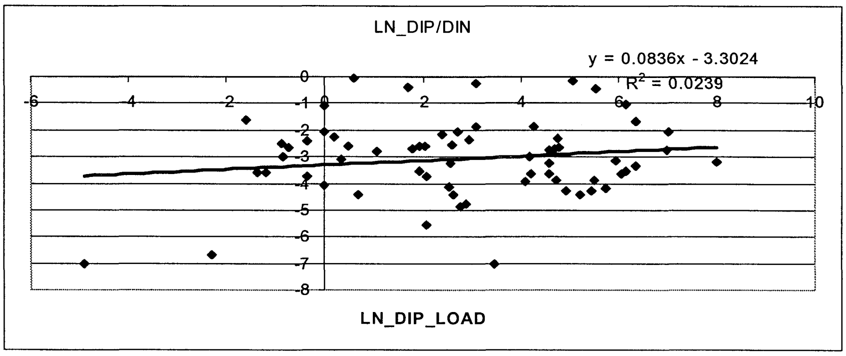
Basin area vs DIN load



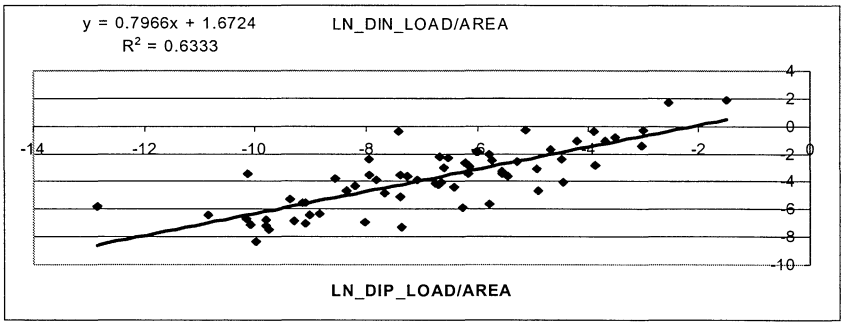
Basin area vs DIP:DIN



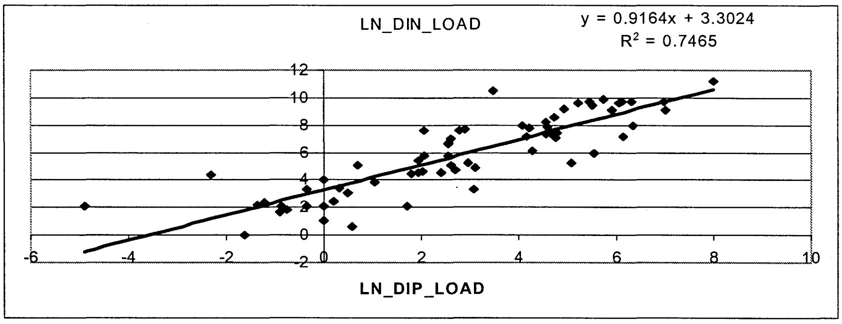
DIP load vs DIP:DIN



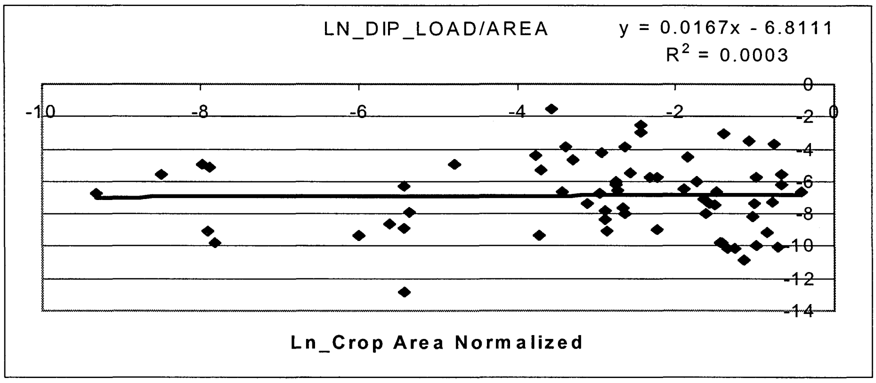
DIP load per area vs DIN load area



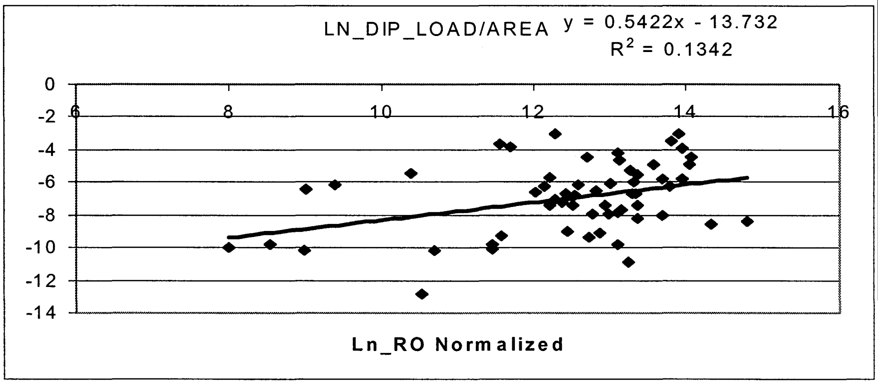
DIP load vs DIN load



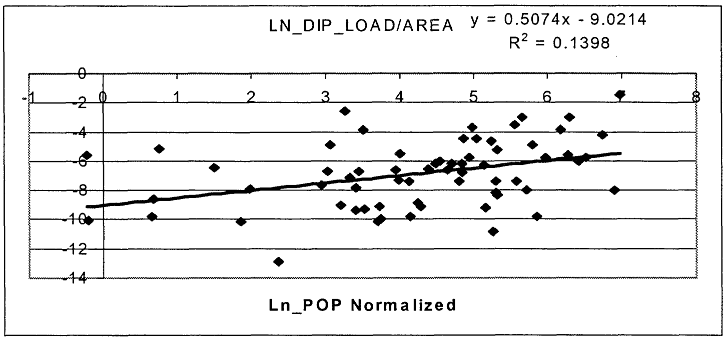
Crop area vs DIP load per area



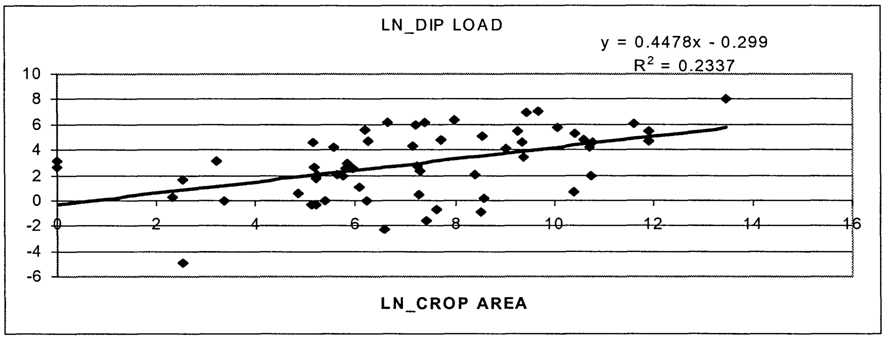
Runoff vs DIP load per area



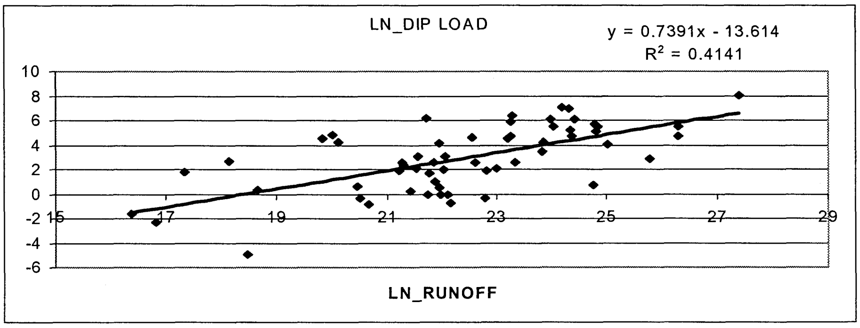
Population vs DIP load per area



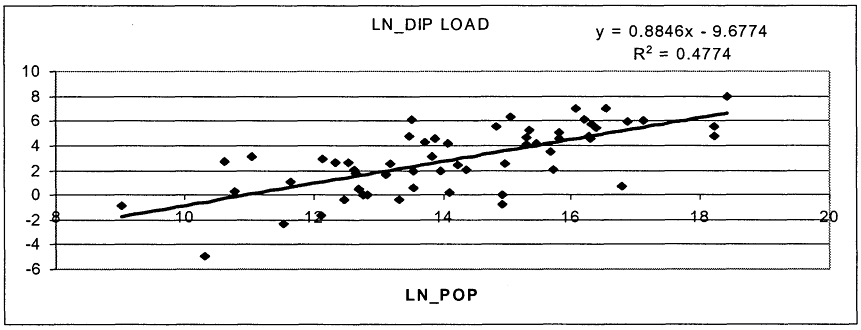
Crop area vs DIP load



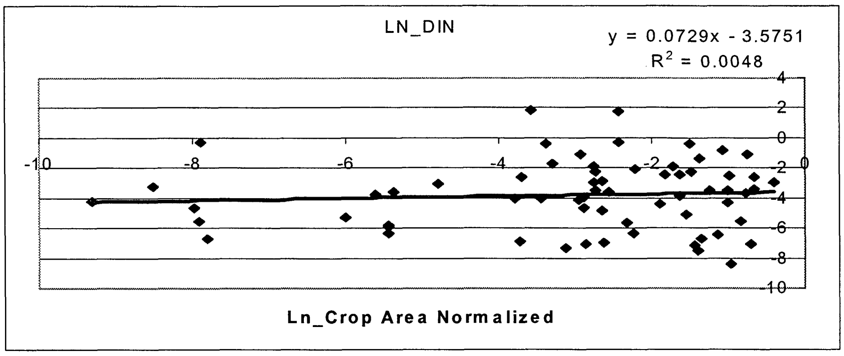
Runoff vs DIP load



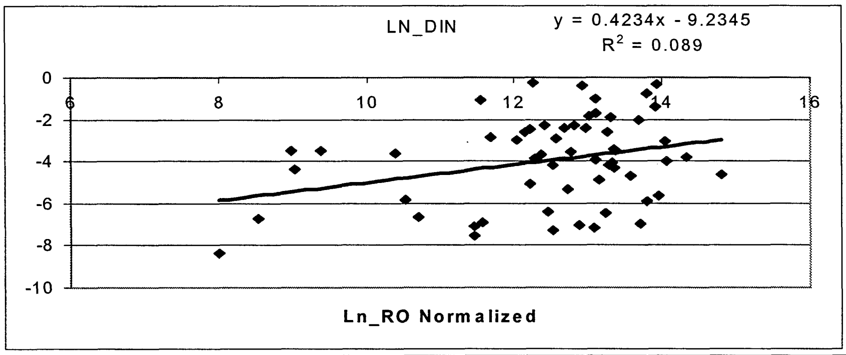
Population vs DIP load



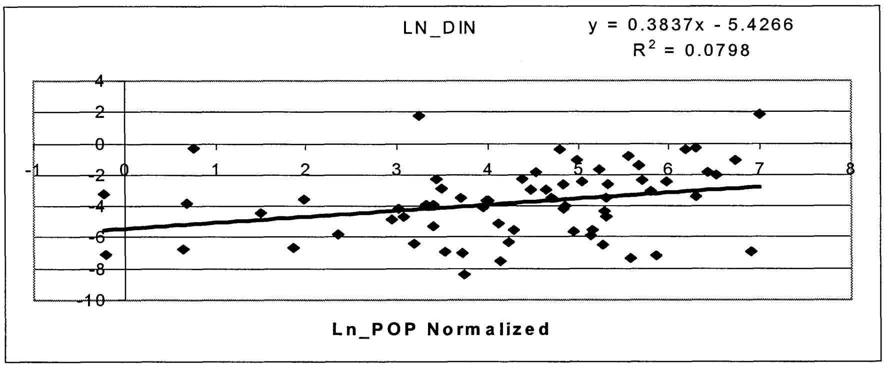
Crop area vs DIN load



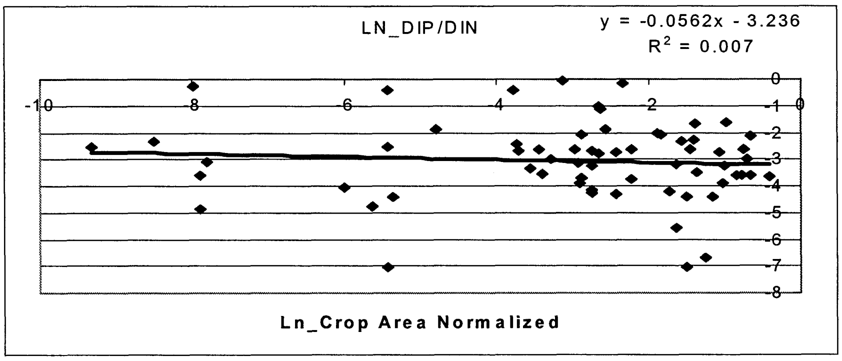
Runoff vs DIN load



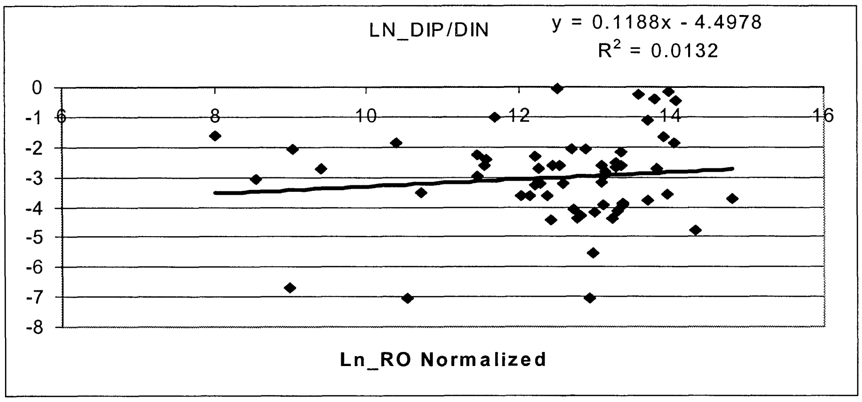
Popopulation vs DIN load



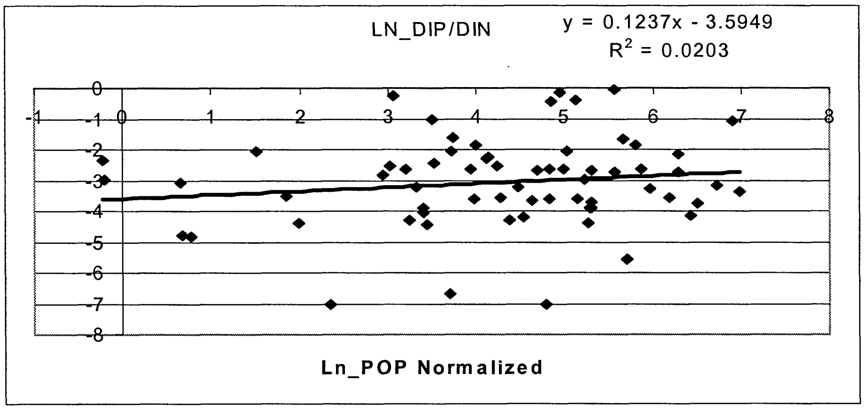
Crop area vs DIP:DIN



Runoff vs DIP:DIN



Population vs DIP:DIN



Appendix III.3 Summary data tables DIP and DIN load.

SUMMARY OUTPUT	LN DIP LOAD							
Regression Statistics								
Multiple R	0.723047							
R Square	0.522797							
Adjusted R Sq	0.486782							
Standard Error	1.904228							
Observations	58							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regression	4	210.5448	52.63621	14.51599	4.54E-08			
Residual	53	192.1825	3.626086					
Total	57	402.7274						
	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-13.212	2.607896	-5.06616	5.26E-06	-18.4428	-7.98125	-18.4428	-7.98125
Ln_area	0.325225	0.329339	0.987509	0.32788	-0.33535	0.985796	-0.33535	0.985796
Ln_crop	-0.11962	0.164209	-0.72846	0.469538	-0.44898	0.209741	-0.44898	0.209741
Ln_SBRO	0.190495	0.21745	0.87604	0.384962	-0.24565	0.626643	-0.24565	0.626643
Ln_Spop	0.668241	0.221369	3.018681	0.003898	0.224232	1.112251	0.224232	1.112251

SUMMARY OUTPUT		LN DIN LOAD						
Regression Statistics								
Multiple R	0.760927							
R Square	0.57901							
Adjusted F	0.547238							
Standard E	1.896883							
Observatio	58							
ANOVA								
	df	*SS*	*MS*	*F*	*ignificance F*			
Regressior	4	262.2841	65.57103	18.22345	1.81E-09			
Residual	53	190.7028	3.598167					
Total	57	452.987						
	Coefficients	*tandard Err*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*ower 95.0%*	*pper 95.0%*
Intercept	-10.4743	2.597837	-4.03193	0.000178	-15.6849	-5.26369	-15.6849	-5.26369
Ln_area	0.625439	0.328069	1.906425	0.062023	-0.03258	1.283461	-0.03258	1.283461
Ln_crop	-0.04335	0.163575	-0.26504	0.792005	-0.37144	0.284736	-0.37144	0.284736
Ln_SBRO	0.108558	0.216611	0.501166	0.61833	-0.32591	0.543025	-0.32591	0.543025
Ln_Spop	0.569754	0.220515	2.583747	0.012566	0.127458	1.012051	0.127458	1.012051

Appendix IV: Print summary of System Performance Working Group

Detailed outcomes to the Working Group report are largely in the form of image-intensive supporting information, such as color-coded cluster summary maps and slide-show presentations. Most of this information is included on the electronic CD-ROM version of the report.

The data contained in Appendix IV of the CD-ROM includes:

IV.1a Some statistical investigations of the budget datasets – draft report prepared at workshop by Dennis Swaney

IV.1b Slide-show (from Powerpoint) presentations from workshop

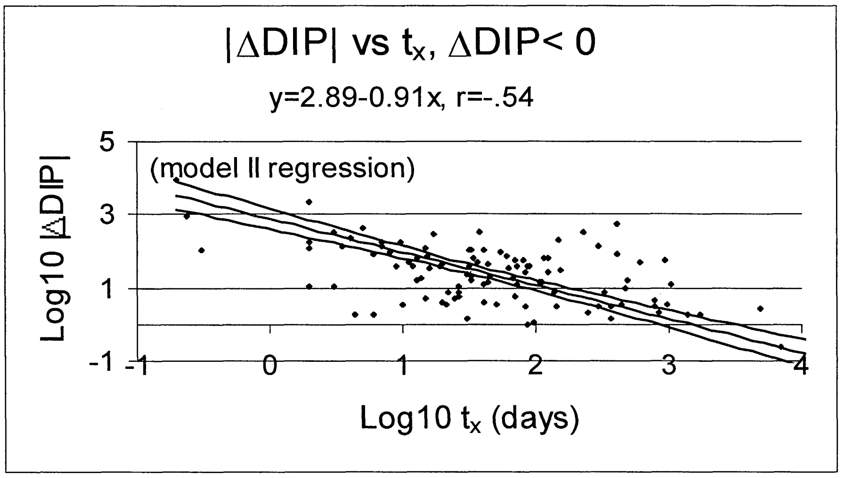
- *v. Working Group Summary Report*
- *vi. Comparisons and regressions of budget variables and their log transforms*
- *vii. Quadrant Typology – an exploration of the relationships of ΔDIN, ΔDIP, and environment, by Laura David*
- *viii. Environmental vulnerability – preliminary developments by Laura David*

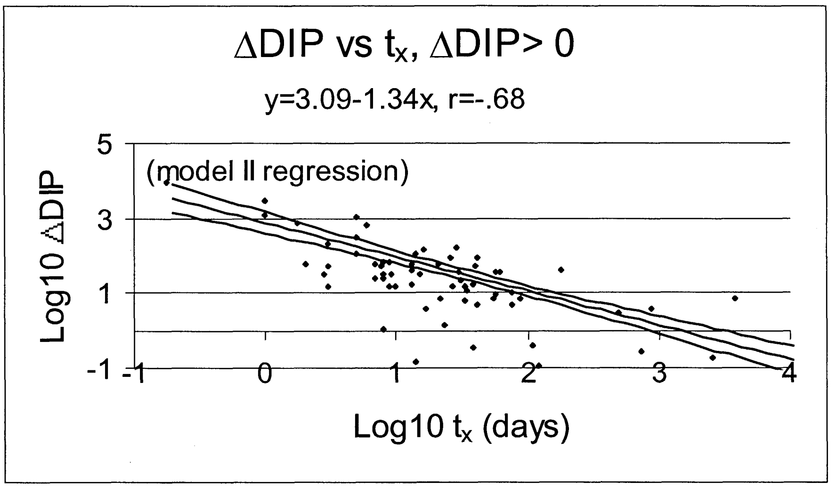
IV.2 Cluster summaries and related information on Working Group 'experiment' results.

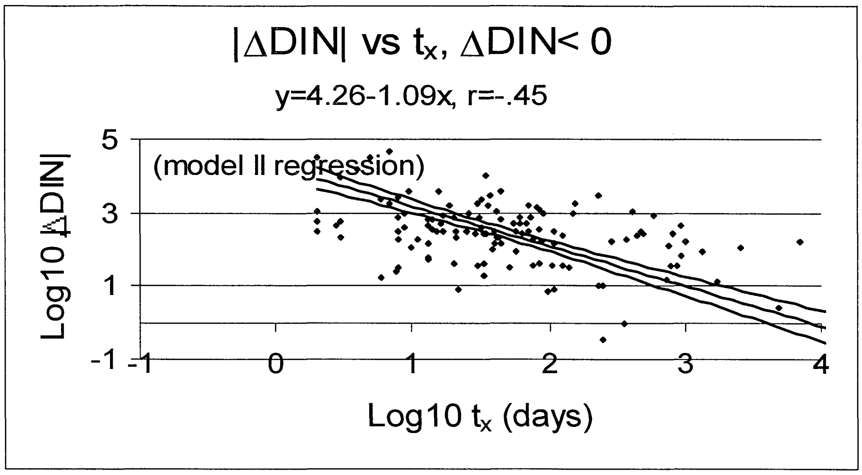
Appendix V: Print summary of Synthesis and Conclusions

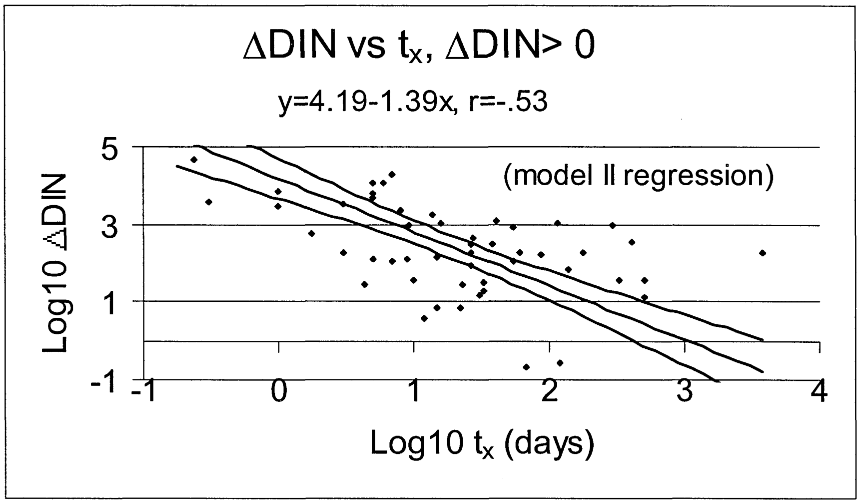
Support data and analyses for several nutrient flux assessments described in Chapter 5 are included below. This and allied information is included on the electronic CD-ROM version of the report;.

V.1 Comparison of selective regression results with plots of ΔDIN and ΔDIP against logTexchange.






|ΔDIN| vs t_x, ΔDIN< 0
y=4.26-1.09x, r=-.45
(model II regression)
Log10 |ΔDIN|
Log10 t_x (days)
5
3
1
-1
-1
0
1
2
3
4


ΔDIN vs t_x, ΔDIN> 0
y=4.19-1.39x, r=-.53
(model II regression)
Log10 ΔDIN
Log10 t_x (days)
5
3
1
-1
-1
0
1
2
3
4

V.2 DIN and DIP loads as functions of catchment area, runoff, and population.

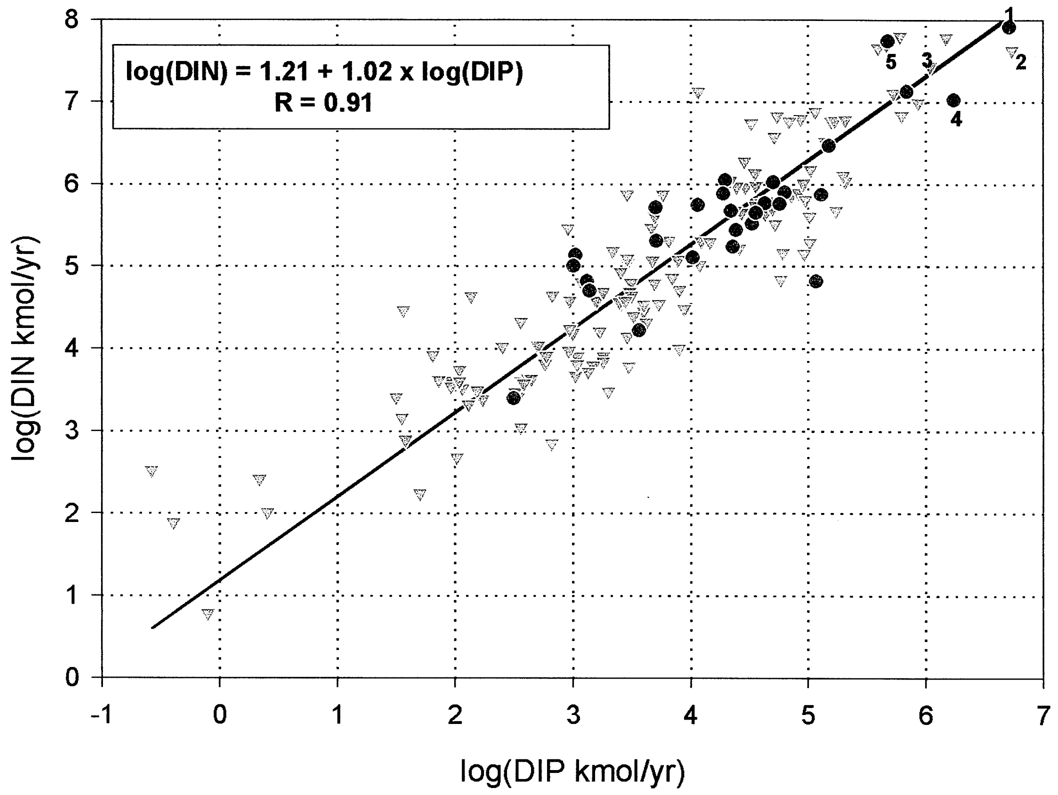
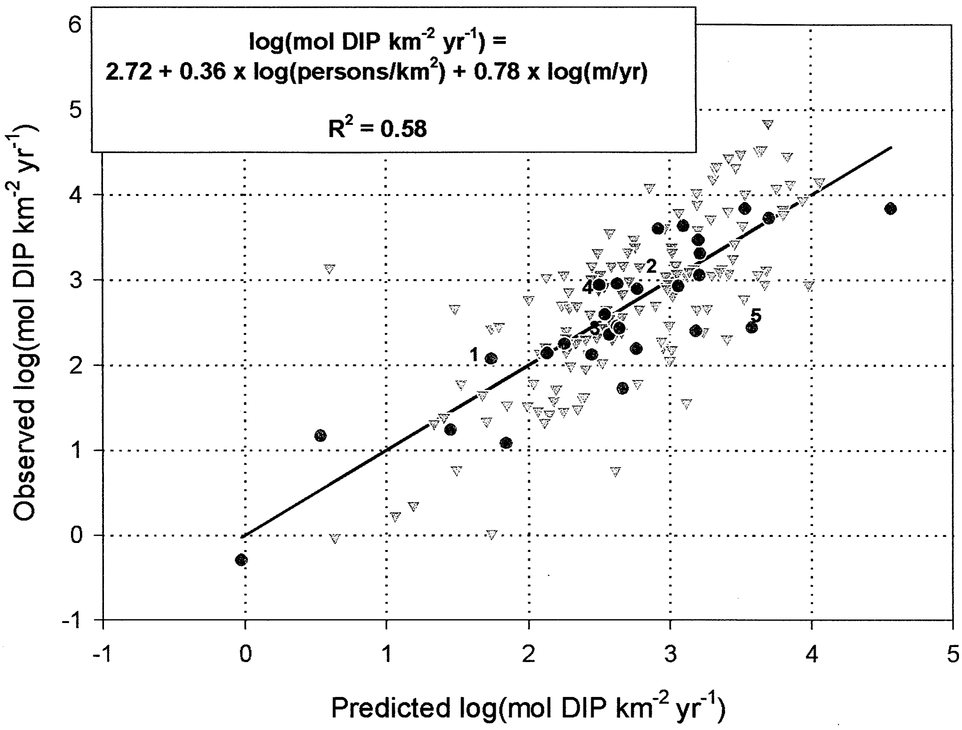
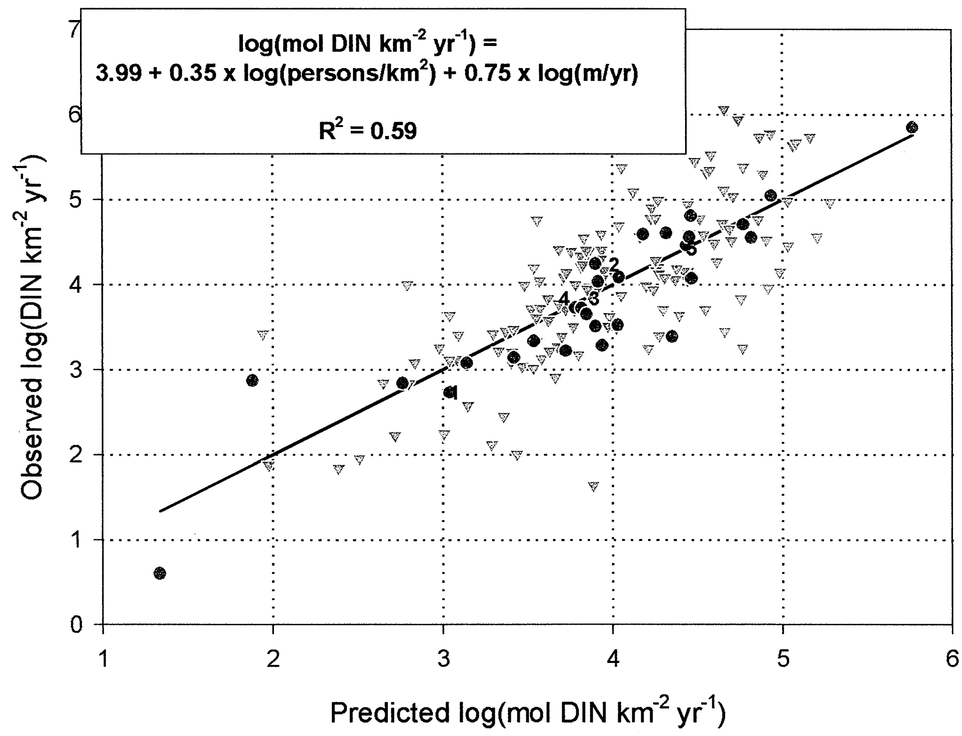


Figure V.2a. Type II regression line for log(DIN) *vs* log(DIP). Note that the slope does not differ significantly from 1. Green Triangles represent LOICZ biogeochemical budget sites; red circles represent data from Meybeck and Ragu (1997). Numbered points represent the 5 largest river basins in the data set: (1) Amazon; (2) Congo; (3) Rio de la Plata; (4) Amur; (5) Chiang Jian.





Figures V.2b,c: Predicted vs. observed values for DIN and DIP load, based on the regression equations best describing both variables in terms of basin area, population, and runoff. Color-coding of points and the large river basin identifying numbers are the same as in the top figure. Over most of the data range, these equations generate an N:P loading ratio of about 19:1.

Appendix VI Glossary of Abbreviations

APN	Asia Pacific Network for global change
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
C	Carbon
CA	Crop area
Chloro (a)	Chlorophyll_a
cv	Coefficient of variation
denit	Denitrification
DIN	Dissolved inorganic nitrogen
ΔDIN	Non-conservative flux of DIN
DIP	Dissolved inorganic phosphorus
ΔDIP	Non-conservative flux of DIP
GDP	Gross domestic product
GEF	Global Environmental Facility
GM	Geometric Mean (regression)
IGBP	International Geosphere-Biosphere Programme
IOC	International Oceanographic Commission of UNESCO
KGS	Kansas Geological Survey
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
LUCC	Land-Use/Cover Change (IGBP)
MDL	Minimum description length
N	Nitrogen
nfix	Nitrogen fixation
nfix-denit	Net nitrogen fixation minus denitrification
OBIS	Ocean Biogeographic Information System
OECD	Organisation for Economic Cooperation and Development
p	Primary production
P	Phosphorus
pop	Population
ppt	Precipitation
p-r	Net primary production minus respiration
r	Respiration
RMA	Reduced Major Axis (regression)
RO	Runoff
SST	Sea surface temperature
Std Dev. (SD)	Standard deviation
ToR	Terms of reference
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNH	University of New Hampshire
US NSF	United States National Science Foundation
WLV	Web LOICZView