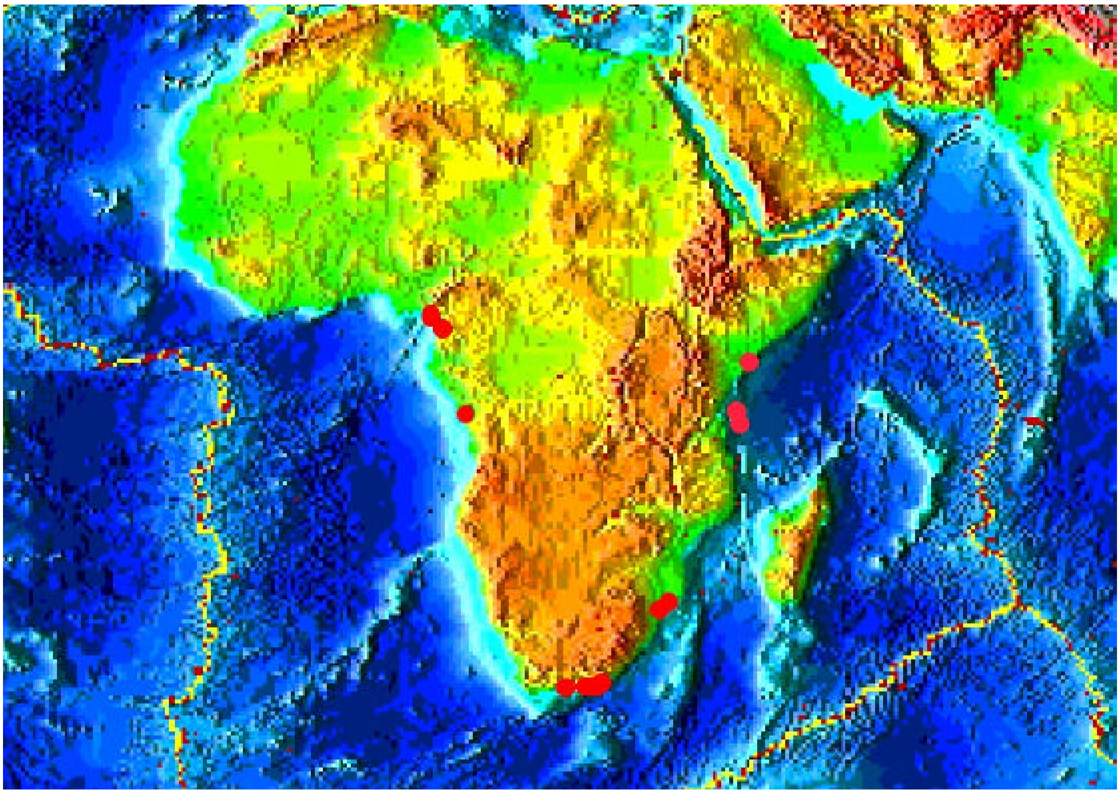
LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)
Core Project of the
International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)

and

UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)
Supported by the Global Environment Facility (GEF)



ESTUARINE SYSTEMS OF SUB-SAHARAN AFRICA: CARBON, NITROGEN AND PHOSPHORUS FLUXES

Compiled and edited by V. Dupra, S.V. Smith, J.I. Marshall Crossland and C.J. Crossland

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Cover: The cover shows an image of Africa (GTOPO30 elevation map), with the budgeted estuaries circled.

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APPENDICES

1. OVERVIEW OF WORKSHOP AND BUDGETS RESULTS

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 our 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, have established a project: "The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles" to address these mutual interests. This Workshop is the fifth of a series of regional activities within the project.

Sub-Saharan Africa extends across 50 degrees of latitude (about 15^{o}N to 35^{o}S) and about 70 degrees of longitude. Coastal regions include tropical to temperate climate regimes and feature river catchments ranging from arid to wet monsoonal systems. The influence of large ocean current systems and their interplay with climatic patterns confers great diversity to the shelf physics, and the chemistry and biology of the shelf and marine coastal systems. Riverine inputs are highly diverse, with some regions driven by major monsoon patterns and events, frequently modified by cyclonic weather systems (especially in the eastern African region). By contrast, arid catchments and ephemeral river flows are characteristic of a number of regions. Major river systems are common near the tropics and in western Africa; damming, irrigation uptake and groundwater withdrawal are common modifiers. There is a huge number of smaller rivers discharging to estuarine and shelf areas. Land use pressures and change is a characteristic of the river catchments and with increasing population trends, changing and intensifying human resource uses and pockets of industrialisation, the region offers a tapestry for a diverse range of biogeochemical estuarine functions, patterns and changes. Comprehensive data and information on estuarine processes and coastal ecosystems are limited. While this situation often reflects limited effort and opportunity for research and measurement of these systems, much historical data has been dispersed (or lost) in transitions of countries in the Sub-Saharan region. Concerted effort is being made by scientists and governments, together with international agencies, to reclaim available information, to build and improve capacity and to initiate scientific study of ecosystems. This Workshop is a contribution to these efforts.

The Workshop was held at the Fisherman's Resort, Zanzibar on 12-14 September 2000. The terms of reference for the Workshop (Appendix IV) and a summary of activities (Appendix I) are contained in this report. The resource persons worked with Workshop participants (Appendix III) from five countries (Tanzania, Kenya, Cameroon, Guinea and South Africa) to develop and assess biogeochemical budgets for eleven coastal systems in the region, ranging from estuarine environments associated with large and small river catchments to large bays. Further site budgets are being developed at home institutions and through additional contact within the region initiated by workshop participants.

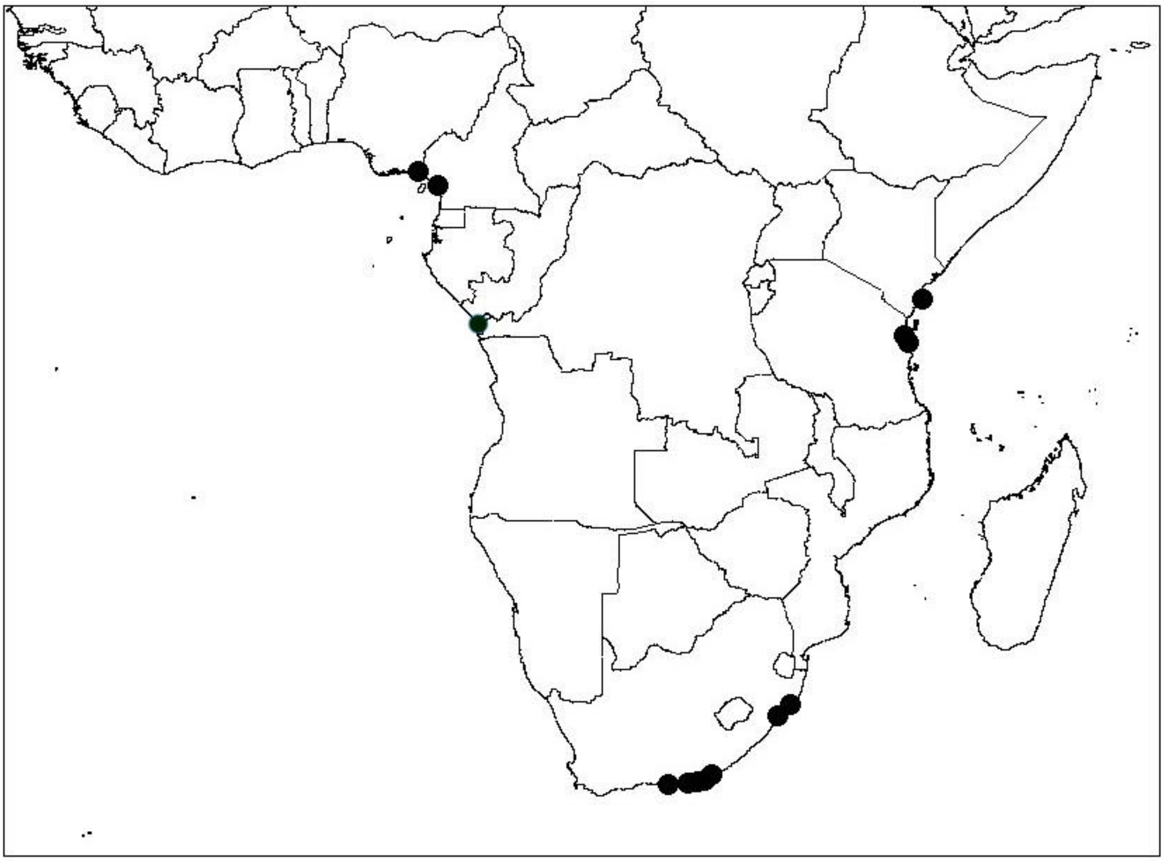

Figure 1.1 Map of budget sites developed by the sub-Saharan Africa regional workshop.

Dr Amani Ngusaru, Zanzibar Institute of Marine of Sciences, University of Dar es Salaam, will take up the LOICZ/UNEP Regional Training Scholarship (Africa) in early 2001, for additional training in budget analysis at the University of the Philippines (with the Regional Mentors) and at the University of Hawaii (with Professor Stephen Smith). Dr Howard Waldron (University of Cape Town) has accepted the role of Regional Mentor – Africa, and has planned a series of activities and network building in the region to expand both training and awareness in biogeochemical budgets development, and site budget derivations for the region.

The initial plenary session of the Workshop outlined the LOICZ approach to biogeochemical budget modelling of nutrient fluxes in estuaries, and described tools that have been developed for site assessment and budget derivations. Presentation of the CABARET software programme (for calculation of sites budgets and models) by Dr Laura David, added a further dimension to the tools and training elements. Up-scaling tools and approaches being developed and applied by LOICZ as part of the UNEP GEF project were described along with the planned agenda for regional and global integration by way of four workshops in 2001. The pivotal role of the LOICZ Budgets and Modelling electronic web-site was emphasised along with its use by global scientists in making budget contributions to the LOICZ purpose. In the web-site publication, contributing scientists are clearly attributed as authors of their budgets, and there is provision to update and provide additional assessment of their budgets.

The group moved from the plenary session to develop further the site budgets individually and in small working groups, returning to plenary sessions to discuss the budget developments and to debate points of approach and interpretation. Eleven budgets were developed during the Workshop (Figure 1.1, Table 1.1), with additional sites identified for future work.

The common element in the site descriptions is the use of the LOICZ approach for biogeochemical budget development, which allows for global comparisons and application of the typology approach. The differences in the descriptive presentations reflect the variability in richness of site data, the complexity of the sites and processes, and the extent of detailed process understanding for the sites. Support information for the various estuarine locations, describing the physical environmental conditions and related forcing functions including history and potential anthropogenic pressure, is an important part of the budgeting information for each site. These budgets, data and their wider availability in electronic form (CD-ROM, LOICZ web-site) will provide opportunities for further assessment, comparisons and potential use across wider scales of pattern assessment for system response and human pressures.

The biogeochemical budget information for each site is discussed individually and reported in units that are convenient for that system (either as daily or annual rates). To provide for an overview and ease of comparison, the key data are presented in an "annualised" form and nonconservative fluxes are reported per unit area (Tables 1.1 and 1.2).

Key outcomes and findings from the Workshop include:

1. Sites for which budgets and models were developed represent a range of locality and climatic settings including an array of small to large estuaries and coastal bays in monsoonal climates and austral temperature conditions. The nutrient models cover wet-dry seasonality and a range of land N and P input situations yielding budget descriptions for land-dominated and ocean-dominated systems; in some the dominance changes with season. Several of the budgets are partially developed (e.g., Chwaka Bay, Zanzibar; Knysna Estuary, South Africa) and, while further fieldwork will provide requisite data and information, this reflects the disparity in data and coastal system research in much of the region.

2. Dry – wet season net metabolic performance changes were shown in some cases, wherein values changed (e.g., Malindi Bay, Kenya) and sign changed (e.g., Rio del Rey, Cameroons; Kromme Estuary, South Africa). These changes reflected a combination of forcing from seasonal precipitation and the interactions of river flow/flushing with tides and ocean inputs affecting water residence times and nutrient loading.

3. Inner and outer estuaries often differed in their estimated net metabolic performance e.g., Knysna Lagoon, South Africa. Water exchange and mixing patterns undoubtedly influence these settings. The Congo River estuary provided an unusual case with the estuary being influenced by deep ocean waters and an apparent remineralisation zone associated with a continental shelf submarine canyon.

4. The estuarine and coastal sites exhibited an array of nutrient regimes, modified by waste discharges from population and land use and in several cases by water management (dams) of terrestrial inflows to the estuaries. Generally there were limited population inputs (see DIP/DIN loads as indicators) but clearly population effects were apparent.

LOICZ is grateful for the support and efforts of Dr Amani Ngusaru and the staff of the Zanzibar Institute of Marine Sciences in hosting the Workshop, and to the resource scientists for their contributions to the success of the Workshop. LOICZ particularly acknowledges the effort and work of the participants not only for their significant contributions to the workshop goals, but also for their continued interaction beyond the meeting activities.

The workshop and this report are contributions to the GEF-funded UNEP project: *The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles*, recently established

with LOICZ and contributing to the UNEP sub-programme: "Sustainable Management and Use of Natural Resources".

Table 1.1 **Budgeted regional sites for Sub-Saharan Africa - locations, system dimensions and water exchange times.**

System Name	**Long.** (E)	**Lat.** (S)	**Area** (km^2)	**Depth** (m)	**Exchange Time** (days)
Tanzania					
Chwaka Bay, Zanzibar	39.47	6.19	50	3	30
Makoba Bay, Zanzibar	39.22	5.92	15	5	63
Kenya					
Malindi Bay	40.15	3.2	18	2	3
Cameroon					
Cameroon estuarine system	9.70	3.90 (N)	2850	15	48-315
Rio-del-Rey system [a]	8.28	4.80 (N)	3300	14	38
Congo					
Congo (Zaire) River estuary [b]	12.30	6.05	241	6-260	2
South Africa					
Knysna River system	23.00	34.10	48	3	97
Kromme estuary	24.85	34.15	3	3	87
Gamtoos estuary	25.07	33.97	2	2	26
Swartkops estuary	25.63	32.87	4	3	34
Sundays estuary	25.42	33.72	3	4	42
Mhlathuze estuary	32.05	28.80	12	2	1-4
Thukela estuary	30.50	29.22	0.6	1.5	<1

a water exchange times show the range estimated for wet and dry seasons
b average depth: shallow estuary, 6m; deep canyon in outer estuary, 260m.

Table 1.2 Budgeted regional sites for sub-Saharan Africa - loads and estimated (*nfix-denit*) and (*p-r*).

System	DIP load	DIN load	*DDIP*	*DDIN*	(*nfix-denit*)	(*p-r*)
	mmol m^{-2} yr^{-1}					
Tanzania						
Chwaka Bay, Zanzibar[a]	7	37	+36	+584	0	-4000
Makoba Bay, Zanzibar[a]	27	117	-25	+730	+1100	+2550
Kenya						
Malindi Bay	1360	5200	-330	-585	+4380	+33200
Cameroon						
Cameroon estuarine system[e]	33	50	-7	+73	+146	$+730_p$ to $+7300_m$
Rio-del-Rey system[e]	18	21	+18	+330	+36	-1820_p to -18200_m
Congo						
Congo (Zaire) River estuary[f]	5450	42400	-2270	-31800	+4540	+240000
South Africa						
Knysna River estuary[b]	<1	1	+7	+26	-73	-730
Kromme estuary	<1	30	+7	+159	+73	-730
Gamtoos estuary	16	1265	-6	+199	+365	+730
Swartkops estuary	138	10800	-62	-10	-9125	+6570
Sundays estuary	12	1435	+5	-226	-329	-365
Mhlathuze Estuary[b,D]	<30	334	+3050 to +950	+6800 to +1850	-14600_p to -7300_m	-109500_p to $>-500000_m$
Thukela Estuary	1825	49275	+9125	242700	**c**	**c**

a annualised values estimated from budget developed for wet season only.
b annualised values estimated from budget developed for dry season only.
c system has a low exchange time and materials will probably behave conservatively, "jetting" through the estuary to the nearshore waters.
d DIP and DIN provide range of values, reflecting different water and mixing calculation.
e system metabolism values reflect use of phytoplankon or mangrove elemental ratios in stoichiometric estimates.
f deep ocean canyon intrusion and apparent remineralisation processes influence estimates.