ESTUARINE SYSTEMS OF THE LATIN AMERICAN REGION (Regional Workshop V) and ESTUARINE SYSTEMS OF THE ARCTIC REGION : CARBON, NITROGEN AND PHOSPHORUS FLUXES

by

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Cover: The cover shows an image of Latin America and an image of the Arctic region (GTOPO30 elevation maps), with the budgeted estuaries indicated.

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1. LATIN AMERICA - 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.

This Workshop and the resulting report are contributions to the GEF-funded UNEP project: *The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles*, established with LOICZ and contributing to the UNEP sub-programme: “Sustainable Management and Use of Natural Resources”.

This Workshop is the seventh in a series of regional activities within the project and derives from efforts by the LOICZ Regional Mentor (Latin America), Dr Victor Camacho-Ibar, Universidad Autónoma de Baja California (México), to extend training and scientific information development in estuarine processes in Latin America. It builds on interests, skills and a network of researchers established at three earlier regional workshops that addressed Mexican, Central American and South American biogeochemical budgets held in Ensenada (México) in June 1997 (LOICZ R&S 10, 1997), Mérida (México) in January 1999 (LOICZ R&S 13, 1999), and Bahía Blanca (Argentina) in November 1999 (LOICZ R&S 15, 2000).

In spite of the previous regional efforts, it was recognized that large sections of the South American coastal region were still under-represented with biogeochemical budgets (see http://data.ecology.su.se/MNODE/wmap.htm). For example, in the South American Atlantic coast, the region from 10.9 °S (northern Brazil) to 12.5 °N (northern Colombia) only included one budgeted site (Laguna Restinga, Venezuela), whereas in the Pacific coast, between 10°N and 45.4°S, there was only one complete (N and P) budgeted site (Aysen Sound, a fjord in southern Chile) and one incomplete (only P) budgeted site (Gulf of Guayaquil, Ecuador). As the LOICZ/UNEP Regional Synthesis Thematic Workshop for the Americas Region (29 April- 2 May, 2001) was approaching, it was decided to take advantage of its organization and to host a preceding “Budgets” workshop, with the participation of regional experts which could contribute both to a better regional coverage with budgeted sites and to the discussions in the regional synthesis effort.

The Workshop was held at the Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, México, 26-27 April 2001. A summary of activities (Appendix II) and the terms of reference for the Workshop (Appendix III) are contained in this report. The resource persons worked with Workshop participants (Appendix I) from four countries (Chile, Argentina, USA and Mexico), to develop and assess biogeochemical budgets for six coastal systems. This report contains final versions of budgets for four of these sites. Budgets for three sites in Brazil and two sites in México, contributed after the Workshop by other researchers from the region, are also included.

Figure 1.1 Map of Latin America showing estuaries for which budgets are presented in this report.

At the initial plenary session of the Workshop, Dr Victor Camacho-Ibar 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 site 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 by Dr Camacho-Ibar and Prof. Stephen Smith, along with an outline of the sequence of workshops and their outcomes. 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 and published reports, contributing scientists are clearly attributed as authors of their budgets, and there is provision to update and provide additional assessment of budgets through the web-site.

The group moved from the plenary session to one-on-one discussions between Workshop participants and resource persons in order to develop further the identified site budgets, returning to plenary sessions to discuss the budget developments and to debate points of approach and interpretation. Different degrees in progress of final versions of the budgets were achieved both before and during the Workshop.

- Dr Victor Rivera-Monroy reported data and calculations for Cienaga Grande de Santa Marta, a large coastal lagoon in Colombia for which his group has a multi-annual dataset, and committed to prepare N and P budgets for the Guayas River estuary, Ecuador, for which he has access to a multi-annual dataset.
- Dr Jorge Herrera reported on his review to the Celestún (México) lagoon system for which new data are available for better estimates of groundwater discharges and nutrient budgets. Based on recent surveys, Dr Herrera is revising groundwater discharge estimates for other coastal lagoons in Yucatán (i.e., Chelem, Ría Lagartos, Dzilam and Chetumal), however calculations and data analyses for these lagoons are still in progress and are not reported here.
- Dr Laura Farías presented data for Gulf of Arauco, located in the upwelling region of central Chile, providing a fruitful discussion on how to define boundaries to budget open coast type of bays.

- Dr Ramón Ahumada presented hydrographic data for Concepción Bay, central Chile, a coastal site also strongly influenced by upwelling; uncertainties on the estimation of water exchange between the bay and the ocean did not allow further progress on nutrient budget calculations.
- Dr Jorge Marcovecchio reported preliminary N and P budgets for Mar Chiquita lagoon, Argentina; however, a lack of site-specific precipitation and evaporation data is holding budget calculations from further advancement.

Authors were notified that all pending budgets not included in the printed version will be posted on the LOICZ web-site when finalised.

In addition to budgets prepared during the Workshop, N and P budgets for the Brazilian sites:

- Conceição Lagoon,
- Marapendi Lagoon and
- the Mundau-Manguaba lagoonal system

were presented by Mr Weber Friedrichs Landim de Souza and Prof. B. Knoppers from Universidade Federal Fluminense in Rio de Janeiro, Brazil. These budgets were largely prepared by Mr Landim de Souza during training in budget analyses with Dr Camacho-Ibar; this training took place in Ensenada, México, in September 2000 under a LOICZ/UNEP Regional Training Scholarship (South America).

N and P budgets for Las Guásimas coastal lagoon were submitted by Mr Gustavo Padilla-Arredondo, Mr José A. Arreola-Lizárraga and Dr Carlos Lechuga-Devéze. Mr Padilla-Arredondo and Mr Arreola-Lizárraga attended the course "Introduction to LOICZ Biogeochemical Modelling" taught by Dr Camacho-Ibar in La Paz, México (10-12 April 2000) with financial support from LOICZ/UNEP.

A revision of the budget for Estero de Punta Banda, México, was reported by Dr Martín Hernández-Ayón and colleagues, showing that groundwater inputs of freshwater may be important for the water balance in this coastal lagoon.

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 reported here reflect the variability in richness of site data, the complexity of 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 regional and global assessment, comparisons and potential use in evaluating patterns of coastal system responses to human pressures.

The biogeochemical budget information for sites shown in Figure 1.1, 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).

The overall conclusion from the reported budgets is that the estuarine systems exhibit a wide range in size, N and P loads, metabolic performance and human impact. Marapendi Lagoon, the smallest of the systems, showed the highest water exchange time. In contrast, Cienaga Grande de Santa Marta, with an area more than two orders of magnitude larger than Marapendi, showed water exchange times of only 6-17 days. Celestún Lagoon showed an annual N loading of 746 mmol m^{-2} yr^{-1}, a value close to the mean for the ten systems (Table 1.2), but essentially received no P loading, while the mean P loading was 84 mmol m^{-2} yr^{-1}. The Gulf of Arauco showed the highest net autotrophic condition and the highest net N-fixing value, whereas Marapendi also showed a highly autotrophic condition but was the system with the highest net apparent denitrification value. These contrasting observations result from a complex interaction of climate, physiographic and oceanographic conditions, human pressures and other variables.

Table 1.1 Budgeted regional sites for Latin America - locations, system dimensions and water exchange times.

System Name	Long. (W)	Lat. (+N) (-S)	Area (km^2)	Depth (m)	Exchange time (days)
Colombia					
Cienaga Grande de Santa Marta[a]	74.42	10.98	450	1.5	10
- Dry season					17
- Rainy season					6
Ecuador					
Guayas River estuary[a, b]	80.00	-2.63	267	10	9
- Dry season					9
- Rainy season					8
Chile					
Gulf of Arauco (March 1991)	73.40	-37.00	400	30	20
Gulf of Arauco (August 1991)	73.40	-37.00	818	30	55
Brazil					
Conceição Lagoon[a]	48.45	-27.57	19.6	2.3	108
Marapendi Lagoon[a]	43.40	-23.02	3.3	1.8	280
Mundau Lagoon[a]	35.85	-9.68	24	1.5	7
Manguaba Lagoon[a]	35.85	-9.68	43	1.9	61
México					
Celestún Lagoon[a, b]	90.25	20.75	19	1.2	9
- Nortes season					19
- Dry season					11
- Rainy season					6
Las Guásimas Lagoon (spring)	110.59	27.87	37	0.7	10
Las Guásimas Lagoon (summer)	110.59	27.87	37	0.7	3
Estero de Punta Banda[a, b]	116.62	31.77	10.3	1.5	2
- Dry season (Sep 92)					1
- Rainy season (Mar 93)					3
Number of sites	10	10	10	10	10
Mean			127	5	48[c]
Std dev.			175	9	80[c]
Median			31	2	10[c]
Minimum			3	1	2[c]
Maximum			818	30	280[c]

a - annualised value
b - updated or revised budget
c – only annualised budgets included in the calculations, except for Gulf of Arauco and Las Guasimas for which seasonal data were used as annualised estimates are not available.

Table 1.2 Budgeted regional sites for Latin America - loads and estimated *(nfix-denit)* and *(p-r)*.

System	**DIP load**	**DIN load**	**ΔDIP**	**ΔDIN**	***(nfix-denit)***	***(p-r)***
	mmol m^{-2} yr^{-1}					
Colombia						
Cienaga Grande de Santa Marta[a]	20	67	-4	37	110	365
- Dry season	8	41	0	-4	-11	-110
- Rainy season	36	103	-11	95	256	1095
Ecuador						
Guayas River estuary[a, b]	189	1871	73	-913	-1900	-6200
- Dry season	118	897	146	73	-2263	-15330
- Rainy season	331	3821	-110	-2884	-1132	11680
Chile						
Gulf of Arauco (March 1991)	1	547	-475	-4161	3285	50370
Gulf of Arauco (August 1991)	2	435	-183	-1752	1095	19345
Brazil						
Conceição Lagoon[a]	15	136	-15	-146	88	1548
Marapendi Lagoon[a]	343	3031	-329	-2957	-2446	35770
Mundau Lagoon[a]	259	2342	-183	-1789	584	16060
Manguaba Lagoon[a]	76	577	-110	-511	438	6205
México						
Celestún Lagoon[a, b]	0	746	15	-402	-621	-1460
- Nortes season	1	519	18	-365	-657	-1825
- Dry season	0	307	0	-219	-219	-37
- Rainy season	0	1191	22	-511	-876	-2190
Las Guásimas lagoon (spring)	0	0	11	-1	-146	-1095
Las Guásimas lagoon (summer)	0	0	7	62	-37	-730
Estero de Punta Banda[a, b]	103	457	62	-294	-1278	-6570
- Dry season (September 1992)	39	298	110	-197	-1935	-11680
- Rainy season (March 1993)	167	617	15	-391	-621	-1460
Number of sites	10	10	10	10	10	10
Mean[c]	84	851	-94	-1069	-69	9467
Std dev.[c]	118	1004	170	1348	1481	17837
Median[c]	18	502	-10	-457	26	957
Minimum[c]	0	0	-475	-4161	-2446	-6570
Maximum[c]	343	3031	73	62	3285	50370

a – annualised values

b – updated or revised budget

c – only annualised budgets included in the calculations, except for Gulf of Arauco and Las Guásimas for which seasonal data were used, as annualised estimates are not available.

LOICZ is grateful for the support and efforts of Dr Victor Camacho-Ibar and the staff of the Universidad Autónoma de Baja California in Ensenada in hosting the Workshop and to the resource scientists for their contributions to the success of the Workshop. LOICZ particularly acknowledges the efforts of the participants not only for their contributed work, but also for their continued interaction beyond the meeting activities.

2. COASTAL SYSTEMS OF MEXICO

2.1 Estero de Punta Banda, Baja California, México (a revision)

J.M. Hernández-Ayón, V.F. Camacho-Ibar and M.G. Galindo-Bect

This budget is an update of an earlier budget for dissolved inorganic nitrogen and phosphorus for the Estero de Punta Banda under summer conditions (see Poumian-Tapia *et al.* 1997; see also http://data.ecology.su.se/MNODE/mexicanlagoons/epb.htm). The original budget only considered summer conditions. The earlier budget determined that Estero de Punta Banda is a net source of DIP (ΔDIP = +0.13 mmol m^{-2} day^{-1}), net heterotrophic ($p\text{-}r$ = -14 mmol m^{-2} day^{-1}), and a net denitrifying ($nfix\text{-}denit$ = -2.1 mmol m^{-2} day^{-1}) system. However, these calculations were based on nutrient data collected in September 1992, a period under the influence of an ENSO event (see Galindo-Bect *et al.* 1999), whereas salinity data were obtained from studies prior to 1992 carried out under non ENSO conditions, when Estero de Punta Banda is typically a hypersaline system during summer. Galindo-Bect *et al.* (1999) reported that salinities in September 1992, which corresponded to the nutrient data set used by Poumian-Tapia *et al.* (1997), were as low as 29 psu in the middle portion of the lagoon during low tide. The lack of surficial runoff suggests these low salinities were due to the input of groundwater.

This budget presents the DIP and DIN budgets for the Estero de Punta Banda using nutrient and salinity data for September 1992 reported by Galindo-Bect *et al.* (1999). Budgets are also presented for March 1993. Due to the lack of groundwater (V_G) and surficial runoff (V_Q) data, and the potential importance of these fluxes in the budgetary calculations, we followed the approaches indicated below to get our best estimate of these quantities.

Study area description

Details of the study area have been described in Poumian-Tapia *et al.* (1997).

Briefly, the estuary is located 12 km south of Ensenada in the Maneadero Valley (31° N, 116° W; see Figure 2.1). The estuary receives input from the San Carlos and Las Animas rivers only during wet winters. Evaporation exceeds precipitation, so the system functions as a negative estuary, with salinity increasing from the mouth to the head. The estuary covers an area of 12 km^2, mean depth is about 2 m, system volume is 24×10^6 m^3. Salt marshes, the dominant vegetation, cover about 3 km^2. Agriculture, cattle raising and tourism are the main activities in the surrounding region.

Figure 2.1. Location and map of Estero de Punta Banda.

Samples for nutrient and salinity analyses were obtained at four sites within the system during spring tides under flow and ebb conditions. Samplings were carried out during two seasons, one with the absence (September 1992) and one with the presence (March 1993) of surficial freshwater runoff (Galindo-Bect. *et al.* 1999). The mean salinity and nutrient concentrations used in our budget calculations (Table 2.1) were obtained by weighing by volume data from each sampling site. No NH_4^+ data were available during these samplings, so the DIN term in our calculations only include NO_3^- + NO_2^-. The average depth of the system was 1.5 m. The average precipitation during summer 1992 was 0 mm month^{-1} and during winter 1993 was 71 mm month^{-1}. Evaporation was 127 mm month^{-1} for summer 1992 and 73 mm month^{-1} for winter 1993 (data from Comisión Nacional del Agua).

Table 2.1. Chemical composition of Estero de Punta Banda and terrestrial inputs.

	Ocean	System	Groundwater	Runoff
Area (10^6 m^2)		10.3		
Volume (10^6 m^3)		15.5		
Summer				
V_G (10^3 m^3 day^{-1})			280	
V_O (10^3 m^3 day^{-1})				0
Salinity	33.4	32.8	0.0	-
DIP (mmol m^{-3})	0.7	1.0	4.0*	-
DIN (mmol m^{-3})**	0.6	0.8	30*	-
Winter				
V_G (10^3 m^3 day^{-1})			280	-
V_O (10^3 m^3 day^{-1})			-	900
Salinity	33.2	24.0	0.0	0.0
DIP (mmol m^{-3})	1.1	2.0	4*	4
DIN (mmol m^{-3})	1.4	2.5	30*	10

* From Camacho-Ibar *et al.* (unpublished results)

** DIN = NO_3^- + NO_2^-; no NH_4^+ data were available.

Water and salt budgets for September 1992

There are no previous estimates of groundwater discharge (V_G) into Estero de Punta Banda. We therefore made a rough estimate of this flow by: a) dividing the system into 4 sections; b) estimating the salinity that would be expected in each section under "typical" hypersaline conditions - i.e., salinity typically increases linearly with distance from the mouth (de la Paz-Vela 1978); c) estimating the volume of freshwater required to dilute each section in order to obtain the observed salinity; and d) adding-up the volumes for each section and multiplying the result by 0.6, as the tidal prism during spring tides is about 60% of the volume of the system (de la Paz-Vela 1978; Pritchard *et al.* 1978). The estimated V_G obtained with this approach was 280x10^3 m^3 day^{-1}.

To get another estimate of the magnitude of V_G, we calculated the mixing term (V_X) by following the non-budgetary approach recommended by Yanagi (2000; see also http://data.ecology.su.se/MNODE/Methods/YanagiMixing/Yanagi.htm). The equation we used was that for a "wide and shallow" system. The estimated V_X value (6,300x10^3 m^3 day^{-1}) was then used to back-calculate V_R and finally V_G using the LOICZ formulas for water and salt budgets. The resulting V_G was ~140x10^3 m^3 day^{-1}.

Figure 2.2 shows the results of the water and salt budgets. These results show that in terms of the water budget, the groundwater flux becomes the most relevant term, controlling the magnitude of the residual flow V_R. The V_X value of 13,500x10^3 m^3 day^{-1} was more than twice the V_X value obtained with Yanagi's approach. The water exchange time was ~1 day with a V_G = 280x10^3 m^3 day^{-1}, and ~3 days with a V_G = 140x10^3 m^3 day^{-1}. These values are significantly lower than the value of 11 days reported by Poumian-Tapia *et al.* (1997).

Water and salt budgets for March 1993

Freshwater runoff estimates are not available for the study area, so we estimated the freshwater discharge from Arroyo San Carlos and Arroyo Las Animas (V_Q) during March 1993 by using the empirical relationship reported by David *et al.* (in press; see also http://data.ecology.su.se/MNODE/Methods/runoff.htm):

$V_Q = 1000 \text{ A r}[\exp(-e_0/r)]$

where: $e_0 = 1.0 * 10^9 \exp(4.62*10^3/T)$; V_Q is monthly runoff (m^3); T is monthly air temperature (in Kelvin degrees); A is the watershed area (in km^2) and r is precipitation (in mm per month). The areas for Arroyo San Carlos and Arroyo Las Animas were 736 and 810 km^2 respectively (Avila-Serrano 1985), the monthly air temperature was 13°C (286.15°F) and the monthly precipitation was 71 mm. The estimated runoff was $900x10^3$ m^3 day^{-1}.

In the water budget calculations for March 1993 (Figure 2.2) we assumed a V_G value similar to that calculated for September 1992. The residual flow V_R ($-1{,}200x10^3$ m^3 day^{-1}) was about 5 times higher than the summer value due to the influence of surficial freshwater inputs. However, V_X was $3{,}700x10^3$ m^3 day^{-1}, about half the value obtained with Yanagi's method and about one third of the V_X obtained for September 1992. Consequently, the residence time during winter was higher (3 days) than in summer.

Budgets of nonconservative materials

The *ΔDIP* value for September 1992 was +3,130 mol day^{-1} when using the high V_G estimate, and +1,250 mol day^{-1} when using the lower estimate. The latter estimate is similar to the value of +1,600 mol day^{-1} reported by Poumian-Tapia *et al.* (1997), and our higher estimate is only twice this value. The (*p-r*) values derived from these data are -32, -13 and -16 mmol m^2 day^{-1} supporting the conclusion by Poumian-Tapia *et al.* (1997) that the Estero de Punta Banda is a net heterotrophic system during the summer. The fact that the inclusion of groundwater inputs significantly modify the water exchange time, but do not significantly affect the nonconservative behavior of DIP, indicates that internal processes and the exchange of DIP with the ocean are dominant.

Table 2.2 shows that in contrast with *ΔDIP*, *ΔDIN* results in our calculations (-5,540 and -2,980 mol day^{-1}) had a different sign than the value (+3,650 mol day^{-1}) previously reported (Poumian-Tapia *et al.* 1997). This difference is due to the lack of groundwater DIN inputs in the earlier budget calculations. In spite of this difference in *ΔDIN*, our calculations confirm that Estero de Punta Banda is a net denitrifying system, as concluded by Poumian-Tapia *et al.* (1997).

Table 2.2. Nonconservative nutrient fluxes and stoichiometric calculations (in mmol m^{-2} day^{-1}) for September 1992 under different groundwater fluxes (10^3 m^3 day^{-1}) and March 1993.

	September 1992			**March 1993**
	$V_G = 280$	$V_G = 140$	Poumian *et al.* (1997)	$V_G = 280$
ΔDIP	+0.30	+0.12	+0.15	+0.04
ΔDIN	-0.54	-0.29	+0.04	-1.07
(nfix-denit)	-5.3	-2.2	-2.4	-1.7
(p-r)	-32	-13	-16	-4
τ(days)	1	3	11	3

Table 2.2 shows that the estimated (*p-r*) and (*nfix-denit*) values calculated considering a $V_G = 140x10^3$ m^3 day^{-1} were 2.5 times lower than those estimated with a $V_G = 280x10^3$ m^3 day^{-1}. These results indicate that the accurate value of (*p-r*) and (*nfix-denit*) is dependent on an accurate estimate of V_G. A sensitivity analysis showed that these parameters do not change significantly when the concentrations of

DIP and DIN in groundwater are modified, when compared with variations of the same magnitude in the value of V_G.

Nonconservative DIP flux (*ΔDIP*) for March 1993 was +453 mol day^{-1}, nearly one order of magnitude lower than the value for September 1992 (Table 2.2). The (*p-r*) value derived from this *ΔDIP* was -4 mmol m^2 day^{-1} indicating that *p* and *r* are nearly in balance during winter. It is interesting to notice that similar summer-winter fluctuations have been was reported for San Quintin Bay (from -20 to -2 mmol m^{-2} day^{-1}: Camacho-Ibar *et al.* 1997) and for Tomales Bay (from ~-20 to 0 mmol m^{-2} day^{-1}: Smith and Hollibaugh 1997). This similarity probably reflects the strong control of the system-ocean interactions on the seasonal variations in net ecosystem metabolism of the Mediterranean-type coastal lagoons neighboring the California Current coastal upwelling region (see Smith and Hollibaugh 1997).

A sensitivity analysis showed that our *ΔDIP* (and thus [*p-r*]) determinations for March 1993 are only marginally affected by variations on the V_G and V_Q terms. However, *ΔDIP* is very sensitive to small variations in the concentration of DIP in the riverine end-member. For example, a shift in DIP_Q from 4 to 5 mmol m^{-3} caused a shift in (*p-r*) from -4 to +5 mmol m^{-2} day^{-1}, whereas a decrease from 4 to 3 mmol m^{-3} caused a shift to from -4 to -13 mmol m^{-2} day^{-1}.

Nonconservative DIN flux (*ΔDIN*) in winter (-11,000 mol day^{-1}) was 2-3 times higher than the summer estimates (Table 2.2). This is consistent with the observation for other coastal ecosystems, in that the larger the terrestrial DIN loading (17,400 and 8,400 mol day^{-1} for winter and summer, respectively), the higher the assimilation by the system (see Figure 3). As in the case of summer, our calculations indicate that Estero de Punta Banda is a net denitrifying system (Table 2.2).

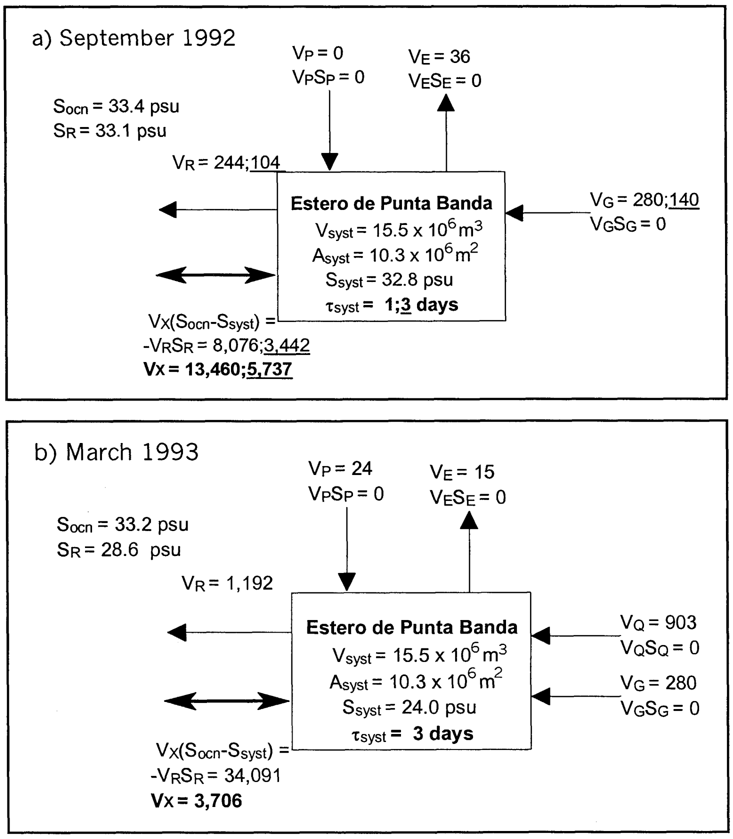


Figure 2.2. Water and salt budgets for Estero de Punta Banda, during September 1992 (summer) and March 1993 (winter). Water flux in 10^3 m^3 day^{-1} and salt flux in 10^3 psu-m^3 day^{-1}. Underlined values for September 1992 represent calculations based on a Vg = 140,000 m^3 day^{-1}.

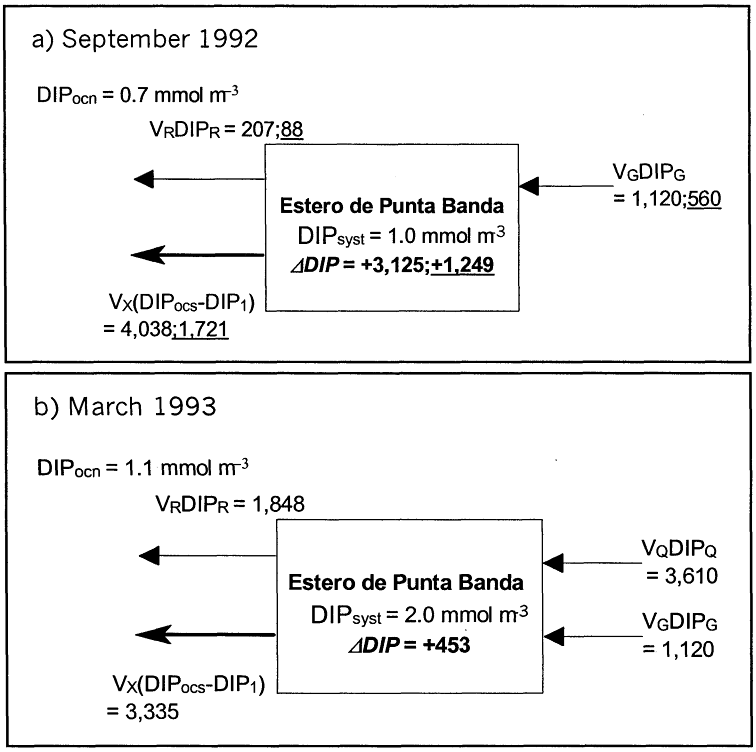


Figure 2.3. DIP budget for Estero de Punta Banda in September 1992 and March 1993. Flux in mol day^{-1}. Underlined values for September 1992 represent calculations based on a Vg = 140,000 m^3 day^{-1}.

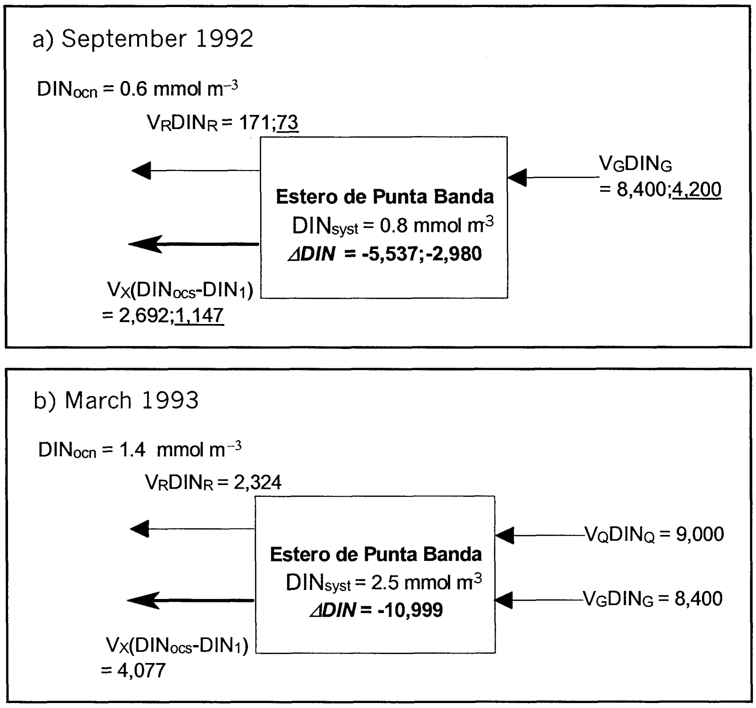


Figure 2.4. DIN budget for Estero de Punta Banda in September 1992 and March 1993. Flux in mol day^{-1}. Underlined values for September 1992 represent calculations based on a Vg = 140,000 m^3 day^{-1}.

2.2 Las Guásimas coastal lagoon, Sonora

Gustavo Padilla-Arredondo, José A Arreola-Lizárraga. and Carlos H. Lechuga-Devéze

Study area description

Las Guásimas is a coastal lagoon located on the east coast of the Gulf of California (27.82° - 27.92°N and 110.48° - 110.75°W), Mexico; it has a surface area of 37 km^2, an average water depth of 0.7 m and a 2 km long mouth that is permanently open to the sea (Figure 2.5). It is influenced by a type- BW (h′) W (e′) climate, i.e. dry-desert with a mean temperature of 22°C and a range of 14°C during the year (García 1973). From October to March, there are frequent 3 to 6-day windy spells of prevailing north-westerly winds with velocities of 8-10 m sec^{-1}; from June until September, the prevailing winds are from the south-east with average velocities of 2-5 m sec^{-1}, but with shorter windy spells (Alvarez-Borrego 1983; Badan-Dangon *et al.* 1985). Based on Kjerfve (1986), Las Guásimas can be classified as a "restricted" coastal lagoon, as it is permanently open to the sea by means of a wide mouth, has well-defined tidal circulation, is strongly influenced by winds, and is well-mixed vertically. Typical coastal vegetation surrounding the lagoon consists of halophytes, mangrove and that characteristic of coastal dunes.

This lagoon is hypersaline as evaporation (2,982 mm $year^{-1}$) exceeds precipitation (290 mm $year^{-1}$) and runoff is a minor component of the fresh water balance. The surface water temperature and salinity range throughout the year from 14-33°C and 34-37 psu, respectively, and the tide is mixed diurnal, with an average amplitude of 0.8 m. There are no additional sources of water discharge to the lagoon. Human population in this area is lower than 500 people and fishing is the predominant activity.

Water from the lagoon was collected during April-May (spring) and August-September (summer) 2000. Mean salinity and nutrient concentrations (Table 2.3) were determined from 12 stations at the interior of bay and 2 stations at the mouth as reference (Figure 2.5). In addition, aquatic primary productivity was determined at two points within the lagoon and one station in the adjacent sea. Inorganic dissolved nutrients (NO_2^-, NO_3^-, NH_4^+, PO_4^{2-}) were determined through standard colorimetric techniques.

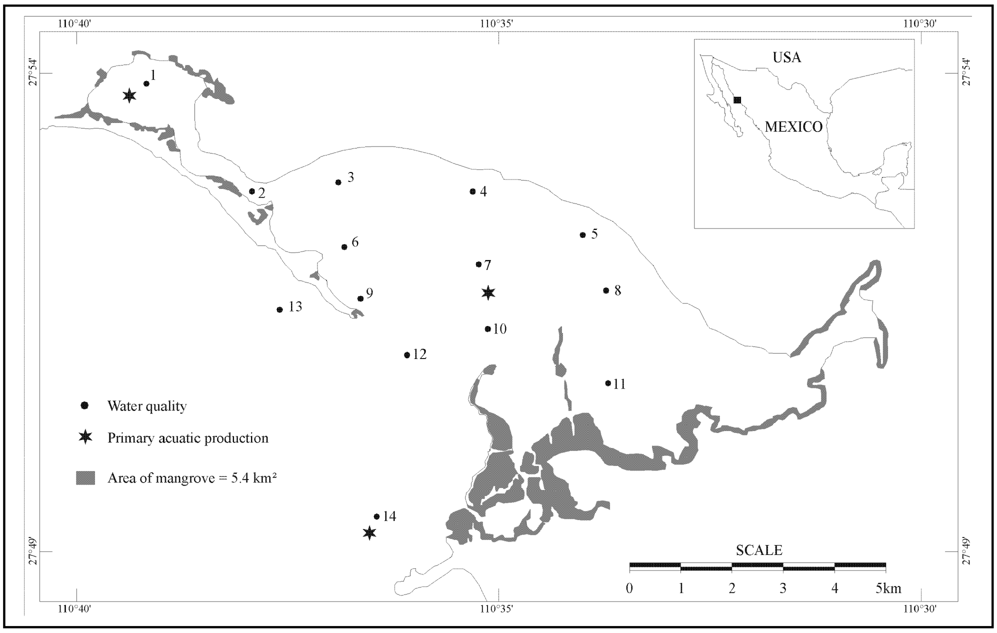


Figure 2.5. Location and map of Las Guásimas coastal lagoon, Sonora, Mexico.

Water and salt balance

The water budgets based on a single-box model (Figure 2.6) showed a positive and similar residual flow during both spring (270x10^3 m^3 day^{-1}) and summer (220x10^3 m^3 day^{-1}) as evaporation largely exceeds precipitation and other freshwater inputs in both seasons. In contrast, the mixing term V_X during summer (8,000x10^3 m^3 day^{-1}) was almost 4 times larger than during spring (2,200x10^3 m^3 day^{-1}). The latter difference resulted in a difference in the water exchange time which was of 10 days in spring and 3 days in summer. Our results contrast with those reported by Urías-Laborín *et al.* (2000) who made a calculation of water exchange times of 1 day for summer and 2 days for spring, based on estimates of the tidal prism. The reason for this discrepancy is not clear.

Table 2.3. Average nutrient concentrations and salinity during spring and summer 2000.

System	$NO_2^-+NO_3^-$	NH_4^+	DIP	DIN	Salinity
	(mmol m^{-3})	(mmol m^{-3})	(mmol m^{-3})	(mmol m^{-3})	psu
Spring					
Lagoon	0.2±0.2	0.3±0.3	0.9±0.6	0.5±0.5	41.3±2.9
Ocean	0.2±0.3	0.3±0.2	0.4±0.2	0.5±0.3	36.5±0.4
Summer					
Lagoon	0.9±1.4	0.6±0.5	0.9±0.4	1.5±1.5	36.0±3.4
Ocean	0.2±0.2	0.3±0.2	0.8±0.1	0.7±0.4	35.0±0.6

Budgets of nonconservative materials

DIP balance

During spring DIP was higher in the system than in the ocean. The positive value of *DI P* in spring (+0.03 mmol m^2 day^{-1}) indicates that there is a net source of DIP within Las Guasimas. If desorption of DIP from particles does not contribute significantly as a source of DIP, the positive *DI P* reflects that organic matter degradation exceeds primary production within the lagoon. *D IP* during summer (Figure 2.7) was also positive (+0.02 mmol m^2 day^{-1}) but smaller than in spring. During spring the system exports 1,100 mol day^{-1} of DIP and during summer the export was of 790 mol day^{-1}.

DIN balance

The *DIN* during spring was relatively small and negative (-0.004 mmol m^2 day^{-1}) indicating that the system was a net DIN sink (140 mol day^{-1}), whereas in summer it was positive (+0.17 mmol m^2 day^{-1}) indicating an export of DIN from the bay to the ocean of 6,100 mol day^{-1} (Figure 2.8).

Stoichiometric calculations of aspects of net system metabolism

Based on the formula (*nfix-denit*)= (DIN_{obs})- (DIN_{exp}) = ($D\,IN_{obs}$- (N:P)$_{part}$ x (*DI P*)) and assuming a Redfield N:P stoichiometry of 16:1, the (*nfix-denit*) estimate for each season was:

Spring 2000: -14,900 mol day^{-1} (-0.4 mmol m^2 day^{-1})
Summer 2000: -3,600 mol day^{-1} (-0.1 mmol m^2 day^{-1})

These results indicate that Las Guásimas coastal lagoon is a net denitrifying system during spring and summer.

A Redfield C:P ratio of 106:1 was also assumed for the estimate of the net metabolism of the system (NEM= [*p-r*]) through the formula (*p-r*)= - ΔDIP x (C: P)$_{part}$. The NEM estimates were:

Spring 2000: -98,050 mol day^{-1} (-2.7 mmol m^{-2} day^{-1}).
Summer 2000: -64,130 mol day^{-1} (-1.7 mmol m^{-2} day^{-1}).

These results indicate that Las Guásimas coastal lagoon is a slightly net heterotrophic system during spring and summer.

The aquatic primary productivity (*p*) measured in spring and summer was 40 and 74 mmol C m^{-2} day^{-1}, respectively. Therefore, as NEM was +3 mmol C m^{-2} day^{-1}, and assuming that phytoplankton is the main source of carbon fixation in the system, the estimated community respiration for the system is ~43 mmol C m^{-2} d^{-1} and the p/r ratio 0.93. In summer the estimated community respiration was ~76 mmol C m^{-2} day^{-1} and the p/r ratio was 0.97. In other words, our data suggest that the system consumes about 7% more organic matter than it produces in spring and about 3% in the summer.

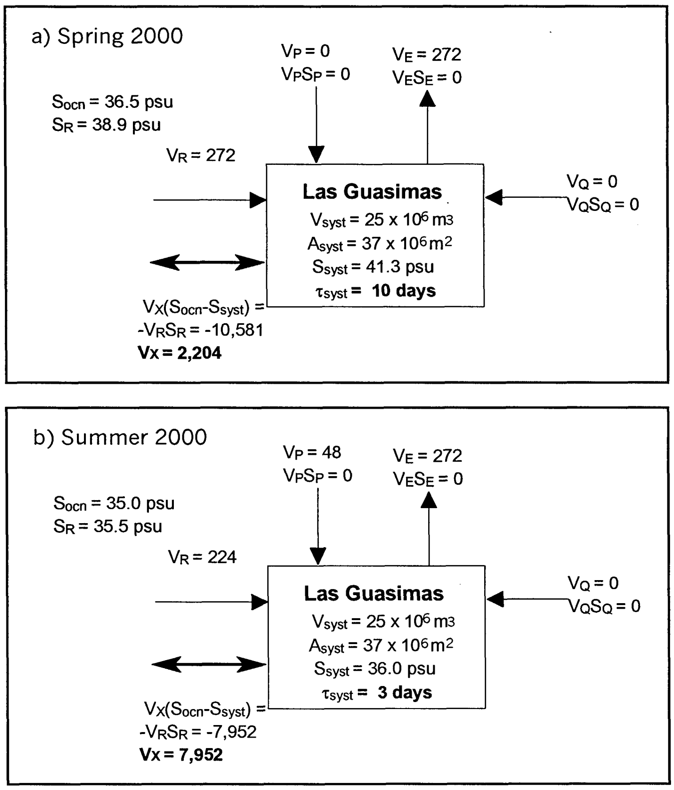


Figure 2.6. Water and salt budgets for Las Guásimas coastal lagoon in spring (a) and summer (b) 2000. Water flux in 10^3 m^3 day^{-1} and salt flux in 10^3 psu-m^3 day^{-1}.

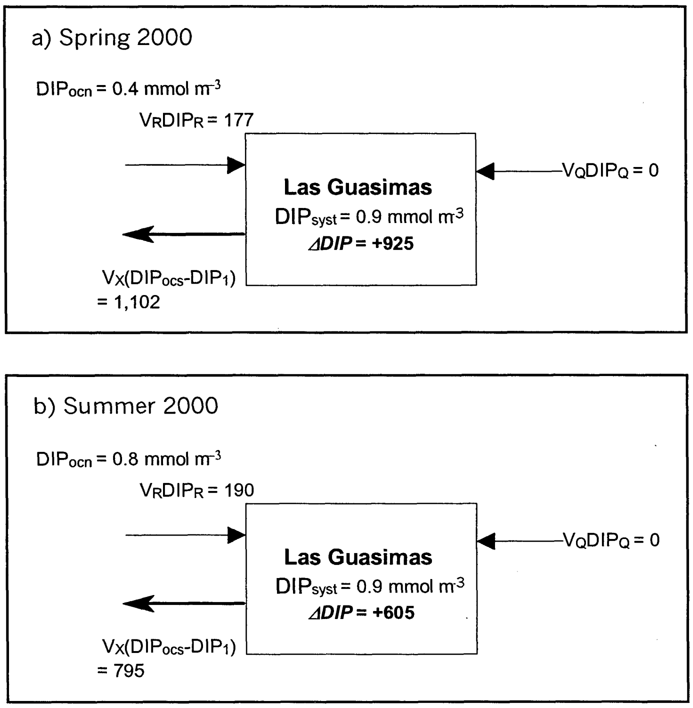


Figure 2.7. DIP budget for Las Guásimas coastal lagoon in spring (a) and summer (b) 2000. Flux in mol day^{-1}.

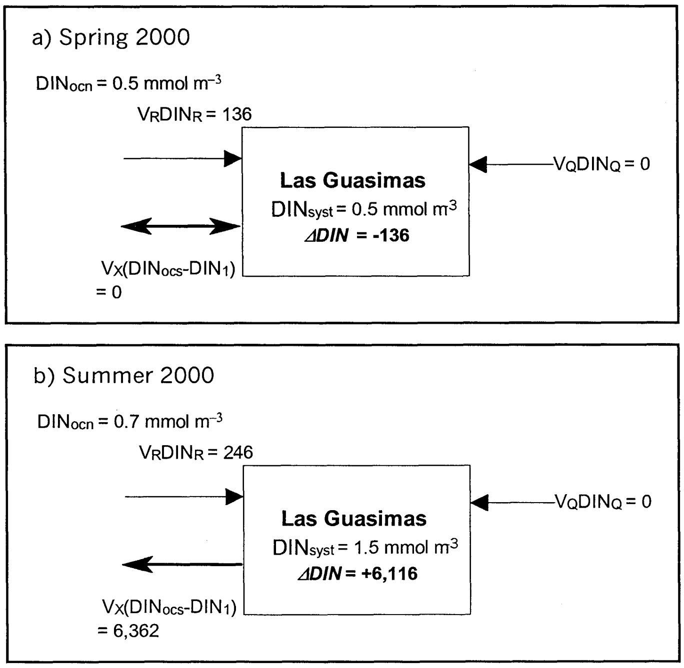


Figure 2.8. DIN budget for Las Guásimas coastal lagoon in spring (a) and summer (b) 2000. Flux in mol day^{-1}.

2.3 Celestún Lagoon, Yucatán (a revision)

Israel Medina Gómez and Jorge Herrera Silveira

A previous LOICZ budget for Celestun Lagoon with seasonal data from a survey carried out in 1994 was reported by Herrera-Silveira *et al.* (1999; see also http://data.ecology.su.se/MNODE/mexicanlagoons/celestun.htm).

In the earlier budget, Celestun Lagoon was divided into three compartments (inner, middle and outer lagoon) and budgets of each of the compartment were developed. In the present budgetary analysis, only budgets for each of the inner and middle compartments were developed and the outer lagoon was treated as the adjacent ocean. In this budget, salinity and nutrient concentrations for each season (Table 2.4) represent mean values obtained from seasonal data between 1990-1999; seasonal data for each year were obtained from monthly surveys. Furthermore, whereas Herrera-Silveira *et al.* (1999) assigned all of the estimated groundwater discharges for the whole lagoon to the inner box, a more complete salinity and silicate data set allowed us to estimate groundwater inputs to each of the boxes. Water, salt and nutrient budgets presented hereby may, therefore, better represent the hydrological and biogeochemical behavior of Celestun Lagoon.

Study area description

Celestun Lagoon is a shallow (0.5-3 m) coastal lagoon located on the western shore of the Yucatan Peninsula (20.75°N, 90.25°W; Figure 2.9) with its main axis parallel to the coastline. Communication with the sea is through a 400 m wide mouth in the southern zone. The tidal channel, a major topographic feature, is only about 20 m wide and extends from the mouth of the lagoon to 12 km beyond the outer zone of the system. The surface area of the whole lagoon is 28 km^2 and the volume is 34x10^6 m^3. The budgeted area and volume of the lagoon presented in this paper are 11 km^2 and 13x10^6 m^3 for the inner lagoon and 8 km^2 and 10x10^6 m^3 for the middle lagoon, respectively.

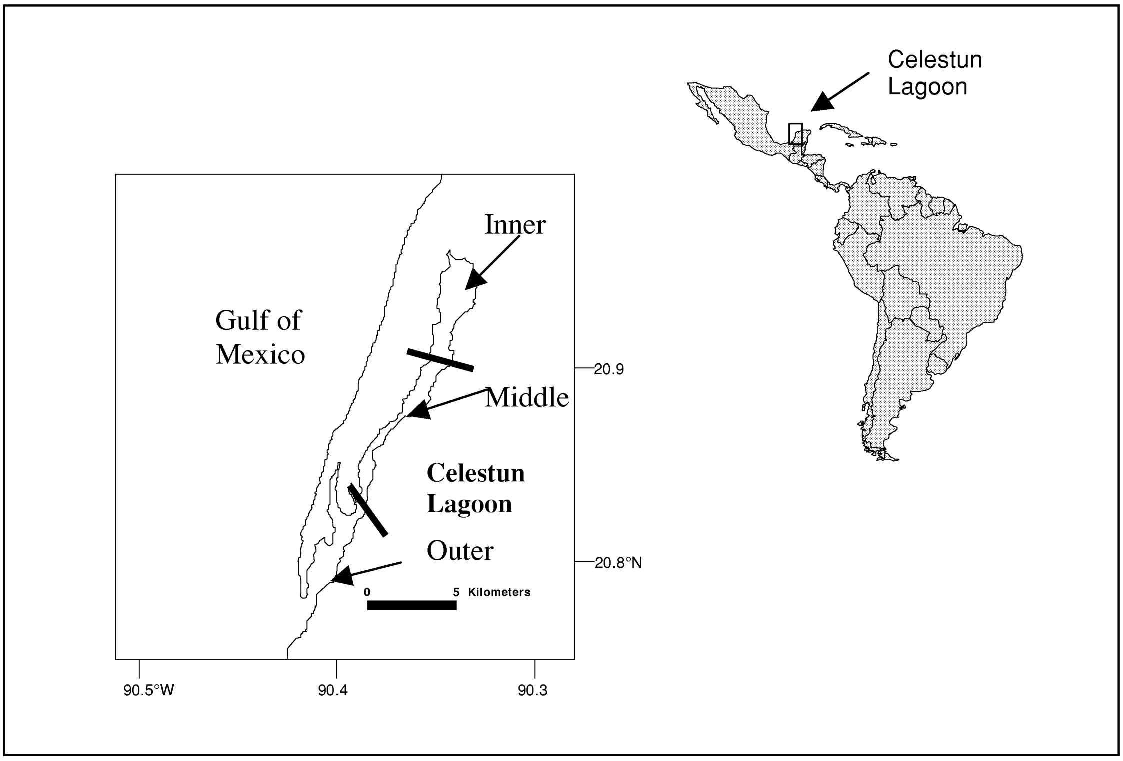


Figure 2.9. Location and map of Celestun Lagoon, Yucatan.

The Yucatan Peninsula coastal region is karstic and highly permeable, with no rivers. Freshwater inputs to the lagoon are represented mostly by groundwater discharges or springs largely near the head of the lagoon. The weather in the coastal zone is characterized by an annual mean temperature of 26°C, fluctuating between 20°C in January to 35°C in May. The mean annual rainfall is 750 mm and evaporation is 1,400 mm. Three climatic seasons are recognized in the coastal zone of the Yucatan Peninsula: the *nortes* season (November-February), characterized by strong winds (>80 km h^{-1}), little rainfall (20-60 mm) and low air temperatures (<22°C), induced by low pressure air masses from the north constituting cold fronts that strongly influence temperature of aquatic ecosystems; the dry season (March-May), with low rainfall, high evaporation and elevated air temperatures; and the rainy season (June-October), with rainfall >500 mm. The annual rainfall-evaporation balance is negative, but is small relative to the estimated groundwater flow.

The shores of the lagoon are covered by fringe mangrove forests *(Rhizophora mangle, Avicennia germinans, Languncularia racemosa, Conocarpus erectus)*. Submerged aquatic vegetation is composed of macroalgae species as *Chara fibrosa, Batophora oerstedi, Chaetomorpha linum*, and seagrasses such as *Ruppia sp*, and *Halodule wrightii.*

Multivariate classification analysis of the hydrology of Celestun Lagoon (Herrera-Silveira 1994) showed that spatial heterogeneity defined three hydrologic affinity zones:

- Inner zone, strongly influenced by groundwater discharges.
- Middle zone, where mixing of freshwater and seawater takes place.
- Seaward zone, where the interchange between lagoon and ocean occurs.

Table 2.4. Chemical composition of Celestún Lagoon.

	Inner	**Middle**	**Outer**	**Groundwater**
Area (10^6 m^2)	11	-8	9	
Volume (10^6 m^3)	13	10	10	
***Nortes* Season**				
Salinity (psu)	22	25	32	6
Phosphate (mmol m^{-3})	2.30	1.20	0.30	0.15
DIN (mmol m^{-3})	27	21	19	87
Silicate (mmol m^{-3})	61	47	42	190
Dry Season				
Salinity (psu)	28	32	35	11
Phosphate (mmol m^{-3})	0.07	0.02	0.03	0.03
DIN (mmol m^{-3})	21	19	15	65
Silicate (mmol m^{-3})	106	62	35	190
Rainy Season				
Salinity (psu)	7	19	23	1
Phosphate (mmol m^{-3})	0.81	0.50	0.21	0.02
DIN (mmol m^{-3})	32	26	20	96
Silicate (mmol m^{-3})	130	88	37	320

Water and salt balance

Total combined groundwater discharge for the inner and middle boxes estimated in this study (310, 246 and 651×10^3 m^3 day^{-1} for the *nortes*, dry and rainy seasons respectively; see Figure 2.10) were higher than the previous estimates for the whole lagoon (286, 157 and 150×10^3 m^3 day^{-1} for the *nortes*, dry and rainy seasons, respectively: Herrera-Silveira *et al.* 1999). These new estimates are now more consistent with the expected seasonality of groundwater discharge, with higher values during the rainy season and lower values during the dry and *nortes* seasons. The estimated total annual discharge normalized by the length of the lagoon (21 km), of $8x10^6$ m^3 km^{-1} $year^{-1}$, is close to the estimate by Hanshaw and Back (1980) for the northern coast of the Yucatan Peninsula.

The revised water exchange times for the inner and middle boxes in Celestun Lagoon (Figure 2.10) are lower than the previous estimates (Herrera-Silveira *et al.* 1999). In some cases such differences were large, as in the case of the middle box during the rainy season where we obtained a $\tau = 2$ days and the previous budget had a $\tau = 11$ days. These differences may largely be attributed to the revised groundwater discharges during winter. Table 2.5 shows the water fluxes and water exchange time for the budgeted part of the lagoon (inner and middle boxes combined) for the *nortes*, dry and rainy seasons. Water exchange time was longest in the *nortes* season (19 days) and lowest in the rainy season (6 days). The annual average water exchange time in the two compartments was 9 days, calculated using the total volume of the compartments and the average residual flow (V_R) and mixing volume (V_X).

Table 2.5. Results from water and salt budgets in the inner and middle Celestún Lagoon. V_R and V_X are in 10^3 m^3 day^{-1} and water exchange times are in days.

	V_G	V_P-V_E	V_R	V_X	τ
***Nortes* season** (4 months)	310	-49	-261	926	19
Dry season (3 months)	246	-38	-208	1,982	11
Rainy season (5 months)	651	-2	-649	3,348	6
Annual	436	-27	-409	2,199	9

Budgets of nonconservative materials

DIP balance

Figure 2.11 illustrates DIP budgets for the inner and middle areas of Celestun Lagoon. Very low DIP concentrations were observed during the dry season, while the highest values were recorded during the *nortes*. Both subsystems were an overall source of DIP, although the middle box showed a negative but low ΔDIP value during the dry season. At the system level, there was a seasonal variability in ΔDIP values, with values of +982 mol day^{-1} or +0.05 mmol m^{-2} day^{-1} in the *nortes*, +1,188 mol day^{-1} or +0.06 mmol m^{-2} day^{-1} in the rainy season, and a very low (+11 mol day^{-1} or +0.0005 mmol m^{-2} day^{-1}) during the dry season (Table 2.6). The revised ΔDIP values were substantially higher than those reported by Herrera-Silveira *et al.* (1999; +405, +2 and +61 mol day^{-1} for the *nortes*, dry and rainy season respectively). On an annual basis, the budgeted part of Celestun Lagoon is a net source of DIP at a rate of ΔDIP = +0.04 mmol m^{-2} day^{-1} (Table 2.6), which contrasts with a ΔDIP = +0.008 mmol m^{-2} day^{-1} calculated by Herrera-Silveira *et al.* (1999).

Table 2.6. Seasonal nonconservative fluxes for the inner and middle Celestun Lagoon.

Seasons	ΔDIP		ΔDIN	
	(mol day^{-1})	(mmol m^{-2} day^{-1})	(mol day^{-1})	(mmol m^{-2} day^{-1})
Nortes (4 months)	+982	+0.05	-19,898	-1.0
Dry (3 months)	+11	+0.0005	-10,727	-0.6
Rainy (5 months)	+1,188	+0.06	-27,481	-1.4
Annual	+825	+0.04	-20,765	-1.1

DIN balance

Figure 2.12 illustrates the DIN budgets. The highest DIN concentrations were observed during the rainy season. Both subsystems showed negative *ΔDIN* values throughout the year, indicating that, in contrast with DIP, the budgeted part of the lagoon is a net sink for DIN. As for *ΔDIP*, *ΔDIN* values in this revision (-19,900 in the *nortes*, -10,700 in the dry and -27,500 mol day^{-1} in the rainy season) are quite different from those reported for the same subsystems by Herrera-Silveira *et al.* (+17,900 in the *nortes*, -873 in the dry and -7,472 in the rainy season). On an annual basis, the system is a net sink for DIN showing a *ΔDIN* value of -1.1 mmol m^{-2} day^{-1} (Table 2.6), whereas the value obtained with the previous data (Herrera-Silveira *et al.* 1999) was +0.14 mmol m^{-2} day^{-1}.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric estimates were based on the assumption that metabolically reacting material in this system is plankton, with a Redfield C:N:P molar ratio of 106:16:1. Results from these calculations are shown in Table 2.7.

Table 2.7. Seasonal (*nfix-denit*) and (*p-r*) for inner and middle Celestun Lagoon.

Seasons	***nfix-denit*)**	**(*p-r*)**
	(mmol N m^{-2} day^{-1})	(mmol C m^{-2} day^{-1})
Nortes (4 months)	-1.8	-5
Dry (3 months)	-0.6	-0.1
Rainy (5 months)	-2.4	-6
Annual	-1.7	-4

Nitrogen fixation minus denitrification (*nfix-denit*) values for the inner and middle lagoon during *nortes,* dry and rainy seasons were -1.8, -0.6 and -2.4 mmol N m^{-2} day^{-1}, respectively, indicating a net denitrification. The corresponding estimates from the previous budget (Herrera-Silveira *et al.* 1999) were +0.6, -0.05 and -0.4 mmol N m^{-2} day^{-1}. The annual (*nfix-denit*) value for the budgeted part of the lagoon is -1.7 mmol N m^{-2} day^{-1}. Our revised budgets indicate that denitrification is more intense in the inner and middle zones of Celestun Lagoon than previously reported.

The whole system net ecosystem metabolism (*p-r*) values were negative for all seasons; (-5, -0.1 and -6 mmol C m^{-2} day^{-1} for the *nortes,* dry and the rainy seasons, respectively) indicating slightly heterotrophic conditions during these periods. The previous budget also indicated that the inner and middle sections of the lagoon were net heterotrophic, but the estimated *(p-r)* values for both subsystems were closer to zero (-2, -0.01 and -0.3 mmol C m^{-2} day^{-1} for the *nortes*, dry and rainy seasons, respectively). On an annual basis, the budgeted part of Celestun Lagoon is apparently slightly heterotrophic at a rate of -4 mmol C m^{-2} day^{-1}. This is higher than the value of -0.8 mmol C m^{-2} day^{-1} for the inner and middle box area calculated by Herrera-Silveira *et al.* (1999).

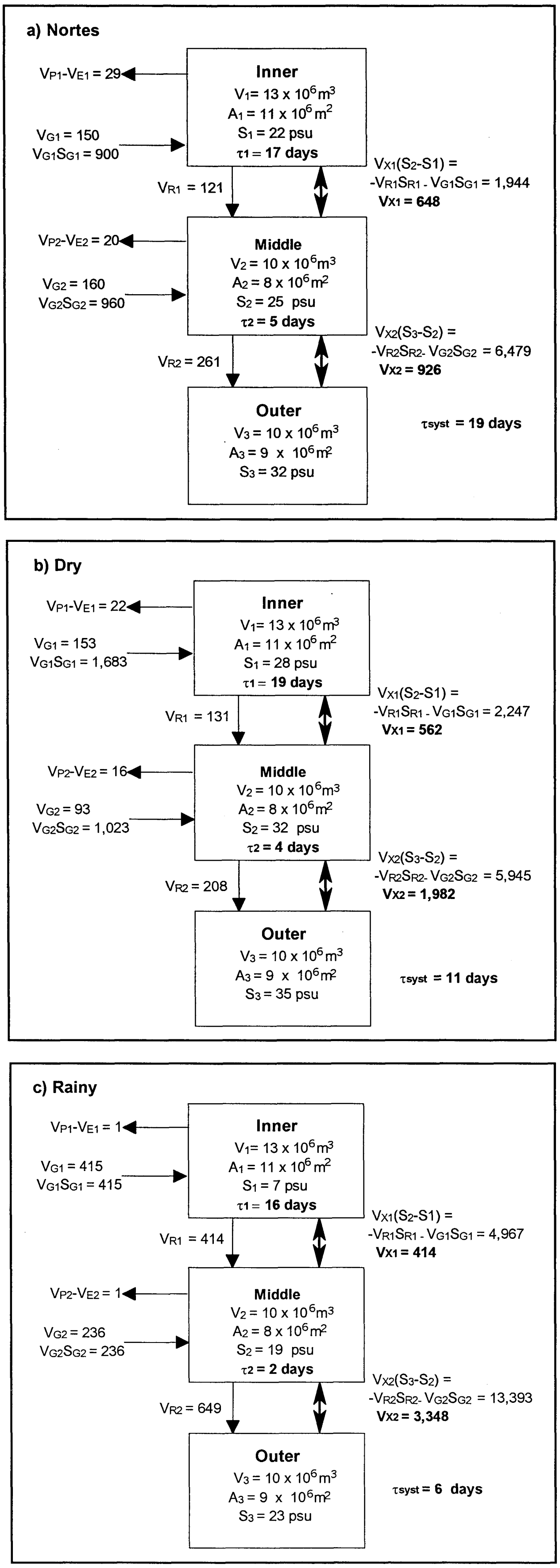


Figure 2.10. Seasonal water and salt budgets for Celestun Lagoon in: a) *nortes* season; b) dry season; and c) rainy season. Water flux in 10^3 m^3 day^{-1} and salt flux in 10^3 psu-m^3 day^{-1}.

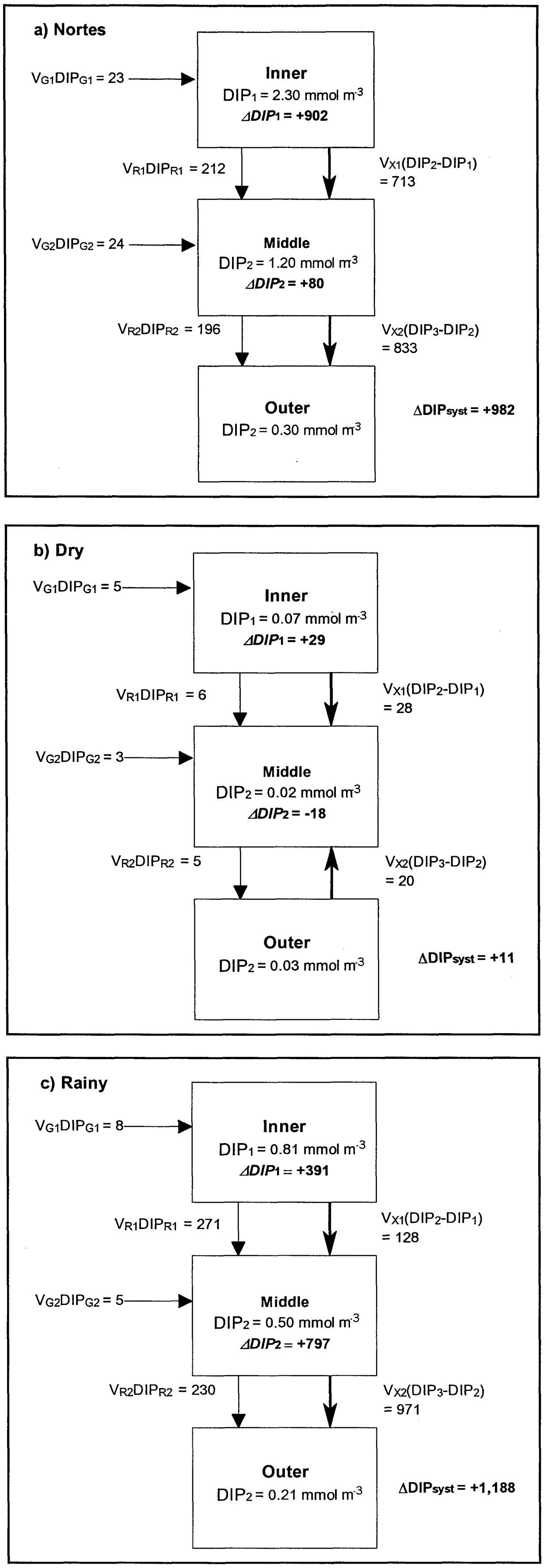


Figure 2.11. Seasonal DIP budget for Celestun Lagoon in: a) *nortes* season; b) dry season; and c) rainy season. Fluxes in mol day^{-1}.

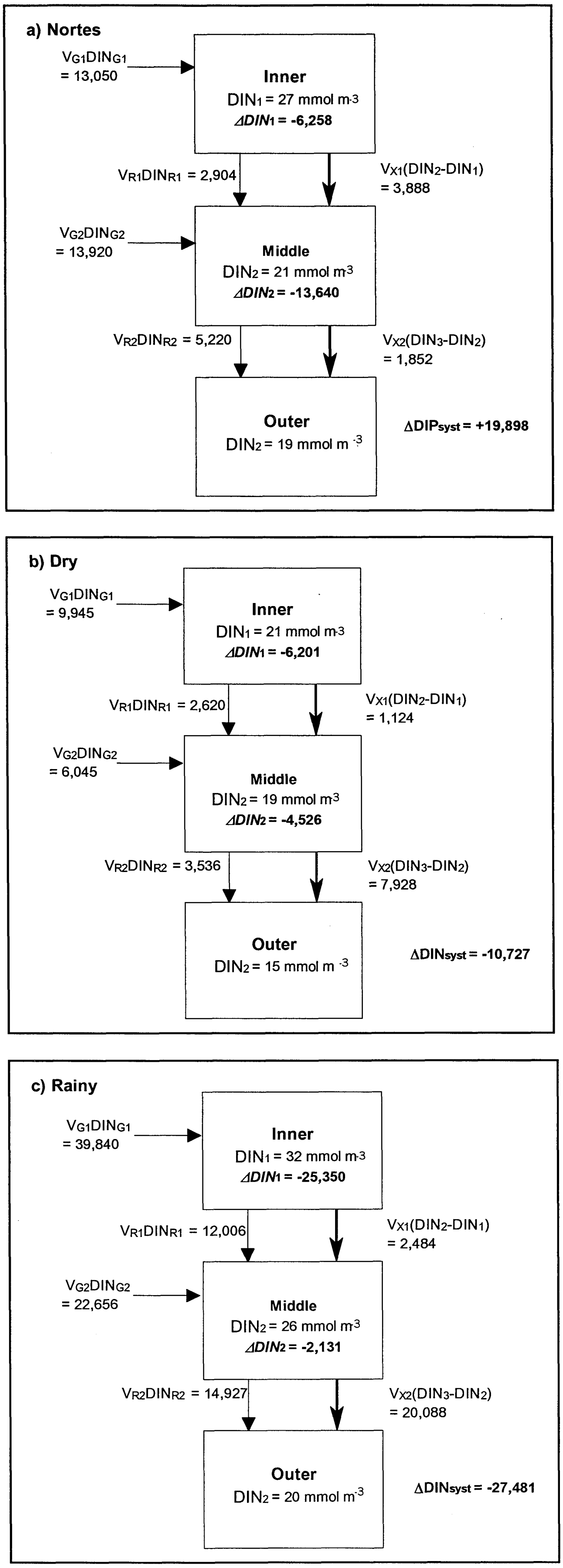


Figure 2.12. Seasonal DIN budget for Celestun Lagoon in: a) *nortes* season; b) dry season; and c) rainy season. Fluxes in mol day^{-1}.

3. ESTUARINE SYSTEMS OF COLOMBIA

3.1 Cienaga Grande de Santa Marta (1993-1999): a tropical coastal lagoon in a deltaic geomorphic setting

Victor H. Rivera-Monroy, Bror Fredrik Jonsson, R.R. Twilley, Oscar Casas-Monroy, Edward Castañeda, Roberto Montiel, Ernesto Mancera, Walberto Troncoso and Felix Daza-Monroy

Study area description

The Cienaga Grande de Santa Marta (CGSM) is a lagoon-delta ecosystem which forms the exterior delta of the Magdalena River. This river is the largest in Colombia with an annual average discharge of 7,000 m^3 sec^{-1}. The lagoon is located between 10.67° and 10.98°N and 74.25° and 74.63°W on the Caribbean coast of Colombia-South America (Figure 3.1). This system can be classified as a type I setting (river-dominated, arid, with low tidal amplitude) containing fringe, basin and riverine mangroves (Thom 1982). The system is the largest coastal lagoon-delta ecosystem in the Caribbean area with an extension of 1,280 km^2 (including coastal lagoons, creeks and mangrove swamps). It comprises two main water bodies, the Cienaga Grande de Santa Marta (CGSM, 450 km^2) and Cienaga de Pajarales (120 km^2), as well as several lagoons. The coastal climate zone is arid tropical, with 6-7 dry-months a year and an annual deficit of 1,031 mm because evapo-transpiration (1,431 mm $year^{-1}$) largely exceeds precipitation (400 mm $year^{-1}$). To the north, the lagoon complex is separated from the Caribbean Sea by a barrier island known as Isla Salamanca, which has an inlet approximately 100 m wide and 10 m deep on its eastern end that connects the largest lagoon (Cienaga Grande) directly to the sea. To the west and south-west the lagoon delta-complex is limited by the flood plain of the Magdalena River, through which five main distributaries historically brought freshwater from the river to the complex until the 1970's. Tidal range is relatively small (±30 cm). Changes in the water level in lagoons and creeks as well as on the mangrove forests are due mainly to seasonal inputs from the Magdalena River, from the rivers flowing from the Sierra Nevada de Santa Marta (Fundación, Aracataca and Sevilla rivers) (Figure 3.1) and from precipitation.

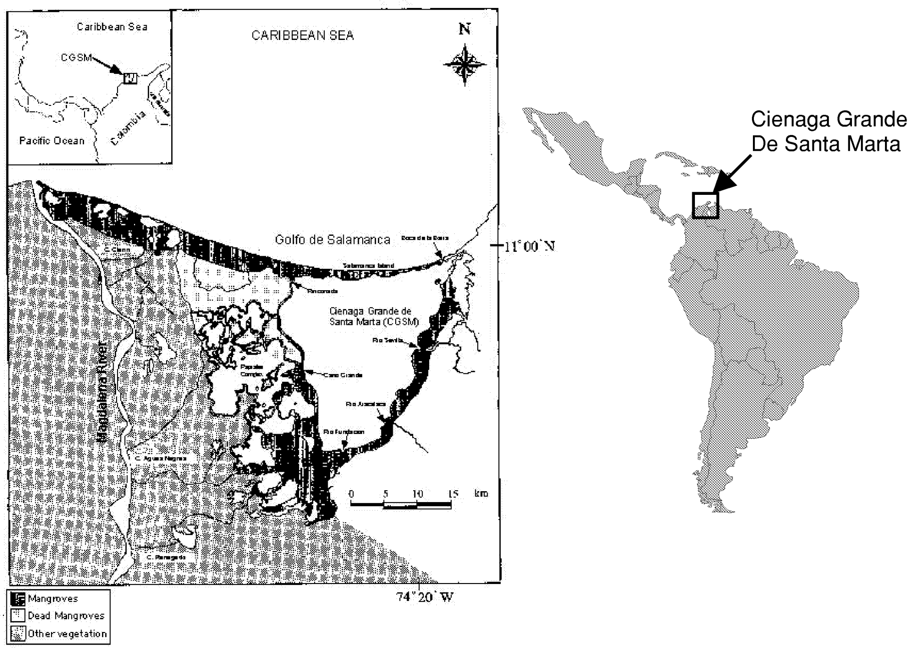


Figure 3.1. Location and map of Cienaga Grande de Santa Marta, Colombia.

The CGSM has been impacted by the construction of a coastal highway and a road levee along the Magdalena River (Figure 3.1). The construction of these two roads has altered the natural flow of marine and freshwaters, respectively, and the resulting water diversion has resulted in severe environmental damage to the mangrove-lagoon ecosystem. Most of the past alterations in coastal hydrology were due to re-diversion of freshwater associated with highway construction, expansion of agriculture (cattle farming and rice), and urban development. Freshwater diversion from the lagoon-delta complex in this arid coastal region has resulted in hypersalinization of mangrove soils (>100 psu, 7 months a year) leading to a die-off of almost 27,000 ha in a 36-year period (Botero 1990; Cardona and Botero 1998). The estuarine regions were surrounded until around 1960 by approximately 52,000 ha of mangrove wetlands.

In 1993 a rehabilitation project was initiated to re-establish the hydrology in some areas of the CGSM to induce both the recovery of the hydrologic regime and the natural regeneration of mangrove forests (Twilley *et al.* 1999). The rehabilitation project consists in opening five of the naturally pre-existing distributaries (giving a maximum total freshwater flow of approximately 150 m^3 sec^{-1}) and a partial connection of the lagoon with the sea through a series of box-culverts built under the coastal highway. All the box-culverts have been reopened (providing a maximum water flow of about 24 m^3 sec^{-1}) and freshwater from the Magdalena River started to flow through Clarin Canal into the northern part of the lagoon in February 1996. In early 1998 two more channels (Aguas Negras and Renegado, each delivering a planned maximum flow of 60 m^3 sec^{-1})) were opened, diverting freshwater from the Magdalena River to the Cienaga de Pajarales and to the southern region of the CGSM (see Figure 3.1).

Water and salt balance

Direct rainfall and river discharge are the major sources of freshwater in the water budget. Since these water inputs change significantly during the rainy and dry seasons, water and salt budgets were estimated for each season per year from 1993 to1999. Nutrient and salinity data were obtained from 7 permanent stations sampled on a monthly basis. Although groundwater should be an important input during the rainy season, there are no estimates of groundwater discharge in the region, and it was therefore not considered in the water budget. Evaporation is a significant water loss from the system (up to 3 times the value of precipitation). Because of the hydrological restoration program to rehabilitate mangrove wetland areas in the Pajarales region, freshwater from the channels (Clarin, Aguas Negras, and Renegado) was included in the budgets from 1996. Area of the CGSM is 450 km^2, average depth 1.5 m, and volume 675x10^6 m^3. Precipitation, evaporation, river and channel discharges in Table 3.1.

Table 3.1. Climatic and river discharge information used in the budget calculations for the Cienaga Grande de Santa Marta.

Year	**Season***	**Precipitation** (mm $year^{-1}$)	**Evaporation** (mm $year^{-1}$)	**River runoff** (m^3 sec^{-1})	**Magdalena** (m^3 sec^{-1})	S_{syst} (psu)	S_{ocn} (psu)
1993	Dry	171	514	65	0	22.3	28.4
	Rainy	500	1,500	120	0	18.0	24.2
1994	Dry	40	121	69	0	26.1	314
	Rainy	553	1,658	127	0	23.8	25.5
1995	Dry	569	1,708	81	0	22.4	29.2
	Rainy	542	1,627	121	0	19.9	21.0
1996	Dry	250	750	81	22	18.1	23.7
	Rainy	485	1,454	132	28	15.6	28.1
1998	Dry	206	619	89	56	21.7	29.1
	Rainy	686	2,059	143	99	19.1	22.8
1999	Dry	628	1,255	105	97	8.3	17.7
	Rainy	1,883	3,765	200	102	1.6	4.6

* number of months per season; dry = 7, rainy = 5

The residual water flow (V_R) was negative for both seasons in all years indicating the strong influence of the discharge from the rivers and channels in the water budget (Table 3.2). Water exchange times ranged from 4 to 25 days and were higher in the dry season than in the rainy season (except in 1996 and 1999). Long-term water exchange times for the dry and rainy seasons were calculated by dividing the volume of the system with the sum of the respective seasonal means of absolute residual flows (V_R) and mixing volumes (V_X). The long-term seasonal water exchange times were 19 days in the dry season and 7 days in the rainy season. The long-term (1993-1999) annual average water exchange time is 11 days calculated using the volume of the system and the long-term annual means of V_R and V_X. Average water exchange estimates in the CGSM are shorter than those values calculated using a water circulation numerical model (approximately 20 days) (Lonin, personal communication). The similar rates estimated before and after the restoration of the Clarin Canal in 1996 and the Renegado and Aguas Negras canals in 1998 suggest that freshwater flow from the channels have not significantly changed the hydrology of the CGSM.

Table 3.2. Water fluxes and water exchange times for Cienaga de Santa Marta coastal lagoon in the dry and rainy seasons.

Year	**Season**	V_R (10^6 m^3 day^{-1})	V_X (10^6 m^3 day^{-1})	**Water exchange time** (days)
1993	Dry	-5.2	21.6	25
	Rainy	-9.1	31.1	17
	Annual	-6.8	25.6	21
1994	Dry	-4.2	22.9	25
	Rainy	-9.6	139.0	5
	Annual	-6.5	71.3	9
1995	Dry	-5.6	21.2	25
	Rainy	-9.1	170.0	4
	Annual	-7.1	83.2	7
1996	Dry	-8.3	31.0	17
	Rainy	-12.6	22.1	19
	Annual	-10.1	27.3	18
1998	Dry	-12.0	41.2	13
	Rainy	-19.2	109.0	5
	Annual	-15.0	69.5	8
1999	Dry	-16.7	23.1	17
	Rainy	-15.1	15.6	22
	Annual	-16.0	20.0	19
Average	Dry	-8.7	26.8	19
	Rainy	-12.5	81.1	7
	Annual	-10.2	49.5	11

Budgets of nonconservative materials

DIP and DIN balance

Since the boundary separating CGSM from the Gulf of Salamanca is the mouth of the estuary (Boca de la Barra), this location was selected as representative of the conditions outside the system (Figure 3.1). Table 3.3 shows nutrient concentrations for the different sources considered in budget calculations.

Nonconservative fluxes (ΔDIP and ΔDIN) suggest that for most of the year, and throughout the 1990's, the system was a slight net sink for inorganic nitrogen and phosphorus (Table 3.4).

Table 3.3. Nutrient concentrations in the different water sources considered in the budgets. Data was collected from 1993 to1999 by the current monitoring program implemented by INVEMAR (Colombia).

Year	**Component**	**Site**	**Dry**		**Rainy**	
			DIP (mmol m^{-3})	DIN (mmol m^{-3})	DIP (mmol m^{-3})	DIN (mmol m^{-3})
1993	Magdalena	Cano Grande	0.3(0.06)	4.0(1.0)	0.9(0.2)	4.6(0.8)
		Rinconada	0.4(0.2)	6.2(1.5)	0.6(0.1)	8.0(3.5)
	System	Centro	0.3(0.07)	3.6(0.6)	0.7(0.1)	5.0(1.0)
	Outside	Barra	0.3(0.06)	5.5(0.9)	0.6(0.1)	4.3(1.5)
	Sierra Nevada	Rio Aracataca	1.3*	6.2*	2.4*	6.4*
		Rio Fundacion	0.8(0.2)	3.2(0.6)	1.1(0.3)	4.2(0.9)
		Rio Sevilla	1.0(0.2)	3.7(0.6)	2.0(0.3)	6.2(2.3)
1994	Magdalena	Cano Grande	1.7(0.4)	17.9(10.4)	1.9(0.7)	32.5(11.5)
		Rinconada	1.3(0.3)	11.5(6.2)	1.0(0.3)	22.9(7.0)
	System	Centro	1.8(0.4)	13.1(8.2)	1.4(0.5)	24.6(8.1)
	Outside	Barra	0.7(0.2)	10.6(6.7)	0.6(0.3)	20.3(7.2)
	Sierra Nevada	Rio Aracataca	1.3*	6.2*	2.4*	6.4*
		Rio Fundacion	1.7(0.4)	11.2(6.0)	2.8(0.8)	27.2(10.1)
		Rio Sevilla	2.3(0.6)	14.7(8.7)	5.3(2.7)	30.3(10.1)
1995	Magdalena	Cano Grande	0.3(0.1)	1.8(1.0)	1.3(1.8)	2.8(1.3)
		Rinconada	0.3(0.1)	1.3(0.6)	1.2(0.8)	2.1(1.1)
	System	Centro	0.3(0.1)	1.3(0.5)	1.2(0.7)	3.9(2.2)
	Outside	Barra	0.4(0.3)	1.4(0.6)	1.2(0.8)	2.8(1.5)
	Sierra Nevada	Rio Aracataca	2.2(0.2)	5.6(1.6)	3.7(1.9)	13.5(10.2)
		Rio Fundacion	1.5(0.4)	2.4(0.7)	3.7(1.7)	4.5(3.6)
		Rio Sevilla	2.3(1.2)	2.8(1.3)	4.7(1.9)	4.3(2.7)
1996	Magdalena	Cano Grande	0.4(0.07)	0.6(0.3)	0.7(0.01)	0.2(0.1)
		Rinconada	0.4(0.07)	0.3(0.1)	0.7(0.2)	0.1(0.0)
	System	Centro	0.4(0.07)	0.4(0.2)	0.7(0.08)	0.2(0.1)
	Outside	Barra	0.1(0.03)	0.4(0.1)	0.5(0.1)	2.8(2.5)
	Sierra Nevada	Rio Aracataca	1.7(0.4)	7.5(1.5)	3.6(0.7)	2.8(0.5)
		Rio Fundacion	1.5(0.4)	2.5(1.2)	4.2(0.9)	1.8(1.3)
		Rio Sevilla	3.1(1.1)	1.6(0.5)	5.4(1.9)	6.6(4.7)
1998	Magdalena	Cano Grande	0.4(0.1)	6.1(5.0)	0.3(0.1)	3.0(2.0)
		Rinconada	0.4(0.1)	5.3(4.0)	0.4(0.1)	4.0(2.4)
	System	Centro	0.4(0.1)	4.8(3.3)	0.3(0.2)	3.1(1.8)
	Outside	Barra	0.3(0.1)	4.1(3.4)	0.5(0.2)	2.3(1.2)
	Sierra Nevada	Rio Aracataca	0.5(0.1)	4.1(3.2)	0.4(0.1)	3.0(1.7)
		Rio Fundacion	0.4(0.0)	4.1(3.2)	0.4(0.1)	3.1(1.7)
		Rio Sevilla	0.5(0.1)	2.0(1.1)	0.4(0.1)	2.4(1.5)

Table 3.4. Nonconservative fluxes (*ΔDIP* and *ΔDIN*) for Cienaga de Santa Marta coastal lagoon in the dry and rainy seasons.

Year	Season	*ΔDIP*		*ΔDIN*	
		(10^3 mol day^{-1})	(mmol m^{-2} day^{-1})	(10^3 mol day^{-1})	(mmol m^{-2} day^{-1})
1993	Dry	-4.6	-0.01	-42.1	-0.09
	Rainy	+9.1	+0.02	-154	-0.34
1994	Dry	+19.7	+0.04	+43.4	+0.10
	Rainy	0	0	+581	+1.29
1995	Dry	-14.2	-0.03	-19.8	-0.04
	Rainy	-30.9	-0.07	+140	+0.31
1996	Dry	-4.1	-0.01	-24.9	-0.06
	Rainy	-39.9	-0.09	-81.1	-0.18
1998	Dry	+2.5	+0.01	+28.6	+0.06
	Rainy	-22.4	-0.05	+74.4	+0.17
1999	Dry	-8.8	-0.02	-75.0	-0.17
	Rainy	-26.1	-0.06	-66.0	-0.15

Stoichiometric calculations of aspects of net system metabolism

Nitrogen fixing minus denitrification (*nfix-denit*) rates ranged from -0.3 mmol N m^{-2} day^{-1} in 1993 to +0.8 mmol N m^{-2} day^{-1} in 1995 (Table 3.5). Most of the (*nfix-denit*) values were positive suggesting that the system is slightly nitrogen-fixing, but the values are close to zero, indicating that system is in balance regarding these two nitrogen transformations. The annual average of each year was weighted with the number of months per season: dry = 7 months and rainy = 5 months. The long-term (1993-1999) annual average for (*nfix-denit*) is +0.4 mmol N m^{-2} day^{-1} calculated from the annual values of each of the six years of observations.

Table 3.5. Apparent net system metabolism for Cienaga de Santa Marta coastal lagoon in the dry and rainy seasons.

Year	Season	*(nfix-denit)*	*(p-r)*
		(mmol N m^{-2} day^{-1})	(mmol C m^{-2} day^{-1})
1993	Dry	+0.07	+1
	Rainy	-0.7	-2
	Annual	-0.3	-0.3
1994	Dry	-0.5	-4
	Rainy	+1.3	0
	Annual	+0.3	-2
1995	Dry	+0.4	+3
	Rainy	+1.4	+7
	Annual	+0.8	+5
1996	Dry	+0.1	+1
	Rainy	+1.3	+10
	Annual	+0.6	+5
1998	Dry	-0.1	-1
	Rainy	+1.0	+5
	Annual	+0.5	+2
1999	Dry	+0.2	+2
	Rainy	+0.8	+6
	Annual	+0.5	+4
Average	Dry	+0.0	0
	Rainy	+0.9	+4
	Annual	+0.4	+2

Net ecosystem metabolism (NEM) or (*p-r*) rates were mostly positive and ranged from -2 mmol C m^{-2} day^{-1} in 1994 to +5.0 mmol C m^{-2} day^{-1} in 1995 and 1996, indicating that the system is slightly net autotrophic (Table 3.6). The long-term (1993-1999) annual average for (*p-r*) is +2 mmol C m^{-2} day^{-1}.

Water column primary productivity studies (oxygen method) in the lagoon showed that the CGSM is a very productive ecosystem. Hernandez and Gocke (1990) and Hernandez and Marquez (1991) estimated an average maximum net rate of 990 g C m^{-2} $year^{-1}$ or 230 mmol C m^{-2} day^{-1}. This high productivity value is associated with high chlorophyll *a* values ranging from 50 to 700 µg L^{-1}. The NEM values estimated by this study and the high chlorophyll *a* values generally found in the CGSM suggest that the system is exporting significant amounts of organic matter to the Gulf of Salamanca. This coastal area is highly productive and currently supports large regional commercial fisheries.

Annual values were weighted by number of months per season; dry = 7, rainy = 5. Long-term seasonal and annual values were calculated from the means of each of the six years of observations.

4. ESTUARINE SYSTEMS OF ECUADOR

4.1 Guayas River estuary, Guayas

V.H. Rivera-Monroy, R.R. Twilley and B.F. Jonsson

This budget replaces an earlier incomplete budget (no DIN budget) (Tutivén 2000).

Study area description

The Gulf of Guayas (Figure 4.1) receives runoff from some 20 rivers in a watershed of 51,230 km^2 forming the largest estuarine ecosystem on the western Pacific coast of South America (Cucalon 1984). The major source of freshwater is the Guayas River, which forms 60 km upstream at the confluence of the Daule and Babahoyo rivers. The mean discharge of 1,144 m^3 sec^{-1} for the Guayas River is the highest among the 30 rivers in the coastal zone of Ecuador, representing 39% of the total discharge from this lowland region. Mean precipitation in the Guayas River drainage system north of Guayaquil is 885 mm year^{-1}, which may range from less than 400 to more 1,800 mm during any one year (Stevenson 1981). Discharge is strongly seasonal ranging from 200 m^3 sec^{-1} during the dry season to 1,600 m^3 sec^{-1} in a wet season with an average precipitation (900 mm year^{-1}). Tides are semidiurnal with equal amplitude of 1.8 m in the Gulf of Guayaquil, amplified to 3-5 m in the Guayas River estuary near the city of Guayaquil.

Years of abnormally warm water temperature and high rainfall are associated with El Niño climate patterns due to the influx of unusually warm surface water in the south-east Pacific Ocean. The warmer offshore waters enhance spawning, maturation and recruitment, resulting in massive populations of white shrimp off the coast of Ecuador (Zimmerman and Minello 1986). In the last century, 10 major El Niño events were recorded (Cucalon 1989) and one of the strongest occurred in 1997-1998 along the coast of Ecuador. The high availability of post-larvae that supported the expansion of the shrimp industry in 1983 and 1984 was associated with an unusually strong El Niño event. The unpredictable nature of the oceanographic events and their influence on river discharge and nearshore recruitment result in complex issues of what factors contribute to reduce the availability of post-larvae along the coast of Ecuador.

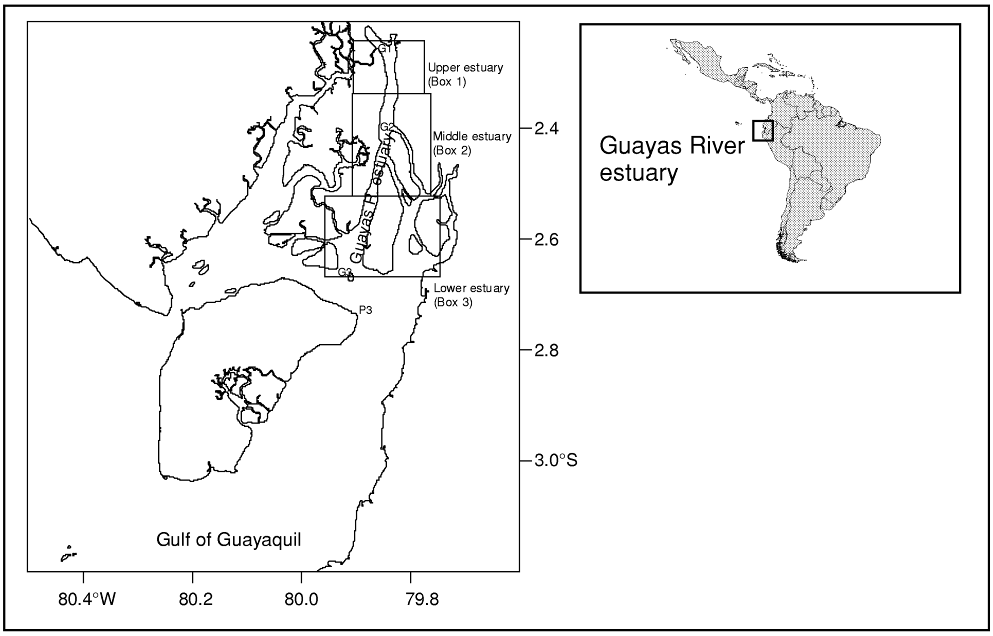


Figure 4.1. Map of the coastal zone of Ecuador, with details of the Guayas River estuary showing the boundaries of the three boxes used to evaluate fluxes of water, salt and nonconservative materials (after Twilley *et al.* 1999).

There have been changes in the environmental quality of the Guayas River basin and its estuary, associated with land use changes both in upland and intertidal watersheds. For example, it has been shown that the quality of water in the estuary may be influenced by introduction of chemicals such as nutrients and pesticides from agriculture, sewage from large urban areas and heavy metals from industry. The most controversial issue related to the environmental quality of coastal resources in Ecuador has been the exploitation of mangroves for the construction of shrimp ponds, particularly in the Guayas River estuary. It has been shown that the impact of mangrove loss on the environmental quality of estuarine resources depends on specific regional land use characteristics. However, the cumulative loss of mangroves along the entire coast of Ecuador is also an issue relative to sustaining habitat necessary for continued recruitment of shrimp to the coastal zone (Turner 1989, Twilley *et al.* 1999).

The Guayas River estuary (2.63°S, 80.00°W) consists of three sub-estuaries: Guayas, Churute, and Salado. Salinity regimes in the Guayas and Churute sub-estuaries, with mean salinities of 18 and 16 psu respectively, reflect the strong seasonal influence of freshwater. The input of freshwater is restricted in the Salado which has mean salinities of 38 psu. Water quality data from a 14 month a survey showed that nitrate is the major form of fixed nitrogen present in the estuary accounting for 70% of DIN. NO_3, DON (dissolved organic nitrogen) and PN (particulate nitrogen) each contributed about 30% of the total nitrogen pool. Soluble reactive phosphorus ranged in all sub-estuaries from 1.5 to 3.3 mmol m^{-3}. The high turbidity of this estuary with suspended sediment concentrations averaging from 115 to 494 mg/L in the main channel may be the key limiting factor to chlorophyll production.

DIN and DIP concentrations were surveyed for 14 months during 1989 and 1990 (Cardenas 1995) (Table 4.3). Nonconservative DIP (ΔDIP) and DIN (ΔDIN) fluxes were estimated only for boxes 2 and 3 due to the lack of nutrient data for the Guayas River end-member. These missing values might affect the overall calculation of ΔDIP and ΔDIN values so further sampling is recommended in the head of the estuary particularly 2-3 km upstream from Guayaquil city.

Water and salt balance

The major source of freshwater considered in the water budget is the river discharge. Hydrological data were separated into rainy (January-April) and dry (May-December) seasons due to significant differences in river discharge throughout the year. The Guayas River estuary is a partially mixed estuary with tidal currents speeds of up to 100 cm sec^{-1} (Murray *et al.* 1975). The dominant upstream flux of mass and salt are apparently associated with the tidal prism. We divided the Guayas River estuary in three regions following the same strategy as Twilley *et al.* (1999). Boundaries of the system are the river in the upper region and the passage formed by the Jambeli Channel in the lower region (Figure 1). Average depths in the upper and lower regions are 8 and 10 m respectively (Table 1).

Table 4.1. Dimensional characteristics of the subsystems (boxes) delimited along the Guayas River estuary.

Box ID	**Area** (km^2)	**% Area**	**Depth** (m)	**Volume** (10^6 m^3)
1	29.5	10	8	236
2	73.7	25	9	663
3	193.3	65	10	1,933
Whole system	296.5	100	10	2,832

Water and salt budgets by season for the three boxes are shown in Figure 4.2. Residual water flow (V_R) was negative for both seasons indicating the strong influence of the discharge from the Guayas River (Table 4.2). Water exchange times were 8 and 9 days in the rainy and dry seasons, respectively (Table

4.2). These water exchange times are similar to the 11 days value estimated by Twilley *et al.* (1999) using a box-model approach (Miller and Mcpherson 1991).

Table 4.2. Water fluxes and water exchange time for the Guayas River estuary in the dry and rainy seasons.

Season	**Residual flow, V_R** (10^6 m^3 day^{-1})	**Mixing volume, V_X** (10^6 m^3 day^{-1})	**Water exchange time** (days)
Rainy (4 months)	121	202	8
Dry (8 months)	27	275	9
Annual	58	251	9

Budgets of nonconservative materials

DIP and DIN balance

The lack of nutrient concentrations for the Guayas River (Table 3) did not allow us to estimate the nonconservative DIP (*ΔDIP*) and DIN (*ΔDIN*) fluxes in Box 1. *ΔDIP* and *ΔDIN* values per season for boxes 2 and 3 are shown in Figures 4.3 and 4.4.

Table 4.3. Nutrient (±SE) and salinity measurements by season for each box delimited along the Guayas River estuary (from Cardenas 1995).

Box ID	**Season**	**Salinity** (psu)	**DIP** (mmol m^{-3})	**DIN** (mmol m^{-3})
Guayas River	Rainy	0.05	nd	nd
	Dry	0.05	nd	nd
1	Rainy	0.1	2.0(±0.4)	23.1(±5.3)
	Dry	4.5	3.2(±0.3)	24.3(±5.2)
2	Rainy	1.4	2.9(±0.7)	27.3(±4.1)
	Dry	12.3	2.5(±0.4)	16.6(±2.6)
3	Rainy	14.7	1.4(±0.4)	4.4(±0.1)
	Dry	27.1	2.2(±0.1)	10(±1.9)
Gulf of Guayaquil	Rainy	27.3	1.4(±0.4)	3.3(±1.1)
	Dry	29.9	1.7(±0.1)	8.3(±1.5)

nd = no data.

Table 4.4 also shows the nonconservative flux values for the whole system. In summary, the innermost box (Box-2) was a source of DIP during the rainy season (*ΔDIP* = +126x10^3 mol day^{-1}) but the outer box was a DIP sink (*ΔDIP* = -199x10^3 mol day^{-1}), and a result the whole system acted as a net DIP sink (*ΔDIP*$_{syst}$ = -73x10^3 mol day^{-1}). ΔDIN showed a similar trend as DIP with an overall negative balance ((*ΔDIN*$_{syst}$ = -22,107x10^3 mol day^{-1}). In contrast with the wet season, during the dry season the whole system was net source of DIP and DIN (*ΔDIP*$_{syst}$ = +105x10^3 mol day^{-1} and *ΔDIN*$_{syst}$ = +59x10^3 mol day^{-1}).

Stoichiometric calculations of aspects of net system metabolism

Table 4.5 shows the seasonal and the annualized (as a weighted average for both seasons) apparent rate of nitrogen fixation minus denitrification (*nfix-denit*) and the net ecosystem metabolism (NEM). The annualized (*nfix-denit*) rate was -5.2 mmol m^{-2} day^{-1}, and the NEM rate -17 mmol m^{-2} day^{-1}. These values indicate that the system has nitrogen losses due to denitrification and is net heterotrophic on an annual basis. However, there were seasonal variations in (*nfix-denit*) and NEM values, as apparent denitrification increased towards the dry season, whereas the system shifted from autotrophic (*p-r* = +32 mmol m^{-2} day^{-1}) during the rainy season to net heterotrophic (*p-r* = -42 mmol m^{-2} day^{-1}) during the dry season.

Table 4.4. Nonconservative DIP and DIN fluxes for the Guayas River estuary.

Box ID	**Season**	***ΔDIP*** (10^3 mol day^{-1})	***ΔDIN*** (10^3 mol day^{-1})	***ΔDIP*** (mmol m^{-2} day^{-1})	***ΔDIN*** (mmol m^{-2} day^{-1})
2	Rainy	+126	+772	+1.7	+10.5
	Dry	-15	-112	-0.2	-1.5
3	Rainy	-199	-2,879	-1.0	-14.9
	Dry	+120	+171	+0.6	+0.9
Average	Rainy	-73	-2,107	-0.3	-7.9
	Dry	+105	+59	+0.4	+0.2
	Annual	+46	-663	+0.2	-2.5

Table 4.5. Stoichiometric net system metabolism.

Box ID	**Season**	***(nfix-denit)*** (mmol m^{-2} day^{-1})	***(p-r)*** (mmol m^{-2} day^{-1})
2	Rainy	-16.7	-180
	Dry	+1.7	+21
3	Rainy	+1.1	+106
	Dry	-8.7	-64
Average	Rainy	-3.1	+32
	Dry	-6.2	-42
	Annual	-5.2	-17

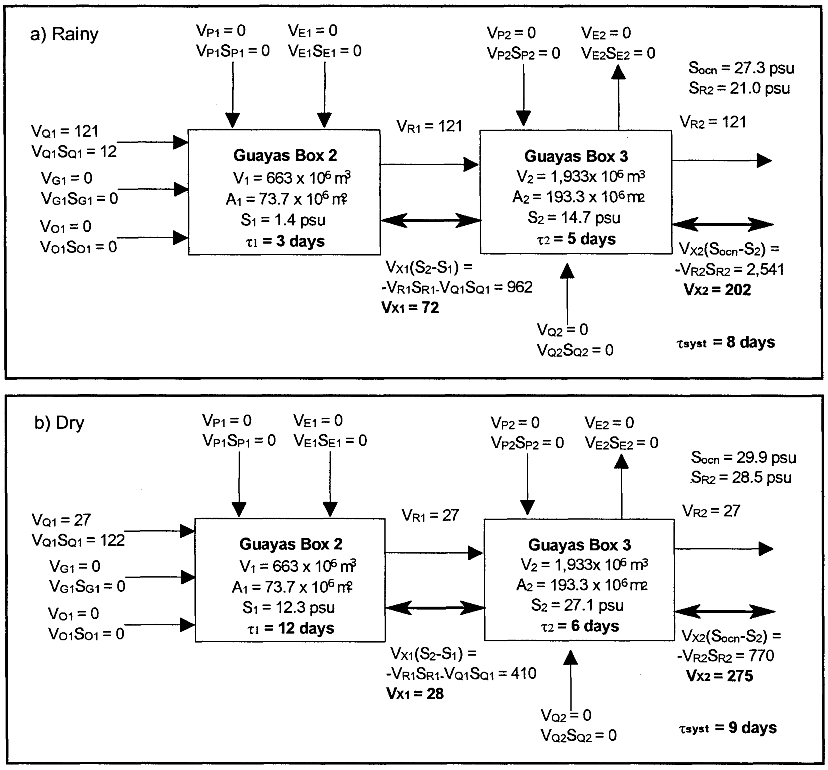


Figure 4.2. Water and salt budgets for the Guayas River estuary in the rainy (a) and dry (b) seasons. Water flux in 10^6 m^3 day^{-1} and salt flux in 10^6 psu-m^3 day^{-1}.

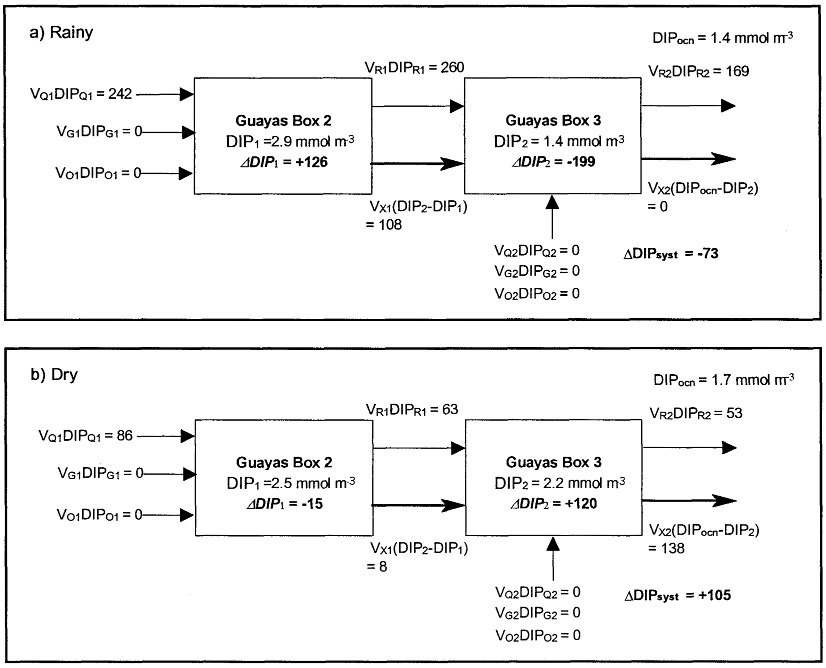


Figure 4.3. DIP budget for the Guayas River estuary in the rainy (a) and dry (b) seasons. Flux in 10^3 mol day^{-1}.

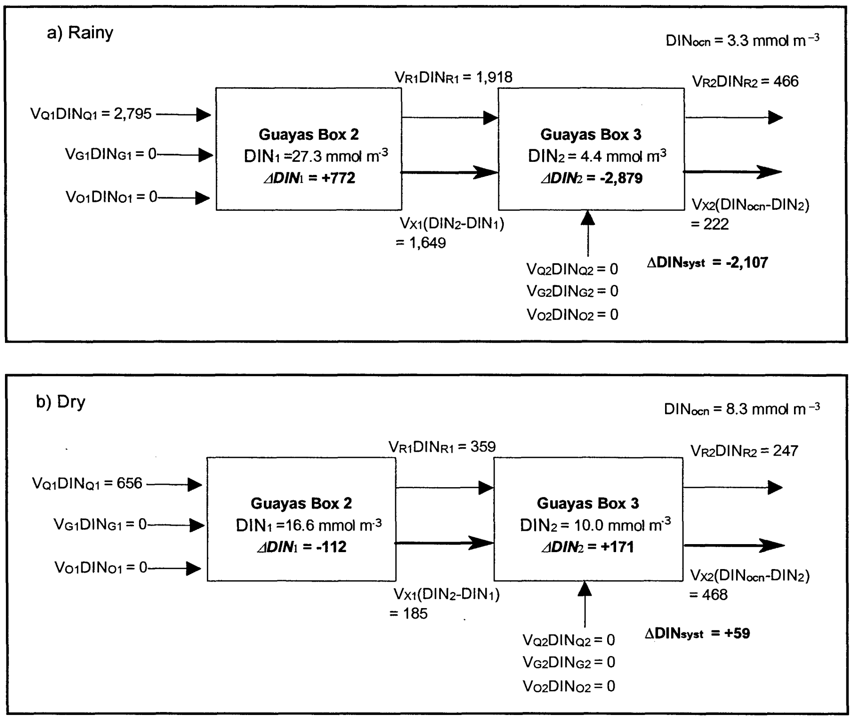


Figure 4.4. DIN budget for the Guayas River estuary in the rainy (a) and dry (b) seasons. Flux in 10^3 mol day^{-1}.

5. ESTUARINE SYSTEMS OF BRAZIL

5.1 Mundau/Manguaba coastal lagoon system

Weber F. Landim de Souza, Eunice C. Machado and Bastiaan Knoppers

Study area description

The Mundau/Manguaba coastal lagoon system in north-eastern Brazil is a 79 km^2, shallow tropical system located between 9.58° and 9.77°S and 35.73° and 35.97°W (Figure 5.1). Mundau Lagoon (area 24 km^2, average depth 1.5 m) and Manguaba Lagoon (area 43 km^2, average depth 2 m) are connected to the sea by the same narrow channel system (area 12 km^2). Water exchange is strongly dampened by the channel system. Tidal attenuation is about 86% in Maundau Lagoon and 98% in Manguaba Lagoon (Oliveira and Kjerfve 1993).

Annual average precipitation and evaporation are 1,654 and 1,109 mm, respectively. The climate is tropical, semi-humid with well-defined wet (April to August) and dry (September to March) seasons. As a response to wet and dry seasons the main rivers Paraiba do Meio (Manguaba Lagoon) and Mundau (Mundau Lagoon) have an extremely variable discharge throughout the year, with historical discharges (1963-1974) ranging from 0-1 m^3 sec^{-1} to 500 m^3 sec^{-1} with averages of 23 m^{3}sec^{-1} for the Paraiba do Meio River and 35 m^3 sec^{-1} for the Mundau River (Tenorio and Almeida 1979).

Figure 5.1. Location and map of the Mundau-Manguaba coastal lagoon system.

The main economic activities in the system are tourism and artisanal fisheries of a number of fish and shrimp species, and in Mundau Lagoon the benthic mussel *sururu* (*Mytella falcata*), the latter being specially important to the low-income segment of the population. Inputs of domestic wastes are from several cities in the drainage basin, including part of Maceio city (population 700,000 in 1991: IBGE

2000). More than 50% of the system and about 30% of *sururu* catches have counts of fecal coliforms above the limit considered acceptable for human health (Normande *et al.* 1998; Villela *et al.* 1998).

Apart from domestic waste inputs, fringing mangroves and tropical rainforests have been systematically altered by buildings and sugar-cane cultivation (Tenorio and Almeida 1979; Medeiros 1996). Organic matter pollution by the sugar-cane industry substantially increases during the harvest season, December-March. The wash water and the waste product (*vinhoto*), rich in fructose with BOD of 3,000 mg l^{-1} (Lobo *et al.* 1988), are discharged to rivers. During this period there is an increase of ammonia concentrations from 4 to 35 mmol m^{-3} and there is a change of the main primary producers from diatoms to cyanobacteria blooms (Machado 1989). Algal blooms are now more frequent throughout the year and consist of several species of cyanophyceae, mainly *Anabaena spiroids* and *Microcystis aeruginosa* which can reach concentrations of 800 µg l^{-1} of chlorophyll *a* (Medeiros 1996; Melo-Magalhaes *et al.* 1998).

Nutrient and salinity data presented in this study represent mean annual concentrations for 1988 in Mundau and Manguaba lagoons and in the Paraiba do Meio River (Machado 1989). Nutrient data for the Mundau River are from Trindade (1998). Salinities were low, with a mean of 10 psu in Mundau Lagoon and 3 psu in Manguaba Lagoon. DIN and DIP were similar in both lagoons, about 10 mmol m^{-3} and 2 mmol m^{-3}, respectively. Oceanic concentrations were obtained from the national oceanographic databank (BNDO-DHN). These data were used to construct a nutrient annual budget using the LOICZ approach (Gordon *et al.* 1996).

Water and salt balance

In both lagoons the main freshwater inputs are from river runoff. Data for river runoff were obtained from SIH/ANEEL and represent a mean from 1974 to 1998 for the Mundau River (30 m^3 sec^{-1}) and from 1989 to 1998 for Paraiba do Meio River (9.8 m^3 sec^{-1}). When compared with means from the period of 1963 to 1974 (Tenorio and Almeida 1979) the Mundau River is stable. However, the Paraiba do Meio River (mean of 23 m^3 sec^{-1}) shows a drastic reduction in flow which may reflect modifications in the drainage basin manangement, since mean precipitation is not significantilly different in the two periods. Anthropogenic inputs of freshwater were estimated from demographic census of 1991 (IBGE) assuming a *per capita* water consumption of 0.22 m^3 day^{-1} (Tchobanouglous and Schroeder 1987). Results of the water and salt budgets are presented in Figure 5.2. Our conclusions do not change significantly for the water and salt budgets for Mundau Lagoon if a river runoff of 40 m^3 sec^{-1} (as calculated by Holland 1978, and Kjerfve 1990) is used in the calculations.

Budgets of nonconservative materials

DIP and DIN balance

Anthropogenic inputs of DIP and DIN were estimated using effluent discharge coefficients from San Diego-McGlone *et al.* (1999), from the population census of 1991, piggery and poultry counts and sugar-cane production from census of 1996 (Table 5.1; IBGE 2000).

Sugar-cane waste inputs were not considered in the calculations as their major impact is in the receiving rivers where high ammonia concentrations, BOD and DO (i.e 36 mmol m^{-3}, 135 mg l^{-1} and 0 mg l^{-1}) during the sugar-cane harvest and processing can be observed (Medeiros 1996). Although river runoff variations may be important in the residual flow (V_R) and in the water exchange time, especially in Manguaba Lagoon, this is not reflected in the budgets of nonconservative materials which are mainly controlled by the anthropogenic fluxes (Table 5.2). Both lagoons represent a net sink of DIP (-7 to -10×10^3 mol day^{-1}) and DIN (-60 to -121×10^3 mol.day^{-1}) (Figures 5.3 and 5.4).

Table 5.1. Fluxes of nitrogen and phosphorus derived from population, piggery and poultry counts of the cities of the Mundaú-Manguaba system.

System	City	Type of Waste	Counts	Fluxes	
				P	N
			Head	10^6 mol year^{-1}	
Mundaú	Macéio	Population	72,314	2.3	21
	Rio Largo		58,244	1.9	17
	Satuba		10,954	0.35	3.1
	Santa Luzia do Norte		6,357	0.21	1.8
	Coqueiro Seco		5084	0.16	1.5
Manguaba	Marechal Deodoro	Population	28,215	0.91	8.1
		Piggery	40	0.003	0.02
		Poultry	1,101		0.024
	Pilar	Population	30,178	0.97	8.6
		Piggery	3,230	0.24	1.7
		Poultry	5		0.00011

Stoichiometric calculations of aspects of net system metabolism

Assuming that the production and decomposition of organic mater follow the phytoplanktonic ratio, we used the Redfield ratio (C:N:P = 106:16:1) for the estimation of nitrogen fixation minus denitrification *(nfix-denit)* and net ecosystem metabolism (NEM = [*p-r*]). Mundau and Manguaba lagoons have very similar fluxes with net fixation of nitrogen 39-52x10^3 mol day^{-1} and an autotrophic metabolism of 740-1,060x10^6 mol dayr^{-1}. When normalized by area, rates for (*nfix-denit*) of +1.6 mmol m^{-2} day^{-1} and +1.2 mmol m^{-2} day^{-1} were estimated for Mundau and Manguaba lagoons respectively, and their corresponding rates of (*p-r*) were +44 mmol m^{-2} day^{-1} and +17 mmol m^{-2} day^{-1}. Estimated anthropogenic inputs largely control the rates of nitrogen fixation and autotrophic production. The two-fold higher rates of Mundau Lagoon in comparison to Manguaba Lagoon are probably due to the smaller volume and larger anthropogenic inputs to Mundau Lagoon. The shorter water exchange time of Mundau Lagoon does not seem to be sufficient to diminish anthropogenic effects.

Table 5.2. River, anthropogenic and nonconservative fluxes of DIP and DIN in the Mundaú-Manguaba system.

System	River concentrations		River fluxes		Anthropogenic fluxes		Nonconservative fluxes	
	DIP	DIN	DIP	DIN	DIP	DIN	DIP	DIN
	mmol m^{-3}		mol m^{-2} yr^{-1}					
Mundaú	1.3	12.9	0.05	0.5	0.2	1.8	- 0.2	- 1.8
Manguaba	3.6	20.7	0.03	0.2	0.1	0.4	- 0.1	- 0.5

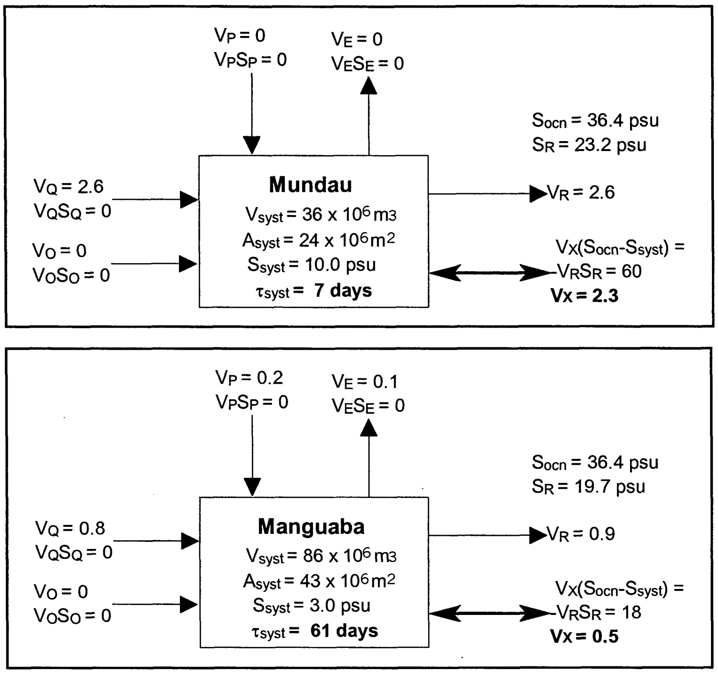


Figure 5.2. Average salt and water budgets for Mundau and Manguaba lagoons. Water flux in 10^6 m^3 day^{-1} and salt flux in 10^6 psu-m^3 day^{-1}.

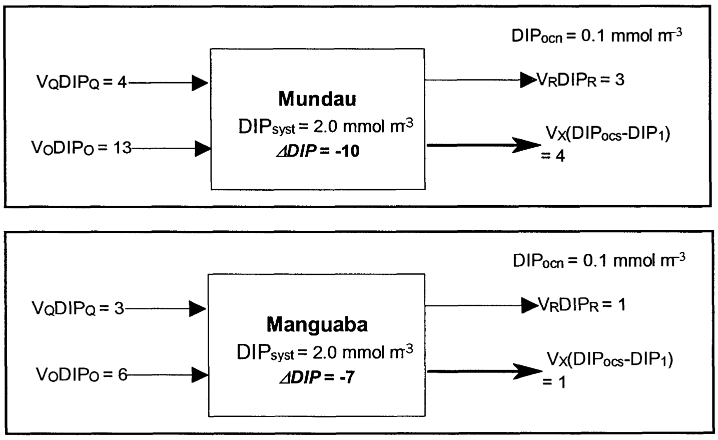


Figure 5.3. Average DIP budgets for Mundau and Manguaba lagoons. Flux in 10^3 mol day^{-1}.

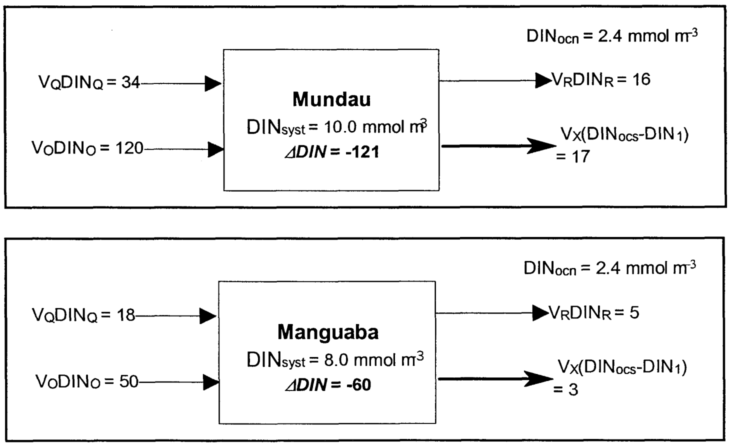


Figure 5.4. Average DIN budgets for Mundau and Manguaba lagoons. Flux in 10^3 mol day^{-1}.

5.2 Marapendi Lagoon, Rio de Janeiro

Weber F. Landim de Souza and Bastiaan Knoppers

Study area description

Marapendi Lagoon is a small (3.3 km^2) and shallow (1.8 m) choked lagoon in the western part of Rio de Janeiro city (23.02°S, 43.40°W). It lies parallel to the coast and is enclosed between two beach ridges, connecting to the sea through the narrow Marapendi Channel (0.5 m) which goes to Barra da Tijuca Channel and from there to the sea. Barra da Tijuca Channel is also the connection to the Jacarepagua Lagoon (Jacarepegua, Camorim and Tijuca lagoons; Figure 1).

The small watershed (4.6 km^2) drains the sand ridges and as a consequence there are no sediment or freshwater inputs from rivers, so the main freshwater inputs are from anthropogenic sources and precipitation. Water exchange with the ocean is strongly restricted by the narrow and straight Marapendi Channel; there is also a long, straight and frequently closed connection to the Sernambetiba Channel in the western part and a possible but not quantified seepage through the outer beach ridge (Muehe and Valentini 1998; Zee *et al.* 1993). The climate is wet tropical and has well-defined wet (December to April) and dry (May to November) seasons, with precipitation of 1,428 mm $year^{-1}$ and evaporation of 1,131 mm $year^{-1}$ (FIDERJ 1980).

In spite of the elongated shape and the several cells of Marapendi Lagoon, nutrient concentrations are almost equal throughout the lagoon (DIP = 2 mmol m^{-3} and DIN = 35 mmol m^{-3}; Zee *et al.* 1993). These high concentrations are a result of the high anthropogenic inputs (35,000 inhabitants), mostly on the eastern side and in the Marapendi Channel where nutrient concentrations are three-fold higher.

Figure 5.5. Location and satellite photograph of Marapendi Lagoon, Brazil.

This annual water and nutrient budget was made using the LOICZ approach (Gordon *et al.* 1996), with early nutrient data (mean annual concentrations; Zee *et al.* 1993), and oceanic concentrations (Weber *et al.* 1994). Estimates of anthropogenic inputs were conducted with coefficients from the literature (San Diego-McGlone *et al.* 1999; Tchobanoglous and Schroeder 1987).

Water and salt balance

Results of water and salt budgets are summarized in Figure 5.6; the balance shows a system controlled by the anthropogenic inputs of freshwater. Marapendi Lagoon has no rivers and runoff from the small sandy drainage area is insignificant. High inputs of freshwater (8,000 m^3 day^{-1}) and slow water exchange (230 days) result in the low salinities of about 16.9 psu (range of 13 to 19 psu).

Budgets of nonconservative materials

DIP and DIN balance

Results of DIP and DIN budgets are shown in Figures 5.7 and 5.8, respectively. The system is a net sink of phosphorus and nitrogen. Both budgets are a system response to anthropogenic inputs (Table 5.3) and the pool of these inputs is very similar to the sink fluxes.

Table 5.3. Anthropogenic fluxes in Marapendi Lagoon.

Population	**Anthropogenic fluxes**		
	Water	DIP	DIN
Inhab.	(m^3 day^{-1})	(mmol m^{-2} day^{-1})	
35,000	7,700	0.9	8.3

System net metabolism, estimated using the Redfield ratio (C:N:P = 106:16:1) are apparently high. However, the estimated values for (*nfix-denit*) of +22x10^3 mol day^{-1} (+6.7 mmol m^{-2} day^{-1}) and the apparent autotrophic net ecosystem metabolism of 324x10^3 mol day^{-1} (+98 mmol m^{-2} day^{-1}), are consistent with a system with high inputs of nitrogen and phosphorus and a small volume.

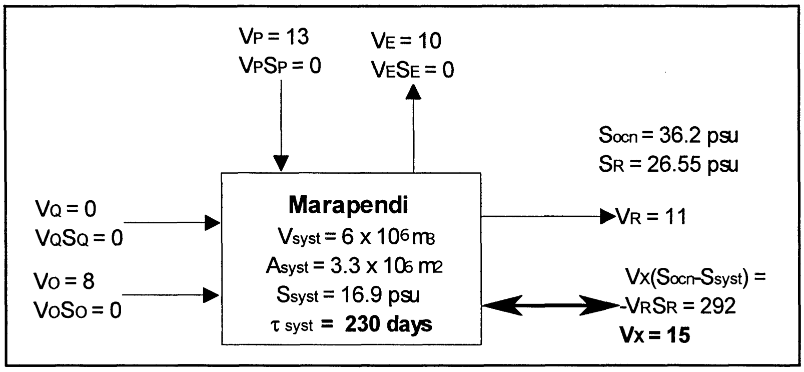


Figure 5.6. Salt and water budget for Marapendi Lagoon. Water flux in 10^3 m^3 day^{-1} and salt flux in 10^3 psu-m^3 day^{-1}.

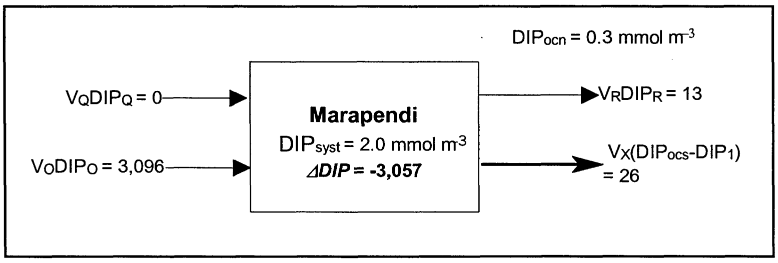


Figure 5.7. DIP budget for Marapendi Lagoon. Fluxes in mol day^{-1}.

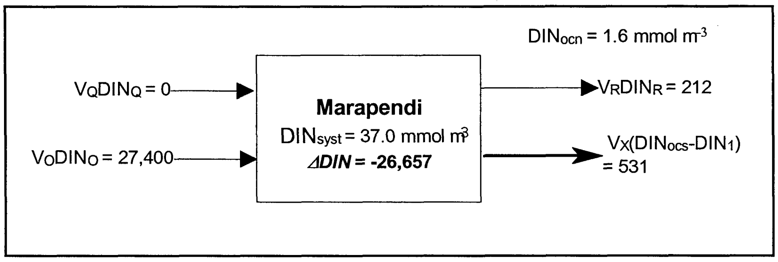


Figure 5.8. DIN budget for Marapendi Lagoon. Fluxes in mol day^{-1}.

5.3 Conceição Lagoon, Santa Catarina State

W.F. Landim de Souza and B. Knoppers

Study area description

Conceição Lagoon is located in Santa Catarina Island, Santa Catarina State, southern Brazil (27.57°S, 48.45°W; Figure 5.9) and has an area of 20 km^2 and a mean depth of 1.7 m. The lagoon lies parallel to the coast, is composed of three sections (north, central and south) and is connected to the sea in the central section by a 2 km long and shallow tidal channel. The cross-sectional area of the channel on the inner side of the lagoon is 40 m^2. The central section (~6.7 km^2) is a 5.5 m deep square- shaped basin, characterized by mesohaline waters at the surface, a marked pycnocline/nutricline between 2.5 and 3.5 m and often stagnant polyhaline bottom waters. Cyanobacterial populations (i.e. high Chlorophyll *a* concentrations) thrive at the pycnocline and filter out nutrients remineralized in the bottom waters. The northern section (~10.1 km^2) has a 4 to 5 m deep western channel, and the southern section (~3.2 km^2) reaches depths of 5 m. Both sections are mesohaline and homogeneously mixed, and are separated from the central section by sub-aqueous sills, which reach depths of 2 to 3 m from the surface (Figure 1); these sills restrict the exchange with the saline waters in the central section. Salinity, nutrient, Chlorophyll *a* and suspended organic matter concentrations are relatively homogeneous in the surface waters of the lagoon, apart from the sites with rivulet inputs. Wind driven circulation dominates the lagoon and maximum tidal elevation in the lagoon may reach 0.2 m (Knoppers *et al.* 1984; Odebrecht 1987; Odebrecht and Caruzo 1987). The lagoon is situated in the Florianopolis municipality and the main economic activities are tourism, especially in the summer, and artisanal fisheries, mainly for *Mugilidae* and *Penaeidae* species (Sierra de Ledo *et al.* 1999). The permanent population comprises approximately 8,000 inhabitants (IBGE census 1980), but may reach 20,000 during the summer.

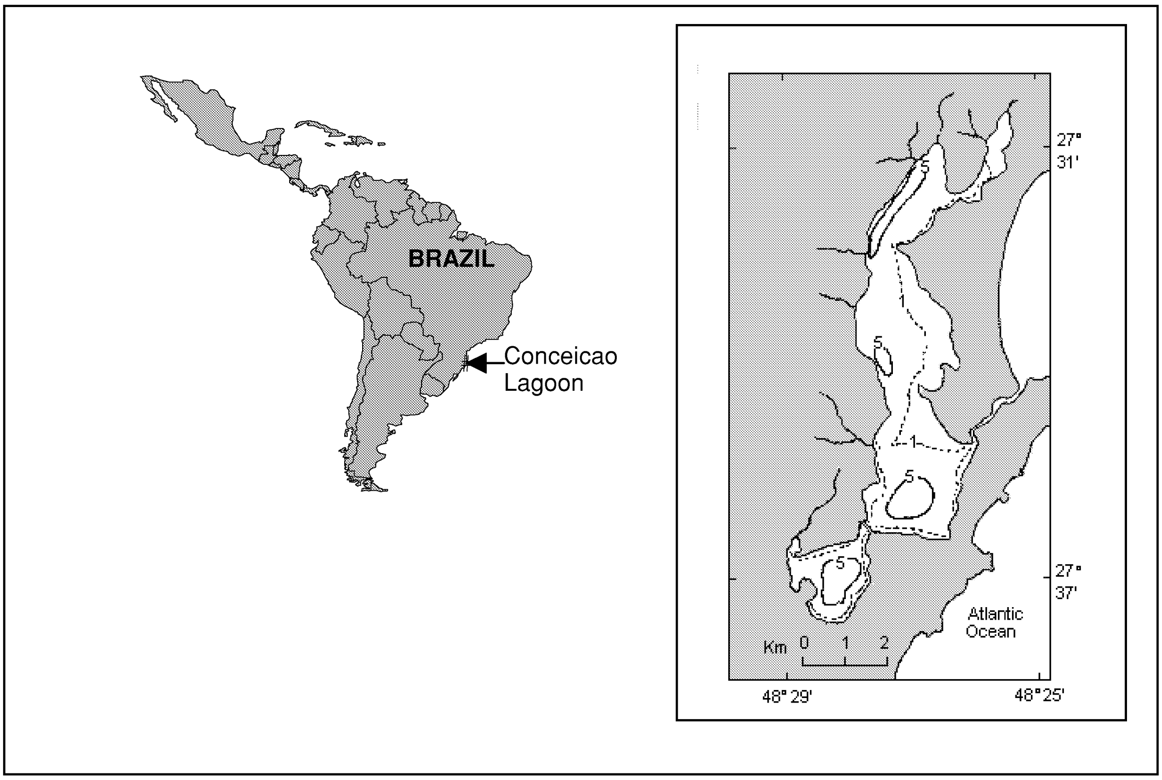


Figure 5.9. Map of Conceição Lagoon, southern Brazil.

Water and nutrient budgets were calculated using the LOICZ approach (Gordon *et al.* 1996). River discharges were calculated as in Holland (1978). Riverine nutrient concentrations are unknown, thus were assumed to be similar to those of the small pristine rivers of Rio de Janeiro coast (Bidone *et al.* 1999; Knoppers, pers. comm.). Information about the oceanic end-member was taken from Weber *et al.* (1994). Separate budgets were calculated with data for the lagoon for winter 1982 reported by Knoppers *et al.* (1984) and with data from Souza Sierra *et al.* (1999) including eleven sampling campaigns between November 1983 and November 1984. The study by Knoppers *et al.* (1984) covered the lagoon with a larger number of stations than the one of Souza Sierra *et al.* (1999), but lacked the temporal component. However, the dataset used by Souza Sierra *et al.* (1999) had inconsistencies between the individual campaigns regarding the number of sampling stations and parameters analyzed: one campaign lacked DIP values; all reported DIN values lacked ammonia concentrations; and two campaigns lacked DIN entirely. We considered both datasets for this exercise as climatic conditions between years differed considerably; the austral summer between 1983 and 1984 was strongly influenced by an ENSO event which was responsible for the third major flood of the century in Santa Catarina State. Estimates of anthropogenic inputs were made using coefficients in the literature (San Diego-McGlone *et al.* 1999; Tchobanoglous and Schroeder 1987). Population numbers were obtained from the 1980 census (8,000 inhabitants). Additionally local statistics were used to derive contributions to each compartment and to estimate inputs from tourism in the summer (IBGE, GAPLAN, 1986; Sierra de Ledo *et al.* 1999).

Water and salt balance

The results of the water and salt balance for the winter 1982 campaign are shown in Figure 5.10 and a summary of the results for the 1983-1984 campaigns are shown in Table 5.4. Precipitation (V_P) and river runoff (V_Q) are the main freshwater inputs. Evaporation (V_E) is less than half the precipitation, except during two months (February and March 1984). We estimated relatively small direct anthropogenic inputs of freshwater (V_O), and approximately 15% from "other sources" were accounted for in V_Q, including seepage and diffuse sources from housing. The residual flow was generally negative (from the lagoon to the ocean), except for February 1984, when the hydraulic balance shifted to positive as evaporation exceeded all inputs. The water exchange times for the three compartments are consistent with the degree of isolation of each compartment, being higher for the southern and northern areas as compared with the central area. The results of exchange times in Table 5.4 do not consider the extreme value of February, which surpassed 4,000 days for the entire lagoon. The extreme values in ranges shown in Table 5.4 reflect the response of the system to the wetter and dryer periods promoted by ENSO.

Table 5.4. Mean, minimum and maximum values for salt and water budgets, 1983/84 campaigns. V_O is assumed in a range of 40 – 160 m^3 day^{-1}.

Area	**Water flux** (10^3 m^3 day^{-1})					**Water exchange time** (days)	**Salinity** (psu)	
	V_Q	V_P	V_E	V_R	V_X	τ	S_R	S_{syst}
North	70.5 8.2–274.1	49.0 26.1– 17.3	-28.6 -14.7 – -59.5	-90.9 -360.1 – 3.7	308.0 0 –1,686	110 11–235	14.6 8.7 – 20.4	11.1 5.6 – 16.1
South	15.3 1.8–59.5	16.0 8.5–38.3	-9.4 -4.8 – -16.2	-22.1 -87.8 – 2.0	32.9 0–110.2	258 47–515	13.2 8.6–9.3	8.3 4.8–13.6
Central	18.5 2.1–71.9	77.3 17.4 – 520	-44.1 -13 .0 –-292.5	-164.7 -575.4–11.0	248.8 0–571.9	48 12 –102	27.1 24.0 – 33.3	18.1 11.8–30.4

Budgets of nonconservative materials

DIP and DIN balance

Results of the DIP balance are shown in Figure 5.11 and Table 5.5. The ΔDIP values both for the individual subsystems (see Figure 5.11) and for the whole system (-760 mol day^{-1}) in 1982 were remarkably similar to the average values shown for 1983-1984 (see Table 5.5). Apparently the effect of the ENSO event was obvious only when monthly results are analyzed. The whole system general behavior was as a net sink of DIP, however, the northern compartment in December 1983 and more clearly the central compartment in November 1983 shifted from net sinks to net sources.

Table 5.5. Mean, minimum and maximum values for DIP and DIN budgets, 1983/84 campaigns. Sewage DIP and DIN loads are assumed to be 0.1 – 0.5 and 1 – 4x10^{3} mol day^{-1}, respectively.

Period	**Concentration** (mmol m^{-3})		**Conservative flux** (10^{3} mmol day^{-1})				**Nonconservative flux** (10^{3} mmol day^{-1})	
	Y_{syst}		$V_R Y_R$		$V_X(Y_{ocn} - Y_{syst})$		ΔY	
	DIP	DIN	DIP	DIN	DIP	DIN	DIP	DIN
North	0.3 0 – 2.2	1.3 0.3–2.3	-58 -460 – 1	-72 -286 – 4	50 -371–775	-28 -164 – 58	-115 -444–291	-1,117 -1,375 – -972
South	0.6 0–5.5	0.8 0.3–1.6	-19 -167–1	-14 -56–3	-3 -39–6	9 -7–40	-363 -440 – -145	-3,290 -3,910 – -3,070
Central	0.5 0 – 4.6	1.3 0.6–2.2	-80 -531– 4	-153 -404–19	-65 -1,076 – 159	62 -137–192	-270 -891–1,364	-3,317 -3,870 – -2,974
Whole System							-748 -1,040 – 776	-7,720 -9,054 – -7,090

Results of the DIN balance are shown in Figure 5.12 and Table 5.5. As for ΔDIP, the observed ΔDIN values within each subsystem as well as the whole system value (-6,900 mol day^{-1}) were similar to the average values during the 1983-1984 period (Table 5.5). Although the system was consistently a net sink of DIN, caution must be observed when comparing both sampling campaigns as the study by Souza Sierra *et al.* (1999) lacked ammonium data. Ammonium represented about half of the DIN concentrations in the July 1982 campaign of Knoppers *et al.* (1984).

Stoichiometric calculations of aspects of net system metabolism

Although about 16% of the system is fringed by submerged macrophytes and seagrasses (Soriano-Sierra 1999), the production and decomposition of organic matter was assumed to follow the phytoplanktonic Redfield C:N:P ratio of 106:16:1 for the estimation of nitrogen fixation minus denitrification (*nfix-denit*) and net ecosystem metabolism. Table 5.6 shows a net nitrogen fixation of 5,300 mol day^{-1} (0.3 mmol m^{-2} day^{-1}) during July 1982, and a mean of 3,100 mol day^{-1} (0.2 mmol m^{-2} day^{-1}) during 1993-1994. This difference between the two data sets however, could be explained by the absence of ammonia concentrations in the 1983-1984 dataset. In any case, (*nfix-denit*) values <0.5 mmol m^{-2} day^{-1} are low and close to zero, indicating that N fixation and denitrification in Conceição are close to a balance.

Although in one month for the central area and in another month for the northern area the net metabolism was heterotrophic, the whole system was overall net autotrophic at a rate of approximately 80,000 mol day^{-1} or 4 mmol m^{-2} day^{-1}. The expected changes in the system metabolism due to ENSO were not able to change the annual metabolism behavior if the July 1982 campaign is considered representative of a non-ENSO year.

Table 5.6. Nitrogen fixation minus denitrification (*nfix - denit*) and net system metabolism (*p-r*) results for the eleven campaigns (mean, maximum, and minimum) and for the winter campaign (*, July 1982).

	Period	(*nfix-denit*)	(*p-r*)	(*nfix-denit*)*	(*p-r*)*
10^3 mol.day^{-1}	North	+1.4 0.5 – 5.7	+12 -31 – 47	+1.6	+17
	South	+2.2 -0.9 – 3.1	+39 15 – 47	+2.5	+37
	Central	-0.5 -25 – 4.9	+29 -146 – 94	+1.3	+27
	Whole System	+3.1 -20 – 7.8	+79 -82 – 110	+5.3	+81
mmol.m^{-2}.year^{-1}	North	+52 19 – 207	+441 -1,114 – 1,701	+60	+640
	South	+243 -97 – 344	+4,261 1,696 – 5,163	+285	+4,220
	Central	-28 -1,393 – 273	+1,604 -8,121 – 5,301	+71	+1,471
	Whole System	+57 -366 – 143	+1,489 -1,508 – 2,022	+99	+1,508

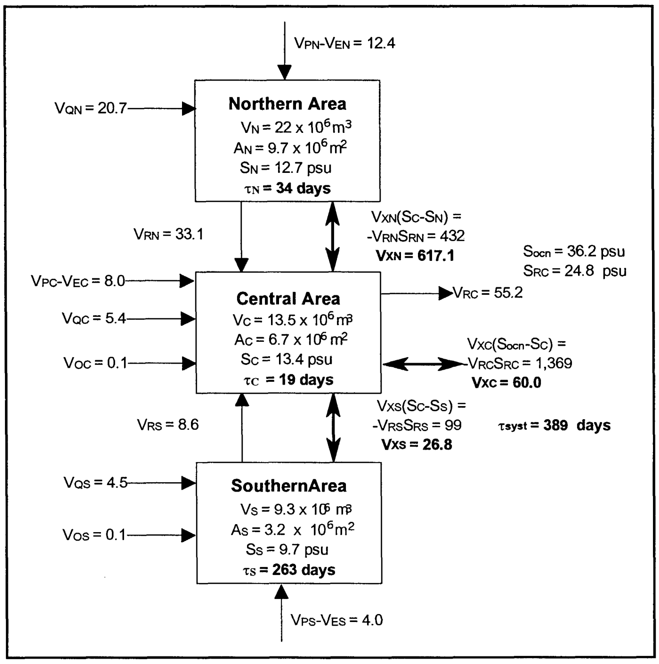


Figure 5.10. Salt and water budgets for Conceição Lagoon, July 1982 campaign. Water fluxes in 10^3 m^3 day^{-1} and salt fluxes in 10^3 psu-m^3 day^{-1}.

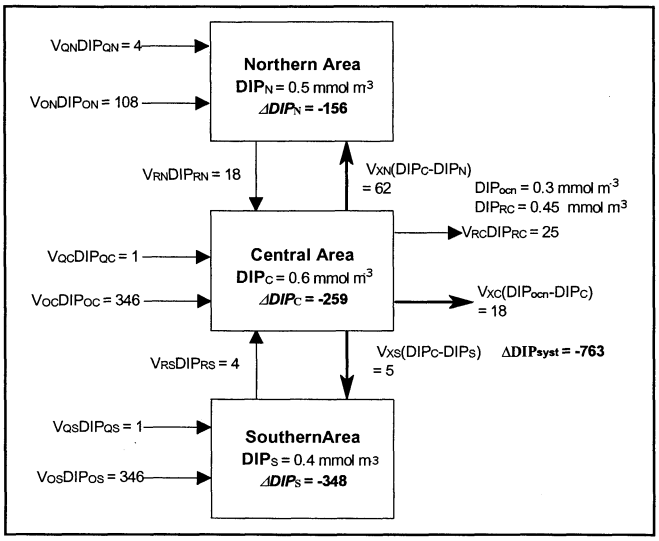


Figure 5.11. Average DIP budget for Conceição Lagoon, July1982 campaign. Fluxes in mol day^{-1}.

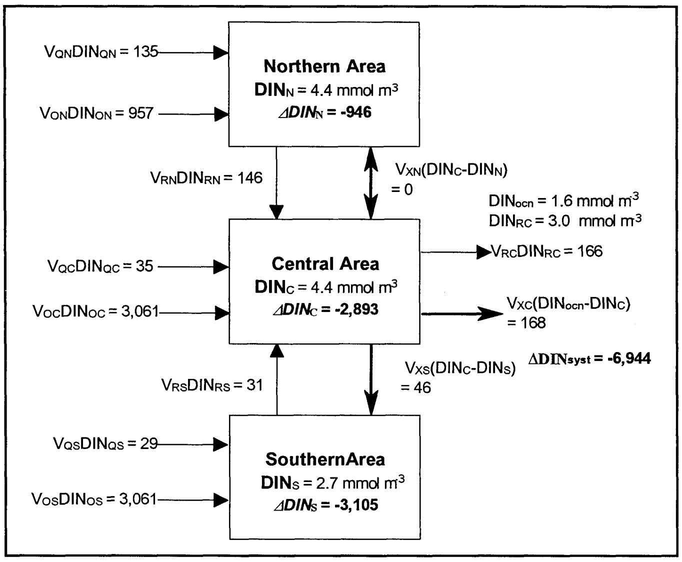


Figure 5.12. Average DIN budget for Conceição Lagoon, July1982 campaign. Fluxes in mol day^{-1}.

6. ESTUARINE SYSTEMS OF CHILE

6.1 The Gulf of Arauco (37°S), a coastal upwelling embayment

Laura Farias

Study area description

The Gulf of Arauco (Figure 6.1) is a semi-opened coastal embayment located off central Chile (36.78°-37.17° S; 73.17°-73.58° W). The gulf covers an area of ca. 818 km^2 and it has a mean water depth of 30 m (excluding the area associated with the Bio Bio Canyon). This system presents three important features:

1. it is under the influence of wind-driven coastal upwelling with a strong seasonal pattern and it is certainly one of the most productive regions in the ocean (Strub *et al.* 1998) with more than 50% of the Chilean fish catch and 4% of the world fish captures;
2. its hydrographic structure is greatly affected by runoff from the Bio Bio River (up to 3000 m^3 sec^{-1}); and
3. its conspicuous topography, characterized by the Bio Bio Canyon, and coastline geometry results in complex hydrodynamics (Sobarzo *et al.* 2001).

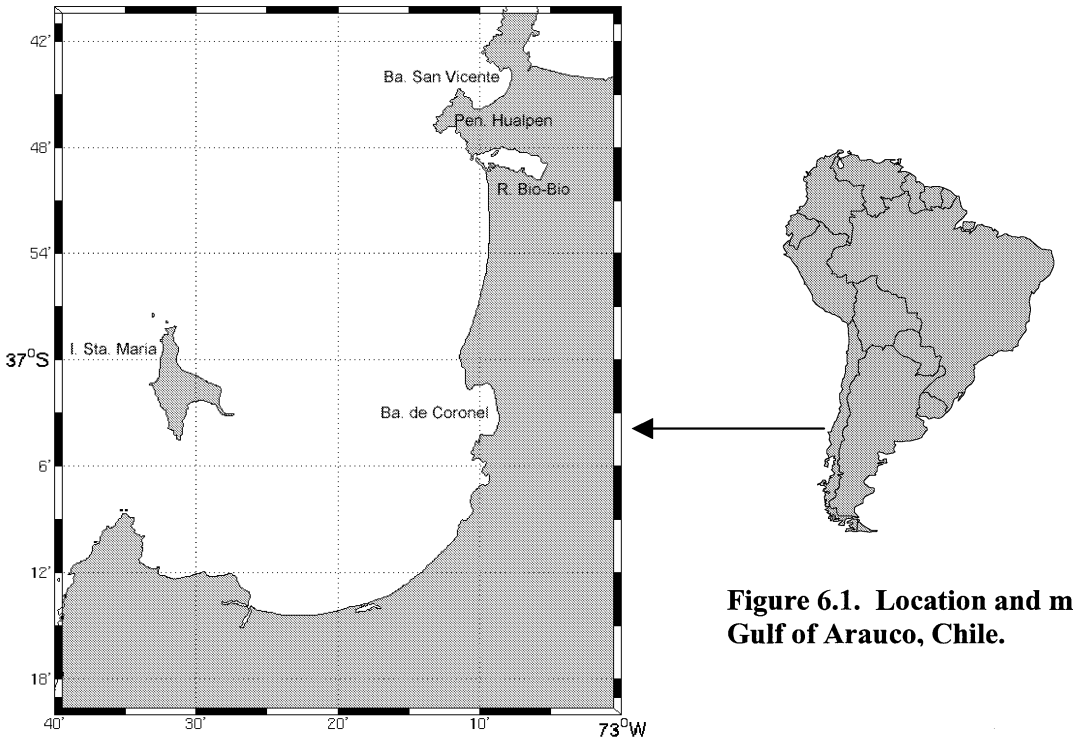
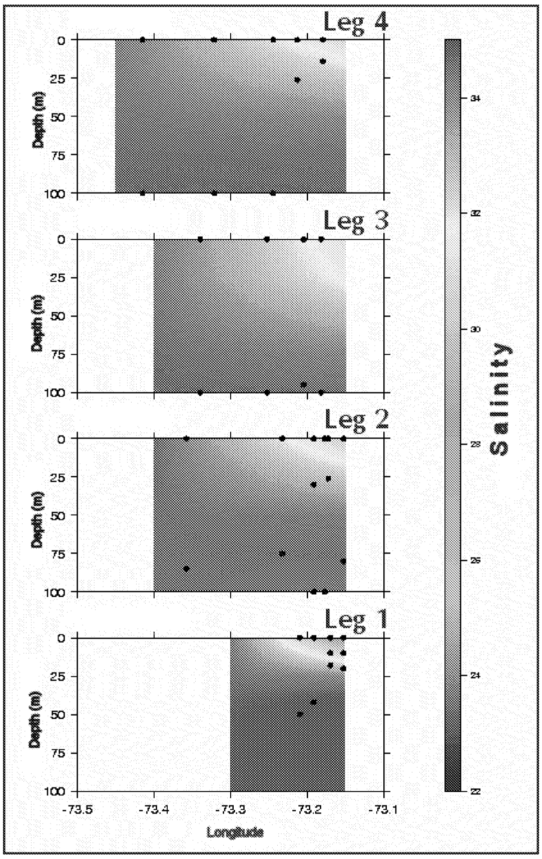


Figure 6.1. Location and map of the Gulf of Arauco, Chile.

The gulf was the subject of an environmental study carried out from 1990 to 1996 by an Italian-Chilean Interuniversity Cooperation Project (EULA-Chile). This project supported extensive socio-economic and water resource studies on the Bio Bio River and its catchment area. The discharge is strongly controlled by the pluvio-nival regime of the region i.e., rainfall and, therefore, Bio Bio River runoff increases by 3-4 times during the austral fall-winter months. The discharge is >1,000 m^3 sec^{-1}, reaching its annual maximum of about 3,000 m^3 sec^{-1} during June-July; while flow may drop to about 100 m^3 sec^{-1} during the summer period. The hydrography of the gulf has been described by Sobarzo *et al.* (1993). It can be summarized as follows: from September to May (late spring to early autumn) there is an upwelling period which coincides with the period of dominance of south and south-westerly winds. The water involved in this process corresponds to Equatorial Subsurface Water (ESSW) which has high salinity (S>34.4 psu), high nutrient levels and low dissolved oxygen content less than 1 ml l^{-1}. Between late May and late August (late autumn and winter) the prevailing wind is from the north. This condition allows Subantarctic Surface Water (SASW) with salinities less than 34.4 psu to occupy the gulf. Due to higher river discharge over the gulf, the SASW is diluted and the surface salinity decreases. This condition creates a structure in density of at least two layers, but the thickness of the layer and the extension of the river plume depend upon river discharge (see Figure 6.2). During winter the surface influence of the river covers almost the entire gulf (ca. 800 km^2), but during summer the river plume moves southward and closer to the coastline (400 km^2).

Taking into account this information, calculations were made for a single-box, two-layer budget of water, salt, inorganic phosphorus (HPO_4^{2-}; DIP) and inorganic nitrogen ($\Sigma[NO_3^-, NO_2^-, NH_4^+]$; DIN). Calculations were based on data collected during two cruises (Gallardo 1991a and 1991b, centro EULA) during March 1991 (upwelling period) and August 1991 (non-upwelling/high river discharge period), respectively.



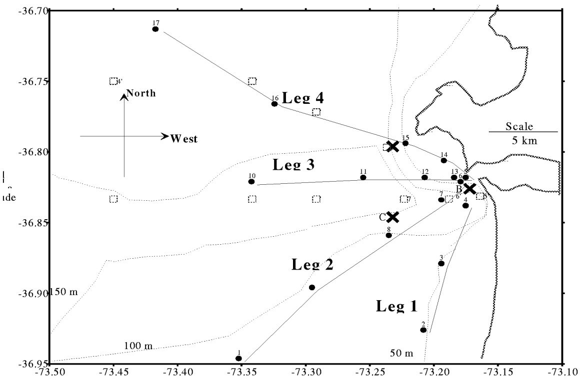


Figure 6.2. Cross-section of salinity during the winter. Map shows the position of each leg.

Riverine DIP and DIN loadings were obtained from a station in the Bio Bio River near the Gulf of Arauco and during the same periods in which oceanographic data were obtained. There are complete historical data records of V_Q, V_E and V_P, all of them measured daily and monthly by Direccion General de Aguas, Chile and Estacion Meteorologica de Bellavista, Universidad de Concepcion. These data are used to calculate DIP and DIN fluxes in the Gulf of Arauco following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996). Data are summarized in Table 6.1. Atmospheric and groundwater inputs of P and N were considered as negligible.

Table 6.1. Data used for budget calculations.

Measured/estimated variables	**Summer 1991**	**Winter 1991**
General variables		
Area (km^2)	400	818
Surface layer depth (m)	5	15
Deep layer depth (m)	25	15
Average system depth (m)	30	30
System volume (10^9 m^3)	12	24.5
V_P (mm month^{-1})	10	93.6
V_E (mm month^{-1})	74	45.5
V_Q river runoff (m^3 sec^{-1})	587	1168
Salinity		
S_Q	0	0
S_P	0	0
S_{syst-s}	31.9	26.5
S_{syst-d}	34.0	34.2
S_{ocn-s}	34.3	32.8
S_{ocn-d}	34.7	34.6
Nutrients (mmol m^{-3})		
DIN_Q	11.8	9.7
DIN_{syst-s}	14.0	8.5
DIN_{syst-d}	20.9	20.1
DIN_{ocn-s}	4.1	8.7
DIN_{ocn-d}	22.3	20.0
DIP_Q	0.03	0.04
DIP_{syst-s}	1.8	0.6
DIP_{syst-d}	2.8	1.8
DIP_{ocn-s}	1.2	1.0
DIP_{ocn-d}	2.9	2.1

Water and salt balance

Figure 6.3 illustrates the water and salt budgets for two cruises performed during a) austral late summer (March 1991) and b) winter (August 1991). During both periods, a deep inflow and a surface outflow between the ocean and the gulf were observed, these patterns probably being associated with the upwelling processes during March 1991 and the river discharge during August 1991. Vertical advective flux varied from 558 (March 1991) to 334 (August 1991). The ratio between V_D and V_Q, ranging from 11 to 3, showed the importance of riverine discharge on the system hydrodynamics. Total water exchange times calculated from water budgets varied from 20 days in summer to 55 days in winter.

Balance of nonconservative materials

DIP and DIN balance

The DIP and DIN budgets for both periods are shown in Figures 6.4 and 6.5. During summer, DIP and DIN were supplied to the gulf from the open ocean as is expected in areas subject to strong seaward Ekman transport typical of coastal upwelling. During the winter, the open ocean continued to be the main source of nutrients but the river assumed a higher relative importance.

In the surface layer, estimated *ΔDIP* and *ΔDIN* were negative, suggesting that net DIP and DIN uptake by phytoplankton prevails in the system during both periods. In the deep layer *ΔDIP* and *ΔDIN* were positive (with the exception of *ΔDIP* in winter), indicating that the system has internal DIP and DIN sources from organic matter oxidation in the deep water column and/or release from the bottom sediments.

Stoichiometric calculations of net system metabolism

Net ecosystem metabolism (*p-r*) was estimated on the basis of a Redfield stoichiometry (Table 6.2). The system acts as a net autotrophic system in both periods, producing organic matter and consuming DIC in both layers during the winter but only at the surface layer during the summer. Net autotrophy should also indicate that DIN should be taken up by net production. A positive balance between observed and expected *ΔDIN* indicates that nitrogen fixation exceeds denitrification in summer and wintertime.

Table 6.2. Nonconservative DIP and DIN fluxes and stoichiometric derivations based on Redfield ratio.

	ΔDIP	***ΔDIP***	**(*p-r*)**	***ΔDIN***	***ΔDIN***	**(*nfix-denit*)**
	10^3 mol day^{-1}	mmol m^{-2} day^{-1}	mmol m^{-2} day^{-1}	10^3mol day^{-1}	mmol m^{-2} day^{-1}	mmol m^{-2} day^{-1}
Summer						
Surface	-656	-1.6	+170	-5,046	-12.6	+13
Deep	+130	+0.3	-32	+502	+1.3	-4
Total	-526	-1.3	+138	-4,544	-11.4	+9
Winter						
Surface	-363	-0.4	+42	-4,179	-5.1	+1
Deep	-80	-0.1	+11	+230	+0.3	+2
Total	-443	-0.5	+53	-3,949	-4.8	+3

The positive (*p-r*) values ranging from +53 to +138 mmol C m^{-2} day^{-1} suggest that there is a high proportion of organic matter left to be exported to the open ocean or buried in the sediments, and that allocthonous inputs of organic matter are not required to support ecosystem metabolism. The (*p-r*) values were in agreement with measured primary production (1.5–6.1 g C m^{-2} day^{-1} or 125–508 mmol C m^{-2} day^{-1}) and community respiration (0.4–3.2 g C m^{-2} day^{-1} or 33–267 mmol C m^{-2} day^{-1}; both integrated to 1% light level) in this region (eg. Daneri *et al.* 2000). Similar rates have also been reported in the north off Chile by Gonzalez *et al.* (1998). The Gulf of Arauco is large enough to facilitate a fairly uniform supply of nutrients to the upper layer, even in the presence of variable wind forcing. Furthermore, such an embayment is shielded from strong seaward Ekman transport typical of open upwelling coasts. A large and fairly constant nutrient supply and a long retention time may explain the great biological productivity of the Gulf of Arauco, which is an important spawning and feeding center for fish (Djurfeldt 1989).

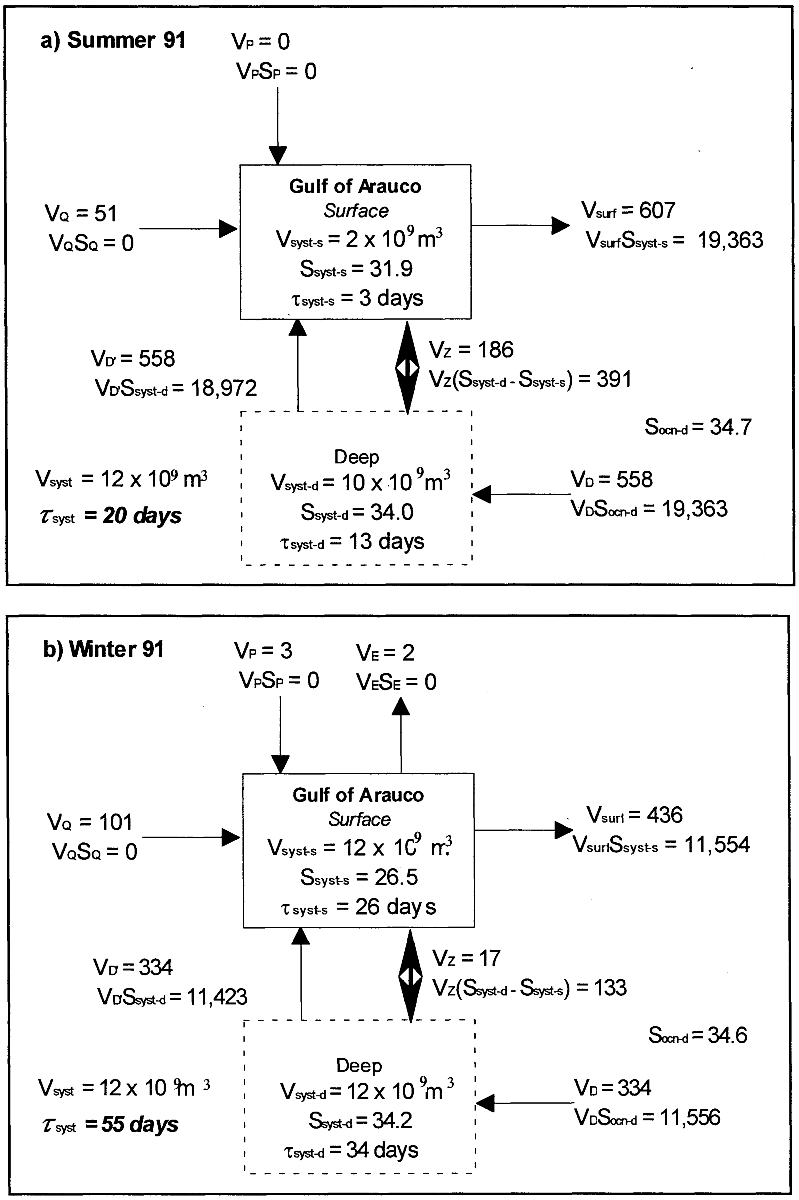


Figure 6.3. Water and salt budgets for the Gulf of Arauco during two contrasting seasons: a) Summer-91 and b) Winter-91. Water flux in 10^6 m^3 day^{-1} and salt flux in 10^6 psu-m^3 day^{-1}.

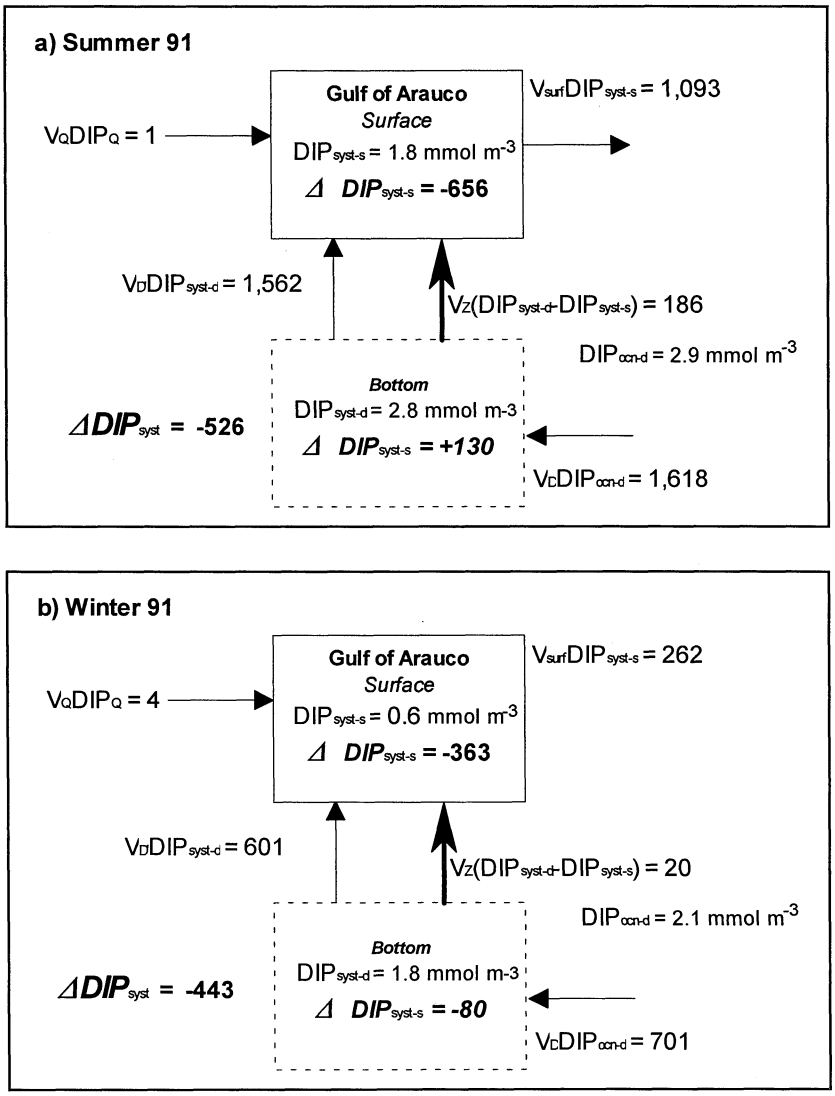


Figure 6.4. DIP budgets for the Gulf of Arauco during two contrasting seasons: a) Summer 1991 and b) Winter 1991. Fluxes in 10^3 mol day^{-1}.

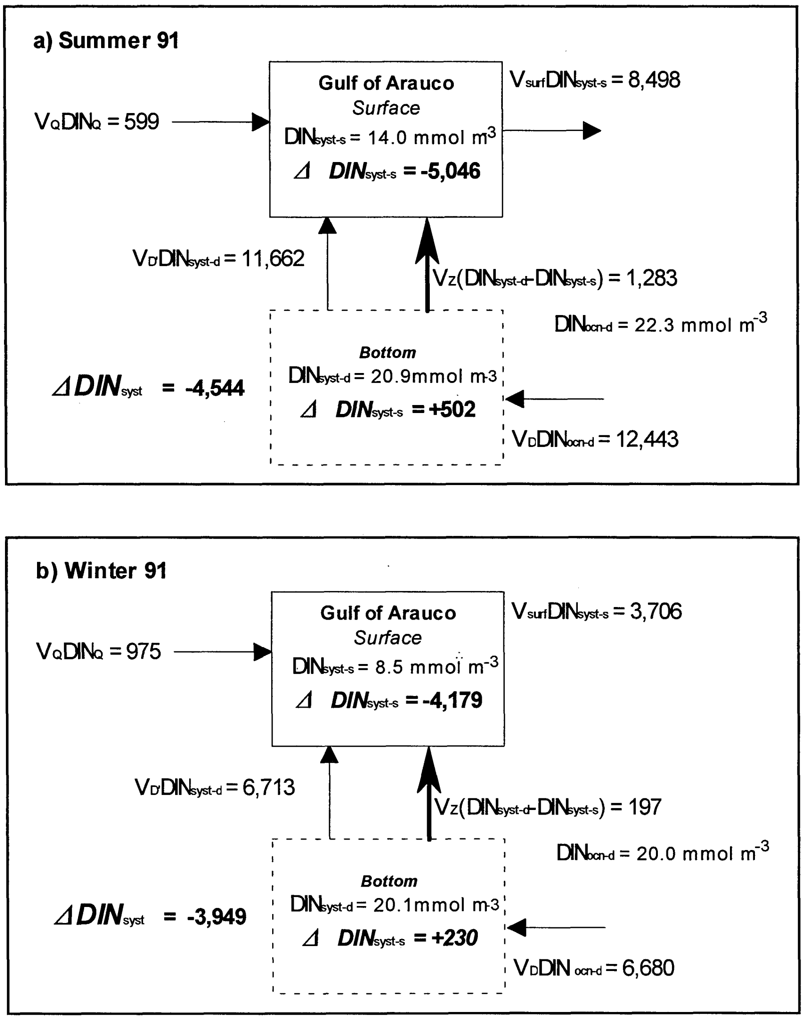


Figure 6.5. DIN budgets for the Gulf of Arauco during two contrasting seasons: a) Summer 1991 and b) Winter 1991. Fluxes in 10^3 mol day^{-1}.

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Appendix II Workshop Report

Welcome

Participants (Appendix I) were welcomed to Ensenada by Professor Victor Camacho-Ibar, on behalf of the Universidad Autonoma de Baja California, Ensenada, and meeting organisation and arrangements were reviewed. The terms of reference for the workshop (Appendix III) were reviewed and various working documents, electronic information and tutorial materials were distributed.

Introduction and Background

A round-table introduction of participants was made. LOICZ goals and approaches were presented by Prof. Steven Smith and emphasis was given to the central questions of evaluating material fluxes and, the influence of human dimensions on global changes in processes within the coastal zone. The purpose of the workshop was outlined within an overview presentation of the LOICZ budgeting and modeling approach for nutrient flux and net ecosystem metabolism of estuarine and coastal sea systems.

In an introductory tutorial, Dr Laura David provided participants with a description of the development and calculation of nutrient budgets models, including single box, stratified and multi-compartment assessments. A tutorial handbook (LOICZ Biogeochemical Budgeting Procedure: A Tutorial Pamphlet, prepared for the UNEP GEF project by the Marine Science Institute, University of the Philippines) was provided to all participants and supported the tutorial presentation.

Various tools developed by LOICZ to assist in estimating water and biogeochemical material inputs to systems were reviewed by Dr Laura David. Calculation parameters, location and access to the tools were identified and examples proved as case evaluations. Electronic versions of the biogeochemical budget calculation software (CABARET), waste load estimations, and river discharge evaluation were provided to participants.

Presentation of Biogeochemical Budgets

The contributing budgets brought by the participants were briefly considered, including an overview of the system settings, data availability and quality, approaches being taken to build budgets, and the status and problems in making the model assessments. System sites included:

Cienaga Grande de Santa Marta, Colombia
Guayas River estuary, Ecuador

Celestún Lagoon, México

Gulf of Arauco, Chile
Concepción Bay, Chile

Mar Chiquita Lagoon, Argentina

Conceição Lagoon, Brazil
Marapendi Lagoon, Brazil
Mundau-Manguaba lagoonal system, Brazil

Las Guásimas Lagoon, Mexico
Estero de Punta Banda, México

Budgets Development

Break-out groups worked interactively on the development of these site budgets, supplemented with methodological and site/issue-based tutorials and discussions. Estimates for sites, and budget model refinement emerged from resolution of techniques, application of derivative data and assessment of watershed information.

Plenary and discussion sessions were held throughout the workshop. These enabled review of the status of budgets development and discussion of key issues raised by participants.

Outcomes and Wrap-up

Budgets for all systems were developed to a final or interim draft stage of completion during the workshop; additions to text descriptions and a check on data sources were required by most budgets before final contribution. A schedule for contribution and publication of the printed and CD-ROM report, and posting to the LOICZ website, was agreed:

20 October	revised final budgets to Prof. Smith and Vilma Dupra
30 November	final budgets to IPO for LOICZ R&S preparation
15 January	draft R&S report to UNEP for comment
29 January	R&S to printer

Additional sites were identified for which data is available and which may yield budgets. Participants committed to making other site budgets, subject to data availability, and to participate in a mutual review process for budget descriptions.

The participants joined with LOICZ in expressing thanks to Professor Victor Camacho-Ibar and staff from the Universidad Autonoma de Baja California, Ensenada for support and hosting of a fruitful training and information workshop. The financial support of the Global Environment Facility was gratefully acknowledged.

Appendix III Terms of Reference

LOICZ-UNEP WORKSHOP ON ESTUARINE SYSTEMS OF THE LATIN AMERICAN REGION

25-26 April 2001
Instituto de Investigaciones Oceanologicas
Universidad Autonoma de Baja California
Ensenada, Mexico

Primary Goals:

To work with researchers dealing with estuarine and coastal systems of the Latin American region, in order to extract C, N, P budgetary information from as many systems as feasible using existing data. The Latin American systems include one of the major coastal regions of the world oceans Three earlier Latin American regional workshop have helped establish a number of biogeochemical models for sites, but there is both opportunity to extend this geographical coverage and a need to do so within the LOICZ context. The workshop provides the opportunity to characterize terrigenous inputs to the estuaries of the region, and outputs from the estuaries – hence, the net role of the estuarine zone of this region as a source or sink for carbon, nitrogen and phosphorus.

This workshop will complement earlier, successful workshops in Mexico (Central and South Americas: 1997, 1999, 2001), Australia (Australasia: 1998), Manila (South-East Asia: 1999), Argentina (South America: 1999), Goa (South Asia: 2000), Hong Kong (East Asia: 2000), Zanzibar (Sub-Saharan Africa: 2000), and Athens (Mediterranean and Black Seas: 2001).

Anticipated Products:

1. Develop budgets for as many systems as feasible during the workshop.
2. Examine other additional data, brought by the researchers, or provided in advance, to scope out how may additional systems can be budgeted over an additional 2 months.
3. Prepare a LOICZ technical report and a CD-ROM summarizing this information.

Participation:

The number of participants will be limited to fewer than 10 persons, to allow the active involvement of all participants.

Workplan:

Participants are expected to come prepared to participate in discussions on coastal budgets. Preparation should include reading the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), an earlier workshop report (see Dupra *et al.* on LOICZ web site), examination of the budgets and tutorials presented on the LOICZ Modelling web page (http://data.ecology.su.se/MNODE/), and arriving with preliminary budgets, electronic maps, and 1-3 page write-ups from "their sites." In order to be included in the workshop report, the budgets should conform as best possible to the budgeting protocol laid out in the above documentation. Guidelines for budget preparation and write-ups and a tutorial package entitled CABARET can (and should) be downloaded from the LOICZ Modelling web-site.

NOTE: Please try to conform to materials on that web-site as closely as possible, because this will greatly aid in report preparation. We anticipate structuring the workshop very strongly towards instruction and then working with individuals to complete budgets during the workshop.

Further Details:

At a minimum, each participant is expected to arrive at the workshop (or send in advance) the following materials:

1. A 1-3 page description of the area (see materials posted on the Web and in the various workshop reports) and a map of the site. These should be in electronic format.

2. Within the context of needs for the overall LOICZ project, some estimate of water exchange (most commonly via water and salt budgets) and budgets for the dissolved inorganic nutrients, nitrogen and phosphorus, constitute the minimum useful derivations from the biogeochemical budgeting. Budgets of other materials, while potentially interesting for other purposes do not satisfy this minimum requirement. The minimum data requirements are as follows:
    a. The primary seasonal pattern of the region is at least one wet season and one dry season per annum. Ideally, a budget for each season would be developed. If a system is vertically stratified, then a 2-layer budget is preferred over a single-layer budget. If a system has a strong land-to-sea salinity gradient, then it is preferable to break the system along its length into several boxes.
    b. Data requirements to construct a satisfactory water and salt budget include: salinity of the system and the immediately adjacent ocean, runoff, rainfall, evaporation, and (if likely to be important) inputs of other freshwater sources such as groundwater or sewage. Preferably, the salinity and freshwater inflow data are for the same time period (for example, freshwater inflow data for a month or so immediately prior to the period of salinity measurement). In the absence of direct runoff estimates for small catchments, estimations can be made from a knowledge of catchment area and monthly rainfall and air temperature for the catchment. See materials on the LOICZ biogeochemical modelling web site.
    c. Data requirements for the nutrient budgets are: concentrations of dissolved nutrients (phosphate, nitrate, ammonium, and if available dissolved organic N and P) for the system and the adjacent ocean, concentrations of nutrients in inflowing river water (and if important, in groundwater), some estimate of nutrient (or at least BOD) loading from sewage or other waste discharges. If atmospheric deposition (particularly of N) is likely to be important, an estimate of this is also useful. If direct waste load measurements are not available, estimations can be made from a knowledge of the activities contributing to the waste loads and the magnitudes of those activities. See the materials on the web site.

Workshop Schedule:

April 24: Arrival of participants

April 25: General introduction to the budgeting procedure and related issues; presentation of preliminary budgets. Breakout groups to revise, refine budgets. This will vary, as needed, from tutorial, through detailed help, to procedural discussions.

April 26: Continue breakouts; afternoon plenary to evaluate progress and develop synthesis.

April 28 to 2 May: Participants are expected to take part in the LOICZ-UNEP Americas – Regional workshop on typology and biogeochemical assessment

Background Documents:

1. Gordon, D.C. Jr., Boudreau, P.R., Mann, K.H., Ong, J.-E., Silvert, W.L., Smith, S.V., Wattayakorn, G., Wulff, F. and Yanagi, T. 1996 LOICZ Biogeochemical Modelling Guidelines. LOICZ Reports and Studies 5, LOICZ, Texel, The Netherlands, 96 pages.
2. Smith, S.V., Ibarra - Obando, S., Boudreau, P.R. and Camacho Ibar, V.F. 1997 Comparison of carbon, nitrogen and phosphorus fluxes in Mexican coastal lagoons. *LOICZ Reports and Studies* **10**, LOICZ, Texel, The Netherlands, 84 pages.
3. LOICZ Modelling web page, for everyone with www access:(http://data.ecology.su.se/MNODE/).

- The web pages, including the guidelines, are frequently updated. If you have not looked at them within the last two weeks, you should go through them again (for example, there are recent additions on estimation of runoff and estimation of waste loads).
- If you do not have access to the worldwide web but do have access to a computer with a CD-ROM, please let us know; we will send you a CD-ROM with the web page. Please do not request the CD-ROM at this time if you have access; you will be furnished one during the workshop.
- CABARET (Computer Assisted Budget Analysis, Research, Education, and Training). *Note*: a version of this software is available on the web-site.

8. ARCTIC REGION - 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.

This Workshop and the resulting report are contributions to the GEF-funded UNEP project: *The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles*, established with LOICZ and contributing to the UNEP sub-programme: "Sustainable Management and Use of Natural Resources". The training activities and outcomes of the Workshop also contribute to the LOIRA (Russian LOICZ) programme.

This Workshop is the ninth in a series of regional activities within the project and provides a first assessment of the functioning vital and fascinating polar systems. The stimulus for the workshop arose from the combined interests of Baltic Sea researchers under the leadership of Prof. Fred Wulff, Department of Systems Ecology, Stockholm University, Sweden and Russian arctic researchers from the Arctic and Antarctic Research Institute (AARI), St Petersburg, Russian Federation, contributors to LOIRA.

The Workshop was held at the Department of Systems Ecology, Stockholm University, Sweden, 9-11 September 2001. A summary of activities (Appendix II) and the terms of reference for the Workshop (Appendix III) are contained in this report.

The Workshop participants (Appendix I) developed and assessed biogeochemical budgets for five coastal systems, spending some time considering data quality and availability and particularly discussing the ramifications and constraints imposed by the strong seasonality in the Arctic region. The complex meteorological conditions influencing summer and winter states provided challenge in the consideration of nutrient inputs from landward sources (surface and ground waters), coastal sea and estuarine water masses and stratification regimes, and seasonal productivity. The biogeochemical budget information for sites shown in Figure 8.1 is discussed individually and reported in units that are convenient for that system (either as daily or annual rates).

Efforts were made to consider boundaries of systems and to nest the river estuary locations with a larger coastal sea geography. Attempts were made to include a wider assessment of the White Sea (inner and outer parts) and the related river systems. Incomplete data sets and variable data quality and location of sampling curtailed the attempt to construct a biogeochemical model assessment at a wider spatial scale for the White Sea. One sub-set estuarine system is described (the Chupa estuary) and current Russian field campaigns are expected to yield the requisite database to allow completion of the task.

The AARI group in St. Petersburg refined and further developed budgets for the Laptev Shelf Sea (which includes discharge from the Lena River and its delta system, Khatanga, Yana, Olenek and Anabar rivers) and the Kara Sea region (including the Ob and Yenisei rivers' discharge). Budgets for other Russian systems are expected to be posted on the LOICZ web-site when they are completed.

The Lulealven River estuary flowing in the Baltic Sea via Bothnian Bay has a rich database and the opportunity was taken to assess its biogeochemical function in terms of both the general LOICZ approach using dissolved inorganic N and P, as well as total N and P models.

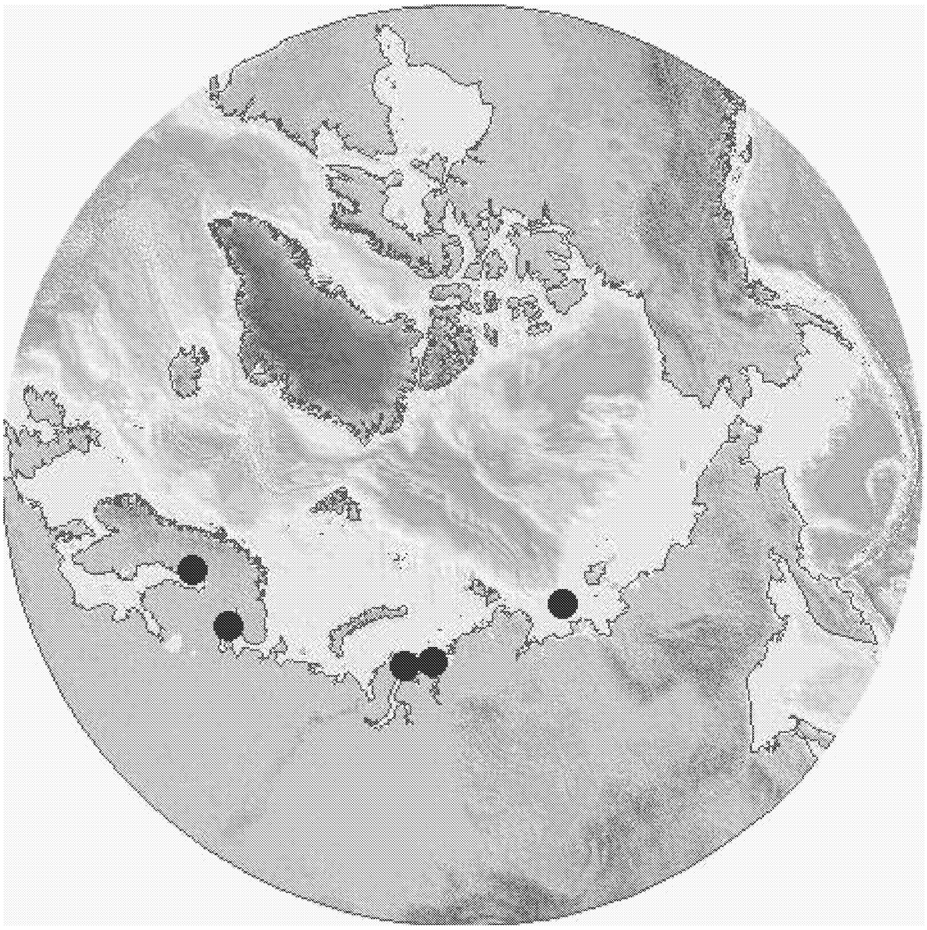

Figure 8.1 Map of the Arctic region showing seas and estuaries for which budgets are presented in this report.

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. These budgets, data and their wider availability in electronic form (CD-ROM, LOICZ web-site) will provide opportunities for further regional and global assessment, comparisons and potential use in evaluating patterns of coastal system responses to human pressures.

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 8.1 and 8.2).

The estuarine and shelf systems exhibit a wide range in size, N and P loads, metabolic performance but generally have low human impact. The systems are relatively shallow and show strong seasonality in metabolic performance and land inputs from surficial flows; groundwater flows are as relatively continuous. Nutrient inputs to the Arctic Sea systems were dominated by or significantly contributed to by ocean sources rather then land-based discharge; the Bothnian Bay estuarine system was more dominated by land-based N and P load, despite the virtual absence of human pressures. Generally net annual metabolic rates were in the low range and variable in sign, and showed summer-winter seasonal variability.

LOICZ is grateful for the support and efforts of Prof. Fred Wulff and the staff of the Department of Systems Ecology, Stockholm University, in hosting the Workshop and to the resource scientists for their contributions to the success of the Workshop. LOICZ particularly acknowledges the efforts of the participants and contributors for their continued interaction beyond the meeting activities.

Table 8.1 Budgeted regional sites for the Arctic region - locations, system dimensions and water exchange times.

System Name	**Long.** (E)	**Lat.** (+N)	**Area** (km^2)	**Depth** (m)	**Exchange time** (days)
Sweden					
Lulealven River estuary	22.2	65.8	50	20	9
Russian Federation					
Chupa River estuary (dry season only)	33.65	66.36	57	<65	24
Laptev Sea Shelf	110-140	71-78	475000	50	
- winter					15600
- summer					5900
Kara Sea					
- Ob Gulf	73.5	72.8	5635	15	208 (w), 96 (s)
- Yenisei Gulf	79.85	72.75	19950	25	907 (w), 377 (s)

(w) = winter, (s) = summer

Table 8.2. Budgeted regional sites for the Arctic region: loads and estimated (*nfix-denit*) and (*p-r*).

System	**DIP load**	**DIN load**	**ΔDIP**	**ΔDIN**	**(*nfix-denit*)**	**(*p-r*)**
	mmol m^{-2} yr^{-1}					
Sweden						
Lulealven River estuary	24	1292	34	985	475	-3650
Russian Federation						
Chupa River estuary (dry season only – values extrapolated to annual)	1	5	-23	-160	22	2445
Laptev Sea Shelf	<1	1	-0.5	-6.5	2	57
Kara Sea						
- Ob Gulf	18	72	40	185	-447	-4380
- Yenisei Gulf	5	94	-3	-38	6	320

9. ESTUARIES OF THE BALTIC SEA

9.1 Luleälven estuary: a well-monitored subarctic estuary importing nitrogen from Bothnian Bay

Christoph Humborg

Study area description

The southern part of the Baltic Sea is nutrient-enriched due to increased human-induced nutrient loads, while oligotrophic conditions are found in the northernmost basins of the Baltic Sea, including Bothnian Bay (Figure 9.1, Hagström *et al.* 2001). The basin of Bothnian Bay has an average depth of 43 m. Because of its northern location, Bothnian Bay freezes over every winter. In spring and autumn, the entire water column turns over as a consequence of spring warming and autumn cooling. This promotes high oxygen concentrations down to the sediments throughout the year in most parts of the basin (HELCOM 1996). Saline waters enter Bothnian Bay from the Bothnian Sea over a shallow sill at ~20m depth. Average salinity in the open Bothnian Bay is only 3.5 psu.

Ecosystem types within most river catchments flowing into the Bothnian Bay can be classified as arctic alpine and northern boreal (www.grida.no). Most of the catchment area of Bothnian Bay is sparsely populated. Nutrient emissions are generally low with practically no agricultural activities in the catchment. Hydrological alterations, i.e., river dams, are the most obvious human impact within most river systems of the northern Baltic Sea (Humborg *et al.* 2000).

The most intensively studied estuary of the Bothnian Bay is the Luleälven estuary (see area indicated in Figure 9.1), where a total of 21 quasi-synoptical surveys, each covering 16 stations, were carried out in 1976 (Wulff *et al.* 1976). The Luleälven represents the most intensively dammed river in Eurasia with 72% recorded live storage (Dynesius and Nilsson 1994). The dammed rivers of the northern Baltic Sea have a water discharge more evenly distributed over the year (Carlsson and Sanner 1994). One might argue that this river is heavily dammed, and that nutrient concentrations are therefore lower than in undammed rivers (Humborg *et al.* 2000). However, the pristine Torneälven and Kalixälven rivers (Figure 9.1) show similar nitrogen and phosphorus concentrations as the Luleälven (Humborg, unpublished data). All rivers draining into Bothnian Bay are extremely oligotrophic with mean DIP concentrations of about 0.1 mmol m^{-3}. Thus, the Luleälven estuary can be expected to behave differently from well-studied nutrient-enriched estuaries of the southern Baltic.

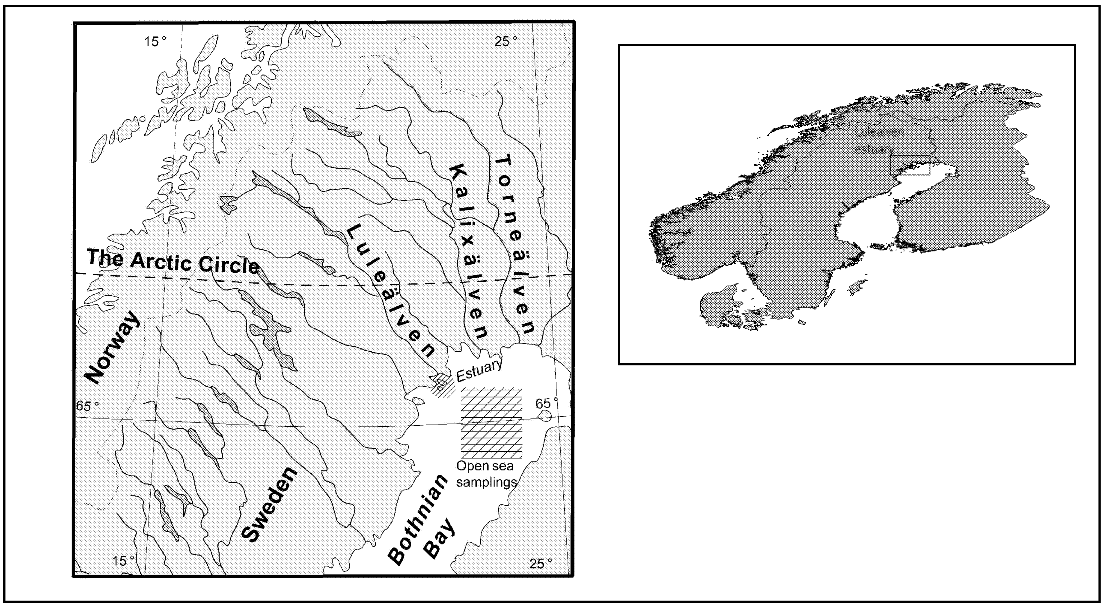

Figure 9.1. Location of Bothnian Bay and the Luleälven River and estuary. Sampling sites are indicated as hatched.

The Luleälven drains into a shallow archipelago-type estuary (Figure 9.1). The area of the estuary is about 50 km^2; the volume about $1x10^9$ m^3. The mean depth is about 20 m; the maximum depth is indicated as 24 m. The estuary is separated from Bothnian Bay by a shallow sill at 12 m depth. The community of Luleå, situated at the river mouth, contributes about $1.5x10^3$ mol day^{-1} TP and $65x10^3$ mol day^{-1} TN emissions, respectively (HELCOM 1996).

River nutrient concentrations have been measured monthly at the Luleälven river mouth since 1970 by the Swedish University of Agricultural Sciences, Uppsala, Sweden (http://www.slu.se). Data for the period 1970-2000 have been used to derive mean nutrient values for the Luleälven.

The Baltic Environmental Database (Sokolov and Wulff 1999) was used to extract estuarine nutrient measurements and salinity data as well for the calculation of long-term nutrient concentrations in the open sea. This database (http//:data.ecology.su.se/models/BEDonWeb) holds long-term monitoring and scientific data from all riparian countries. Mean monthly concentrations in the open sea were calculated from main monitoring stations sampled within the frame of the HELCOM programme. HELCOM stands for the "Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area". Since 1972 water samples for environmental variables are frequently analysed for various monitoring stations all over the Baltic Sea, as part of this programme.

A total of 416 water column samplings for Bothnian Bay (see hatched area indicated in Figure 1) for the period 1970-2000 were considered; for the Luleälven estuary a total of 336 water column samples were considered, all sampled in 1976.

To calculate the fluxes of water, salt and non-conservative constituents the one layer approach was adopted (Gordon *et al.* 1996).

Water and salt balance

Due to the relatively small area of the estuary and the neglect of groundwater inflow, freshwater inflow was dominated by the Luleälven River, which appears to be equally distributed over the year (Figure 9.2). Salinity in the Luleälven estuary is about half that in the Bothnian Bay, probably due to the existence of the sill. Exchange flux (V_X) is about 60% higher than residual flux (V_R). Seasonal variations in salinity in the estuary and in the Bothnian Sea were minor so no major seasonal variations in exchange fluxes have been calculated (Table 9.1). Annual water exchange time is about 9 days.

Table 9.1. Water fluxes (in 10^6 m^3 day^{-1}) and water exchange times for Luleälven estuary system.

	Values
Winter (8 months)	
River discharge (V_Q)	45.4
Residual flow (V_R)	-45.6
Mixing volume (V_X)	71.2
Water exchange time (τ, *days*)	9
Summer (4 months)	
River discharge (V_Q)	38.3
Residual flow (V_R)	-38.5
Mixing volume (V_X)	62.8
Water exchange time (τ, *days*)	10
Annual	
River discharge (V_Q)	43.0
Residual flow (V_R)	-43.2
Mixing volume (V_X)	68.4
Water exchange time (τ, *days*)	9

Budgets of nonconservative materials

DIP and TP balance

The DIP budgets (Figure 9.3) show that the Luleälven estuary system exports DIP in excess of the load to it. This means that the system produces DIP of about 60% (4.4x10^{3} mol day^{-1}) of the total DIP export (7.7x10^{3} mol day^{-1}). The DIP export to the Bothnian Bay is 50% of the TP exports. The DIP budgets show that the DIP release within the estuary even exceed the TP release, which theoretically is not possible (Table 2). However, the DIP concentrations (Figure 9.3) were very low in all three systems (river, estuary, Bothnian Bay) throughout the seasons, so that these low values close to the detection limit might bias these calculations.

The Luleälven estuary releases about 0.7x10^{3} mol day^{-1} TP (Table 9.2; Figure 9.4), indicating a phosphorus source. According to these budgets all phosphorus entering the Luleälven estuary essentially leaves the system, showing that this subarctic estuary is not an effective sink for phosphorus.

Table 9.2. Nitrogen and phosphorus fluxes (10^{3} mol day^{-1}) in the Luleälven estuary system estimated from budget calculations. Minus sign denotes an outflow from the system.

	DIP	DIN	P total	N total
Winter (8 months)				
Discharge (river, atm. & point)	3.2	204	15.1	682
Residual flow ($V_R Y_R$)	-3.6	-290	-10.7	-798
Exchange flow [$V_X(Y_{ocn}-Y_{syst})$]	-4.3	-50	-5.0	370
ΔY	4.7	136	0.6	-254
Retention factor	-1.5	-0.7	-0.04	0.2
Summer (4 months)				
Discharge (river, atm. & point)	3.4	123	18.4	716
Residual flow ($V_R Y_R$)	-2.9	-202	-10.4	-683
Exchange flow [$V_X(Y_{ocn}-Y_{syst})$]	-4.4	-57	-8.8	82
ΔY	3.9	136	0.8	-115
Retention factor	-1.1	-1.1	-0.04	0.1
Annual				
Discharge (river, atm. & point)	3.3	177	16.2	693
Residual flow ($V_R Y_R$)	-3.4	-261	-10.6	-760
Exchange flow [$V_X(Y_{ocn}-Y_{syst})$]	-4.3	-52	-6.3	274
ΔY	4.4	136	0.7	-208
Retention factor	-1.3	-0.8	-0.04	0.2

DIN and TN balance

The DIN concentrations were lower in the river than in the estuary, but were higher than in the bay, indicating significant transformation processes in the estuary. In fact, as with DIP, the estuary exports more DIN than it receives from the river (about 80% more than the inputs; Table 9.2; Figure 9.6). The Luleälven estuary exports DIN to the open Bothnian Bay. According to these budget calculations about 14% (136x10^{3} mol day^{-1} DIN) of the TN inputs (967x10^{3} mol day^{-1} TN) is remineralized and not denitrified or buried, but exported.

Total nitrogen concentrations (TN) increased from the river over the estuary to the sea, indicating that the Luleälven estuary is importing TN from the Bothnian Bay. The budget calculations revealed that about 63, 28, 7 and 2% of the TN inputs came from the river, the sea, the community of Luleå and the atmosphere, respectively. About 20% of these TN inputs are retained in the estuary with a higher retention factor during winter (Table 9.2; Figure 9.5).

Stoichiometric calculations of aspects of net system metabolism

Table 9.3 presents the net system metabolism of Luleälven estuary calculated from the nonconservative fluxes of DIP and DIN using the Redfield ratio of C:N:P (106:16:1). The system seems to behave as net heterotrophic and net nitrogen-fixing.

Table 9.3. Nonconservative fluxes and net system metabolism for in the Luleälven estuary system.

	ΔDIP	*ΔDIN*	*(p-r)*	*(nfix-denit)*
	(mmol m^{-2} day^{-1})			
Winter (8 months)	+0.09	+2.7	-10	+1.3
Summer (4 months)	+0.08	+2.7	-9	+1.4
Annual	+0.09	+2.7	-10	+1.3

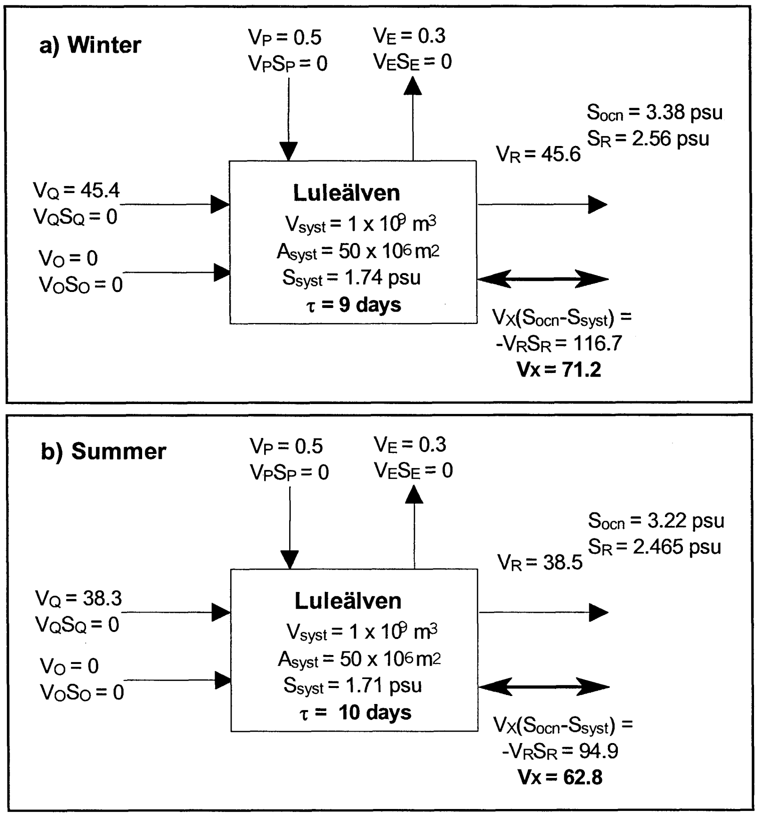

Figure 9.2. Major components of the water and salt budgets of the Luleälven estuary. Water flux in 10^6 m^3 day^{-1} and salt flux in 10^6 psu-m^3 day^{-1}.

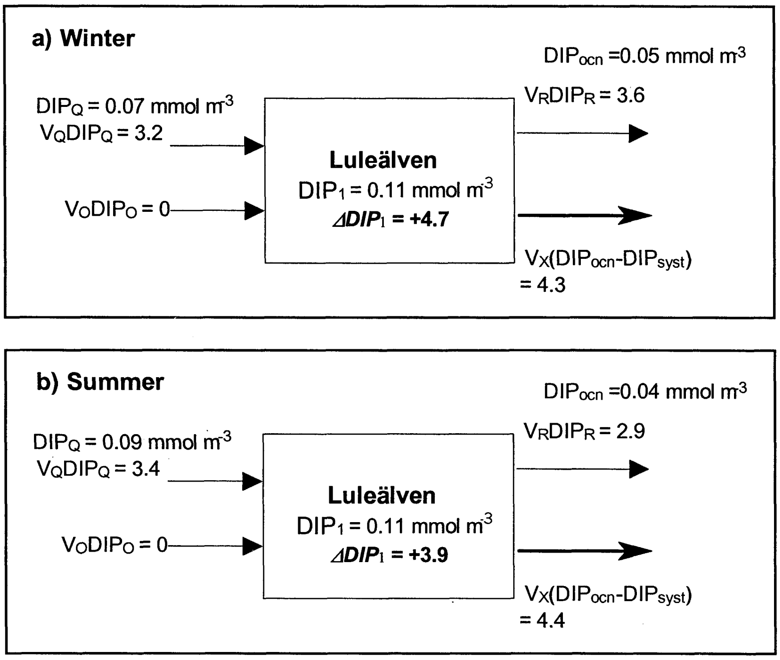

Figure 9.3. Major components of the dissolved inorganic phosphorus (DIP) budget of the Luleälven estuary. Flux in 10^3 mol day^{-1}.

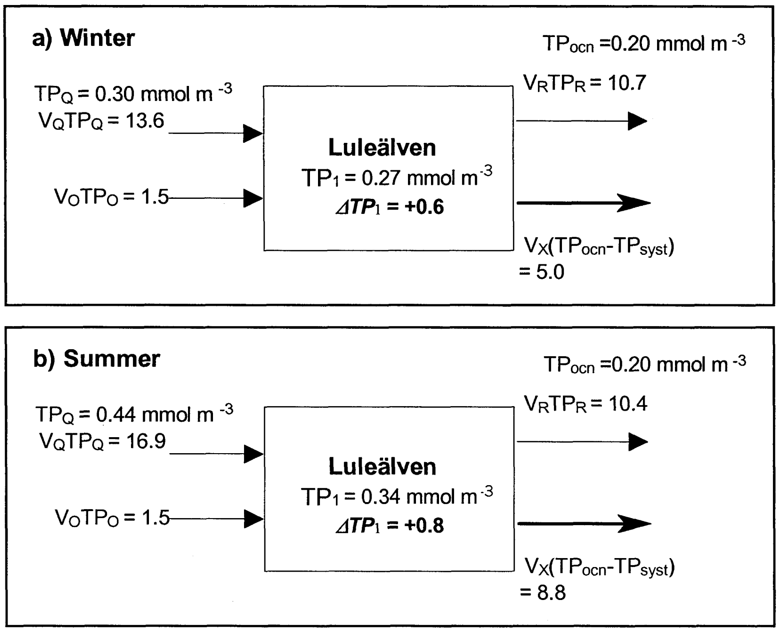

Figure 9.4. Major components of the phosphorus (TP) budget of the Luleälven estuary. Flux in 10^3 mol day^{-1}.

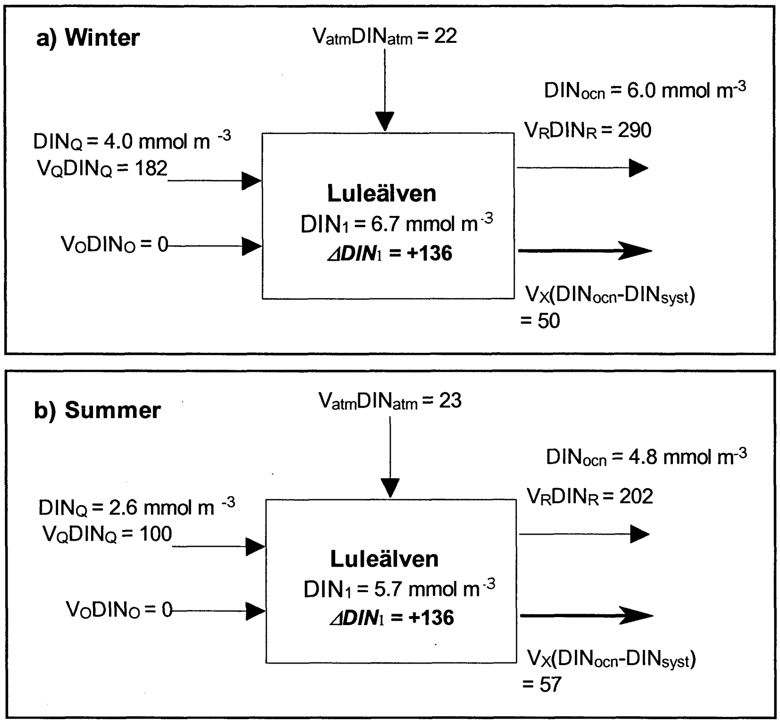

Figure 9.5. Major components of the dissolved inorganic nitrogen (DIN) budget of the Luleälven estuary. Flux in 10^3 mol day^{-1}.

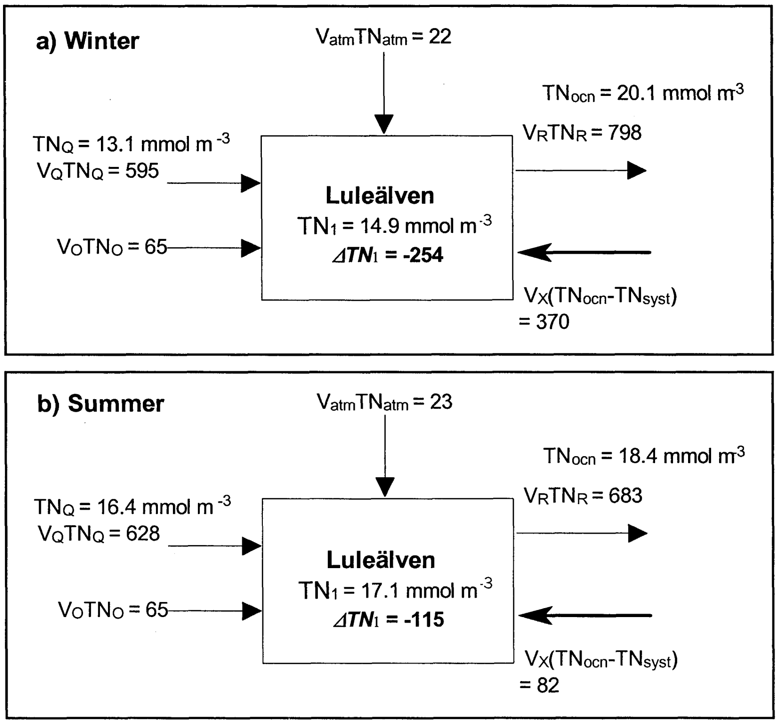

Figure 9.6. Major components of the nitrogen (TN) budget of the Luleälven estuary. Flux in 10^3 mol day^{-1}.

10. ESTUARIES OF THE RUSSIAN FEDERATION

10.1 The Chupa estuary (White Sea) during the dry season: nutrient and oxygen budgets

Ricardo Prego and Andrew W. Dale

The importance of the smaller Arctic estuaries to the hydrology and biogeochemistry of the Arctic Seas remains to be fully investigated. The generalised concepts of estuarine biogeochemistry fashioned from extensive studies of temperate zone estuaries may be not applicable to Arctic areas, and thus specific studies of these estuaries are required. The Chupa estuary provides a good example of such a system.

Study area description

The Chupa estuary (66.36°N, 33.65°E; Figure 10.1) is the largest estuary in Kandalaksha Bay (the White Sea), with a length of 37 km, average width of 1 km and an overall area of 57 km^2. Freshwater input to the Chupa mainly originates from the Chupa River at the estuary head and the Pulonga River situated mid-estuary. Two deep basins (65 m depth) in the Chupa are connected by a sill (25 m depth) about 7 km long. Thus, the Chupa is a fjord-type estuary (Farmer and Freeland 1983) but without the steep coastal profile generally associated with fjords. The city of Chupa (population 6,000) is situated near the head of the estuary and local industry on the coast includes an active China clay works (Figure 10.1, near Station 9) and two disused muscovite mines (near stations 2 and 6, Figure 10. 1).

The tidal range in Chupa estuary varies between 1.7 m at springs and 0.7 m at neaps. Therefore, the brackish water exchange at the mouth of the estuary is dominated by the residual circulation due to freshwater contributions. Since river discharge into the White Sea is controlled by meteorological conditions (Timonov 1950), three seasons may be defined: (a) winter from November to April when the sea surface is usually covered with ice (Klenova 1966); (b) the thaw season (spring) from May to July when the river flow is highest (Gordeev 2000); and (c) the dry season from August to October when the river flow decreases to the winter levels.

A salt-water budget following the LOICZ modelling guidelines (Gordon *et al.* 1996) can be used to quantify the flows and the subsequent nutrient exchange across the Chupa-Kandalaksha boundary. Initially, however, an estimate of freshwater contribution must be calculated, which is complicated during the winter since the bays and estuaries of the White Sea are ice-covered, thus limiting freshwater runoff. Further complications arise during spring when ice-melt brings a short period of extreme flow when freshwater inputs occur along the entire coast of the estuary. Therefore, the most appropriate conditions for modelling occur when there is no ice along the estuarine margin, that is to say, during the dry season.

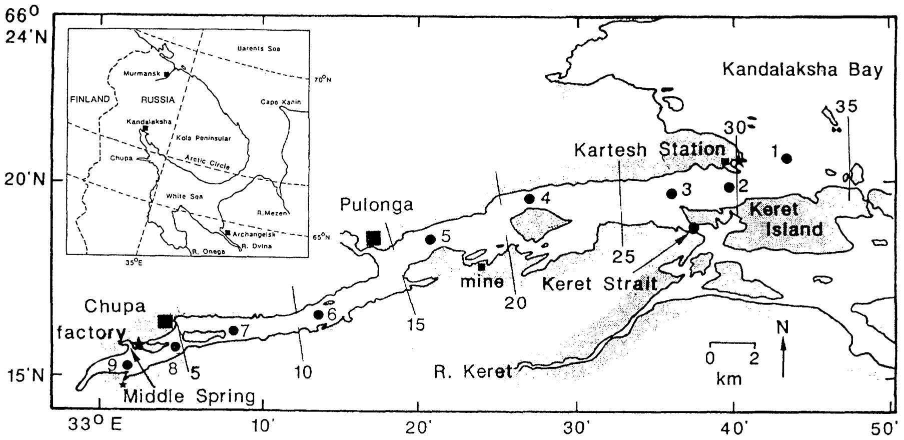

Figure 10.1. Location and map of the Chupa estuary.

A survey was carried out in September 1995 on the R/V "Professor Vladimir Kuznetzov" during spring and neap tidal states, and consisted of axial transects with vertical profiling at nine fixed stations along the estuary with moored diurnal stations at key points. Measurements were made of salinity and temperature (EPM 2000), current speed and direction (BFM 108 MkII), dissolved oxygen (Winkler method as described by Aminot 1983) and nutrients (Hansen and Grasshoff 1983) every 5 m from the surface to the bottom.

Water, salt, dissolved oxygen and nutrient budgets

Before application of the LOICZ budget to the Chupa estuary during the dry season, the estuarine hydrography must be considered.

The Chupa is a fjord-type estuary with a three-layer vertical structure observed at Station 2 in the estuary mouth (Howland *et al.* 1999) where there is a comparatively free connection with Kandalaksha Bay via the Kartesh mouth (1,760 m wide and 65 m depth). The thin, fresh and warm surface layer (0-8 m) and the deep layer below the sill depth (25-65 m) provide residual down-estuary water transport. On the other hand, the intermediate layer (8-25 m) drives residual up-estuary transport. In view of the fact that the resolution of the current meter is measured in cm sec^{-1}, the error in the residual current direct calculation is high, and therefore a salt-water balance is considered here. The salinity flows considered are those of the two upper layers (0-25 m depth), since the deeper flux can be ignored due to low residual currents (Howland *et al.* 1999) and the section is narrow and faces a sill of 25 m depth. The influence of the Keret River near the Chupa estuary mouth can also be ignored due to the small brackish water exchange through Keret Strait over most of the water column (Howland *et al.* 1999), since the connection is narrow (500 m width, 36 m depth) and currents are approximately 30% of those at Kartesh mouth.

The freshwater nutrient flux to the Chupa estuary originates from the Chupa and Pulonga rivers. There is no historical flow data of freshwater inputs, although on-site estimates during the fieldwork amount to 3 and 7 m^3 sec^{-1}, respectively. Nutrient and oxygen concentrations are summarized in Table 10.1.

Table 10.1. Water flow, dissolved oxygen and nutrient concentrations for freshwater inputs in Chupa estuary.

Flow (10^6 m^3 day^{-1})	**Oxygen** (mmol m^{-3})	**Nitrate** (mmol m^{-3})	**Nitrite** (mmol m^{-3})	**Phosphate** (mmol m^{-3})	**Silicate** (mmol m^{-3})
0.9	348-369	0.81	0.04	0.21	26.9

To quantify the Chupa-Kandalaksha exchange at the Kartesh mouth, the physico-chemical parameters were first averaged from three-hourly results over a single tidal cycle. The variability of the parameters over this time-frame was low. Employing the measured residual current depth separation of 7.5 m, the calculated concentrations at the mouth are presented in Table 10.2.

Table 10.2. Salinity, dissolved oxygen and nutrient concentrations of outgoing and incoming flow at the mouth of the Chupa estuary.

Flux	Depth (m)	Section area (m^2)	Salinity (psu)	Oxygen (mmol m^{-3})	Nitrate * (mmol m^{-3})	Phosphate (mmol m^{-3})	Silicate (mmol m^{-3})
outgoing	0.0 - 7.5	12,500	25.511	312.7	0.60	0.92	3.48
incoming	7.5 - 27.5	23,500	26.166	306.6	1.31	1.04	3.68

* *Nitrate plus nitrite*

There are insufficient salinity, nutrient and current data to resolve the vertical exchange within the estuary, and so only the exchange at the Chupa-Kandalaksha trough at Kartesh is quantified. The water-salt budget (Prego and Fraga 1992; Gordon *et al*., 1996) allows calculation of the residual water flow and the oxygen and nutrient (nitrate plus nitrite, phosphate and silicate) fluxes in the Chupa estuary (Figures 10.2-10.6).

The estuary volume is estimated as 839×10^3 m^3 and, consequently, the Chupa water exchange time is 24 days under dry season conditions. Nonconservative fluxes for DIP, DIN, dissolved oxygen and silicate are -3.6, -25, +167 and -28 $\times10^3$ mol day^{-1}, respectively.

Stoichiometric linkage and discussion

The nutrient-poor Chupa and Pulonga rivers contribute only 3% and 6% to the nitrate and phosphate budget, respectively, and thus the Kandalaksha Bay seawater is the main nutrient source. However, the relatively high concentrations of silicate in the freshwater input almost equal the estuary budget for diatomic frustule building. In the dry season, inorganic nitrogen is the limiting nutrient and the incoming phosphate and silicate are returned to the bay. These results agree with the concept of the relatively pristine nature of the Chupa and therefore its role as a vital baseline for comparative biogeochemical studies of Arctic estuaries (Prego and Howland 2000).

Stoichiometric linkages using the Redfield C:P ratio (106:1) and the phosphate budget permit an estimate of production minus respiration [(*p-r*) or net ecosystem metabolism] in the Chupa of +6.7 mmol C m^{-2} day^{-1}or +80 mgC m^{-2} day^{-1}. This dry season value falls within the range of primary production measured in the White Sea during summer (71-117 mgC m^{-2} d^{-1}) and October (49-98 mgC m^{-2} d^{-1}) by Naletova *et al.* (1994) and Fedorov and Bobrov (1977), respectively.

The N:Si relationship, demonstrated to be 15:16 by Richards (1958), was 0.90 in the Chupa budget, illustrating the fact that phytoplanktonic activity was dominated by diatoms. This may be expected when the silicate concentration in the water column exceeds 2 mmol m^{-3} (Egge and Aksnes 1992) and may be typical for Kandalaksha Bay where diatom proliferations have been observed in summer (Beklemishev *et al.* 1975).

The N:P ratio of 7:1 in the Chupa is lower than the Redfield value of 16:1. Following the LOICZ protocol (Gordon *et al.* 1996), denitrification can be calculated as:

$$(nfix\text{-}denit) = -25.0 - [(-3.6)\times16] = +32.6\times10^3 \text{ mol N day}^{-1}$$

Accordingly, net nitrogen fixation equals +0.6 mmol N m^{-2} day^{-1} or 0.35 mg N m^{-2} h^{-1} in the Chupa estuary. Nevertheless, our estimation of nitrification must be interpreted with caution since nutrient depletion can vary from N:P 3:1 to 30:1 depending on nutrient availability (Ryther 1969) and, in addition, other inorganic processes may affect the phosphorus cycle (Prego 1993). Furthermore, there is no data for ammonium, although concentrations are likely to be low due to high oxygen levels in Chupa (>87% saturation throughout).

Net ecosystem metabolism in the Chupa Estuary amounts to 500×10^3 mol O_2 day^{-1} or 5.8 mol O_2 sec^{-1} using stoichiometric linkage considering the RKR photosynthesis equation (Murray 1992), where C:O_2 is 106:138. According to the budget, there is a nonconservative dissolved oxygen flux of $+167\times10^3$ mol O_2 day^{-1} or 1.9 mol O_2 sec^{-1}. The discrepancy may be explained by the absence of an atmospheric exchange correction for O_2 and a possible sink of to the third (bottom) layer of the estuary. There is also a possiblity of an overestimation of NEM as a result of uncorrected DIP adsorption.

The biogeochemical fluxes obtained are summarised in Figure 10.7.

Acknowledgement

The authors wish to express our gratitude to INTAS for their support under the projects "Mesoscale physical and biogeochemical processes in the Russian Arctic, ref. 97-1881 and "Arctic Interdisciplinary Estuarine Study", ref. 1010-CT93-0019.

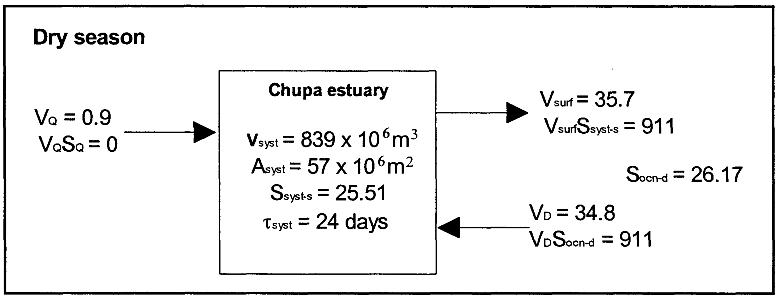

Figure 10.2. Water and salt budgets for the Chupa estuary in the dry season. Water flux in 10^6 m^3 day^{-1} and salt flux in 10^6 psu-m^3 day^{-1}.

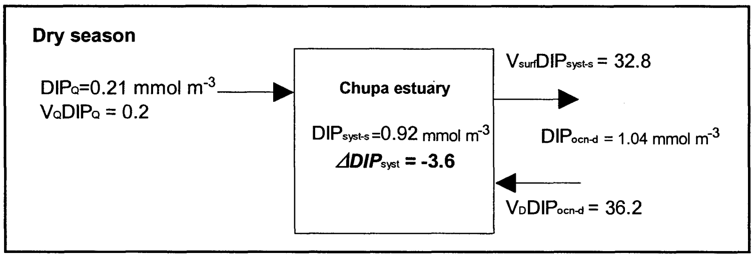

Figure 10.3. DIP budget for the Chupa estuary in the dry season. Flux in 10^3 mol day^{-1}.

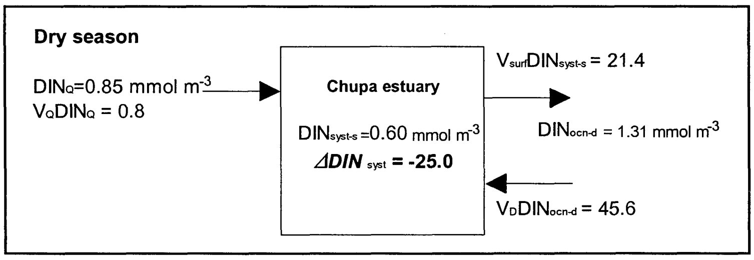

Figure 10.4. DIN budget for the Chupa estuary in the dry season. Flux in 10^3 mol day^{-1}.

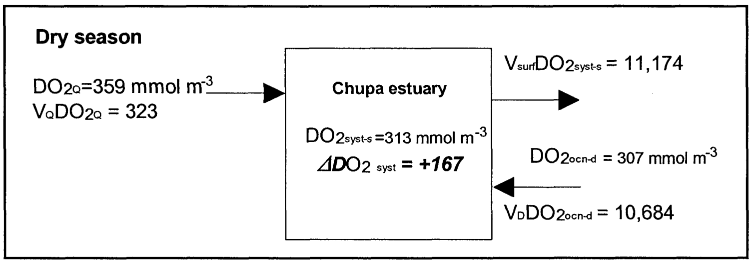

Figure 10.5. Dissolved oxygen budget for the Chupa estuary in the dry season. Flux in 10^3 mol day^{-1}.

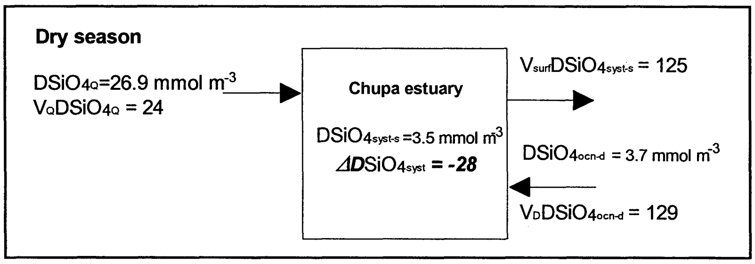

Figure 10.6. Silicate budget for the Chupa estuary in the dry season. Flux in 10^3 mol day^{-1}.

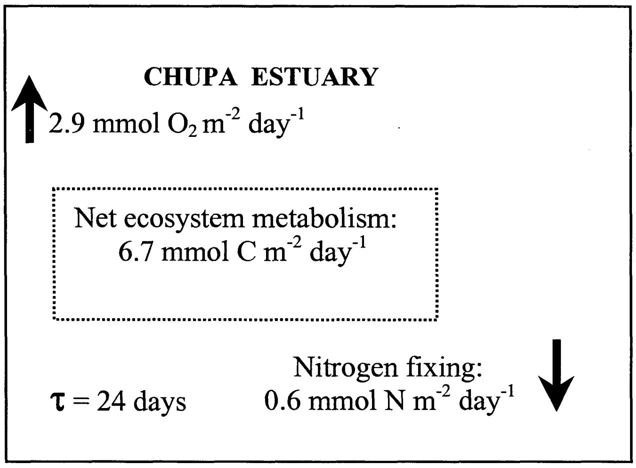

Figure 10.7. Biogeochemical fluxes for the Chupa estuary in the dry season.

10.2 The Ob and Yenisei Gulfs, in the Kara Sea

A. Novikhin

Study area description

The Kara Sea is one of the largest of the peripheral shelf seas of the Arctic Ocean. Most of the sea is located on the shallow Siberian shelf. Except for the two canyons at the north and the East Novaya Zemlya Trough, depths are less than 200 m (The Atlas of the Arctic 1985). Complex seabed surface relief, indentations of the shoreline and numerous islands determine the water column structure, hydrological and hydrochemical regimes of the Kara Sea.

The Kara Sea, located within the Polar Circle, is influenced by the Arctic Ocean from the north and the Asian continent from the south. Climatic conditions are severe and the sea is covered by ice during most of the year. Total solar radiation is 2,700-3,000 MJ m^{-2} yr^{-1} (The Atlas of the Arctic 1985). About 50% of the total radiation occurs in May-June, but about 60% of the radiation is reflected to the atmosphere because of the high albedo of snow and ice.

One of the remarkable features of the Kara Sea is receipt of a large continental runoff, with a volume of about $1,350\text{x}10^9$ m^3 $year^{-1}$ (Ivanov 1976), or about 41% of total river runoff into the Arctic seas. Such a huge amount of warm fresh water has great significance for the hydrological, hydrochemical and biological regimes in the coastal regions as well as in the Arctic Basin. Moreover, the river runoff contributes 76% of the sediment to the Kara Sea. Several big rivers (including the Ob, Yenisei, Pyasina, Pur and Taz) and many small rivers flow into the Kara Sea. The Ob and Yenisei rivers are two of the largest rivers in Russia. Most suspended matter enters the Kara Sea from river runoff and coastal erosion. The rivers transport more than 150 million tonnes of suspended and dissolved organic and inorganic matter to the sea every year (Ivanov 1976). The associated additional nutrient influx plays an important ecological role, because it stimulates primary production. The river runoff is the main source of organic matter for the Kara Sea sediments as well as for plankton and benthic organisms.

The Ob River estuary

The Ob River is the third largest river in Russia, after the Yenisei and Lena rivers, in terms of water discharge. Its length is 3,650 km (or, combined with the Irtysh River, 5,410 km). The Ob River catchment area is $2,990\text{x}10^9$ m^2. Snow and rain are the main water sources. The average annual runoff of the Ob River is $395\text{x}10^9$ m^3. Total flow of fresh water into the Ob Gulf is $553\text{x}10^9$ m^3 $year^{-1}$(Ivanov 1991). Most of the river runoff takes place in spring and summer, and contributes more than 75% of the total annual runoff. Annual discharge of suspended matter is about $16\text{x}10^6$ tonnes, and total annual solid discharge is about $50\text{x}10^6$ tonnes (Suzdalsky 1974). The average annual discharge of silicate, for the period 1955 to 1974, was about $2\text{x}10^6$ tonnes.

The Ob Gulf (72.80° N, 73.50° E, Figure 10.8), the estuary of the Ob River, is 800 km long and its surface area is 40,800 km^2. It forms a common estuary system with the Tazovskaya Gulf. The maximum width of the Ob Gulf is 95 km (between Cape Shaitansky Nos and Shokalsky Island). The minimum width is 35 km (between Cape Kamenny and Cape Parusny). The average depth of the Gulf is 12 m. The maximum depth is in the northern region of the Ob Gulf , 20-25 m (The Atlas of the Arctic 1985; Stanovoy and Nøst 2001). The area of the budgeted region of the Ob Gulf is 5,635 km^2. The average depth of this region is 15 m.

The Ob Gulf is the natural settling basin for the matter contributed by river runoff. However, the northern part of the Gulf can be considered separately as a transition zone.

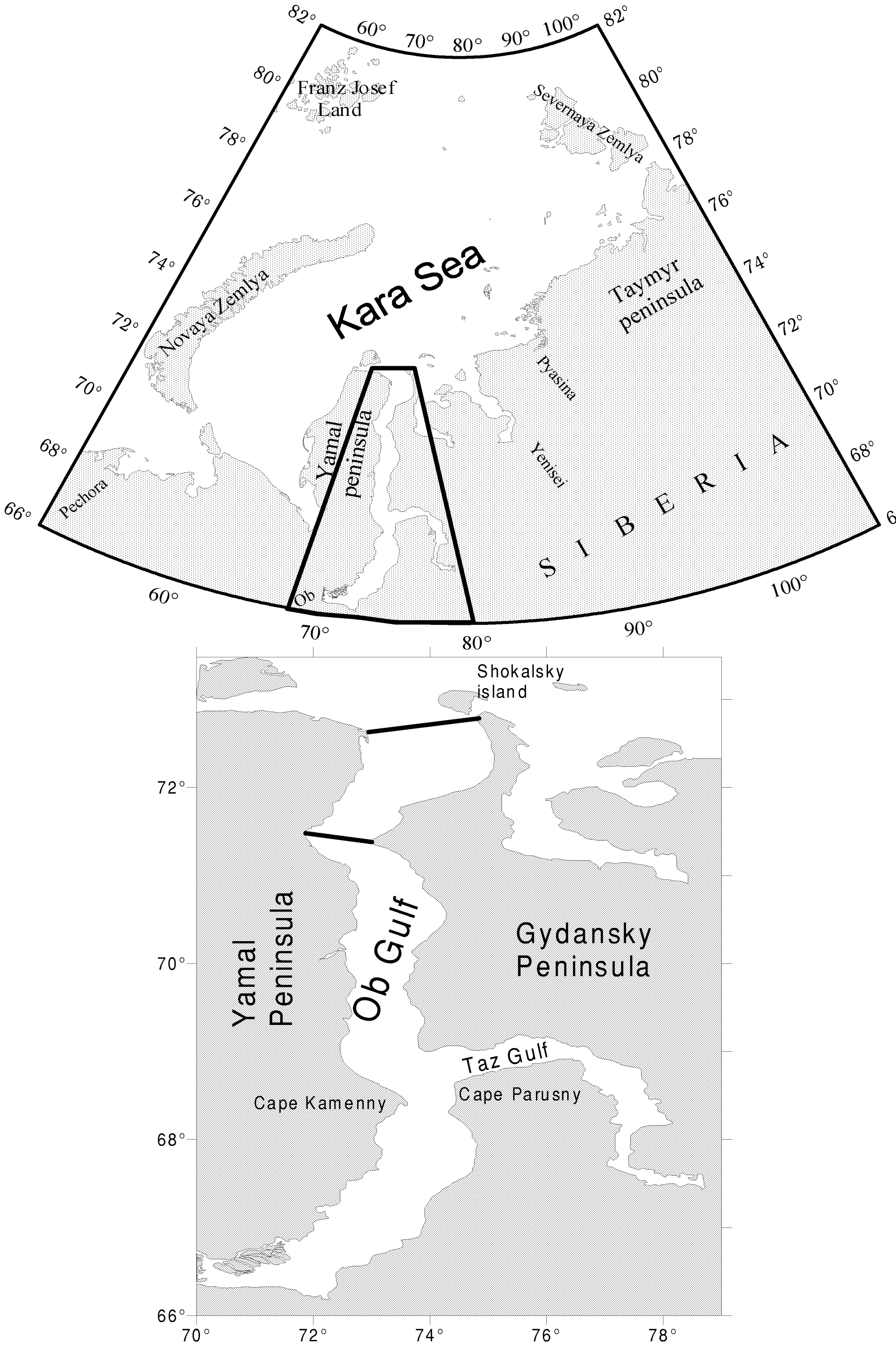

Figure 10.8. The study area in the Ob Gulf.

Total annual precipitation is 400 mm yr^{-1} in this region, increasing a little from north to south. The mean evaporation is about 350 mm yr^{-1} (Soviet Arctic 1970; Doronin 1986).

The maximum tidal amplitude is 0.25-0.30 m at the exit to the sea in summer, but southward along the gulf the amplitude increases up to about 10 m in response to decreasing depth and width of the system. In winter, wind-driven oscillations are high in the northern part of the Gulf (0.7-0.8 m) because of the polynya. The height of the tidal wave changes from 0.25-0.30 m in the southern part of the Gulf to 1.80 m in the northern part of the Gulf near the western coast. The tides are semi-diurnal (Stanovoy 1985; Stanovoy 1997).

Water and salt balance

The input model data is presented in Table 10.3. River runoff DIP and DIN concentrations are from Bryzgalo and Ivanov (2000), groundwater discharges from Gordeev *et al.* (1999). DIP and DIN concentrations for the study region were taken from electronic database (Hydrochemical Atlas of the Arctic Ocean 2001) with using of the ODV software (Schlitzer 2000). Figure 3 shows the water and salt budgets in the northern part of the Ob River estuary during summer (July-September) and winter (October-June). Freshwater inputs include precipitation, the Ob River discharge and groundwater inputs. The mean salinity of the northern part of the Ob Gulf is 5.5 psu in the upper layer and 16.5 psu in the bottom layer in summer, and 5.5 psu and 17.4 psu in winter.

Table 10.3. Mean fluxes, salinity and nutrients data for the Ob Gulf.

	Surface		**Bottom**	
	Summer	Winter	Summer	Winter
System area (km^2)	5,635			
Layer depth (m)	10		15	
Number of months per season	3	9	3	9
Precipitation (10^6 m^3 day^{-1})	10	12	0	0
Evaporation (10^6 m^3 day^{-1})	-3	0	0	0
River discharge (10^6 m^3 day^{-1})	1,130	380	0	0
Groundwater (10^6 m^3 day^{-1})	53	160	0	0
Salinity outer box (psu)	14.2	20.2	29.0	30.0
Salinity system (psu)	5.5	5.5	16.5	17.4
DIP outer box (mmol m^{-3})	0.5	0.8	0.8	1.4
DIP system (mmol m^{-3})	0.9	1.5	1.4	2.1
DIP$_Q$ (mmol m^{-3})	0.4	0.6	0	0
DIP$_{G-s}$ (mmol m^{-3})	0	0	0	0
DIP atmosphere (mmol m^{-3})	0	0	0	0
DIN outer box (mmol m^{-3})	4.2	4.4	4.9	5.4
DIN system box (mmol m^{-3})	5.0	6.5	12.5	13.9
DIN$_Q$ (mmol m^{-3})	1.6	2.3	0	0
DIN$_{G-s}$ (mmol m^{-3})	1.6	2.3	0	0
DIN atmosphere (mmol m^{-3})	2.0	0	0	0

Budgets of nonconservative materials

DIP balance
The DIP balance (Figure 10.12) indicates that the system is a net producer of DIP in both layers in summer and winter.

DIN balance
The DIN balance (Figure 10.14) indicates a net removal in the summer and a net production in the winter in the upper layer of the system. The bottom layers are net producers of DIP in both summer and winter. Overall, there is a net production of DIN in the Ob Gulf during the year.

Stoichiometric calculations of net system metabolism
The (*p-r*) estimates (Table 10.4) indicate that the system is net heterotrophic in both layers in summer and in winter.

Table 10.4. Stoichiometric calculations of net system metabolism for the Ob Gulf.

Stoichiometric relationships				
	ΔDIP	*ΔDIN*	*(p-r)*	(n*fix-denit*)
	(10^3 mol day^{-1})	(10^3 mol day^{-1})	(mmol m^{-2} day^{-1})	(mmol m^{-2} day^{-1})
Summer				
Surface layer	+320	-356	-6	-1.0
Bottom Layer	+327	+3,234	-6	-0.4
System	+647	+2,878	-12	-1.3
Winter				
Surface layer	+447	+827	-8	-1.1
Bottom Layer	+165	+2,023	-3	-0.1
System	+612	+2,850	-12	-1.2

Overall, the Ob Gulf is a net denitrifying system.

The Yenisei Gulf

The southern boundary of the Yenisei Gulf (72.75° N - 79.85° E) is considered to be the end of the Yenisei River delta (Figure 10.9).

The sea boundary of the gulf is a line from Dikson Island to the northern cape of Sibiryakov Island and then south-west to Oleniy Island. The length of the Yenisei Gulf is about 400 km, and its width ranges from 9 to 70 km. The surface area of the Yenisei Gulf is about 20,000 km^2 (Sysko 1977; The Atlas of the Arctic 1985). The estuary is shallow (5-30m) and is characterized by extremely gentle slopes downstream from the river mouth. However, there is a narrow bottom depression near Dikson Island where the depth is more than 45 m. The area of the budgeted region of the Yenisei Gulf is 19,950 km^2. The average depth of the region is 25 m. The Yenisei River is the largest single river in Russia with a length of 4,102 km and a catchment area of 2,580x10^9 m^2. Average runoff is about 580x10^9 m^3 and more than 78% is discharged into the sea in May-September. Snow, rain and underground waters are the main water sources (50, 34 and 16%) to the river system. Estimated annual sediment discharge is about 13 millions tonnes for the Yenisei River (Lisitsin 1996).

Sea level variability in the Yenisei Gulf is a function of river runoff, wind and tides. The spring flood passes the gulf before the break-up of ice cover. Sea level increases during spring flood up to 5 m near Cape Sopochnaya Karga. Tidal waves penetrate into the gulf from the Kara Sea. A noticeable increase of sea level and partial reflection of the tidal wave occurs near Cape Sopochnaya Karga in summer. In winter, ice cover decreases tidal amplitude by up to 30%.

Water and salt balance

The input data for the model is presented in Table 10.5. Sources are as for the Ob Gulf. Figure 10.11 shows the water and salt budgets in the Yenisei River estuary during summer (July-September) and winter (October-June). Freshwater inputs are summed from precipitation, the Yenisei River discharge and the groundwater inputs. The mean system salinity is 10.2 psu in upper layer and 23.1 psu in the bottom layer in summer, and 12.8 psu and 23.9 psu in winter.

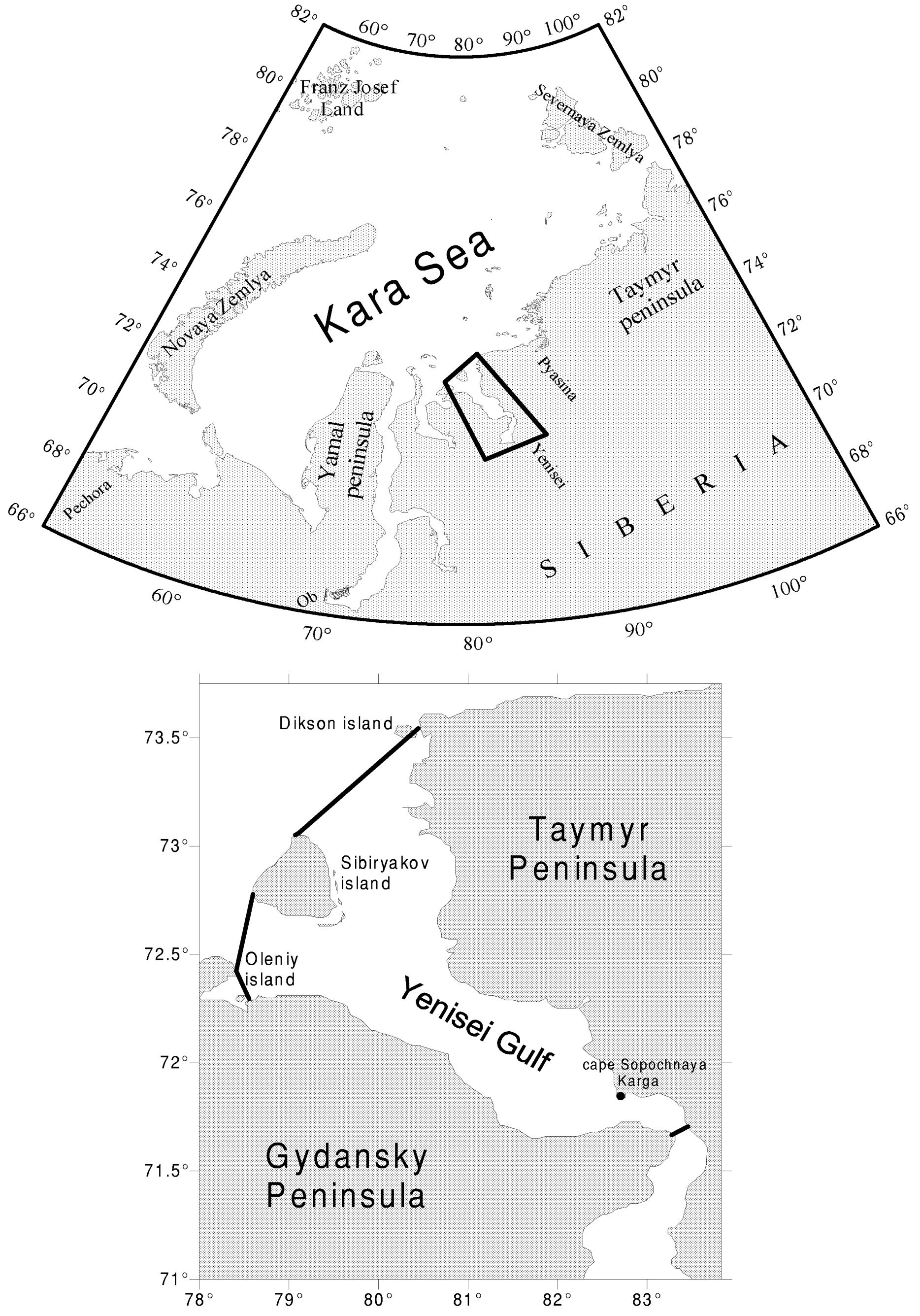

Figure 10.7. The study area in the Yenisei Gulf estuary.

Budgets of nonconservative materials

DIP balance

The DIP balance (Figure 10.13) indicates net removal of DIP in the upper layer and net production in the lower layer in summer. Overall, there is net removal of DIP in the Yenisei Gulf in summer. There is a net removal of DIP for both layers in winter.

DIN balance

Budgeting results (Figure 10.14) indicates that the estuary is a net sink for DIN in the upper layer and a net producer in the lower layer during the whole year. Overall, there is net removal of DIN for both seasons.

Table 10.5. Mean fluxes, salinity and nutrients data for the Yenisei Gulf.

	Surface		**Bottom**	
	Summer	Winter	Summer	Winter
System area (km^2)	19,950			
Layer depth (m)	10		25	
Number of months per season	3	9	3	9
Precipitation (10^6 m^3 day^{-1})	10	12	0	0
Evaporation (10^6 m^3 day^{-1})	-19	0	0	0
River discharge (10^6 m^3 day^{-1})	1,200	350	0	0
Groundwater (10^6 m^3 day^{-1})	27	80	0	0
Salinity outer box (psu)	14.7	18.0	29.7	30.0
Salinity system box (psu)	10.2	12.8	23.1	23.9
DIP outer box (mmol m^{-3})	0.4	0.7	0.9	1.2
DIP system box (mmol m^{-3})	0.4	0.6	0.9	0.9
DIP$_Q$ (mmol m^{-3})	0.4	0.5	0	0
DIP$_{G-S}$ (mmol m^{-3})	0.5	0.5	0	0
DIP atmosphere (mmol m^{-3})	0	0	0	0
DIN outer box (mmol m^{-3})	3.1	4.7	6.0	6.8
DIN system box (mmol m^{-3})	4.2	6.5	7.4	8.5
DIN$_Q$ (mmol m^{-3})	8.8	9.6	0	0
DIN$_{G-S}$ (mmol m^{-3})	9.6	9.6	0	0
DIN atmosphere (mmol m^{-3})	2.0	0	0	0

Stoichiometric calculations of net system metabolism

The (*p-r*) results (Table 10.6) indicate that the system is net autotrophic in the upper layer while the lower layer is net heterotrophic in summer. The Yenisei Gulf is net autotrophic in both layers in winter. Overall, the system is autotrophic.

The Yenisei Gulf is a net-denitrifying system in summer. Net denitrification occurs in the upper layer of the Yenisei Gulf in winter, while the lower layer is net nitrogen-fixing. Overall, the system is net nitrogen-fixing in winter.

Table 10.6. Stoichiometric calculations of net system metabolism for the Yenisei Gulf.

Stoichiometric relationships				
	ΔDIP	***ΔDIN***	***(p-r)***	***(nfix-denit)***
	(10^3 mol day^{-1})	(10^3 mol day^{-1})	(mmol m^{-2} day^{-1})	(mmol m^{-2} day^{-1})
Summer				
Surface layer	-474	-8,546	+3	-0.05
Bottom layer	+163	+1,935	-1	-0.03
System	-311	-6,611	+2	-0.08
Winter				
Surface layer	-62	-1,507	+0.3	-0.03
Bottom layer	-45	+922	+0.2	+0.08
System	-107	-585	+0.5	+0.05

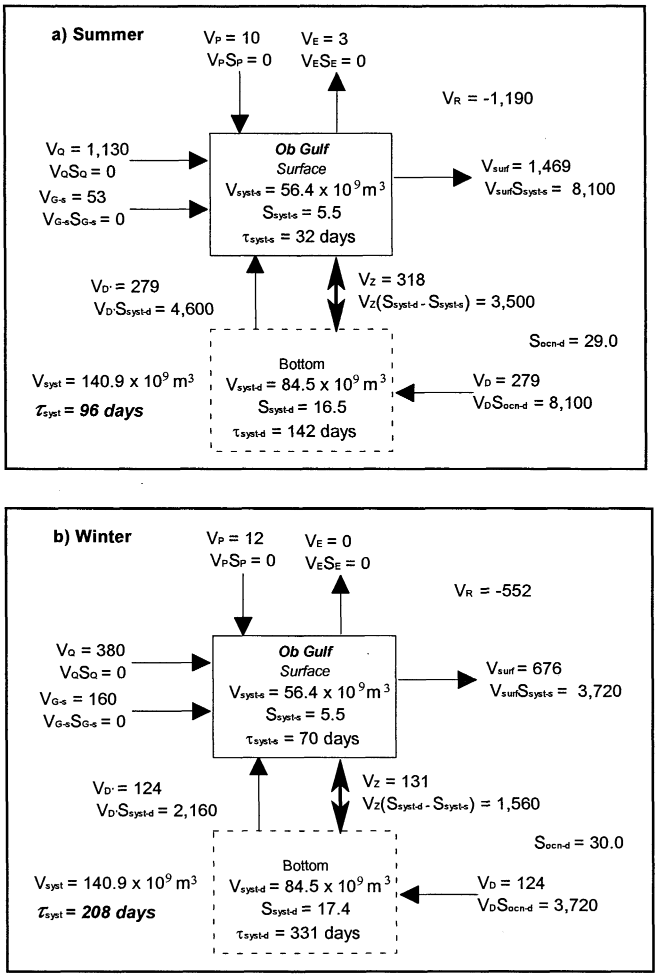

Figure 10.10. Water and salt budgets for the Ob Gulf estuary (a) in summer and (b) in winter seasons. Water flux estimates in 10^6 m^3 day^{-1} and the salt flux estimates in 10^6 psu-m^3 day^{-1}.

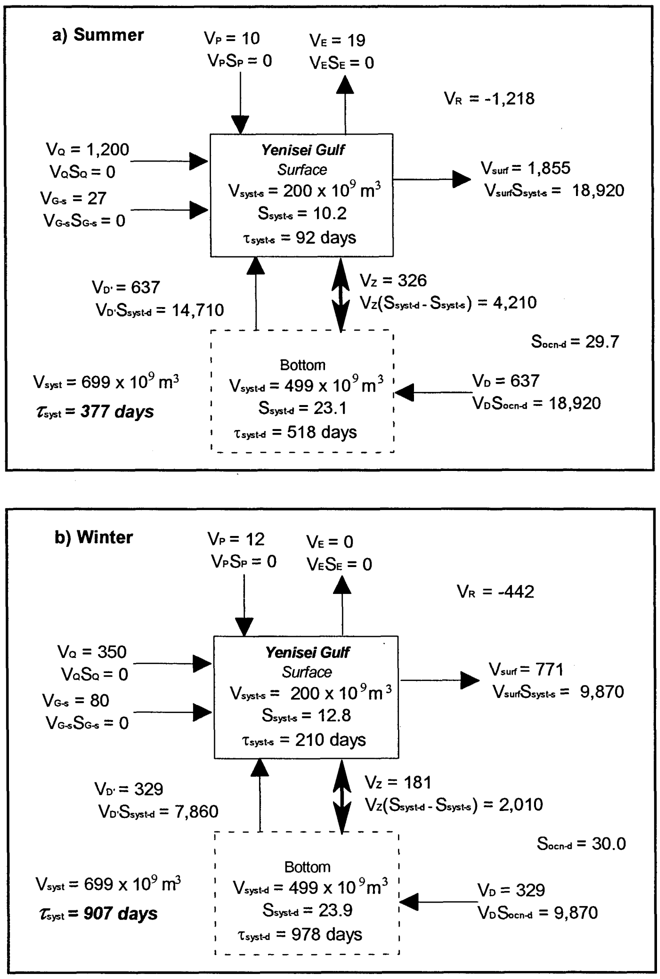

Figure 10.11. Water and salt budgets for the Yenisei Gulf estuary (a) in summer and (b) in winter seasons. Water flux estimates in 10^6 m^3 day^{-1} and the salt flux estimates in 10^6 psu-m^3 day^{-1}.

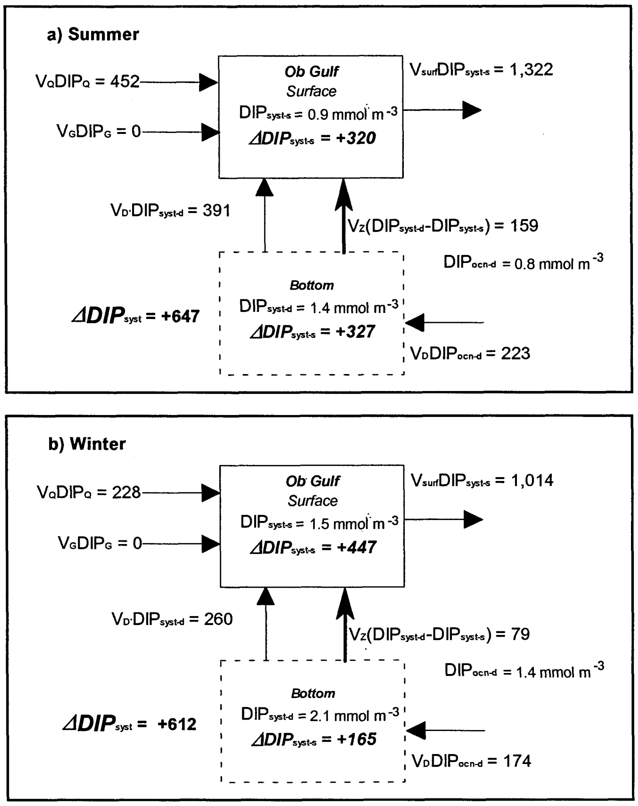

Figure 10.12. DIP budget for the Ob Gulf estuary (a) in summer and (b) in winter seasons. Flux estimates in 10^3 mol day^{-1}.

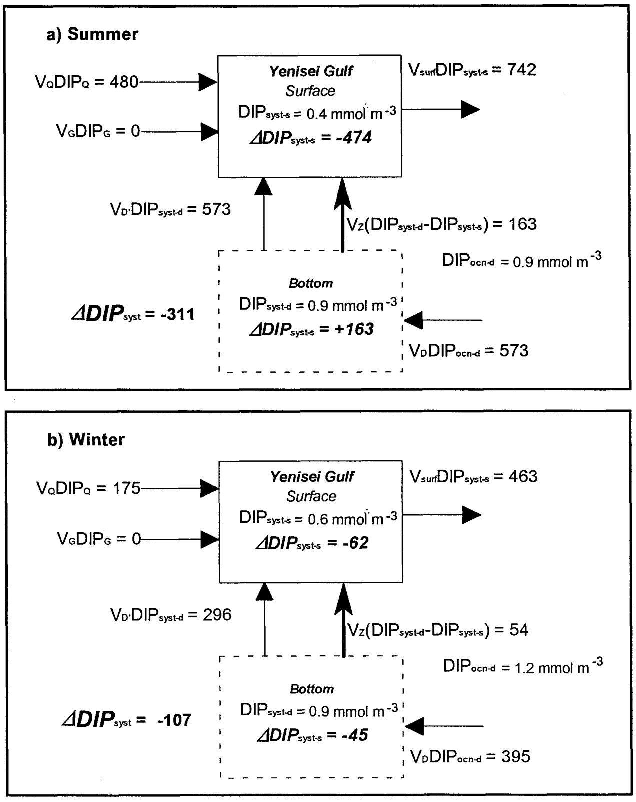

Figure 10.13. DIP budget for the Yenisei Gulf estuary (a) in summer and (b) in winter seasons. Flux estimates in 10^3 mol day^{-1}.

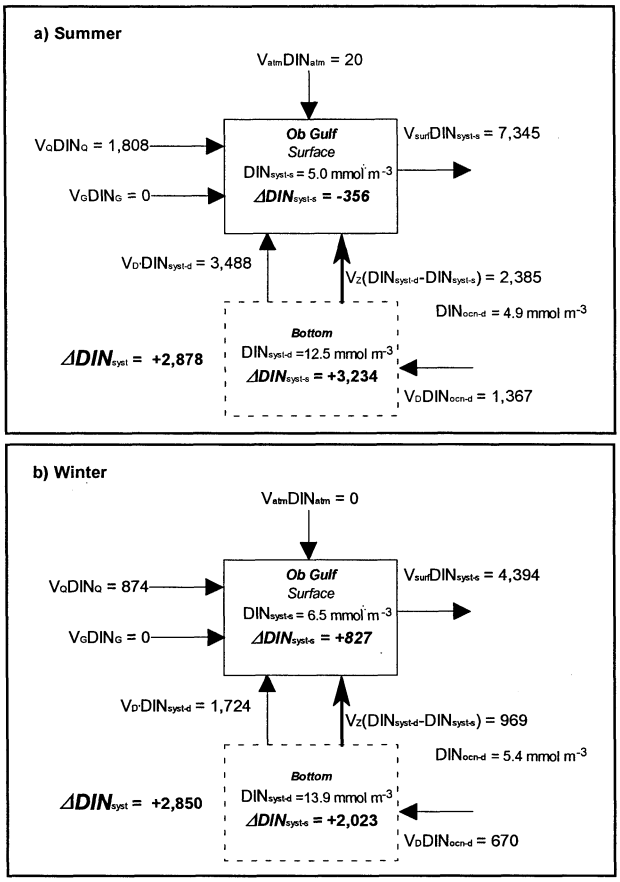

Figure 10.14. DIN budget for the Ob Gulf estuary (a) in summer and (b) in winter seasons. Flux estimates in 10^3 mol day^{-1}.

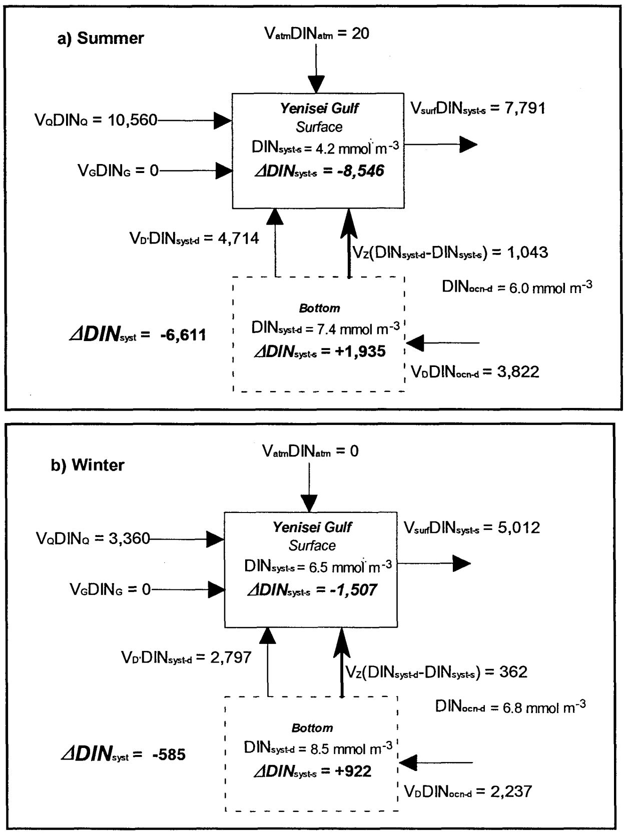

Figure 10.15. DIN budget for the Yenisei Gulf estuary (a) in summer and (b) in winter. Flux estimates in 10^3 mol day^{-1}.

10.3 The Laptev Sea Shelf

Miroslav Nitishinsky

Study area description

The Laptev Sea is located in the middle of the Arctic shelf (110°E, 71°N–140°E, 78°N, Figure 10.16). Geographically, the greatest part of the Laptev Sea is located on the shelf, and the smallest part occupies the continental slope and deep basin. The Laptev Sea shelf occupies all of the southern part of the sea from the shoreline to the continental slope. Its area is 475,000 km^2, about 71% of the total sea area (The Atlas of the Arctic 1985). There are a few underwater valleys, highlands and banks on the shelf. There is a wide and short underwater valley in front of the Lena River mouth, an underwater valley expanding to the north from the Olenek Gulf and a long, narrow valley stretching northward from Stolbovoy Island. The Semyonovskaya and Vasil'evskaya banks are located in the eastern part of the sea. The mean depth of the Laptev Sea shelf is less than 50 m. The bottom topography influences water circulation (Ipatov and Yakovlev 1999, Baskakov *et al.* 1999). Bottom depressions are characterized by high sedimentation rates (Thiede *et al.* 1999) and stagnant water formation (Pivovarov and Smagin 1995).

The Laptev Sea is considered to be one of the most severe seas of the Arctic Ocean because of its high latitude geographical location and remoteness from the Atlantic and Pacific Oceans (Danilov *et al.* 1994). Air temperature over the sea is characterized by great seasonal fluctuations (The Atlas of the Arctic 1985).

Solar radiation is a very important factor controlling primary production through photosynthesis. The maximum solar influx on the sea surface is observed in May and June (45-50 % of the total annual amount). However, a large proportion of solar radiation is reflected by the surface and returns to the atmosphere due to the high albedo of snow and ice and only a smaller part can be absorbed (Petrov 1986).

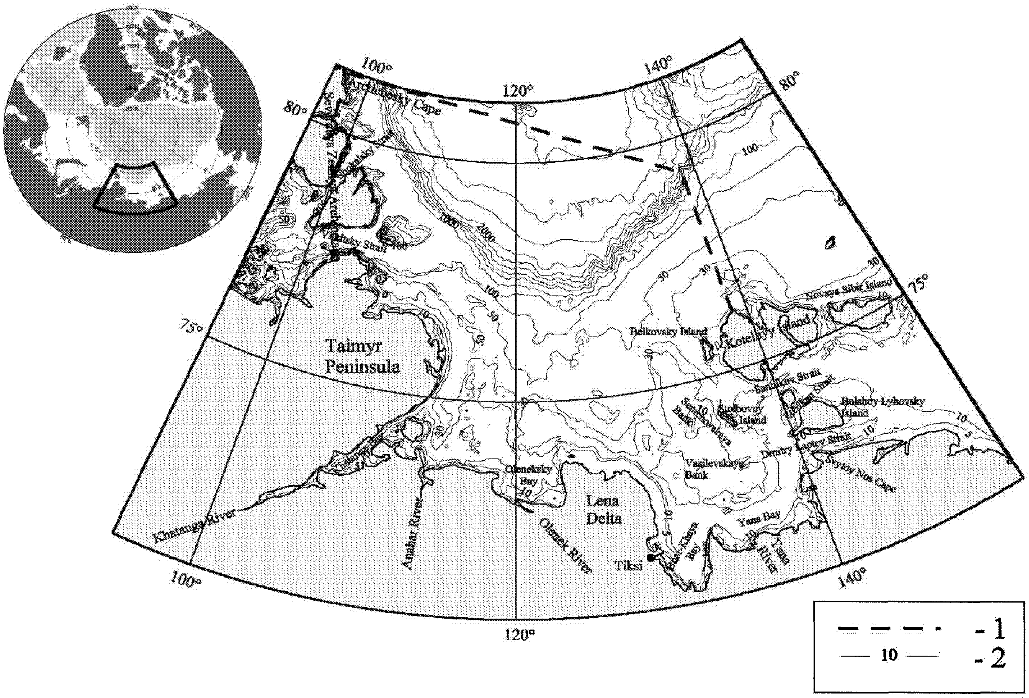

Figure 10.16. Map of the Laptev Sea. (1 - the northern boundary, from The Atlas of the Arctic 1985; 2 - isobaths, IBCAO data.)

A few large and a great number of small rivers ring their waters into the Laptev Sea. The Lena River is one of the largest, with an annual discharge of about 515x10^9 m^3. The Khatanga River brings about 100x10^9 m^3 of fresh water into the sea, the Yana River more than 30x10^9 m^3, the Olenek River 35x10^9 m^3, and the Anabar River 20x10^9 m^3. The remaining rivers together account for approximately 20x10^9 m^3 of water annually (The Atlas of the Arctic 1985). River runoff changes seasonally. Approximately 90% of the total annual runoff enters the sea from June to September (Brizgalo and Ivanov 2000).

From October to June, the Laptev Sea is covered by sea ice of various thicknesses and ages. "Fast ice" is very well developed and expands into the eastern part of the Laptev Sea shelf. The fast ice occupies about 30% of the total Laptev Sea area. The rate of establishment of fast ice cover and its areal extent are controlled mainly by the dispersal of river water in the eastern Laptev Sea (Dmitrenko *et al.* 1999), wind stress and bottom topography. The Laptev Sea is a region with one of the highest net ice production rates in the Arctic Ocean. It has been estimated that total net export ranges between 300x10^9 and 700x10^9 m^2. Export into the East Siberian Sea is considerable, with mean winter values of 100x10^9 m^2. Part of this ice grows throughout the winter in a system of coastal polynyas and flaw leads. The polynya width varies from tens to hundreds of kilometers (Zakharov 1996). Ice conditions influence physical and chemical properties of water masses and they are an important component of the Laptev Sea ecosystem (Nikiforov and Shpaicher 1980, Rusanov *et al.* 1979, Thiede *et al.* 1999). Ice melting begins in June-July, so in August-September there are large areas of open water in the sea. During summer a great amount of sea ice melts in the sea. An average volume of thawing water is approximately 800x10^9 m^3 per summer (Zakharov 1996).

The circulation pattern of the sea is complex and variable. The variability is the result of the temporal fluctuations of river discharges and wind patterns. Changes in the prevailing wind direction lead to the restructuring of the overall water circulation system, formed in accordance with water density, seabed topography and the Coriolis effect. Water masses typically circulate cyclonically. Seven types of elementary processes each imparting a particular set of hydrological conditions have been identified for the Arctic seas; variables include water circulation, temperature and salinity fields, the nature and movement of ice cover and fluctuations in sea level (Krutskikh 1978). The formation of each process type is connected with specific meteorological conditions. There are some more or less permanent surface currents in the sea, e.g., the Eastern Taimyr current, the Novosibirsky current, the coastal current - a part of which flows through the straits into the East Siberian Sea (Ipatov and Yakovlev 1999). Mean velocities of the currents are very low (about 2 cm s^{-1}) and there are some calm zones within the sea (Ipatov and Yakovlev 1999; Baskakov *et al.* 1999).

The water column of the sea is a mosaic of multi-layered structures. The water body can be divided vertically into three structural zones: surface, intermediate, and bottom, comprising water masses of corresponding types. Water masses are the basic elements of the water column. They are recognized by different temperature, chemical and biological properties.

Nutrient distributions and variability in the Laptev Sea are related to life cycles of marine organisms, river influx, water mass advection from the Arctic Basin and adjacent seas and hydrometeorological conditions. Some 119 species of phytoplankton have been found in the Laptev Sea, dominated by diatom assemblages. Microscopic algae appear in the second half of April as a result of insolation increasing and longer daylight. They usually reach maximum densities in mid-July and their growth depends on nutrients accumulated in the surface zone during the winter. The vegetative period in the Arctic seas lasts three to four months. Seasonal changes have no strictly defined dates or spatial sequence. The main reasons for interannual differences in the biological seasons are meteorological, hydrological and glacial conditions (Okolodkov 1988, 1992). Primary production is one of the main characteristics of the phytoplankton lifecycle. It ranges from 75 to 640 mg C m^{-3} for 24 hours in the Buor-Khaya Gulf. Primary production in the eastern region of the shelf ranges from 40 to 90 mg C m^{-3} for 24 hours; in the western region, from 24 to 41 mg C m^{-3} for 24 hours; and in the northern region near the continental slope and ice edge, from 115 to 154 mg C m^{-3} for 24 hours (Sorokin *et al.* 1993; Gleitz and Grossmann 1997; Tuschling 2000). Phytoplankton biomass values within the Laptev Sea vary between 200 and 1500 mg m^{-3} (Gleitz and Grossmann 1997; Tuschling 2000).

The coastline of the Laptev Sea is almost uninhabited. There are a few small settlements (Tiksi and Khatanga), with a total population not exceeding 10,000 people. The catchment area of the rivers is located in the territory of the Yakutia (Saha) republic, in which a few towns (Yakutsk, Lensk) are located along the middle and upper Lena River, but the population density is low. Mining industries located in the middle and upper regions of the Lena River influence sediment transport of the river.

Water and salt balance

The Laptev Sea was divided into two layers to calculate water and salt budgets. Calculations were performed for two seasons: summer (July – September) and winter (October – June). The data used are shown in Table 1 and the water and salt budgets are shown in Figure 10.16. The water exchange time (τ) was 5,900 days for summer and was 15,600 days for winter. The water influx from Arctic Ocean into the system was close to expert estimations of flow on the Laptev Sea Shelf (Nikiforov and Shpaicher 1980).

Budgets of nonconservative materials

DIP balance

Water flux data from Figure 10.16 were used to calculate the DIP budget (Figure 10.17). The system, excluding the bottom layer in winter, acts as a net sink of DIP.

DIN balance

Budgeting results show that the estuary is also a net sink of DIN (Figure 10.18). However, the surface layer acts as a net sink of DIN while the bottom layer serves as a net source of DIN.

Table 10.7. Mean flux, salinity and nutrient data of the Laptev Sea Shelf.

	Surface		**Deep**	
	Summer	Winter	Summer	Winter
Box Area (km^2)	475,000			
Layer depth (m)	10		40	
Number of months per season	3	9	3	9
Precipitation (10^6 m^3 day^{-1})	65	200	-	-
Evaporation (10^6 m^3 day^{-1})	-260	0	-	-
River discharge (10^6 m^3 day^{-1})	1,800	200	-	-
Groundwater (10^6 m^3 day^{-1})	39	120	-	-
Salinity outer box (psu)	31.8	31.8	34.3	34.3
Salinity system box (psu)	19.9	22.6	29.4	29.8
DIP outer box (mmol m^{-3})	0.9	0.9	0.9	0.9
DIP system box (mmol m^{-3})	0.2	0.5	0.6	0.8
DIP river discharge (mmol m^{-3})	0.3	0.5	-	-
DIP groundwater (mmol m^{-3})	0.5	0.5	-	-
DIP atmosphere (mmol m^{-3})	0	0	-	-
DIN outer box (mmol m^{-3})	7.8	7.8	7.8	7.8
DIN system box (mmol m^{-3})	0.1	3.2	6.3	7.0
DIN river discharge (mmol m^{-3})	1.4	4.4	-	-
DIN groundwater (mmol m^{-3})	4.4	4.4	-	-
DIN atmosphere (mmol m^{-3})	2.0	0	-	-

Stoichiometric calculations of net system metabolism

Table 10.8 presents the calculated net system metabolism of the Laptev Sea Shelf. The system is net autotrophic, exclude the bottom layer in winter. The system is also net nitrogen-fixing in both summer and winter.

Table 10.8. Stoichiometric calculations of net system metabolism in the Laptev Sea.

	Stoichiometric relationships			
	ΔDIP	***ΔDIN***	***(p-r)***	***(nfix-denit)***
	(10^3 mol day^{-1})	(10^3 mol day^{-1})	(mmol m^{-2} day^{-1})	(mmol m^{-2} day^{-1})
Summer				
Surface	-1,646	-24,583	+0.37	+0.004
Deep	-218	+3,955	+0.05	+0.016
System	-1,864	-20,628	+0.42	+0.02
Winter				
Surface	-389	-5,945	+0.09	+0.0006
Deep	+87	+1,583	-0.02	+0.0004
System	-302	-4,362	+0.07	+0.001

Acknowledgements

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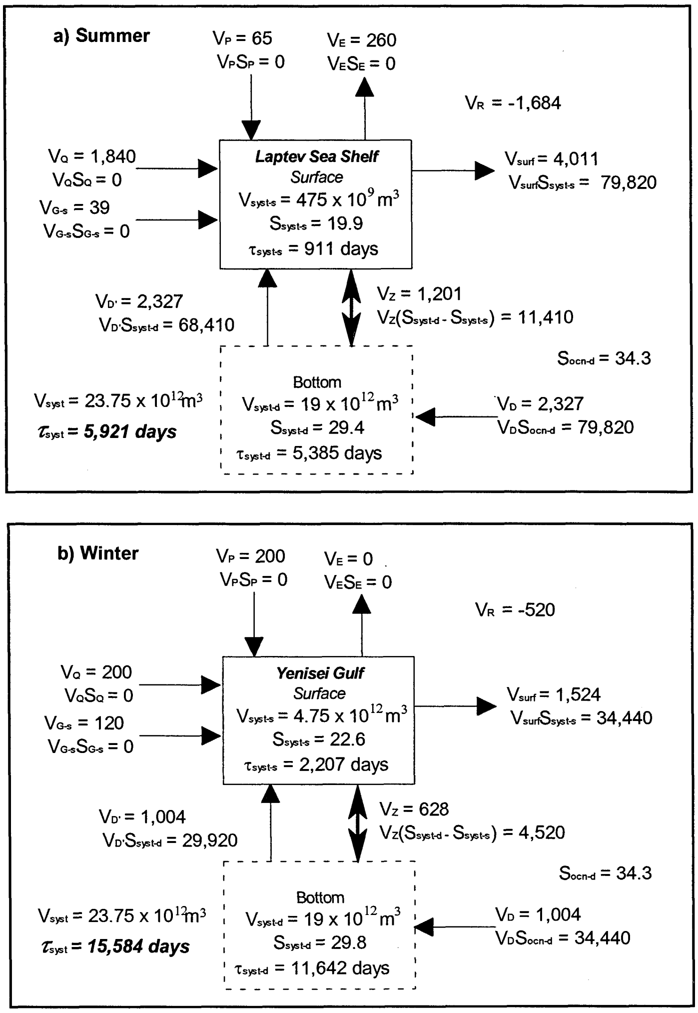

Figure 10.17. Water and salt budgets for the Laptev Sea Shelf (a) in summer and (b) in winter. Water flux estimates in 10^6 m^3 day^{-1} and salt flux estimates in 10^6 psu-m^{-3} day^{-1}.

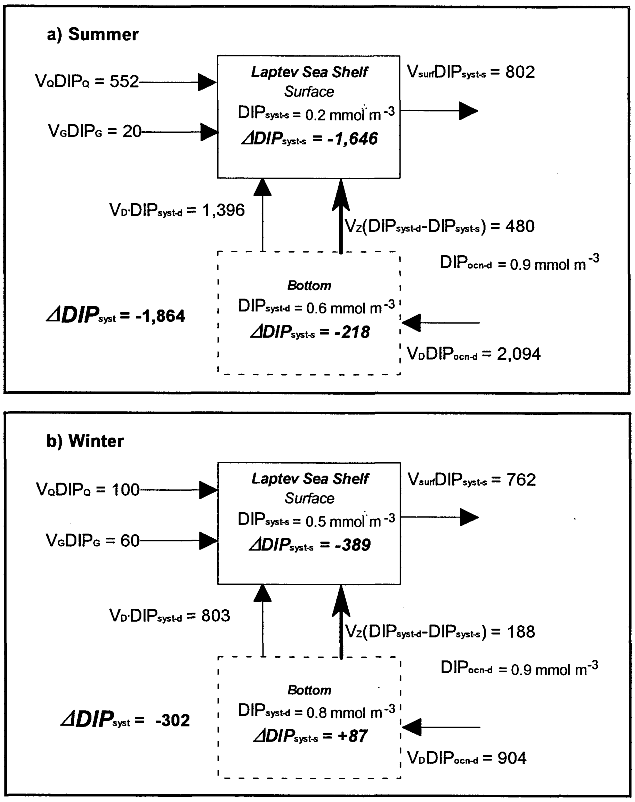

Figure 10.18. DIP budget for the Laptev Sea Shelf (a) in summer and (b) in winter. Flux estimates in 10^3 mol day^1.

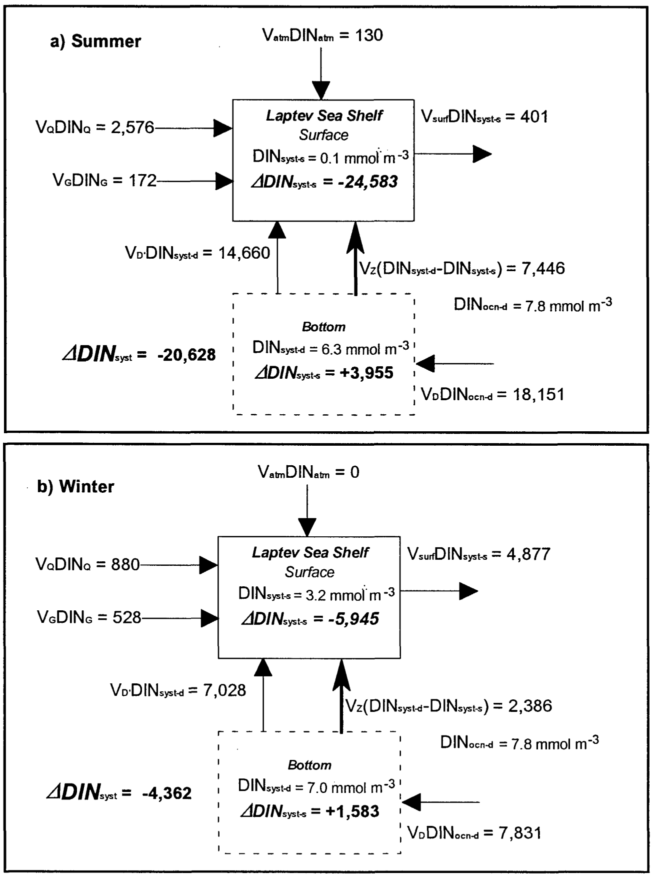

Figure 10.19. DIN budget for the Laptev Sea Shelf (a) in summer and (b) in winter. Flux estimates in 10^3 mol day^{-1}.

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Appendix II Workshop Agenda

Saturday, 8 September

Participants arrive in Stockholm

Sunday, 9 September

1000 Welcome and announcements – Prof. Fred Wulff
Introduction of participants
1030 Introduction to LOICZ and IGBP – Chris Crossland
1100 Introduction to LOICZ budgeting approach and project overview – Dennis Swaney
1130 Bothnian Sea system – Christoph Humborg
1230 Lunch
1330 Participant presentations of sites and preliminary budgets
1600 Breakout groups
1800 Session close

Monday, 10 September

0830 Plenary discussion and work plan
0900 Breakout groups
1230 Lunch
1330 Breakout groups
1700 Plenary and session close

Tuesday, 11 September

0830 Breakout groups
1230 Lunch
1330 Budget presentations
1500 Synthesis and wrap-up session
1600 Workshop close

Wednesday, 12 September

Participants depart Stockholm

Appendix III Workshop Report

Welcome

Participants (Appendix I) were welcomed to the Department of Systems Ecology, University of Stockholm by Prof. Fred Wulff, and meeting support arrangements were reviewed. The workshop agenda (Appendix II) was introduced and various relevant Arctic region publications, working documents, electronic information and tutorial materials were distributed. Participants were introduced.

Introduction and Background

The LOICZ goals and approaches were presented by Dr Chris Crossland and the workshop was placed in the context of the wider purpose of LOICZ in evaluating nutrient flux models of estuaries and coastal seas worldwide in assessing material fluxes in the coastal zone.

The specific objectives of the workshop were outlined by Dennis Swaney within an overview presentation of the LOICZ budgeting and modelling approach for nutrient flux and net ecosystem metabolism of estuarine and coastal seas systems. The various tools developed by the LOICZ-UNEP project (e.g., Cabaret software; runoff, waste and groundwater estimation techniques) were identified, along with the use and utility of the "budgets" web-site (http://data.ecology.su.se/MNODE/). The allied integrating and up-scaling analyses being done by LOICZ through the typology tools and approach were outlined. Expected products were discussed.

The somewhat unique features of the arctic coastal zone were discussed as vital elements and setting for the budget and model developments. It was noted that about one-sixth of the global river discharge is from arctic basins. In some regions, water flow of large rivers in March has been estimated as about 60 times less than that during June. Small rivers and many large rivers are frozen in winter with little run-off occurring but groundwater input may remain stable throughout the year. Spring bloom periods (late May – June) are key times of maximal biological activity and probably cause major forcing of annual biogeochemical cycles in system processes in estuaries and coastal seas of the Arctic.

Dr Christoph Humborg provided an outline of the MARE project of which a part is the development of biogeochemical budgets for all estuaries in the Baltic Sea. He discussed the northern Bothnian Bay region and river system discharge patterns and loads. The effects of damming, in this otherwise relatively un-impacted and oligotrophic region, were highlighted along with the resultant changes on ocean *versus* land-derived nutrient (N, P) supply, and the influence on silicate availability and potential for system changes.

Presentation of Biogeochemical Budgets

The contributing budgets brought by participants were considered, including system settings, data availability and quality, approaches taken in building budgets for the systems, and the status and problems encountered in model derivation. System sites included:

Bothnian Sea
    Lulealven River estuary

Kara Sea, including
    Yenisei River estuary
    Ob River estuary

Laptev Sea
    Lena River and delta system

White Sea, including
    Chupa River estuary

An initial assessment of an Antarctic site (Ellis Fjord, Davis Base) was made, taking advantage of the skills and experience of the Workshop participants for the Arctic region.

Dr Slava Gordeev provided an assessment of the quality of river data presently available for the Russian arctic rivers, noting that ammonium values are unreliable (often 10-100 fold in excess). Groundwater inputs are very important in the region and should be considered in budget development. Similarly, atmospheric inputs of nutrients are likely to be significant, especially in the western regions of the Russian arctic. Coastal erosion is also an important phenomenon with capacity to influence nutrient contributions into coastal seas. He outlined some current work estimating nutrient supply to the East Siberian Sea which ascribes about 90-95% of the nutrient requirements for plankton as coming from "ocean" sources and only 5-10% from land sources.

Budgets Development

Individuals and small groups worked interactively on developing the site budgets, from time to time meeting in plenary session to address issues and source data.

Key elements for discussions included description of hydrographic conditions, setting of system boundaries and boxes for models, determining winter outputs and assessments of icing periods, river contributions of load, and locating data or proxies for processes.

Outcomes and Wrap-up

Budgets calculations and system data needs for all systems were developed to an interim stage of completion during the workshop. Additional data were needed to be sourced from home institutions and agreements were entered into between participants for the finalisation and text descriptions to complete site models and write-ups.

A schedule for contribution and publication of the printed report, and posting to the LOICZ web site was agreed:

31 October	final draft budgets to Prof. Wulff (for circulation to Dennis Swaney and Dr Crossland) for editing and review
20 December	final budgets to IPO for LOICZ R&S preparation entry of site budgets on LOICZ web-site
January 2002	publication of report.

The participants identified opportunities to develop either additional site or nested budgets. Dr Christoph Humborg is to follow up on an inorganic-based budget as well as the total nutrient assessment budget for the Lulealven River system. Dr Sergey Pivovarov (with Prof. Oleg Savchuk) will do further work with colleagues from the St Petersburg Arctic and Antarctic Research Institute.

All participants joined with LOICZ in expressing thanks to Prof. Fred Wulff and staff from the Department of Systems Ecology, Stockholm University for support and hosting a challenging and fruitful workshop. The financial support of the Global Environment Facility was gratefully acknowledged.

Appendix IV Terms of Reference for Workshop

LOICZ-UNEP Workshop on Estuarine Systems of the Arctic Region
Department of Systems Ecology
University of Stockholm
Stockholm, Sweden
9-11 September 2001

Primary Goals:
To work with researchers dealing with estuarine and coastal systems of the Arctic region, in order to extract C, N, P budgetary information from as many systems as feasible using existing data. The polar systems, north and south, include one of the major coastal regions of the world oceans and are little described in system model terms. The workshop provides the opportunity to characterize terrigenous inputs to the estuaries of the region, and outputs from the estuaries – hence, the net role of the estuarine zone of this region as a source or sink for carbon, nitrogen, and phosphorus.

This workshop will complement earlier, successful workshops in Mexico (Central and South Americas: 1997, 1999, 2001), Australia (Australasia: 1998), Manila (South East Asia: 1999), Argentina (South America: 1999), Goa (South Asia: 2000), Hong Kong (East Asia: 2000), Zanzibar (Sub-Saharan Africa: 2000) and Athens (Mediterranean and Black Seas: 2001), by the analysis of data from another important coastal region.

Anticipated Products:
1. Develop budgets for as many systems as feasible during the workshop.
2. Examine other additional data, brought by the researchers, or provided in advance, to scope out how may additional systems can be budgeted over an additional 2 months.
3. Prepare a LOICZ technical report summarizing this information.

Workplan:
Participants will be expected to come prepared to participate in discussions on coastal budgets. Preparation should include reading the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), an earlier workshop report (see Dupra *et al.* on LOICZ web-site), examination of the budgets and tutorials presented on the LOICZ Modelling web page (http://data.ecology.su.se/MNODE/), and arriving with preliminary budgets, electronic maps, and 1-3 page write-ups from "their sites." In order to be included in the workshop report, the budgets should conform as best possible to the budgeting protocol laid out in the above documentation. Guidelines for budget preparation and write-ups and a tutorial package entitled CABARET can (and should) be downloaded from the LOICZ Modelling web-site.

NOTE: Please try to conform to materials on that web-site as closely as possible, because this will greatly aid in report preparation. We anticipate structuring the workshop very strongly towards instruction and then working with individuals to complete budgets during the workshop.

Further Details:
At a minimum, each participant is expected to arrive at the workshop (or send in advance) the following materials:
1. A 1-3 page description of the area (see materials posted on the Web-site and in the various workshop reports) and a map of the site. These should be in electronic format.
2. Within the context of needs for the overall LOICZ project, some estimate of water exchange (most commonly via water and salt budgets) and budgets for the dissolved inorganic nutrients, nitrogen

and phosphorus, constitute the minimum useful derivations from the biogeochemical budgeting. Budgets of other materials, while potentially interesting for other purposes do not satisfy this minimum requirement. The minimum data requirements are as follows:

a. The primary seasonal pattern of the region is at least one wet season and one dry season per annum. Ideally, a budget for each season would be developed. If a system is vertically stratified, then a 2-layer budget is preferred over a single-layer budget. If a system has a strong land-to-sea salinity gradient, then it is preferable to break the system along its length into several boxes.
b. Data requirements to construct a satisfactory water and salt budget include: salinity of the system and the immediately adjacent ocean, runoff, rainfall, evaporation, and (if likely to be important) inputs of other freshwater sources such as groundwater or sewage. Preferably, the salinity and freshwater inflow data are for the same time period (for example, freshwater inflow data for a month or so immediately prior to the period of salinity measurement). In the absence of direct runoff estimates for small catchments, estimations can be made from a knowledge of catchment area and monthly rainfall and air temperature for the catchment. See materials on the LOICZ biogeochemical modeling web site.
c. Data requirements for the nutrient budgets are: concentrations of dissolved nutrients (phosphate, nitrate, ammonium, and if available dissolved organic N and P) for the system and the adjacent ocean, concentrations of nutrients in inflowing river water (and if important, in groundwater), some estimate of nutrient (or at least BOD) loading from sewage or other waste discharges. If atmospheric deposition (particularly of N) is likely to be important, an estimate of this is also useful. If direct waste load measurements are not available, estimations can be made from a knowledge of the activities contributing to the waste loads and the magnitudes of those activities. See the materials on the web site.

Workshop Schedule

September 8: Arrival

September 9: General introduction to the budgeting procedure and related issues; presentation of preliminary budgets (no details, simply a quick summary to see who has what).

Breakout groups to revise, refine budgets. This will vary, as needed, from tutorial, through detailed help, to procedural discussions.

September 10: Continue breakouts; afternoon plenary to evaluate progress.

September 11: Breakouts/plenary as required to develop synthesis.

September 12: Departure.

Background Documents:

1. Gordon, D.C. Jr., Boudreau, P.R., Mann, K.H., Ong, J.-E., Silvert, W.L., Smith, S.V., Wattayakorn, G., Wulff, F. and Yanagi, T. 1996. LOICZ Biogeochemical Modelling Guidelines. LOICZ Reports and Studies 5, LOICZ, Texel, The Netherlands, 96 pages.
2. Smith, S.V., Ibarra - Obando, S., Boudreau, P.R. and Camacho Ibar, V.F. 1997 Comparison of carbon, nitrogen and phosphorus fluxes in Mexican coastal lagoons. *LOICZ Reports and Studies* **10**, LOICZ, Texel, The Netherlands, 84 pages.
3. LOICZ Modelling webpage, for everyone with www access: (http://data.ecology.su.se/MNODE/).

- *The web pages, including the guidelines, are frequently updated. If you have not looked at them within the last two weeks, you should go through them again (For example, there are recent additions on estimation of runoff and estimation of waste loads).*
- *If you do not have access to the worldwide web but do have access to a computer with a CD-ROM, please let us know; we will send you a CD with the web page. Please do not request the CD at this time if you have access; you will be furnished one during the workshop.*
- *CABARET (Computer Assisted Budget Analysis, Research, Education, and Training). Note: a version of this software is available on the web-site.*

Appendix V Glossary of Abbreviations

NH_4	Ammonium
NO_3	Nitrate
DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
DIP	Dissolved inorganic phosphorus
DOP	Dissolved organic phosphorus
PTN	Particulate total nitrogen
PTP	Particulate total phosphorus
POP	Particulate organic phosphorus
PON	Particulate organic nitrogen
ON	Organic nitrogen
OP	Organic phosphorus
TN	Total nitrogen
TP	Total phosphorus
DOC	Dissolved organic carbon
DIC	Dissolved inorganic carbon
POC	Particulate organic carbon
OC	Organic carbon
SiO_4	Silicate
nfix	Nitrogen fixation
denit	Denitrification
p	Primary production
r	Respiration
TDN	Total dissolved nitrogen
TDP	Total dissolved phosphorus
CTD	Conductivity Temperature Depth