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

LaguNet
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Nutrient fluxes in transitional zones of the Italian coast

Compiled and edited by G. Giordani, P. Viaroli, D.P. Swaney,
C.N. Murray, J.M. Zaldívar and J.I. Marshall Crossland

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This report and allied workshops are contributions to the LOICZ biogeochemical budgeting and modeling core project which started with global assessments under the name “United Nations Environment Programme project: The Role of the Coastal Ocean in the Disturbed and Undisturbed Nutrient and Carbon Cycles (Project Number GF 1100-99-07), financially supported by the Global Environment Facility (GEF) and implemented by IGBP-LOICZ. This core project is being continued as work in progress into LOICZ II and the study presented has been co-supported by the European Commission (Joint Research Centre, Ispra, Italy).

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Cover: The cover shows an image of Italy (GTOPO30 elevation map, courtesy Professor S.V. Smith), with the budgeted estuaries indicated.

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1. OVERVIEW OF WORKSHOP AND BUDGETS RESULTS

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

- gain a better understanding of the global cycles of the key nutrient elements carbon (C), nitrogen (N) and phosphorus (P);
- understand how the coastal zone affects material fluxes through biogeochemical processes; and
- characterize 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 recognized 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.

LaguNet is an example of such a scientific observational network studying the fluxes of nutrients and other contaminants from lagoon catchments to the near-coastal environment. The idea of developing a network of Italian researchers involved in the study of lagoons and coastal transitional ecosystems was developed during a workshop "Coastal and estuarine systems of the Mediterranean and Black Sea regions: carbon, nitrogen and phosphorous fluxes" organized in Athens (2-5 February 2001) by LOICZ (Land Ocean Interactions in Coastal Zones) with the support of UNEP and ELOISE. In the proceedings of the workshop is included a first series of estimates on the fluxes of nitrogen and phosphorus from selected transitional ecosystems of the Italian coast (Dupra *et al.* 2001) which contributed to filling an information gap on information on the Mediterranean region.

LaguNet was inaugurated during the workshop "Nutrient fluxes in the transition zones along the Italian Coast: evaluation of fluxes and derived ecosystem functions " held in Venice 14-15 April 2002, and has the following objectives:
i. Provide a forum for discussion and cooperation between researchers who are studying biogeochemical processes in lagoons, wetlands and salt- marshes at sites along the Italian coast.
ii. Evaluate available information and present understanding of the biogeochemistry of carbon, nitrogen and phosphorous in transitional and coastal waters under the influence of catchment basins.
iii. Discuss the feasibility of the application of the LOICZ Biogeochemical Model to such areas.
iv. Promote an agreed common approach to studies of biogeochemical processes in these transitional ecosystems that can provide support to management or policy applications.
Consider the feasibility of developing one or more projects either in Italy or in Europe (with Mediterranean EU partners and eventually from Eastern Europe and North Africa).

At present, LaguNet (www.dsa.unipr.it/lagunet) comprises sites distributed around the entire Italian peninsula and islands (Figure 1.1). Some, such as the Port of Genoa and the Marinello lakes, consist of several independent systems (see Table 1.1). There are currently 22 ecosystems under investigation in which the LOICZ Biogeochemical Model has been applied for a well-defined time period. In total, 94 flux estimations have been undertaken considering a wide range of systems and different time periods. For some sites (for example, the S'Ena Arrubia Lagoon) it has been possible to compare the results obtained with the model for different periods of time to obtain valuable information on the evolution of the lagoon. Some results have already been published in LOICZ Reports and Studies Volume 19

(Dupra *et al.* 2001), while others are reported here. The preliminary results of the exercise have been presented in various national and international conferences:

- Viaroli, P., G. Giordani, C.N. Murray and J.M. Zaldivar: **LaguNet: Italian Lagoon Observational Network.** Presentation at the First Italian IGBP Conference: Mediterraneo e Italia nel Cambiamento Globale: un ponte fra scienza e società Paestum (Salerno) 14-16 November 2002
- Viaroli, P., G. Giordani, C.N. Murray, J.M. Zaldivar, S. Guerzoni, A. Bergamasco, C. Solidoro, S. Rabitti, G. Castaldelli, M. Abbiati, M. Ponti, E. Manini, R. Danovaro, A. Basset, M. Azzaro, A. Mazzola, T.L. Maugeri, S. Porrello, M. Lenzi, M. Innamorati, C. Melillo, M. Fabiano, P. Povero, P. Magni, G. De Falco, F. Trebini and N. Sechi. **Nutrient fluxes in the transition zones along the Italian Coast: evaluation of fluxes and derived ecosystemic functions.** Presentation at the III National Congress of Marine Sciences, Bari, Italy, 27-30 November, 2002.
- Giordani, G., P. Viaroli, C.N. Murray, J.M. Zaldivar, M. Ponti, M. Abbiati, A. Barbanti, C. Castellani,, A. Basset, I. Cappello, A. Pomes, L. Palmisano, S. Bencivelli, A. Bergamasco, M. Azzaro, G. Carrada, G. Castaldelli, M. Mistri, A. E. Fano, A. Castelli, C. Lardicci, F. Maltagliati, G. Ceccherelli, F. Trebini, B.M. Padedda, N. Sechi, S. Guerzoni, S. Rabitti, F. Collavini, L. Zaggia, R. Zonta, R. Danovaro, A. Pusceddu, M. Fabiano, P. Povero, N. Ruggieri, S. Fonda Umani, P. Giordani, M. Ravaioli, F. Frascari, P. Giordano, T.S. Hopkins, V. Hull, M. Falcucci, M. Innamorati, S. Marsili-Libelli, G. Izzo, C. Creo, M. Lenzi, P. Magni, G. De Falco, E. Manini, F. Spagnoli, M. Mauri, X.F. Niell, R. Pastres, G. Pernice, S. Porrello, P. Gennaro, V. Saggiomo, C. Solidoro, G. Cossarini, M. Vazzoler, A. Mazzola, T.L. Maugeri, A. Bernstein, G. Cecconi, L. Montobbio. **Evaluation of fluxes and derived ecosystem functions in the transition zones along the Italian Coast.** Poster at the XIII National Congress of the Italian Society of Ecology (S.It.E.), Como 8-10 September 2003.
- Giordani, G., P. Viaroli, C.N. Murray, J.M. Zaldivar, M. Ponti, M. Abbiati, A. Barbanti, C. Castellani,, A. Basset, I. Cappello, A. Pomes, L. Palmisano, S. Bencivelli, A. Bergamasco, M. Azzaro, G. Carrada, G. Castaldelli, M. Mistri, A. E. Fano, A. Castelli, C. Lardicci, F. Maltagliati, G. Ceccherelli, F. Trebini, B.M. Padedda, N. Sechi, S. Guerzoni, S. Rabitti, F. Collavini, L. Zaggia, R. Zonta, R. Danovaro, A. Pusceddu, M. Fabiano, P. Povero, N. Ruggieri, S. Fonda Umani, P. Giordani, M. Ravaioli, F. Frascari, P. Giordano, T.S. Hopkins, V. Hull, M. Falcucci, M. Innamorati, S. Marsili-Libelli, G. Izzo, C. Creo, M. Lenzi, P. Magni, G. De Falco, E. Manini, F. Spagnoli, M. Mauri, X.F. Niell, R. Pastres, G. Pernice, S. Porrello, P. Gennaro, V. Saggiomo, C. Solidoro, G. Cossarini, M. Vazzoler, A. Mazzola, T.L. Maugeri, A. Bernstein, G. Cecconi and L. Montobbio. **LaguNet, the Italian lagoon observational network. Evaluation of fluxes and derived ecosystem functions in the transition zones along the Italian Coast.** Poster at the 17th Biennial Conference of the Estuarine Research Federation (ERF). Estuaries on the Edge. Seattle, WA, USA, September 14-18, 2003.
- Giordani, G., C.N. Murray, J.M. Zaldivar, P. Viaroli. LaguNet, the Italian lagoon observational network. Evaluation of fluxes and derived ecosystem functions in the transition zones along the Italian Coast. Presentation at the International Conference: Southern European Coastal Lagoons: The Influence of River Basin-Coastal Zone interactions. Castello Estense (Ferrara, Italy), 10-12 November 2003.
- Viaroli P., **The Italian network: LaguNet.** Presentation at the national workshop: the Greek lagoons in the framework of the European networks. Mytilini, Lesvos, Greece. March 20, 2004.

Figure 1.1 Map of Italy showing 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. 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. A LaguNet workshop organized by G. Carrada and A. Basset was held 17-19 June 2004 in Naples (Italy) to discuss the typology of coastal systems at national, southern Europe and Mediterranean scales, (http://www.ecologia.ricerca.unile.it/TWTypology/). The final document of the meeting is in Appendix IV.

The biogeochemical budget information for sites shown in Figure 1.1 is discussed individually in the text that follows, and is reported as average daily rates for the period studied. To provide for an overview and ease of comparison, the key data are presented in "annualized" form and non-conservative fluxes are reported per unit area (Tables 1.1 and 1.2).

Due to the shape of the Italian peninsula, it has been possible to study systems that cover a wide range of latitudes: from the Lagoon of Venice in the North (45.40° N) to the Rada di Augusta in the South (37.21°N) (Figure 1.1). Although the distances between these ecosystems are relatively modest compared to other LOICZ studies that have been organized at continental scales, the network of sites presented here represents a very wide range of characteristics and a very high density of data.

The exploitation and management of these systems are very varied: fish farming, oyster or mussel farming, tourism, recreation and water sports or nature reserves are all represented. Many of the ecosystems are in protected areas, others are subject to intense anthropogenic pressures, and still others are exposed to only slight human impact and stress. Further the biological communities are very diversified; in some systems the dominant primary producers are phytoplankton, whereas in others they may be macroalgae or rooted phanerogams.

In the first applications of the LOICZ budgeting procedure to these systems, the simplest one-box, one-layer model was generally applied. However, for some systems, it was necessary to apply more complex versions of the procedure, such as the 2-box or 2-layer models. In the Old Port area of Genoa, a mixed model was applied: the inner box of a 2-boxes model was separated in 2 layers. The budget of dissolved organic phosphorus (DOP) and nitrogen (DON) was calculated for Sacca di Goro for 1992. Most of the budgets were calculated using a dedicated MS Excel spreadsheet template (http://www.dsa.unipr.it/lagunet/documenti/calcoliLOICZ.xls) but an online tool for one-box one-layer budgets, called LOICZ Calculator, was built and made available by M. Ponti and G. Giordani at the web-site: http://www.ecology.unibo.it/LOICZ-Calculator/loicz_calculator.htm. This tool represents yet another piece of software for LOICZ budgeting, to complement CABARET which was built by L. David (http://data.ecology.su.se/MNODE/Methods/cabaret.htm).

Most of the watersheds are subjected to intense agricultural exploitation; as a consequence the nutrient loads are generally richer in DIN than DIP if we consider the theoretically balanced Redfield N:P ratio (Figure 1.2). Higher loads were found for the Lagoon of Venice which is the largest LaguNet system. The Sacca di Goro, which was investigated in the 1992 and 1997, shows a considerable decrease in nutrient loads, partially due to the reduction of the Po di Goro input, a more efficient use of wastewater treatment plants in the catchment and to the introduction of laws restricting the P concentrations in detergents (Viaroli *et al.* in press). Of all the systems studied by LaguNet, the highest external loads of dissolved inorganic phosphorus and nitrogen were estimated for the Pialassa Baiona Lagoon (290 and 6870 mmol m^{-2} y^{-1} respectively) (Figure 1.3), which receives large inputs from industrial wastewater treatment plants plus many other sources around the city of Ravenna. The loads of S'Ena Arrubia are rich in DIP even though this system is located in an agricultural area. The case of Torre Guaceto is quite peculiar because the inputs are dominated by groundwater rich in DIN and poor in DIP. About 50% of the systems receive loads higher than 0.05 or 0.8 mol m^{-2} y^{-1} of DIP and DIN respectively, indicating the heavy anthropic pressure to which they are subjected. Systems with the lowest nutrient loads are the Stagnone di Marsala and the system of Capo Feto, which are located in areas with minimal human activities. For all systems, DIP inputs directly from the atmosphere are considered negligible; for S'Ena Arrubia, where a study on dry deposition was performed, such P input was estimated at about 0.1% of the total DIP input. In contrast, DIN inputs from the atmosphere are relevant, in particular in northern Italy where concentration of 100-300 mmol m^{-3} were measured along the east coast and 50-60 mmol m^{-3} along the west coast. These high concentrations are probably related to human activities which are more developed along the north-east coast of Italy. In southern Italy, lower DIN concentrations were measured (Mosello 1993) but measuring stations were few and not uniformly distributed. The DIN loads through precipitation are an important input for many systems (Table 1.2): they are the main estimated DIN inputs for Valli di Comacchio, about 20 % for the Lagoon of Venice, 5-10% for the Gulf of Genova and S'Ena Arrubia and 1-5 % for Sacca di Goro.

Sites range from very large ecosystems such as the Venice Lagoon (the area open to tidal expansion and assessed as relevant for budgeting is 360 km^2, the total area of the system is 550 km^2) to extremely small ones such as Marinello - Fondo Porto (0.013 km^2), from deep coastal systems such as the Gulf of Genoa (28 m) to very shallow ones such as Torre Guaceto or S'Ena Arrubia (0.40 m). Figure 1.4 illustrates the geomorphologic and hydrologic variability of the LaguNet systems. Large systems, as the Lagoon of Venice, have relative low water residence time whilst small systems as the lakes of Marinello, positioned in a dry area, have relative high τ. Most of the systems have surface area from 1 to 100 km^2 (median value = 2.4 km^2) and τ from 5 days to 1 year.

Among LaguNet sites, a relationship between *ΔDIP* and DIP loads are observed (Figure 1.5). At low loads, systems are more or less in balance or they act as a source of DIP (positive *ΔDIP*) while at high loads they act as sinks of DIP. The case of Pialassa Baiona is peculiar since even at the highest DIP loads, the system shows a *ΔDIP* close to zero. This can be due to the presence of heavy metals or other toxic compound that inhibited P uptake and release. A trend similar to DIP input/*ΔDIP* can be observed also for DIN input/*ΔDIN* (Figure 1.6).

The higher values (both positive and negative) of the estimated Net Ecosystem Metabolism, which indicate that a system is highly heterotrophic or highly autotrophic, are estimated for systems dominated by floating macroalgae such as Sacca di Goro and S'Ena Arrubia (-8 and +12 mol C m^{-2} y^{-1}, respectively) indicating that this kind of primary producer can be considered as a source of disturbance within the system. As expected from Figure 1.5, since NEM is estimated from *ΔDIP* and N/P ratio, balanced or respiration dominated system prevail at low DIP load while production dominate at high DIP load (Figure 1.7). No clear relationships exist among NEM and DIN loads (Figure 1.8).

The resulting (*nfix-denit*) is the difference between nitrogen fixation and denitrification in the system (Figure 1.9). These 2 microbial processes are linked to the availability of nitrogen rather then to production and respiration processes. In general, at high nitrogen loads, the LaguNet systems show a dominance of denitrification over N fixation.

The principal component analysis (PCA) was applied to all the LaguNet sites, considering area, depth, τ , annual DIP and DIN inputs and mean concentrations in the system, Δ*DIP*, Δ*DIN*, NEM and (*nfix-denit*). The first four component explain the 76% of the system variance. The scattergram of the first 2 components (54% of the system variance) shows a separation of the most impacted lagoons from the well preserved ones (Figure 1.10)

Comparing LaguNet budgets to the global budgets of the LOICZ database as of 2003, we can see similar general trend (Figures 1.11-1.18). The median area of LaguNet sites is smaller than that of global dataset (Figure 1.11). Median depth (Figure 1.12) and water residence time (Figure 1.13) of the two distributions are roughly the same. The nutrient loads of LaguNet sites cover only the lower half of the overall budget but follow the same trends (Figure 1.14). *ΔDIP* and *ΔDIN* distribution of the LaguNet sites conform to the general global distribution with a dominance of negative values (Figures 1.15-1.16). As for the overall budgets, the LaguNet systems are mostly autotrophic with a dominance of denitrification (Figures 1.17-1.18).

With this volume, we continue to increase the coverage of nutrient fluxes in much of the global coastal zone. Some trends are emerging, such as the dominance of autotrophic systems and net-denitrifying systems in the global coastal zone, though quantitative relationships with other variables seem to be generally nonlinear and noisy. Other statistical approaches (principal components and cluster analysis) may be more robust and have to be considered. In any case, extrapolating from individual budget sites to the "global coastal zone" remains a challenge although the Italian sites appear to reproduce patterns observed at the global scale

Input to national and European policy

Other than the application of LOICZ methodology for the purpose of studying the impact of climatic change and human activities on fluxes of nutrients to coastal ecosystems, there is an increasing need of policy-oriented scientific information.

Information on the impact of watershed processes on nearshore coastal environments is becoming increasingly important for the protection of biodiversity and sustainability of terrestrial aquatic ecosystems as well coastal systems under their influence. Such integrated systems require an approach that closely links science and policy for a more efficient development and implementation of EU Directives. Too often, available scientific information is not adequately assessed in the development of policy, even if it is well prepared, or alternatively, the information is not presented in a form that can be easily used for policy development. One role of networks of environmental researchers, such as LaguNet, is to contribute to bridging the gap between science and policy. Such networks bring together individual research groups working on similar or common themes, using benchmarked methodologies, allowing comparison of processes over a wide range of ecosystems (under varying pressures and impacts), and can thus identify information gaps and build a basis in solid science for the development and implementation of Directives and input to national or EU policy discussions. We expect that LaguNet will also provide a strong basis for cooperation with other national or European networks.

List of reference persons for groups collaborating in LaguNet

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Table 1.1. Budgeted LaguNet sites for Italy - locations, system dimensions and water exchange times.

System Name/ Description	**Province**	**Lat.** (+°N)	**Long.** (+°E)	**Area** (km^2)	**Depth** (m)	**Period studied**	**No. of layers**	**No. of boxes**	**Exchange time** (days)
Lagoon of Venice	Venezia	45.40	12.40	360	1.5	1999, 2001	1	1 and 2	10-14
Sacca di Goro	Ferrara	44.80	12.29	26	1.5	1992 1997	1	1	2 7
Valli di Comacchio	Ferrara-Ravenna	44.60	12.17	114.5	0.8	1997	1	1	247
Valle Smarlacca	Ravenna	44.58	12.23	1.9	0.8	1997	1	1	434
Pialassa Baiona	Ravenna	44.50	12.25	9.9	0.9	2000	1	1	3
Lagoon of Lesina	Foggia	41.88	15.45	51.5	0.8	1998-99	1	1	100
Lagoon of Varano	Foggia	41.88	15.75	64.0	4.0	1997-99	1	1	1032
Torre Guaceto marshland	Brindisi	40.71	17.80	1.19	0.3	2001-02	1	1	26
Torre Guaceto Bay	Brindisi	40.71	17.80	1.44	4	2001-03	1	1	na
Acquatina Lake	Lecce	40.44	18.24	0.45	1.0	1995	1	1	4
Lake Alimini Grande	Lecce	40.20	18.45	1.4	1.5	1998-99	1	1	232
Rada di Augusta	Siracusa	37.21	15.23	23.5	14.9	1998-99	1	1	169
Capo Feto	Trapani	37.68	12.48	1.4	1.75	2001	1	1	105
Stagnone di Marsala	Trapani	37.83	12.45	21.35	0.95	1996	1	1	63
Ganzirri Lake	Messina	38.26	15.62	0.34	2.5	1998-99	1	2	149* (44-15)
Marinello Lakes-Verde	Messina	38.13	15.05	0.017	1.6	1997-98	1	1	156
Marinello Lakes - Fondo Porto	Messina	38.13	15.05	0.013	1.5	1997-98	1	1	95
Orbetello Lagoon	Grosseto	42.44	11.23	25.25	1.0	1999-00	1	1	8
Ligurian Coast (Gulf of Genoa)	Genova	44.40	8.93	52	28.0	summer 1996	2	1	16
Port of Genoa - Old Port	Genova	44.40	8.90	2.7	13.2	summer 2002	2/1	2	11* (20-7)
Port of Genoa - Multedo oil terminal	Genova	44.40	8.90	1.4	15.0	summer 2002	1	1	60
Port of Genoa – Voltri Container Terminal	Genova	44.40	8.90	2.1	15.0	summer 2002	1	1	99
S'Ena Arrubia	Oristano	39.83	8.57	1.2	0.40	1994, 1995, 2001-02	1	1	8 20 4

* for the 2 boxes budgets, τ of the whole system is indicated with the values of the inner and outer boxes in brackets.
na= not available

Table 1.2 Budgeted LaguNet sites for Italy - loads and estimated (nfix-denit) and (p-r). Torre Guaceto marine area budget is not considered due the uncertainty in the V_X estimation (see the relevant budget).

System Name/ Description	V_R	V_X	DIP load*	DIN load*	DIN_P load[#]	*ΔDIP*	*ΔDIN*	(*nfix - denit*)	(*p-r*)
	10^6 m^3 yr^{-1}		mmol m^{-2} yr^{-1}						
Lagoon of Venice 1999	-1216	19248	11.5	741	202	9.2	-511	-657	-986
Lagoon of Venice 2001	-1136	12511	12.4	751	202	-3.9	-694	-628	438
Sacca di Goro 1992	-726	6467	42.1	5517	56	3.3	-7230	-7099	1234
Sacca di Goro[SG] 1997	-361	1717	20.1	1227	58	24.6	1774	916	-8249
Valle di Comacchio[VC]	18	117	0	0	59	0.4	-72	-80	-40
Valle Smarlacca[VS]	-2	0[VS]	4.0	182	58	-3.6	-226	-146	402
Pialassa Baiona	-472	667	291.3	6802	66	-3.3	-3459	-3405 – -3343[$]	354-1117[$]
Lagoon of Lesina	-45	105	43.3	954	na[£]	-43.2	-911	-212	4636
Lagoon of Varano	-24	67	2.2	76	na[£]	-2.1	-72	-37	234
Torre Guaceto	-5	0	0.1	3784	na[£]	0.8	-3134	-3146	-88
Acquatina Lake	-15	44	8.9	2300	na[£]	-7.3	-651	-526	803
Alimini Grande[AG]	-2	7	0.2	242	na[£]	-0.03	-11	-11	0
Rada di Augusta	-17	741	4.0	914	na[£]	-0.4	-827	-818	44
Capo Feto marshland	0.04	8	0.3	8	na[£]	8.6	33	-106	-913
Stagnone di Marsala	7	110	0.0	0	na[£]	0.04	-0.5	-1.1	-18
Ganzirri Lake	-0.5	1.5	3.4	109	na[£]	-3.0	-61	-13.2	319
Marinello-Verde	-0.02	0.04	5.0	84	na[£]	-3.9	-47	14.6	405
Marinello-Fondo Porto	-0.01	0.07	0.6	10	na[£]	-0.5	16	25.6	58
Orbetello Lagoon	-179	995	12.4	576	45	-1.4	1239	1347	1022
Ligurian Coast (Gulf of Genoa)	198 §	15968 §	41.7	595	18	-48.9	-825	-44	5183
Port of Genoa – Old Port	-27	1203	107.3	6558	150	-83	-6227	-4897	8813
Port of Genoa – Multedo oil terminal	-4	124	8.1	130	149	87	145	-1256	-9271
Port of Genoa - Voltri Terminal Container	-4	113	0	0	149	-1.2	-251	-237	110
S'Ena Arrubia [SEA] 1994	-9	14	159.1	1048	32	-111	-1034	767	11863
S'Ena Arrubia [SEA] 1995	-2	7	91.9	215	16	-45	-176	548	4818
S'Ena Arrubia 2000-01	-8	45	92.5	695	14	-34	-329	212	3599

* = sum of loads from runoff (V_Q), direct sources (Vo), groundwater (V_G) if present and known, expressed per unit area of the system (not the drainage basin)

[#] DIN loads from precipitation (Vp) if present and known, expressed per unit area of the system (not the drainage basin)

na[£] data not available; DIN_P loads are assumed to be zero.

$^{\$}$ lower value obtained using Redfield ratio C:P; Higher value using macroalgal C:P from Atkinson and Smith,1983
§ V_{deep} is reported for V_X; V_{surf}-V_{deep} for V_R
^{SG} see Viaroli *et al.* 2001b or http://data.ecology.su.se/mnode/Europe/Med_Aegean_BlackSea/Italy/SaccadiGoro/saccadigorobud.htm
^{VC} see Viaroli and Giordani 2001 or http://data.ecology.su.se/mnode/Europe/Med_Aegean_BlackSea/Italy/comacchio/comacchiobud.htm
^{VS} see Giordani and Viaroli 2001 or http://data.ecology.su.se/mnode/Europe/Med_Aegean_BlackSea/Italy/smarlacca/smarlaccabud.htm
^{AG} see Vadrucci *et al.* 2001 or http://data.ecology.su.se/mnode/Europe/Med_Aegean_BlackSea/Italy/Alimini/aliminibud.htm
^{SEA} see Giordani *et al.* 2001 or http://data.ecology.su.se/mnode/Europe/Med_Aegean_BlackSea/Italy/arrubia/arrubiabud.htm

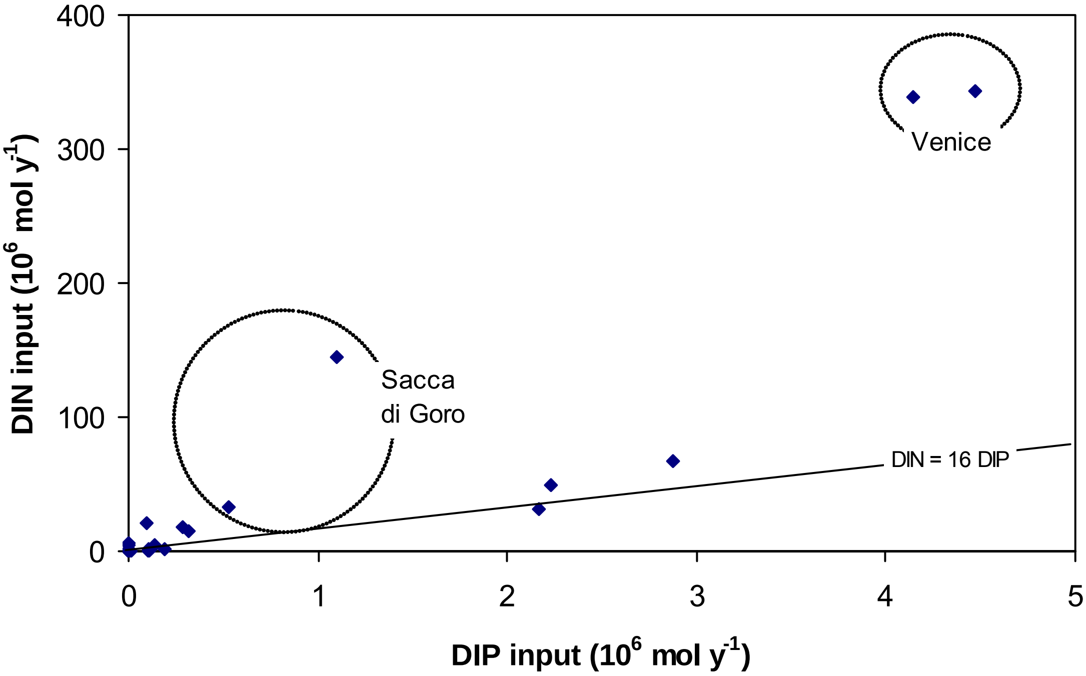

Figure 1.2. DIP and DIN loads to the LaguNet systems.

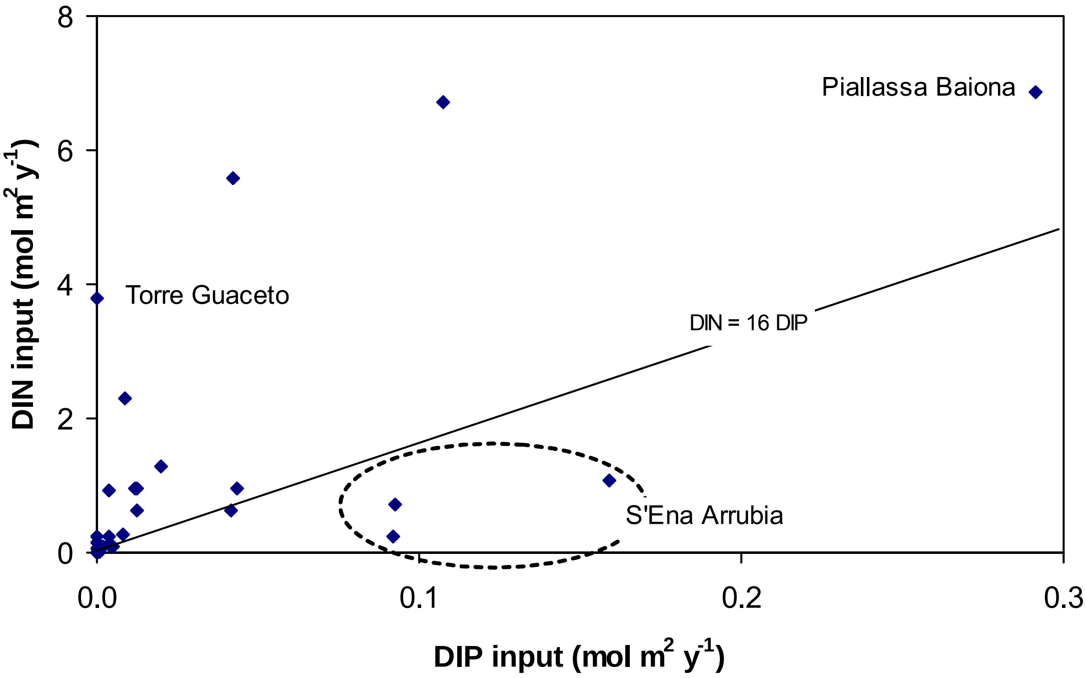

Figure 1.3. DIP and DIN loads to the LaguNet systems per square meter of lagoon.

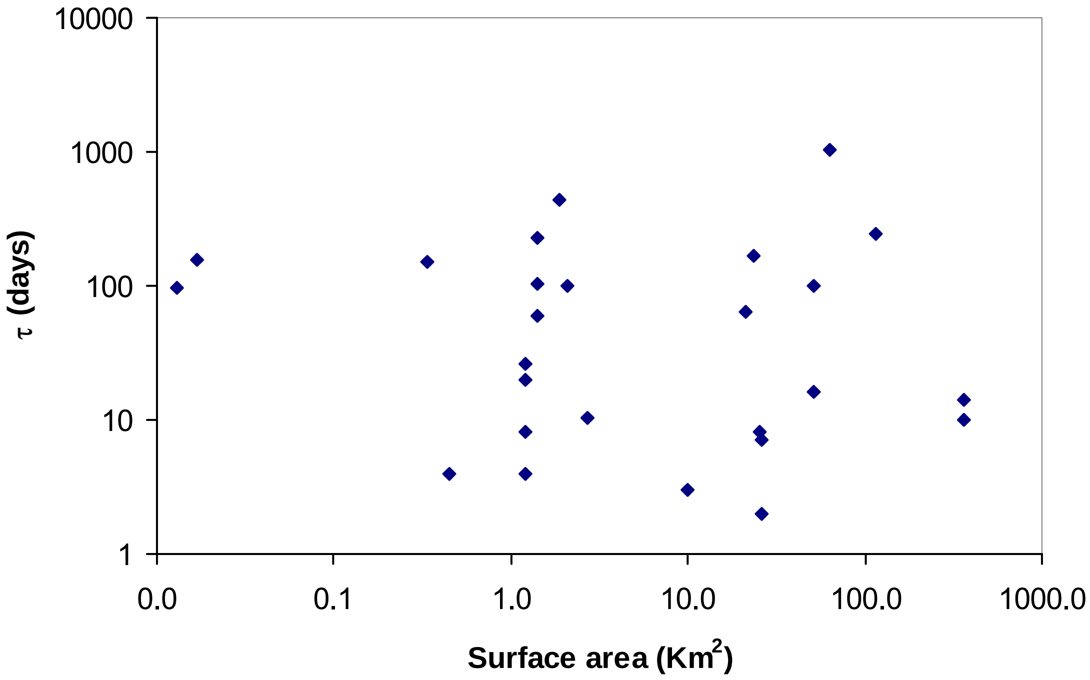

Figure 1.4. Surface area and estimated mean water residence time (log scales) among LaguNet sites.

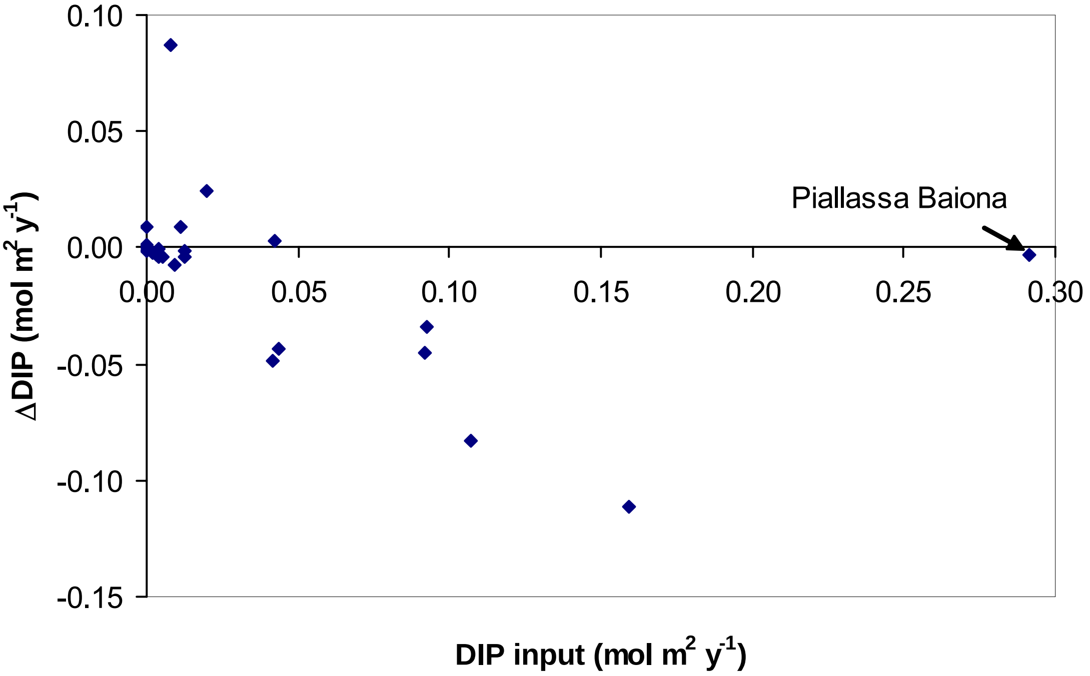

Figure 1.5. Non-conservative behaviour of DIP in relation to DIP loads among the LaguNet sites.

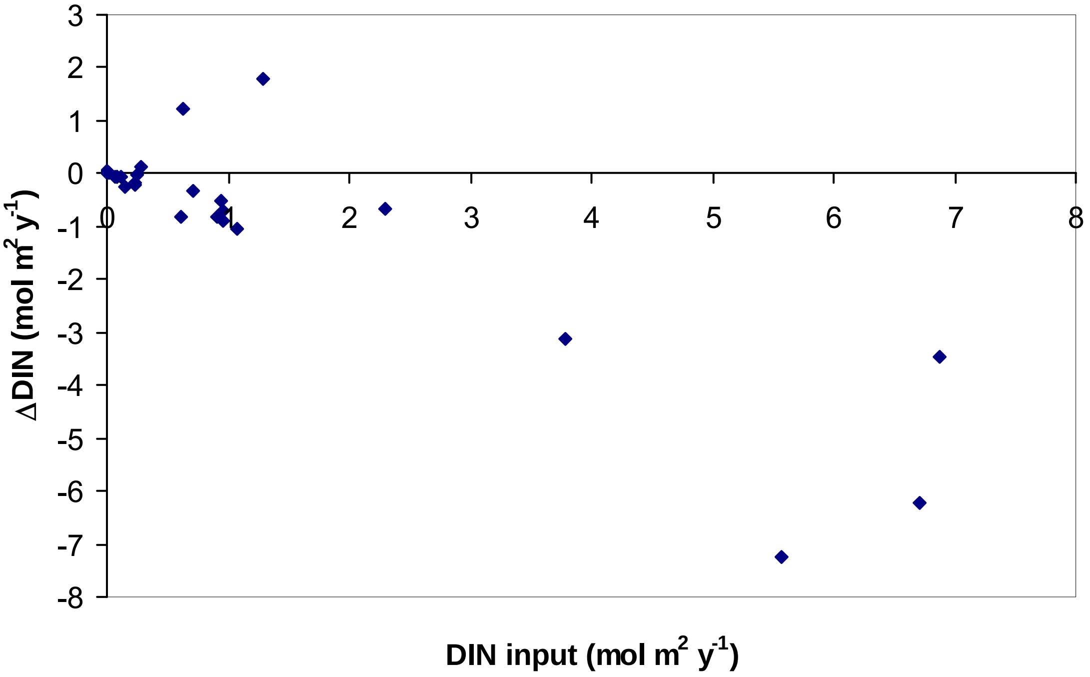

Figure 1.6. Non-conservative behaviour of DIN in relation to DIN loads.

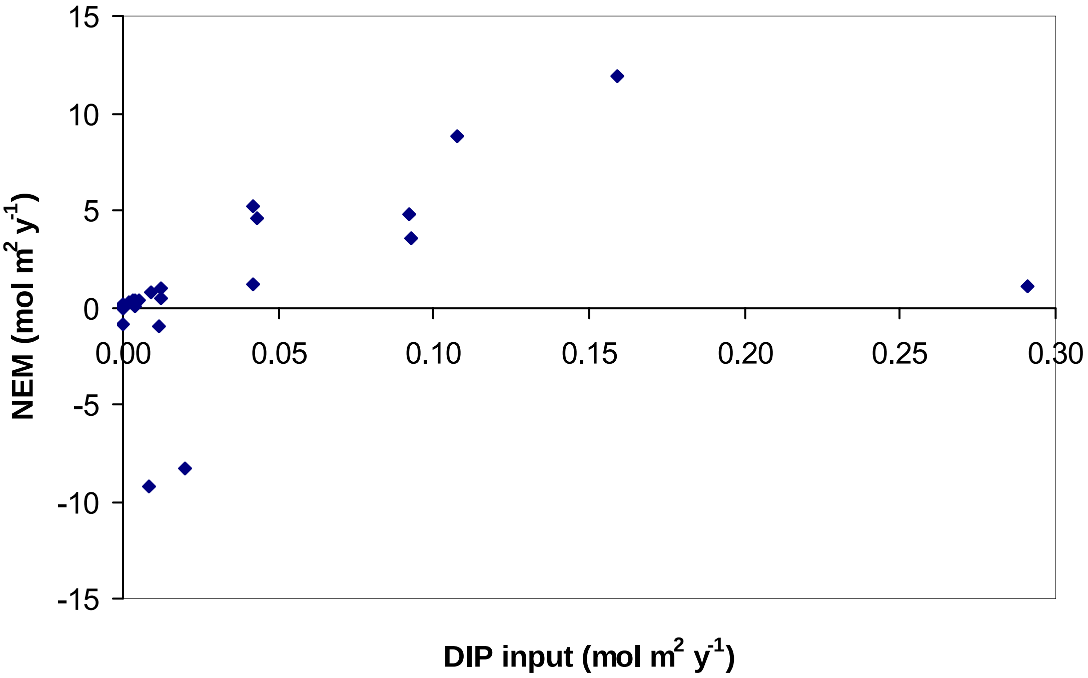

Figure 1.7. Relationship between NEM and DIP loads in the LaguNet sites. NEM is the difference between production and respiration processes in the system.

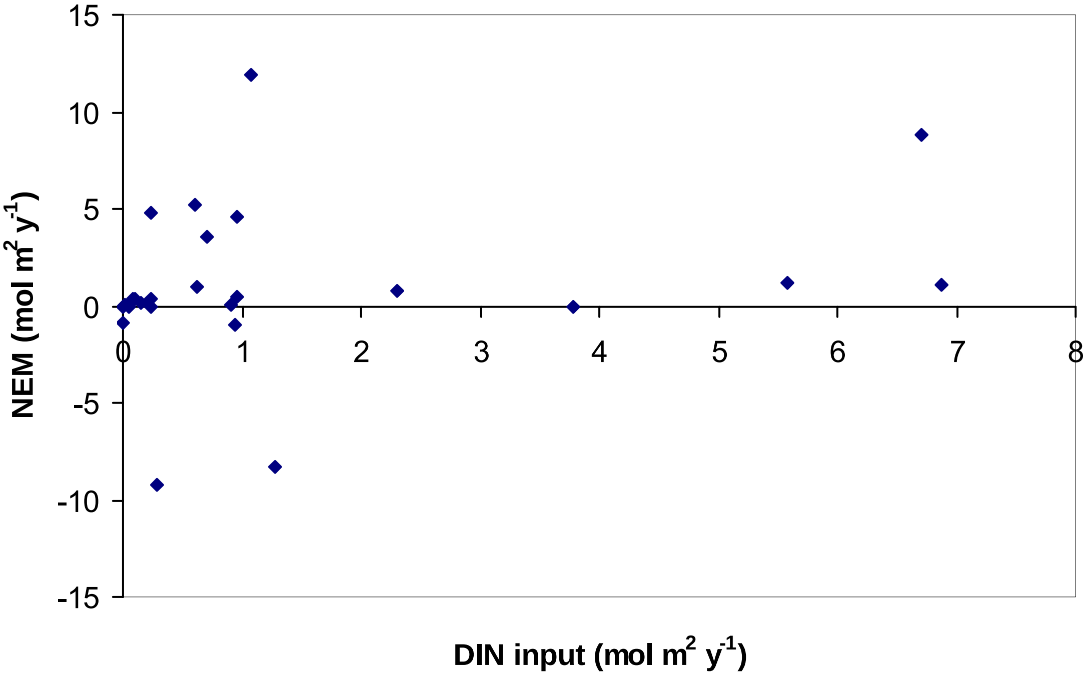

Figure 1.8. Relationship between NEM and DIN loads in the LaguNet sites. NEM is the difference between production and respiration processes in the system..

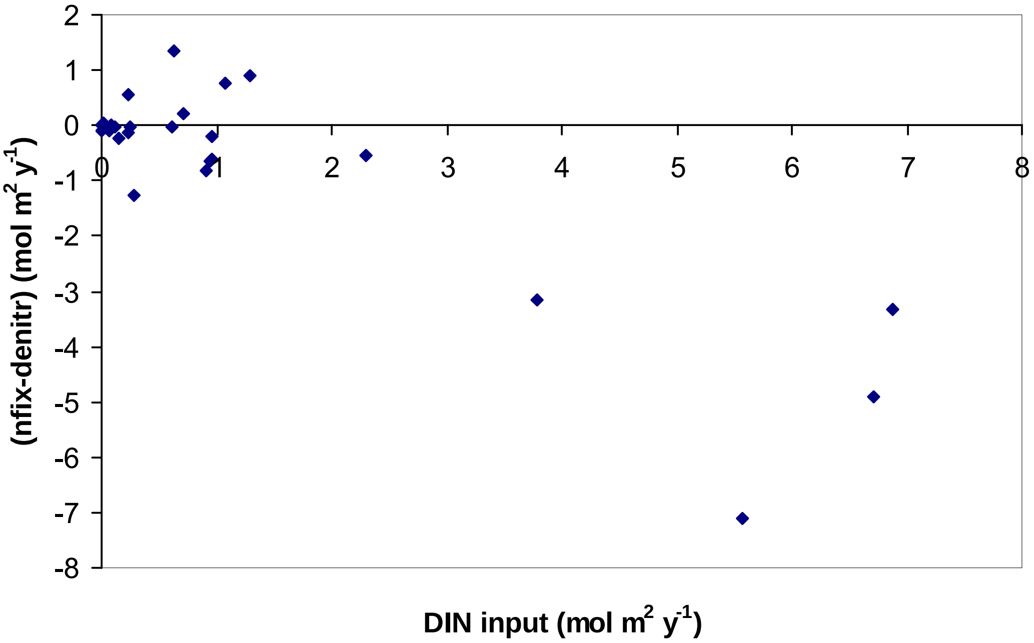

Figure 1.9. **Relationship between (*nfix-denit*) and DIN loads in the LaguNet sites.** (*nfix-denit*) is the difference between nitrogen fixation and denitrification in the system.

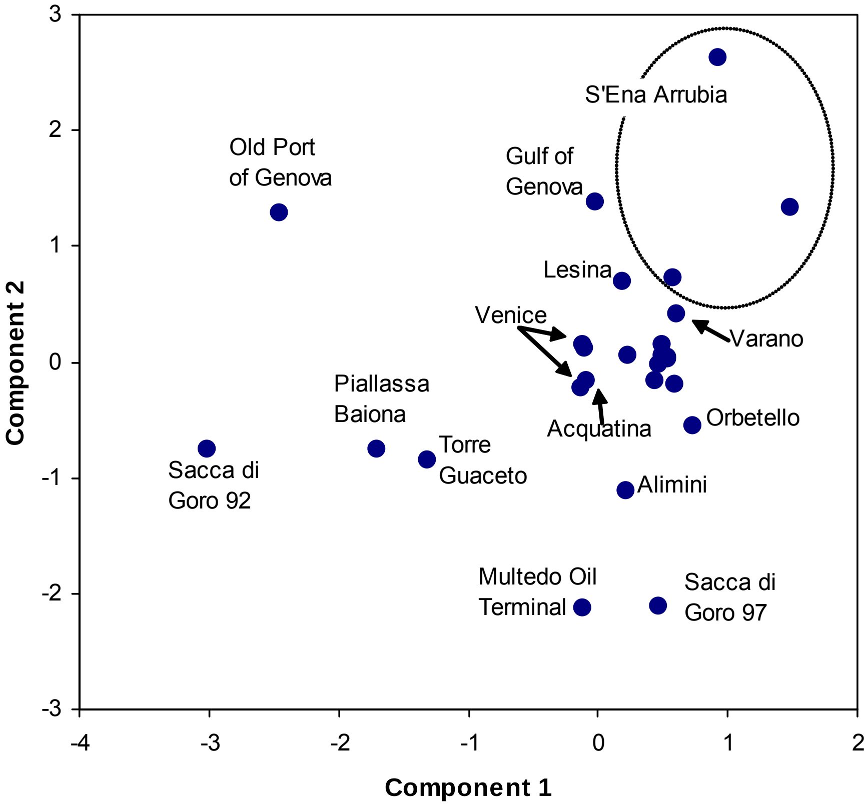

Figure 1.10. **Ordination of the LaguNet sites as shown by the Principal Component Analysis of morphometric data (area, depth, water residence time), DIP and DIN inputs and concentration in the system, Δ*DIP,* Δ*DIN*, NEM and (*nfix-denit*).** Component 1 (33%) correlates with (*nfix-denit*) (r = +0.96), Δ*DIN* (r = +0.92) and DIN input (r = -0.90); Component 2 (20%) correlates with NEM (r = +0.91), Δ*DIP* (r = -0.89) and DIN_{sys} (r = -0.66). The other 2 components (not indicated) (14 and 10 %) correlate respectively with DIP_{sys} (r = -0.70) and area (r = -0.88).

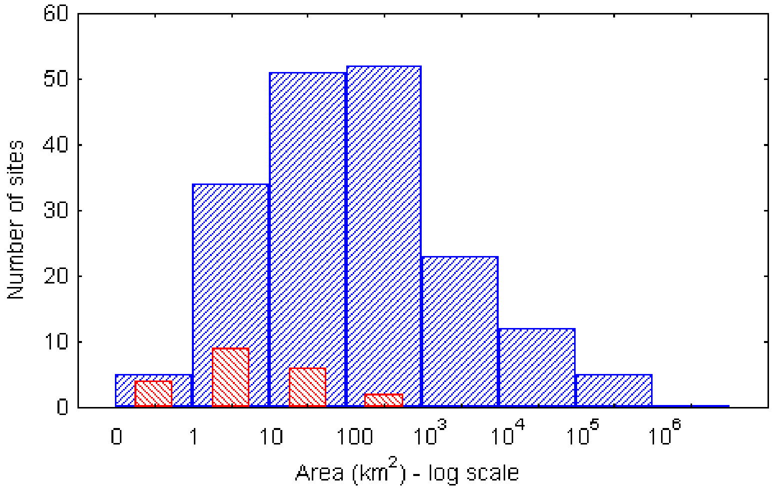

Figure 1.11. Comparison between the areas of LOICZ (blue) and LaguNet (red) sites as of 2003. The areas of LaguNet sites span 4 orders of magnitude and the median area is smaller than that of global budget dataset.

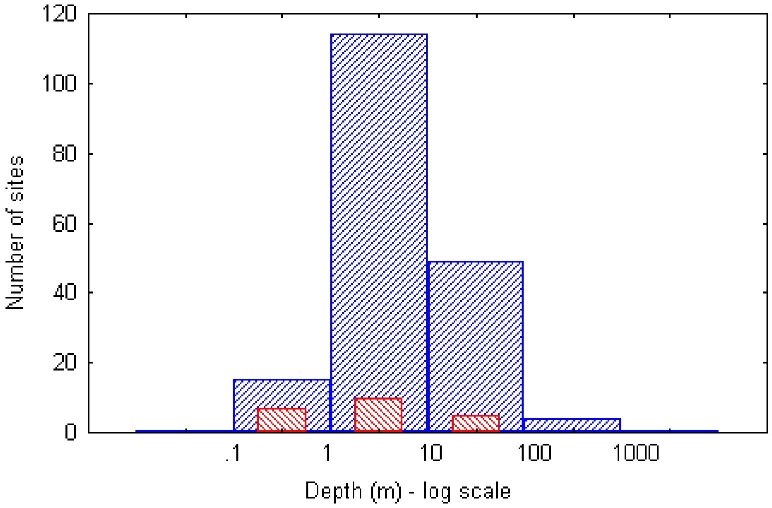

Figure 1.12. Comparison between the depth of LOICZ (blue) and LaguNet (red) sites as of 2003. The depths of LaguNet sites span 3 orders of magnitude and the median area value is similar to that of global budget dataset.

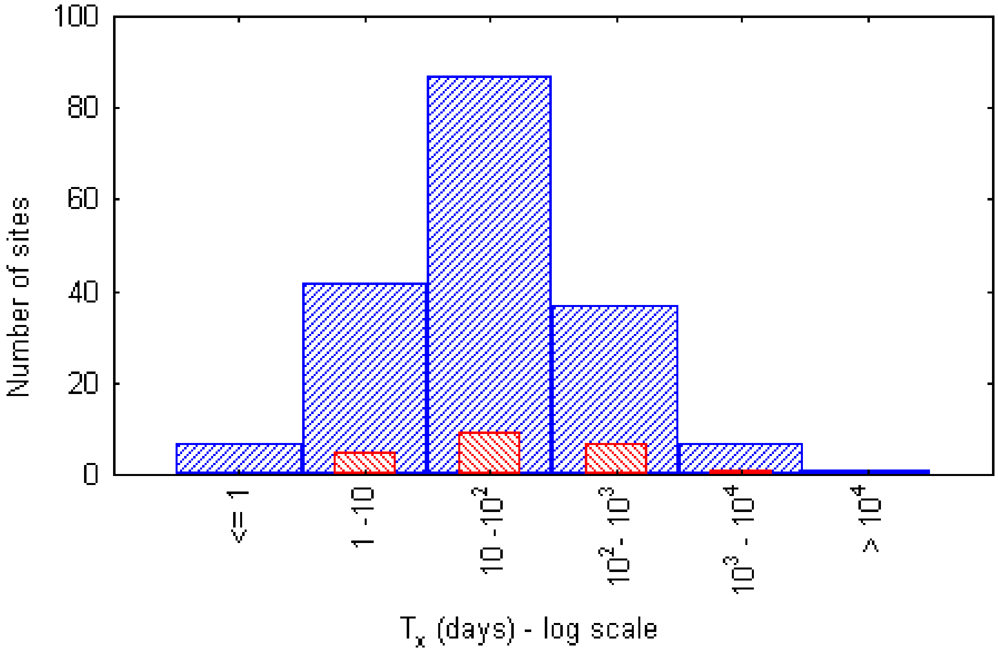

Figure 1.13. Comparison between water residence time of LOICZ (blue) and LaguNet (red) sites as of 2003. Residence time distribution of the LaguNet sites spans over three orders of magnitude and is centred on roughly the same median value as the overall distribution.

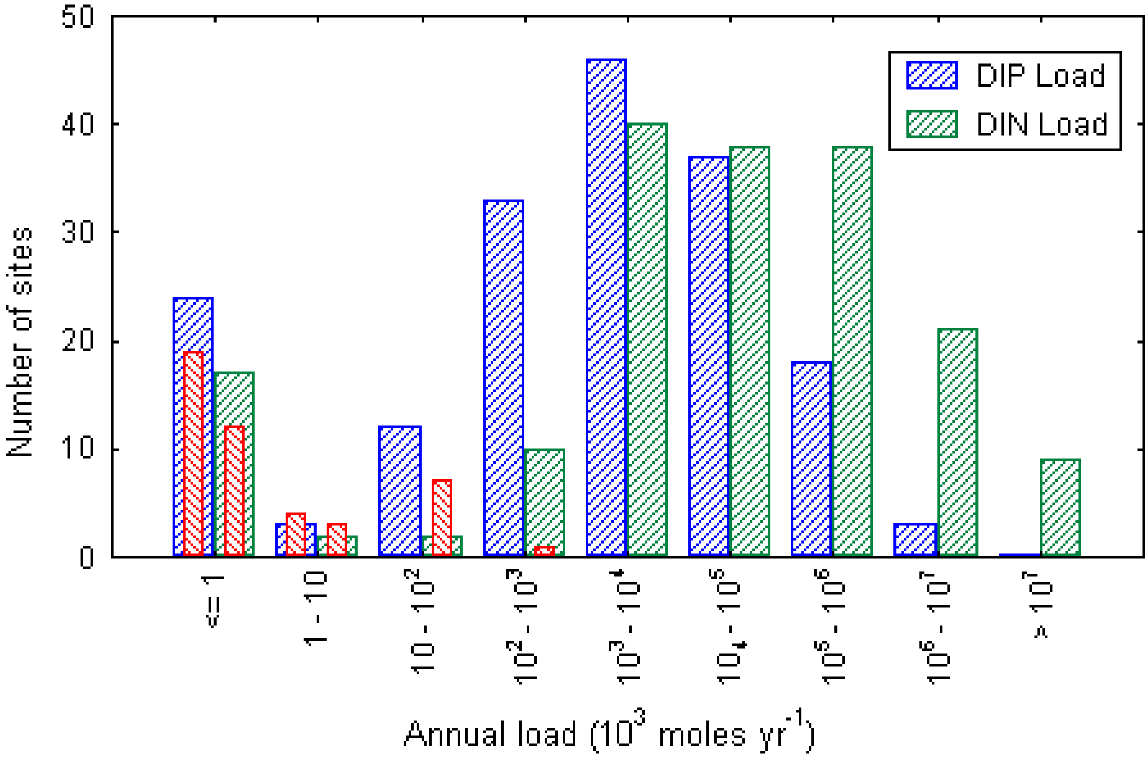

Figure 1.14. Comparison between nutrient loads of LOICZ (blue/green) and LaguNet (red) sites as of 2003. Nutrient loads (unscaled) span over 3+ orders of magnitude. Overall budgets show a bimodal distribution for both DIN and DIP LaguNet sites follow these general patterns even with low values related to the smaller catchment areas.

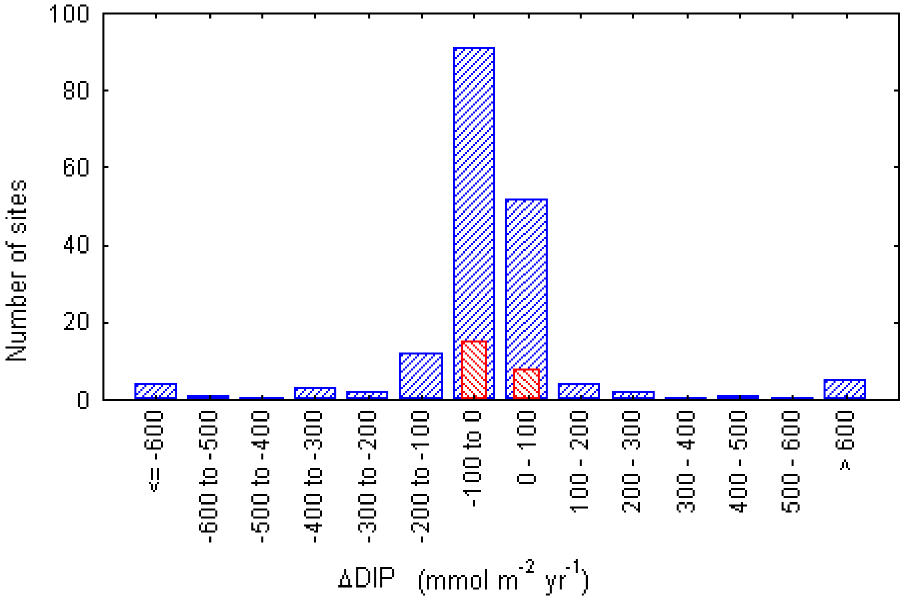

Figure 1.15. Comparison between *ΔDIP* of LOICZ (blue) and LaguNet (red) sites as of 2003. Both distributions are unimodal and skewed left on a linear scale (negative values). Most LaguNet sites fall in the same category as the global budget dataset.

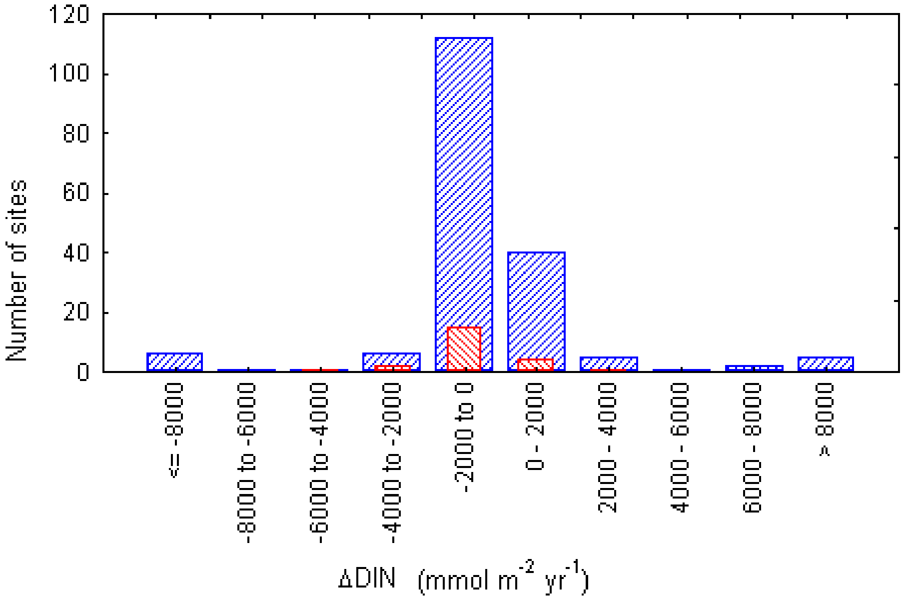

Figure 1.16. Comparison between *ΔDIN* of LOICZ (blue) and LaguNet (red) sites as of 2003. Both distributions are unimodal and skewed left on a linear scale (negative values). Most LaguNet sites fall in the same category as the global budget dataset.

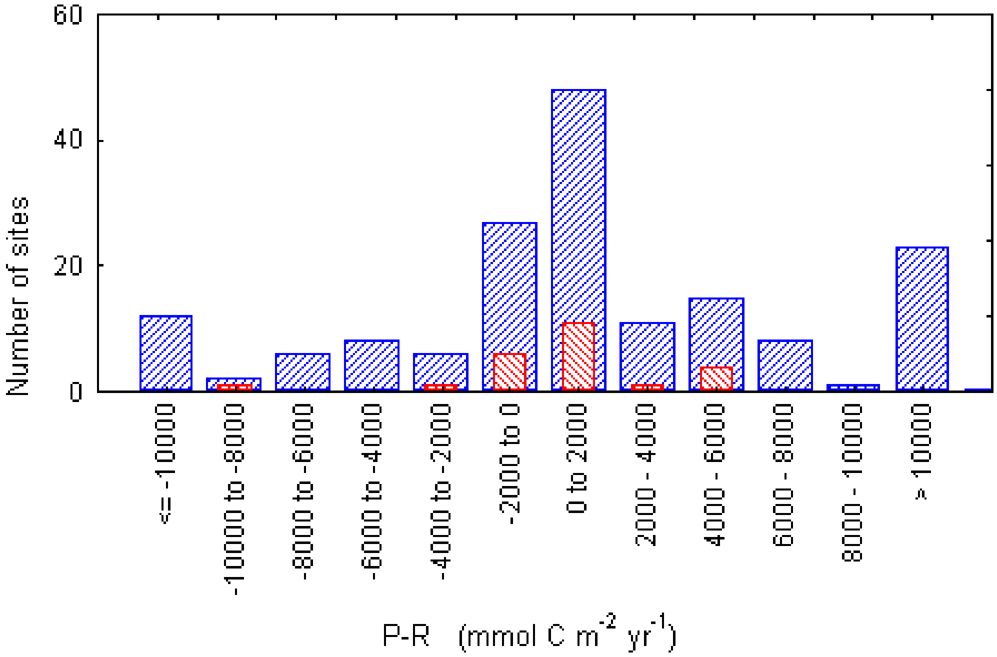

Figure 1.17. Comparison between (*p-r*) of LOICZ (blue) and LaguNet (red) sites as of 2003. More sites are autotrophic than heterotrophic. The distribution of the Italian sites is similar to the general global distribution. Extreme values (beyond ± 10^4) are questionable.

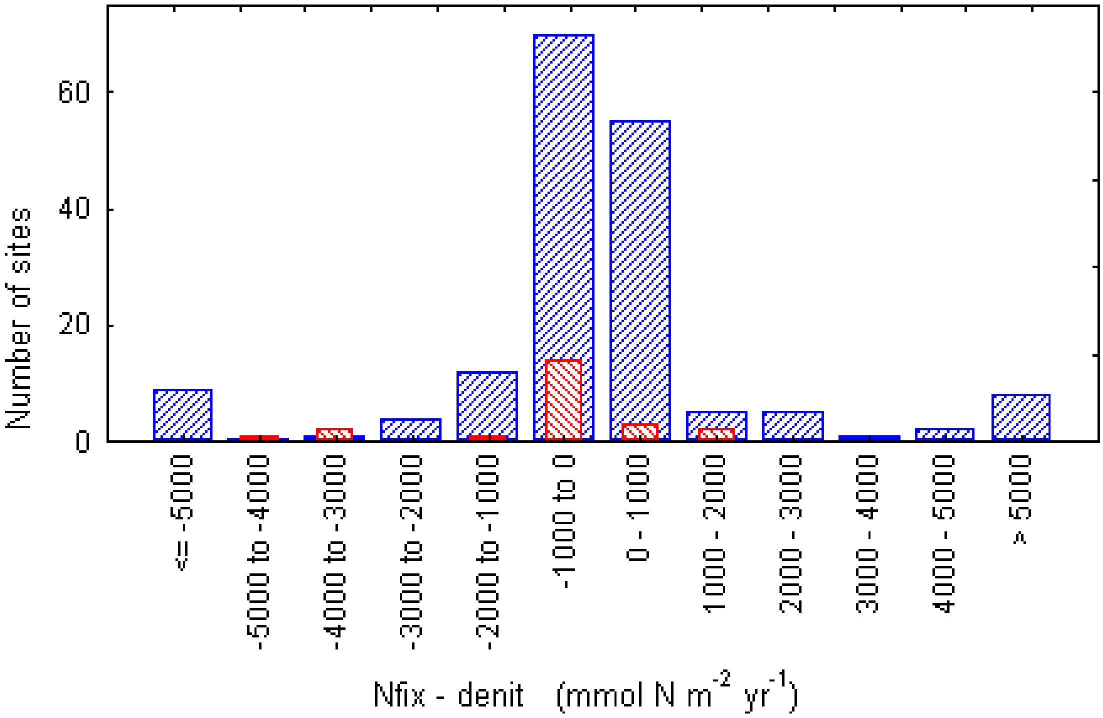

Figure 1.18. Comparison between (nfix-denit) of LOICZ (blue) and LaguNet (red) sites as of 2003. More sites are denitrifiers. The distribution of the Italian sites is similar to the global distribution pattern. Extreme values (beyond ± 5000) are questionable.

2 NORTH-EASTERN ITALIAN COASTAL SYSTEMS

2.1 Lagoon of Venice

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Study area description

The Lagoon of Venice is the largest lagoon in Italy and one of the largest in Europe. It is located in the northern part of the Adriatic Sea (45.2°N - 45.6°N 12.2 - 12.6°E). Three narrow inlets connect the Lagoon of Venice to the Adriatic Sea, subdividing the lagoon into three sub-basins divided by two watersheds, along which the intensity of the tidal currents is low. Part of the lagoon is devoted to aquaculture and closed to water exchanges; the surface open to tidal exchange and assessed as relevant for LOICZ computation (estimated from CVN 1990 bathymetry), is 360 km^2, with a volume of 0.540 km^3 and an average depth of 1.5 m.

Figure 2.1. The Lagoon of Venice and its drainage basin (Source: CVN).

The drainage basin is densely populated and carries into the lagoon both industrial and agricultural wastewaters. The loads of nitrogen and phosphorus discharged into the lagoon by the tributaries were assessed during the DRAIN project (DeteRmination of pollutAnt INputs from the drainage basin; MAV-CVN 2001), in which the main tributaries were monitored for almost two years (1998 - 2000). The largest fraction of these loads of nitrogen and phosphorus is discharged into the northern sub-basin. Other relevant nutrient sources come from the industrial area of Porto Marghera (MAV-SAMA 2000-2002), from a civil wastewater treatment plant located close to the lagoon (ASPIV 2000; VESTA 2002) and from atmospheric deposition, which was investigated within the "2023 project" (MAV-CVN 2000a).

In the last few decades several projects have studied the lagoon environment. Data dealing with the concentrations of dissolved nitrogen and phosphorus in the lagoon were systematically collected by MAV-CVN (MELa1 Project, Monitoraggio Ecosistema Lagunare). Analysis of results shows that the lagoon is a complex system, exhibiting spatial and temporal variability of dissolved nutrients, chlorophyll *a*, dissolved oxygen and turbidity (MAV-CVN 2002a, MAV-CVN 2002b). Dissolved nitrogen and phosphorus are higher in the northern sub-basin than in other sub-basins, while within each basin concentrations are inversely correlated with salinity, suggesting the importance of nutrient loads from freshwater sources.

The LOICZ budgeting approach was applied to the datasets presented in Table 2.1. These data allowed us to estimate annual budgets of salt and nutrients for the years 1999 and 2001, which were computed under the standard 1-box, steady-state hypothesis (Gordon *et al.* 1996). We also show and briefly discuss the results of a seasonal analysis calculated for the year 1999, and of a steady-state analysis of the 2001 annual budget which was based on the assumption that the lagoon could be divided into two homogeneous boxes.

Single box analysis: 1999 and 2001 annual budgets

Water and salt budget

In 1999, river discharges (V_Q) and direct atmospheric precipitation (V_P) accounted for about 70% and 20% of the freshwater input (Table 2.2). The discharges from sewage treatment plants (V_O) accounted for the remaining 10%. The evaporation volume, V_E, estimated according to Hargreaves' equation (Hargreaves 1975) was about 7% greater than direct precipitation. As a result of the water balance, the residual flow, V_R, was -3.33×10^6 m^3 d^{-1}. The exchange flow, V_x, computed on the values of salinity of system and sea and residual flow, was 52.74×10^6 m^3 d^{-1}.

Lacking more recent data, fluvial and atmospheric input for 2001 were considered to be as for 1999, since precipitation into the lagoon during the two years was comparable, at least for the model aims and on annual basis. For 2001, $V_R = -3.11 \times 10^6$ m^3 d^{-1} and $V_X = 34.28 \times 10^6$ m^3 d^{-1}, suggesting a change with respect to 1999 values: V_R increased 7% while V_X decreased ~ 35%.

Residence time estimates using LOICZ methodology were 10 days for 1999 and 14 days for 2001. These values are consistent with estimates of the residence time obtained by hydrodynamic model simulations previously performed for the Lagoon of Venice (MAV-CVN 1998). LOICZ results are within the range of variation of the model-simulated residence time of the lagoon, which exhibits strong variability depending on the spatial heterogeneity of the system and tidal conditions. The net exchange flow V_X accounts about for 9-14% of the average daily volume of water flowing into the lagoon from the sea through the three inlets (385×10^6 m^3 d^{-1}) (MAV-CVN 2000b). However, any consideration of the V_X and τ values must take into account their high sensitivity to the average salinity values attributed to the lagoon and to the sea.

Results of the water and salt budget for the years 1999 and 2001 are summarized in Table 2.2 and Figure 2.3.

Table 2.1. Data used in budget calculations for the Lagoon of Venice.

Year of budget	Type of data	Spatial resolution	Frequency of sampling or estimation	Sources
1999-2001	V_Q, DIP_Q, DIN_Q	Main inflowing rivers	Monthly 1999	MAV-CVN 2001
1999-2001	V_P, DIP_P, DIN_P	4 stations in the lagoon	Monthly from August 1998 to July 1999	MAV-CVN 2000a
1999	V_O, DIP_O, DIN_O	Campalto sewage treatment plant; P. Marghera industrial discharge	Monthly 1999 Annual, 1999-2000	ASPIV 2000 MAV-SAMA 2000
2001	V_O, DIP_O, DIN_O	Campalto sewage treatment plant; P. Marghera industrial discharge	Monthly 2001 Monthly 2000	VESTA 2002 MAV-SAMA 2002
1999	Sal_{sys}, DIP_{sys},DIN_{sys}	26 stations located in the central part of the lagoon	Monthly from January to July 1999	MAV-CVN 1999
		10 stations located near inland of Venice and urban centres of Lido and Chioggia, and in southern sub-basin	Monthly 1999	MAV-SAMA 2001
		7 stations located in northern sub-basin	Monthly 1999	IBM-CNR
2001	Sal_{sys}, DIP_{sys}, DIN_{sys}	28 stations over the whole lagoon	Monthly 2001	MAV-CVN 2002a,b
1999	Sal_{sea}, DIP_{sea}, DIN_{sea}	Transects along Adriatic coast	Monthly 2000	Interreg II Project (IBM-CNR) and ARPAV coastal data
2001	Sal_{sea}, DIP_{sea}, DIN_{sea}	Transects along Adriatic coast	Monthly 2001	Interreg II Project (IBM-CNR) and ARPAV coastal data

Table 2.2. Summary of salt and water budget for the 1-box model for the Lagoon of Venice
* = values estimated from the 1999 data

Year	V_Q 10^3 m^3 d^{-1}	V_O 10^3 m^3 d^{-1}	V_P 10^3 m^3 d^{-1}	V_E 10^3 m^3 d^{-1}	Sal_{sys} psu	Sal_{sea} psu	V_R 10^3 m^3 d^{-1}	V_X 10^3 m^3 d^{-1}	τ_r days
1999	2980.8	407.8	846.1	903.5	30.97	32.99	-3,331	52735	10
2001	2980.8*	407.8*	655.5	903.7	30.16	33.03	-3,113	34276	14

Budgets of non-conservative materials

The main sources of N and P were the discharges from the rivers, which in 1999 accounted for 67% and 50% of the total annual inputs respectively (Table 2.4). Atmospheric precipitation was also important, accounting for 27% and 21% of DIP and DIN inputs respectively. Because recent data are lacking on inputs from the rivers and from atmospheric deposition, 1999 estimates are also used in the annual budget for 2001. Inputs from the direct discharges, which were independently estimated for the years 1999 and 2001, collectively accounted for about 23% and 11% of the total DIP and DIN inputs for 1999 and 29% and 12% for 2001.

Table 2.3. DIP concentrations in the inflowing rivers, the Lagoon of Venice and the adjacent Adriatic Sea.
*data obtained from V_PDIP_P of 1999 and V_P 2001

Year	**DIP_Q** **mmol m^{-3}**	**DIP_P** **mmol m^{-3}**	**DIP_O** **mmol m^{-3}**	**DIP_{sys}** **mmol m^{-3}**	**DIP_{sea}** **mmol m^{-3}**	**DIP_R** **mmol m^{-3}**
1999	1.92	3.56	6.45	0.45	0.08	0.27
2001	1.92	4.59*	8.64	0.38	0.16	0.27

Table 2.4. DIP budget for the Lagoon of Venice.

Year	**V_Q DIP_Q** **mol d^{-1}**	**V_P DIP_P** **mol d^{-1}**	**V_O DIP_O** **mol d^{-1}**	**V_R DIP_R** **mol d^{-1}**	**VxDIPx** **mol d^{-1}**	***ΔDIP*** **mol d^{-1}**	***ΔDIP*** **µmol m^{-2} d^{-1}**
1999	5723	3012	2630	-899	-19512	9046	25
2001	5723	3009	3523	-841	-7541	-3873	-11

The results of the budget calculations for DIP and DIN, presented in Tables 2.3-2.6 and Figures 2.4 and 2.5 show that V_RDIP_R and V_RDIN_R obtained for the years 1999 and 2001 are of the same order of magnitude. However, in 1999, the fluxes of DIP and DIN due to the mixing process (V_X), which is the most significant term, were in both cases higher than those calculated for the year 2001. The difference is mainly due to the fact that in 1999 the DIP gradient between the system and the sea was almost twice as high as that in 2001, while DIN was almost 50% higher in 1999 than in 2001. Average values of the DIP gradient between system and sea were 0.37 mmol m^{-3} for 1999 and 0.22 mmol m^{-3} for 2001, while the DIN gradients were 6.49 mmol m^{-3} in 1999 and 5.44 mmol m^{-3} in 2001.

As a result of the balance between input and output flows of DIP, the lagoon mobilized 9046 mol d^{-1} in 1999 but took up 3873 mol d^{-1} in 2001. *ΔDIN* estimates for the two years have the same sign, with a higher consumption during 2001 than during 1999.

Table 2.5. DIN concentrations in the inflowing rivers, the Lagoon of Venice and the adjacent Adriatic Sea.
*data obtained from V_PDIN_P of 1999 and V_P 2001

Year	**DIN_Q** **mmol m^{-3}**	**DIN_P** **mmol m^{-3}**	**DIN_O** **mmol m^{-3}**	**DIN_{sys}** **mmol m^{-3}**	**DIN_{sea}** **mmol m^{-3}**	**DIN_R** **mmol m^{-3}**
1999	209.95	235.36	258.00	28.39	21.90	25.15
2001	209.95	303.80*	281.48	23.90	18.36	21.13

Table 2.6. DIN budget for the Lagoon of Venice.

Year	V_Q DIN_Q mol d^{-1}	V_P DIN_P mol d^{-1}	V_O DIN_O mol d^{-1}	V_R DIN_R mol d^{-1}	VxDINx mol d^{-1}	*ΔDIN* mol d^{-1}	*ΔDIN* mmol m^{-2} d^{-1}
1999	625819	199138	105212	-83775	-342250	-504144	-1.40
2001	625819	199141	114788	-65778	-189889	-684081	-1.90

Stoichiometric calculations of aspects of net system metabolism

The non-conservative fluxes expressed as daily rates per unit area are summarized in Table 2.7. The system was heterotrophic in 1999 and slightly autotrophic in 2001 as the NEM was -2.7 mmol C m^{-2} d^{-1} in 1999 and +1.2 mmol C m^{-2} d^{-1} in 2001. The values of (*nfix-denit*), which represents the balance of the fixation and the denitrification processes of the two years, are in good agreement. In fact, the estimation for 2001 was just 5% less than for 1999.

In Figure 2.2 the values of NEM (*p-r*) of the two annual budget calculations for the Lagoon of Venice (red bars) are compared with the results from other northern Adriatic lagoons (black medium bars) and some Mediterranean sites (thin grey bars) (Dupra *et al.* 2001). The NEM values for the Lagoon of Venice are rather small relative to other LOICZ sites, implying a state of near-balance between autotrophic and heterotrophic processes.

Table 2.7. Results of stoichiometric calculations for Lagoon of Venice.

Year	NEM mmol m^{-2} d^{-1}	(*nfix-denit*) mmol m^{-2} d^{-1}
1999	-2.7	-1.80
2001	1.2	-1.72

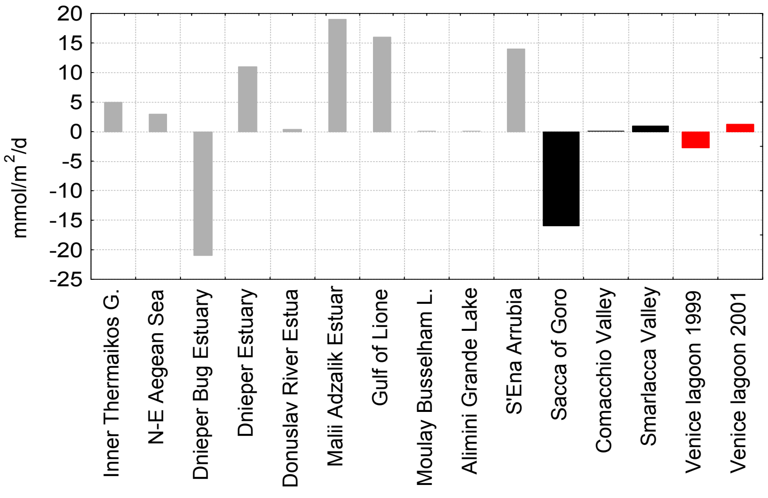

Figure 2.2. Comparison of NEM calculations between Lagoon of Venice and other Adriatic and Mediterranean LOICZ sites.

Single box analysis: 1999 seasonal budget

Salt and water budget

Due to the high monthly variability of data for freshwater flows, lagoon and sea salinity, monthly data were aggregated in order to obtain seasonal estimations of the residual and mixing flow and of the residence time.

The results are summarized in Table 2.8, which shows that in 1999 seasonal variability of advective and mixing fluxes was still quite high. As a consequence, the residence time ranged from 4-5 days in the spring and autumn to 16-17 days during winter and summer. This can be explained by the higher V_Q and V_P fluxes in spring and autumn. However, this pattern can be influenced by the salinity difference between sea and lagoon, which in autumn and spring was slightly lower than 1 psu, the minimum suggested value for a good estimation of V_x and τ.

Table 2.8. Seasonal salt and water budgets for the Lagoon of Venice in 1999.

	V_Q 10^3 m^3 d^{-1}	V_O 10^3 m^3 d^{-1}	V_P 10^3 m^3 d^{-1}	V_E 10^3 m^3 d^{-1}	Sal sys psu	Sal sea psu	V_R 10^3 m^3 d^{-1}	Vx 10^3 m^3 d^{-1}	τ_r d
Jan-Mar	2542.5	405.9	371.0	437.2	31.64	34.78	-2882	30481	16
Apr-Jun	3002.7	411.8	1039.0	1401.2	29.71	30.49	-3052	117776	4
Jul-Sep	2448.2	404.1	632.7	1350.1	31.48	33.82	-2135	29790	17
Oct-Dec	3574.7	409.4	1341.8	425.6	31.77	32.87	-4900	143971	4

Budgets of non-conservative materials and stoichiometric calculations

The DIP input was higher during summer than in the other seasons, while the advection and mixing fluxes of DIP with the Adriatic Sea were both at the lowest levels (Table 2.10). This indicates that the lagoon has a net uptake of DIP only in summer when the net ecosystem metabolism, NEM, was positive (autotrophy) (see Table 2.13). During all the other seasons the system act as a source of DIP as ΔDIP was positive. The system was highly heterotrophic during spring and autumn when NEM was -12.9 and -21.6 mmol d^{-1} m^{-2} respectively.

Table 2.9. DIP concentrations in the rivers, the Lagoon of Venice and the adjacent Adriatic Sea.

	DIP_Q mmol m^{-3}	**DIP_P mmol m^{-3}**	**DIP_O mmol m^{-3}**	**DIP_{sys} mmol m^{-3}**	**DIP_{sea} mmol m^{-3}**	**DIP_R mmol m^{-3}**
Jan-Mar	1.46	8.33	6.67	0.41	0.06	0.24
Apr-Jun	1.82	3.16	6.13	0.55	0.09	0.32
Jul-Sep	2.64	6.16	6.85	0.29	0.05	0.17
Oct-Dec	1.88	1.16	6.13	0.69	0.12	0.41

Table 2.10. DIP budget for the Lagoon of Venice – 1999.

	V_Q DIP_Q mol d^{-1}	**V_P DIP_P mol d^{-1}**	**V_O DIP_O mol d^{-1}**	**V_R DIP_R mol d^{-1}**	**VxDIPx mol d^{-1}**	**ΔDIP mol d^{-1}**	**ΔDIP μmol m^{-2} d^{-1}**
Jan-Mar	3712	3276	2707	-692	-10668	1665	5
Apr-Jun	5465	3283	2524	-977	-54177	43882	122
Jul-Sep	6463	3897	2768	-363	-7150	-5615	-16
Oct-Dec	6720	1556	2510	-2009	-82063	73286	204

The seasonal budgets for DIN, summarized in Tables 2.11 and 2.12, indicate that the lagoon is a sink of DIN during winter, spring and summer when fluxes toward the sea did not remove all DIN loads that the system received. The maximal negative value of ΔDIN was estimated for summer season, during which both $V_X DIN_X$ and $V_R DIN_R$ were at the lowest levels and the input was at its maximum. In autumn the DIN fluxes toward the sea were higher than the input and ΔDIN was positive, indicating a net release of 871255 mol DIN d^{-1}.

The (*nfix-denit*) rate was negative in all seasons and maximal during spring (Table 2.13). Even in autumn the ΔDIN_{exp} is positive and higher that the ΔDIN, due to the high heterotrophy of the system. Also in this season the (*nfix-denit*) value was negative, meaning that denitrification processes prevail over N-fixation during all seasons of the year.

Table 2.11. DIN concentrations in the rivers, the Lagoon of Venice and the adjacent Adriatic Sea, 1999.

	DIN_Q mmol m^{-3}	**DIN_P mmol m^{-3}**	**DIN_O mmol m^{-3}**	**DIN_{sys} mmol m^{-3}**	**DIN_{sea} mmol m^{-3}**	**DIN_R mmol m^{-3}**
Jan-Mar	213.97	341.14	253.84	27.79	16.34	22.07
Apr-Jun	219.58	263.07	264.16	34.26	30.07	32.17
Jul-Sep	135.42	496.14	251.02	12.69	10.04	11.37
Oct-Dec	238.17	63.73	262.31	43.19	31.15	37.17

Table 2.12. DIN budget for the Lagoon of Venice 1999, single-box analysis.

	V_Q DIN_Q mol d^{-1}	**V_P DIN_P mol d^{-1}**	**V_O DIN_O mol d^{-1}**	**V_R DIN_R mol d^{-1}**	**VxDINx mol d^{-1}**	**ΔDIN mol d^{-1}**	**ΔDIN mmol m^{-2} d^{-1}**
Jan-Mar	544019	126563	103034	-63606	-349007	-361003	-1.00
Apr-Jun	659333	273330	108781	-98183	-493481	-449780	-1.25
Jul-Sep	331535	313907	101437	-24275	-78944	-643660	-1.79
Oct-Dec	851386	85513	107390	-182133	-1733411	871255	2.42

Table 2.13. Stoichiometric calculations for the Lagoon of Venice, single-box analysis 1999.

	NEM mmol m^{-2} d^{-1}	**ΔDIN_{exp} mmol m^{-2} d^{-1}**	**(*nfix-denit*) mmol m^{-2} d^{-1}**
Jan-Mar	-0.5	0.08	-1.08
Apr-Jun	-12.9	1.95	-3.20
Jul-Sep	1.7	-0.26	-1.53
Oct-Dec	-21.6	3.26	-0.84

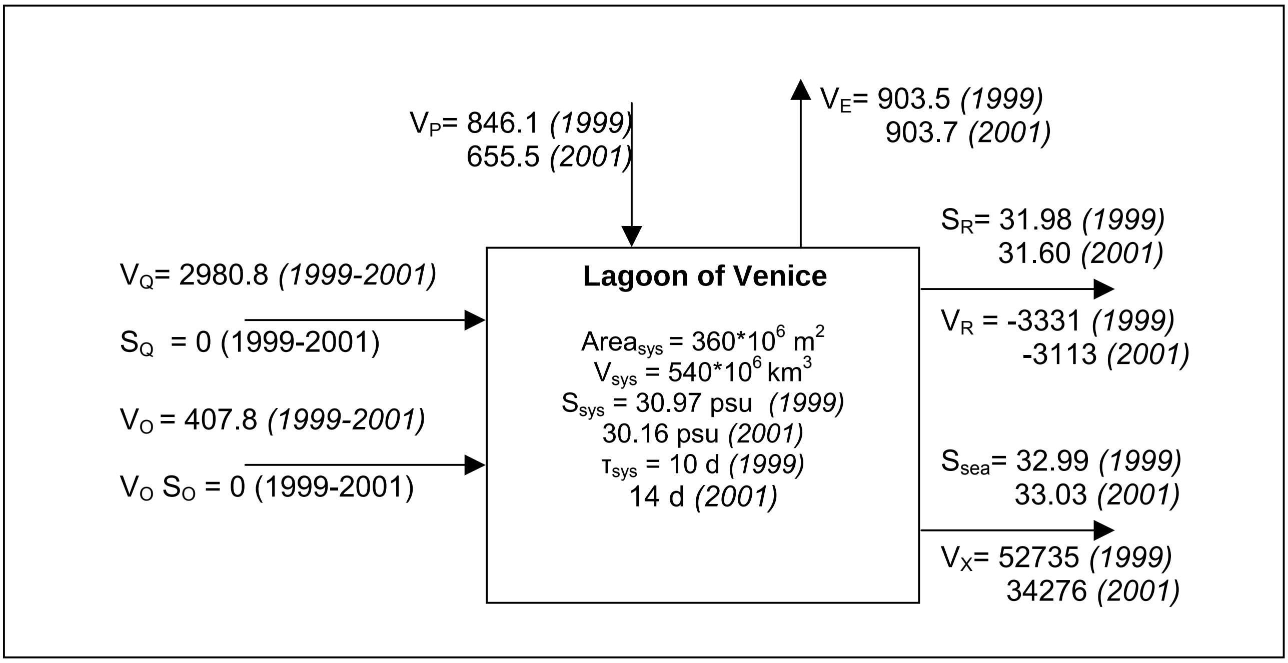

Figure 2.3. Water and salt budgets for the Lagoon of Venice, single-box analysis. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in psu.

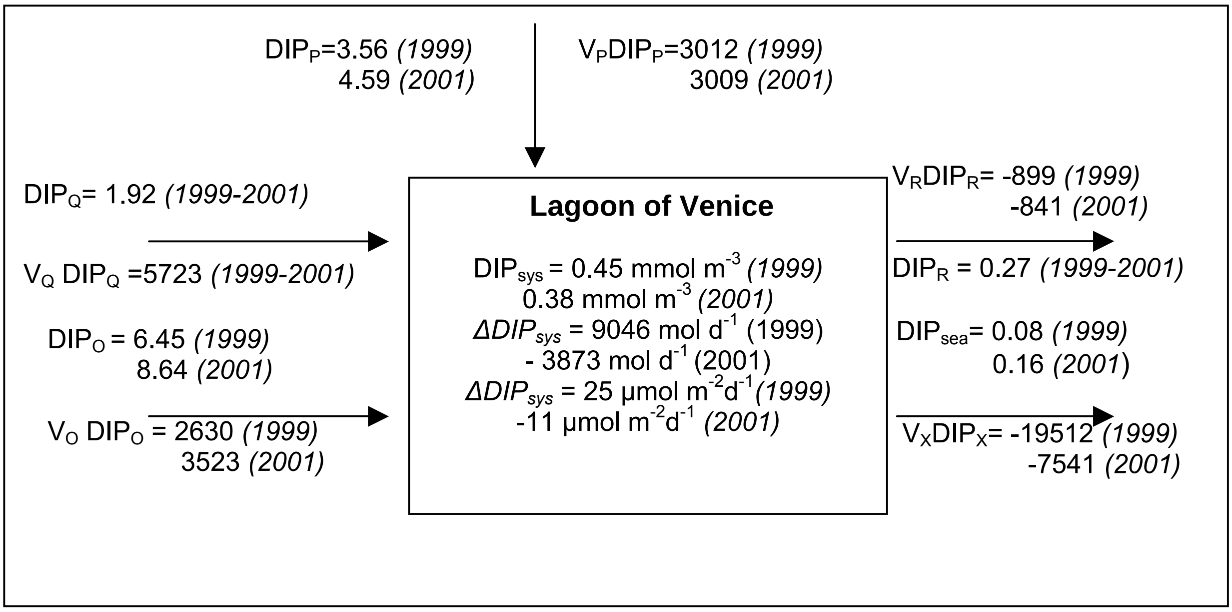

Figure 2.4. DIP budget for the Lagoon of Venice, single-box analysis. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

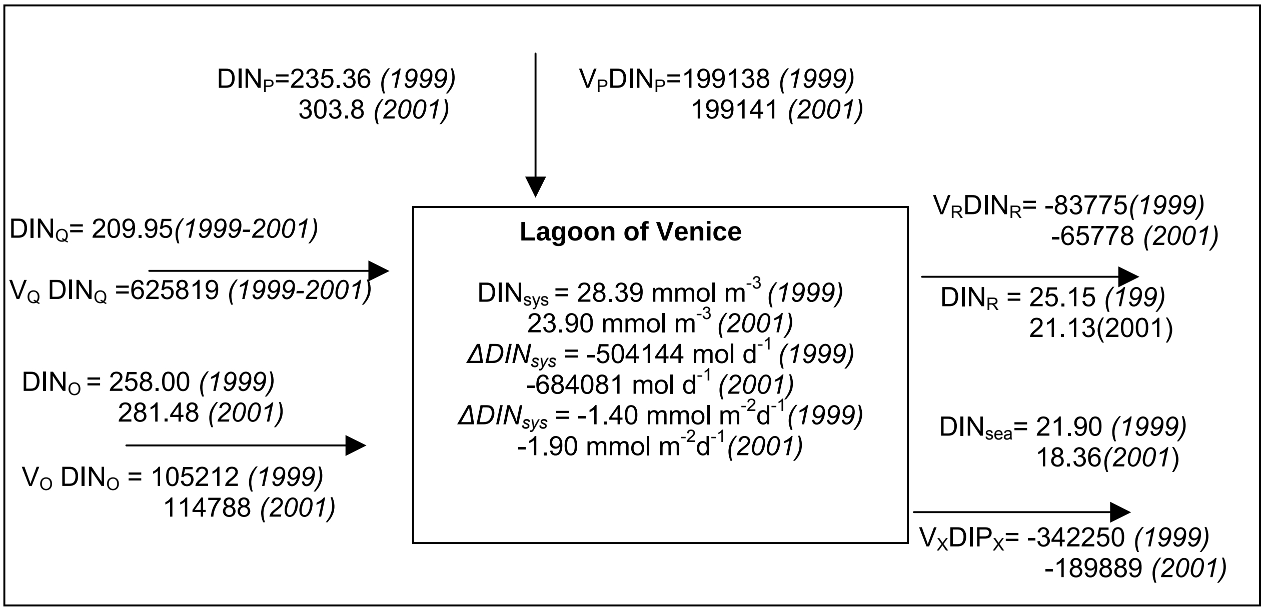

Figure 2.5. DIN budget for the Lagoon of Venice, single-box analysis. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

Two-box 2001 analysis

As was mentioned in the introduction, the Lagoon of Venice has a rather high spatial variability of salinity and concentrations of DIP and DIN, that can not be taken into account when using the 1-box steady-state hypothesis. Therefore, the subdivision of the lagoon into boxes should improve the results of the budget calculations. Furthermore, in order to obtain good results, the salinity gradient should not be less than 1-2 psu (Gordon *et al.* 1996). Considering this constraint, only two boxes could be defined.

The MAV-CVN sampling stations, which covered the whole lagoon for the year 2001, were assigned to the two boxes by statistical analysis. The results of Principal Component Analysis, Cluster Analysis and K-means methodology, applied on standard water quality parameters (MAV-CVN 2002b), were utilized in order to find the composition of the two clusters of stations that minimize the within-group variability. The two groups of sampling stations identified the areas of the two boxes of the model, which are indicated in Figure 2.6 as boxes A and B. Box A, close to the edge of the lagoon, has a surface of 174.86 km^2 with a mean depth of 0.85 m; Box B, directly affected by tidal flow from the Adriatic Sea, has a surface of 185.28 km^2 with mean depth of 2.14 m.

Nutrient loads from rivers and sewage systems enter Box A; atmospheric loads were divided between the boxes in proportion to their surface areas (Table 2.14). The results of water, DIP and DIN budgets for the two-box model for the year 2001 are given in Figure 2.7.

Table 2.14. Salinity, DIP, DIN concentrations in the two boxes budget for the Lagoon of Venice. Units: salinity in psu, concentrations in mmol m^{-3}.

	Salinity	**DIP_Q**	**DIP_P**	**DIP_o**	**DIP_{sys}**	**DIN_Q**	**DIN_P**	**DIN_O**	**DIN_{sys}**
BOX A (inner box)	27.83	1.92	4.59	8.64	0.53	209.95	303.80	281.48	31.68
BOX B (outer box)	32.16	--	4.59	--	0.24	--	303.80	--	17.23
Sea	33.03	--	--	--	0.16	--	--	--	18.36

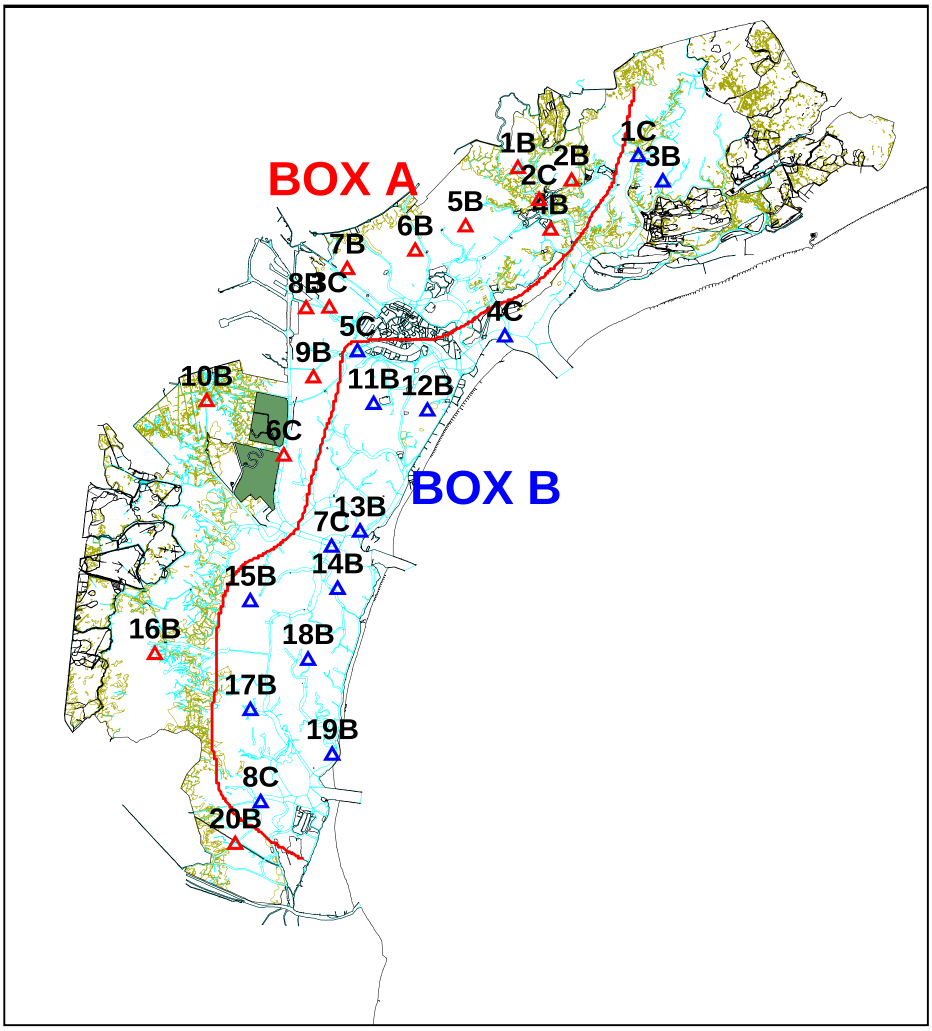

Figure 2.6. Subdivision of the Lagoon of Venice into two boxes. Sampling stations for MAV-CVN 2001, used to define the area of the boxes, are superimposed on the bathymetric map.

Subdivision of the system into two boxes permitted the description of some spatial behaviour of the ecosystem metabolism of the lagoon. Figure 2.7 shows that Box A was autotrophic (NEM positive), while Box B was heterotrophic (NEM negative). This finding is in agreement with the results of studies indicating the presence of a strong negative trophic gradient from the inner part to areas close to lagoon inlets (MAV-CVN 2002b). The trophic gradient is also supported by the fact that on an annual basis, the nutrient flux is from Box A toward Box B, meaning that Box A was richer in nutrients than Box B.

The amount of nutrients exchanged with the sea is the second important difference obtained by the use of the 2-box model compared to the 1-box. While the export of DIP from the lagoon to the Adriatic Sea obtained with the 2-box model (9957 mol d^{-1}) was in near agreement with the 1-box estimation of 8382 mol d^{-1}, for DIN the two models behaved differently. With the 1-box model, DIN export to the sea was estimated at 255,667 mol d^{-1}, while with the two-box model a net import of 75933 mol d^{-1} was estimated, because Box B received a higher input of DIN through mixing than was exported through advective flow. This is in agreement with several studies which suggest that the Adriatic Sea could be a source of DIN for the lagoon, at least for several months of the year and for some parts of the lagoon close to the inlets (Sfriso *et al.* 1994, Cossarini *et al.* 2001). These results again support the idea that the spatial complexity of the Lagoon of Venice ecosystem cannot be adequately and completely represented by a single-box model. A higher spatial resolution allows a focus on processes which otherwise remain hidden at lower resolution.

Finally, according to the two-box model, (*nfix-denit*) was negative in both boxes. For the whole lagoon, it can be estimated at -2.72 mmol m^{-2} d^{-1} (weighted average of the two boxes), 58% greater than the value estimated by the 1-box model. Therefore, the two-box model highlights the importance of the denitrification process, which clearly dominates any nitrogen fixation processes.

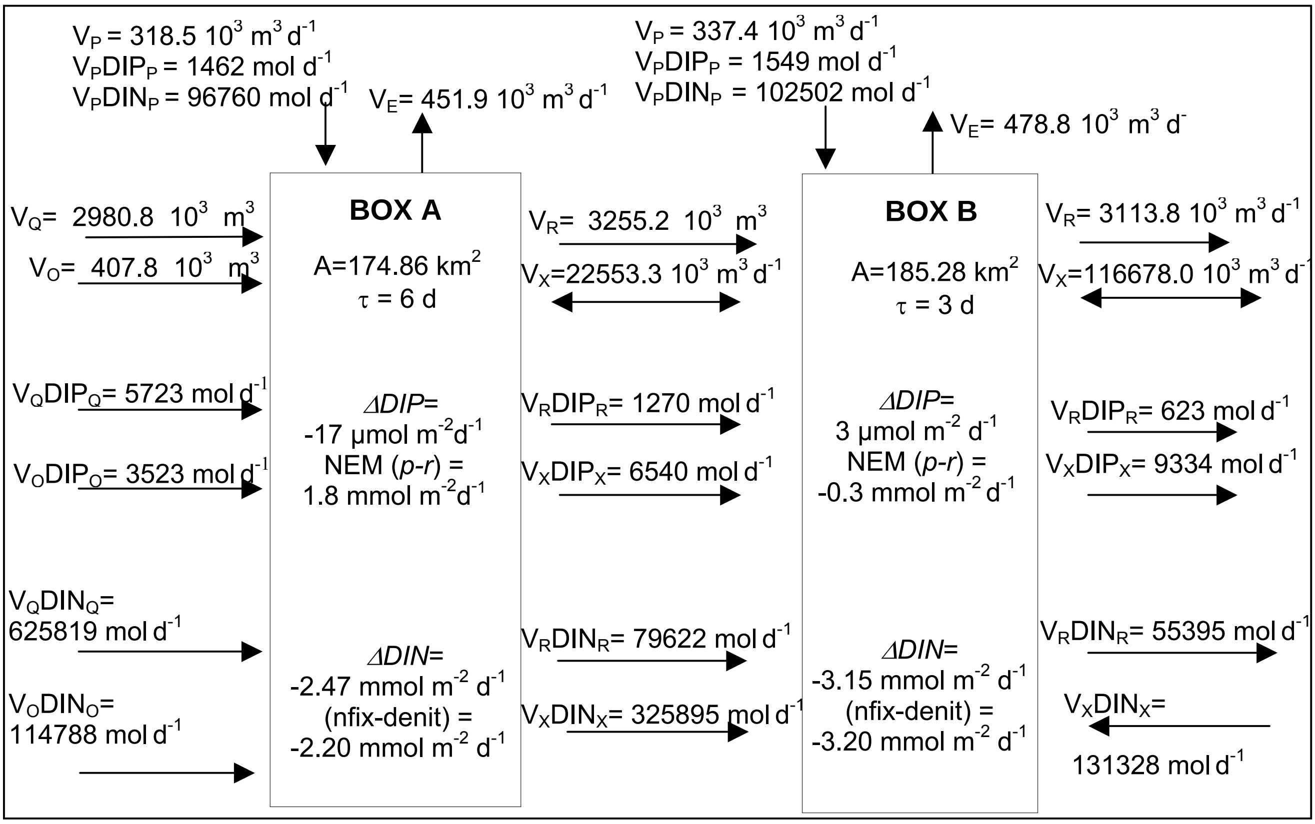

Figure 2.7. Budget calculations using the 2-box model for the Lagoon of Venice.

2.2 Sacca di Goro Lagoon

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Summary

The Sacca di Goro is an eutrophic lagoon located along the North Adriatic coast of Italy in the southernmost part of the Po River delta. The lagoon was investigated in 1992, when annual and monthly budgets were estimated with a single-box, single-layer LOICZ model. Exchange flows were obtained from the application of COHERENS (COupled Hydrodynamical Ecological model for REgioNal Shelf seas) 3-D model. A mean water residence time of 2 days was estimated. The annual mean ΔDIP was positive (0.01 mmol m^{-2} d^{-1}) whereas ΔDIN was negative (-20 mmol m^{-2} d^{-1}), thus the system can be considered as a source of DIP and a sink of DIN. Budgets for DOP and DON were calculated from April onwards (except October). Dissolved nutrients from marine and freshwater sources were dominated by the organic forms of P and the inorganic forms of N. In 1992, the lagoon acted as a net sink of DOP and a net source of DON. The imbalance between input and output of nutrients conformed to the seasonal trends of macroalgal biomass growth and decomposition. From March to June macroalgal blooms were coupled to negative ΔDIP (except for April), ΔDOP and ΔDIN. In July and August, during the decay phase of macroalgae, ΔDIP, ΔDOP and ΔDON were positive indicating a high organic matter mineralisation and a release of inorganic and organic dissolved nutrients. The C, N and P budgets were estimated considering the C:N:P ratios of both macroalgae and phytoplankton. On an annual basis, the lagoon can be considered as slightly autotrophic, with a net ecosystem metabolism (*p-r*) of about 3 mmol C m^{-2} d^{-1}. The net nitrogen budget (*nfix-denit*) was negative, indicating a dominance of denitrification over N-fixation even with values much higher than those expected in this ecosystem.

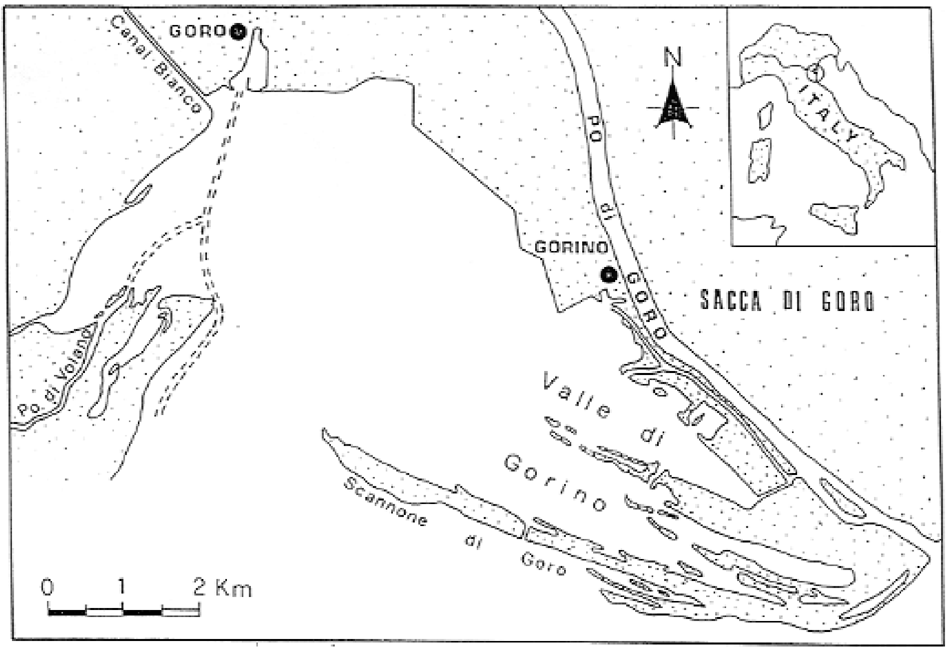

Figure 2.8. Map and location of the Sacca di Goro Lagoon.

Study area description

The Sacca di Goro (Figure 2.8) is a shallow-water embayment of the Po River Delta (44.78°N 12.25°E-44.83°N 12.33°E). The surface area is 26 km^2 with a mean depth of 1.5 m and the total water volume is approximately 39x10^6 m^3. Observation and numerical models have demonstrated a clear zonation of the lagoon with the low-energy eastern area separated from two higher energy zones, the western area which is influenced by freshwater inflow from the Po di Volano and the central area influenced by the sea. Moreover, the eastern zone is very shallow (maximum depth 1 m) and accounts for half of the total surface area and a quarter of the water volume.

The lagoon is surrounded by embankments. The main freshwater inputs are the Po di Volano River, and the Canali Bianco-Romanina, Giralda and Bonello. Freshwater inlets are also located along the Po di Goro River and are regulated by sluices. The freshwater system is mostly located in a subsident area and is regulated by a system of pumping stations (scooping plants).

The bottom of the lagoon is flat and the sediment is composed of typical alluvial mud; the northern and central zones exhibit high clay and silt content, while sand is more abundant near the southern shoreline, and sandy mud occurs in the eastern area.

The climate of the region is mediterranean with some continental influence (wet mediterranean). Wet deposition is approximately 600 mm yr^{-1}, with late spring and autumn peaks. However, this pattern is undergoing significant changes with an increase of short-term intense events.

The catchment is heavily exploited for agriculture, whilst the lagoon is one of the most important aquacultural systems in Italy. About 8 km^2 of the aquatic surface were exploited for Manila clam (*Tapes philippinarum*) farming, with an annual production of about 15,000 tonnes in 1992.

The system was investigated in 1992 using the one box – one layer model at monthly intervals. Meteorological data from the Volano station were supplied by the Agenzia Regionale Prevenzione e Ambiente (ARPA, Regione Emilia-Romagna). Temperature, salinity and nutrient concentrations of coastal waters were provided by the Struttura Oceanografica Daphne, ARPA-Cesenatico (ARPA, 1992). Inorganic nutrient data were recorded at Station 2 (44.7853°N - 12.2625°E; depth: 3 m; distance from coast 500 m), which is in front of the Sacca di Goro. Data of DON and DOP at stations 4 (44.6628°N - 12.2517°E, depth 3 m, distance from coast 500 m) and 304 (44.6628°N – 12.2872°E,, depth 8 m, distance from coast 3000 m) were used, since these data are not available for Station 2. Nevertheless, this approach was robust, since no significant differences were observed among budgets estimated using inorganic nutrient data from stations 2, 4 and 304. Data on freshwater discharge to the lagoon were supplied by the Consorzio di Bonifica 1° Circondario Polesine di Ferrara (Consorzi di Bonifica Ferraresi 1991-1999). Water quality data were recorded by the Province of Ferrara (Bencivelli 1993). Data of temperature, salinity and nutrient concentrations were recorded at stations 4 and 5-8 in the Sacca di Goro (Colombo *et al.* 1994; Viaroli *et al.* 1993; and unpublished data). Evaporative losses were estimated according to Hargreaves (1975). Water exchange fluxes between the system and the sea were estimated with the COHERENS 3D model (Marinov *et al.* 2004).

Water and salt balance

The Sacca di Goro watershed is an artificially regulated network of channels. As a consequence, freshwater flows are partially independent of rain events but more related to human activities such as irrigation (summer) and prevention of flooding (rainy season: autumn) (Viaroli *et al.* in press). In 1992, the main freshwater inputs to Sacca di Goro were Po di Goro (annual mean: 1x10^6 m^3 d^{-1}) and Po di Volano (0.8x10^6 m^3 d^{-1}). High freshwater loads were detected in October (4x10^6 m^3 d^{-1}), June (3x10^6 m^3 d^{-1}) and December (3x10^6 m^3 d^{-1}). No direct estimates of freshwater inputs from the Po di Goro River were available, so we estimated them from the main Po River discharge. The Po di Goro is a branch of the Po River which contributes about 10% of the Po River discharge. The freshwater discharge to the Sacca di Goro was assumed to be 0.25, 0.5 and 1.0% of the discharge of the main Po River when the discharge was 1000 $m^3 s^{-1}$, between 1000 and 2000 $m^3 s^{-1}$ or above 2000 $m^3 s^{-1}$, respectively (Bencivelli pers. comm.). Direct precipitation and evaporation fluxes are very low and groundwater fluxes are considered negligible in comparison to the other freshwater inputs. High negative values of V_R were calculated; this was expected considering that Sacca di Goro is subjected to high riverine discharges.. V_X fluxes, which are the water mixing flows according to LOICZ notation, are not calculated from the salinity budget but from the application of the COHERENS 3D hydrodynamic model (Marinov *et al.* 2004) to the investigated year. The reported V_X values (1.3-2.2x10^7 $m^3 d^{-1}$) are of the range of values estimated for the 1980-2000 period with the method indicated by Yanagi (2000b) and reported in Viaroli *et al.* (2001b) (Figure 2.9). Considering the volume of the system and V_R and V_X, the water residence time is estimated to be about 2 days for the whole period. This value is of the same order of magnitude of the water residence time estimated with the COHERENS model (4-5 days on average). The monthly water budgets of the Sacca di Goro are reported in Table 2.15. The annual budget is shown in Figure 2.10.

Table 2.15. Monthly water fluxes in Sacca di Goro Lagoon. V_Q Tot is the sum of the 5 freshwater inputs. Unit: 10^3 $m^3 d^{-1}$.

	V_{vol}	V_{bon}	V_{gir}	V_{rom}	V_{gor}	V_Q Tot	V_P	V_E	V_R	V_X	τ(d)
Jan	290	18	53	165	207	733	0	6	-727	18800	2
Feb	259	16	41	90	232	638	8	10	-636	19800	2
Mar	299	13	23	67	171	573	9	19	-563	22300	2
Apr	513	9	21	97	673	1313	24	31	-1306	18600	2
May	1656	19	132	11	325	2143	32	48	-2127	18500	2
Jun	1164	16	78	8	2112	3378	45	49	-3374	13200	2
Jul	1145	16	92	13	1032	2298	48	52	-2294	14600	2
Aug	1452	17	126	12	156	1763	12	52	-1723	15100	2
Sep	793	16	79	56	740	1684	40	34	-1690	20100	2
Oct	494	37	99	234	3308	4172	134	18	-4288	16200	2
Nov	288	22	68	125	1181	1684	18	9	-1693	17800	2
Dec	1416	84	195	247	1305	3247	110	6	-3351	17700	2
Annual	818	24	84	94	955	1976	40	28	-1988	17717	2

<u>Budgets of non-conservative materials</u>

Since no monitoring activities were planned for Canali Bianco and Giralda, the relevant nutrient concentrations of Po di Volano were used for these two channels, because water composition is similar and the water loads are low in comparison to Po di Volano. No measures were carried out in the Sacca di Goro in January, February and November, so for January and February we used the mean value of March and for November, we used the October and December mean values.

DIP budget

The annual and monthly DIP concentrations in the freshwater inputs, system and sea are indicated in Table 2.16. DIP inputs and outputs are indicated in Table 2.17. No data about DIP deposition from the atmosphere are available, but this P input can be considered negligible in comparison with other loads (Viaroli *et al.* in press). Peaks of DIP inputs were observed from October to December (6000 mol d^{-1}) and in June (5000 mol d^{-1}). In 1992, the major input of DIP to the lagoon was from the Po di Goro (annual mean 2037 mol d^{-1}). $V_R DIP_R$ was negative for the whole period, indicating that it was a constant output of DIP whilst $V_X DIP_X$ was either positive or negative depending on the DIP concentration gradient between the system and the sea. High concentrations of nutrients were detected in the sea in front of the Sacca di Goro due to the influence of the Po River plume, which can reach this area. On the annual basis, $V_X DIP_X$ was negative due to the high negative values observed in summer when the DIP concentration in the system was high. A net annual export of about 3.2x10^3 mol d^{-1} from the lagoon was estimated (Figure 2.11), whilst the net input of DIP from freshwater was about 3.0x10^3 mol d^{-1}. On average, the lagoon was a net source of DIP to the adjacent sea, contributing about 200 mol d^{-1}. However, monthly Δ*DIP* was negative for a large part of the year but highly positive in August, July and April. These *ΔDIP* variations conformed to the seasonal trends of macroalgal growth and decomposition (Viaroli *et al.* 2001a and Figure 2.15). From March to June, high macroalgal growth was recorded. Afterwards, a sudden and rapid decomposition phase took place with high rates of organic matter mineralisation and DIP release. Further *Ulva* growth occurred in autumn and winter, with a DIP uptake.

Table 2.16 Monthly mean concentrations of DIP in mmol m^3 in the freshwater inputs, lagoonal system and sea.

	DIP_{vol}	DIP_{rom}	DIP_{gor}	DIP_{sys}	DIP_{sea}
Jan	0.32	2.10	3.71	0.03	0.39
Feb	0.00	0.32	3.06	0.03	0.37
Mar	0.00	0.00	1.94	0.03	0.19
Apr	1.94	0.00	1.45	0.44	0.12
May	0.48	1.94	1.94	0.10	0.09
Jun	0.65	1.13	2.10	0.13	0.35
Jul	0.48	2.58	2.10	1.56	0.11
Aug	0.48	1.94	2.10	2.27	0.34
Sep	0.48	0.81	1.77	0.06	0.27
Oct	0.00	1.45	1.94	0.15	0.52
Nov	4.36	5.00	3.06	0.31	0.27
Dec	1.61	4.20	2.10	0.47	0.40
Annual	0.89	1.80	2.27	0.47	0.28

Table 2.17. Monthly mean loads of DIP in mol d^{-1} in the Sacca di Goro; estimates of *ΔDIP* in mol d^{-1} for the whole lagoon and in mmol m^{-2} d^{-1} for the unit of surface area.

	$V_{(vbg)}$ DIP_{vol}	V_{rom} DIP_{rom}	V_{gor} DIP_{gor}	V_R DIP_R	V_X DIP_X	*ΔDIP*	*ΔDIP*
	mol d^{-1}						mmol m^{-2} d^{-1}
Jan	116	347	768	-153	6768	-7846	-0.30
Feb	0	29	710	-127	6732	-7344	-0.28
Mar	0	0	332	-62	3568	-3838	-0.15
Apr	1053	0	976	-366	-5952	4289	0.16
May	867	21	631	-213	-185	-1121	-0.04
Jun	818	9	4435	-810	2904	-7356	-0.28
Jul	602	34	2167	-1927	-21170	20294	0.78
Aug	765	23	328	-2257	-29143	30284	1.16
Sep	427	45	1310	-287	4221	-5716	-0.22
Oct	0	339	6418	-1458	5994	-11293	-0.43
Nov	1648	625	3614	-491	-712	-4684	-0.18
Dec	2729	1037	2741	-1474	-1239	-3794	-0.15
Annual	754	210	2037	-809	-2428	236	0.01

DIN budget

The annual and monthly DIN concentrations in the freshwater inputs, system and sea are indicated in Table 2.18, DIN inputs and outputs in Table 2.19 and the DIN annual budget shown in Figure 2.12. The annual average DIN concentration in precipitation was obtained from Mosello (1993). Higher DIN concentrations were measured in the main freshwater inputs in autumn and winter, whilst the lowest DIN concentrations in the system and in the sea were measured in summer. The monthly *ΔDIN* values were negative for most of the year, except for January when V_XDIN_X was negative.

Table 2.18. Monthly mean concentrations of DIN in mmol m^3 in the freshwater inputs, lagoonal system and the adjacent sea.

	DIN_{vol}	DIN_{rom}	DIN_{gor}	DIN_P	DIN_{sys}	DIN_{sea}
Jan	566	332	287	97	52	21
Feb	463	225	266	97	52	52
Mar	355	169	202	97	52	65
Apr	269	153	160	97	28	95
May	104	123	125	97	21	23
Jun	117	113	154	97	6	31
Jul	56	108	126	97	5	9
Aug	54	95	112	97	9	9
Sep	83	89	153	97	7	22
Oct	296	214	151	97	32	51
Nov	351	225	174	97	28	18
Dec	571	584	228	97	24	41
Annual	273	203	178	97	26	36

The main inputs of DIN were from the Po di Volano- Canal Bianco- Giralda system (207x10^3 mol d^{-1} as annual average). The sea can be considered as an input of DIN for the system since the output of 56x10^3 mol d^{-1} of V_R was lower than the input of 174x10^3 mol d^{-1} estimated from V_X fluxes. Thus a net input of about 120x10^3 mol d^{-1} of DIN was estimated from the sea. The lagoon acted as a sink of DIN with a mean *ΔDIN* of -20 mmol m^{-2} d^{-1}.

Table 2.19. Monthly mean loads of DIN in 10^3 mol d^{-1} in the Sacca di Goro; estimates of *ΔDIN* in 10^3 mol d^{-1} for the whole lagoon and in mmol m^{-2} d^{-1} for the unit of surface area.

	$V_{(vbg)}$ DIN_{vol}	V_{rom} DIN_{rom}	V_{gor} DIN_{gor}	V_PDIN_P	V_R DIN_R	V_X DIN_X	*ΔDIN*	*ΔDIN*
	10^3 mol d^{-1}							mmol m^{-2} d^{-1}
Jan	204	55	59	0	-27	-583	292	11.23
Feb	146	20	62	1	-33	0	-196	-7.54
Mar	119	11	35	1	-33	290	-423	-16.27
Apr	146	15	108	2	-81	1246	-1436	-55.23
May	188	1	41	3	-47	37	-223	-8.58
Jun	147	1	325	4	-64	330	-743	-28.58
Jul	70	1	130	5	-16	58	-248	-9.54
Aug	86	1	17	1	-16	0	-89	-3.42
Sep	74	5	113	4	-25	302	-473	-18.19
Oct	186	50	500	13	-180	308	-877	-33.73
Nov	133	28	205	2	-39	-178	-151	-5.81
Dec	968	144	298	11	-111	301	-1611	-61.96
Annual	207	28	158	4	-56	174	-515	-19.81

Dissolved organic nutrients budgets

Monthly dissolved organic phosphorus and nitrogen concentrations for the rivers, Sacca di Goro lagoon and adjacent Adriatic Sea are summarised in Tables 2.20 and 2.22. Estimates of their concentrations in the freshwater input are available only for the period from April onwards but excluding October. Direct measurements were conducted only in the Po di Volano River.

Table 2.20. Monthly mean concentrations of DOP in mmol m^3 in the freshwater inputs, lagoonal system and adjacent sea. nd: not detected

	DOP_{vol}	DOP_{sys}	DOP_{sea}
Jan	nd	nd	0.05
Feb	nd	nd	0.10
Mar	nd	0.02	0.16
Apr	4.03	0.00	0.05
May	7.20	0.61	0.10
Jun	3.14	0.00	0.16
Jul	4.00	1.25	0.11
Aug	5.67	1.27	0.19
Sep	3.98	0.39	0.08
Oct	nd	0.08	0.03
Nov	2.91	0.08	0.11
Dec	2.91	0.08	0.31
Annual			0.16

DOP budget

A higher DOP load estimated at $15x10^3$ mol d^{-1} was carried by freshwater in May; values of $5\text{-}10x10^3$ mol d^{-1} were estimated for the other months (Table 2.21). These values are considerably higher than the DIP inputs ($1\text{-}6x10^3$ mol d^{-1}, Table 2.17). In May and from July to September, the exchange flow with the sea was an output of DOP to the system, in contrast to the rest of the year. Considering also the inputs from the sea, a mean load of about $10x10^3$ mol d^{-1} of DOP can be estimated, which is twice the load of DIP estimated in the same way (about $5x10^3$ mol d^{-1} as annual average and $4x10^3$ mol DIP d^{-1} for the period investigated for DOP). *ΔDOP* was negative for the whole period except for the summer months (July and August). The monthly evolution of *ΔDOP* follows the trend of *ΔDIP* (Figure 2.13) at least for the months where data are available. This indicate that growth and decay of *Ulva* spp. affected also the DOP pools: during the growth phase from April to June, *Ulva* can use DOP as an additional source of P, probably through enzymatic hydrolysis with phosphatases, while in July and August the decomposition of macroalgae can release organic dissolved compounds rich in P. The negative values of *ΔDOP* calculated for November and December can be related to the second growth phases of *Ulva* observed in these months although with densities lower than the spring blooms (Figure 2.15).

For the period under investigation, the system can be considered as a net sink of DOP with a weighted mean of -0.15 mmol DOP m^{-2} d^{-1}.

Table 2.21. Monthly mean loads of DOP in mol d^{-1} in the Sacca di Goro Lagoon; estimates of *ΔDOP* in mol d^{-1} for the whole lagoon and in mmol m^{-2} d^{-1} for the unit of surface area.

	V_Q DOP_{vol}	V_R DOP_R	V_X DOP_X	*ΔDOP*	*ΔDOP*
	mol d^{-1}				mmol m^{-2} d^{-1}
Apr	5291	-78	2046	-7259	-0.28
May	15429	-851	-7770	-6808	-0.26
Jun	10607	-135	1056	-11528	-0.44
Jul	9192	-1468	-17812	10088	0.39
Aug	9996	-1189	-17516	8709	0.33
Sep	6702	-592	-1608	-4502	-0.17
Oct	nd	-643	2106	-1463	
Nov	4901	-220	1780	-6461	-0.25
Dec	9449	-704	4602	-13347	-0.51
Mean					-0.15

DON budget

DON loads from freshwater source ranged from 7-80x10^4 mol d^{-1} with a peak in December. V_XDON_X was negative for the whole period indicating that the system was exporting DON to the sea (Table 2.23). The DON input to the system was estimated as 3x10^5 mol d^{-1}, whilst DIN was about 6x10^5 mol d^{-1} assuming a contribution by the sea of about 30% (2x10^5 mol d^{-1}). *ΔDON* was positive for the whole period except for December. The trend was opposite to the *ΔDIN* (Figure 2.14). To some extent, the *ΔDIN* correlated with the macroalgal life cycle. During the growth season, the large DIN uptake was inversely related to *ΔDON*, which is typical of macroalgal tissues performing an high photosynthetic rate. In the subsequent decay phase, no inorganic nitrogen was present in the algal tissue so a large release of DON was expected. For the whole period investigated, the system can be considered as a net source of DON with a weighted mean of Δ*DON* of +7.8 mmol m^{-2} d^{-1}

Table 2.22. Monthly mean concentrations of DON in mmol m^3 in freshwater inputs, lagoonal system and the adjacent sea. nd: not detected

	DON_{vol}	DON_{sys}	DON_{sea}
Jan	nd	Nd	11
Feb	nd	Nd	14
Mar	nd	3	18
Apr	121	24	9
May	166	48	22
Jun	129	47	14
Jul	122	49	22
Aug	41	37	12
Sep	82	48	1
Oct	nd	29	2
Nov	255	30	2
Dec	255	31	4
Annual			11

Table 2.23. Monthly mean loads of DON in 10^3 mol d^{-1} in the Sacca di Goro; estimates of ΔDON in 10^3 mol d^{-1} for the whole lagoon and in mmol m^{-2} d^{-1} for the unit of surface area.
nd: not detected

	V_Q DON_{vol}	V_R DON_R	V_X DON_X	ΔDON	ΔDON
	10^3 mol d^{-1}				mmol m^{-2} d^{-1}
Apr	159	-22	-279	142	5.46
May	356	-74	-481	199	7.65
Jun	435	-103	-436	104	4.00
Jul	281	-81	-394	194	7.46
Aug	72	-42	-378	348	13.38
Sep	138	-41	-945	848	32.62
Oct	Nd	-66	-437		
Nov	429	-27	-498	96	3.69
Dec	828	-59	-478	-291	-11.19

Stoichiometric calculations of aspects of net system metabolism

The LOICZ Biogeochemical Model assumes that organic matter production or mineralisation (Net Ecosystem Metabolism :NEM or *p-r*) can be directly estimated from ΔDIP and C:P ratio of primary producers (NEM= $-\Delta DIP$ x C:P). C:N:P ratios of macroalgae were directly measured in 1992 (Table 2.24). When macroalgae were not present in the lagoon, the C:N:P ratio for phytoplankton (Redfield 1961) was used. NEM (Table 2.24) related to the seasonal evolution of macroalgae (Figure 2.15). Positive values of NEM were measured in the whole period (except for April, July and August) with peaks of 110 mmol m^{-2} d^{-1} in June, during the growth phase of *Ulva* spp (density up to 420 g DW m^{-2}) when production largely exceeded respiration. In that period, the surficial sediment was oxidised due to high oxygen concentration in the water column and DIP was actively adsorbed (Giordani *et al.* 1997). A luxury DIP uptake by macroalgae was also often recorded (Viaroli *et al.* 1996b). As a consequence the NEM can undergo unpredictable changes. Negative NEM values down to -120 mmol m^{-2} d^{-1} were detected in July and August, after the collapse of macroalgae when the decomposition of *Ulva* biomasses supported high mineralisation rates with net release of DIP, DOP and DON. The superficial sediment was also reduced due to the anoxic conditions, with a further release of DIP. The negative NEM value of April was not related to this general trend.

Table 2.24. C:N:P molar ratio and NEM (*p-r*), ΔDIN_{exp}, (*nfix-denit*), ΔDN, ΔDN_{exp}, (*nfix-denit*)* (calculated considering both organic and inorganic dissolved forms). Unit : mmol m^{-2} d^{-1}

	C	N	P	(p-r)	ΔDIN_{exp}	*(nfix-denit)*	ΔDN	ΔDN_{exp}	*(nfix-denit)**
Jan	106	16	1	31.80	-4.80	16.03			
Feb	106	16	1	29.68	-4.48	-3.06			
Mar	323	37	1	48.44	-5.52	-10.75			
Apr	600	42	1	-96.02	6.70	-61.93	-49.8	-5.0	-44.7
May	644	40	1	25.75	-1.59	-6.99	-0.9	-11.9	11.0
Jun	399	28	1	111.61	-7.76	-20.82	-24.6	-20.0	-4.6
Jul	113	13	1	-88.44	9.98	-19.52	-2.1	15.0	-17.0
Aug	106	16	1	-122.96	18.56	-21.98	10.0	23.8	-13.9
Sep	106	16	1	23.32	-3.52	-14.67	14.4	-6.2	20.7
Oct	106	16	1	45.58	-6.88	-26.85			
Nov	106	16	1	19.08	-2.88	-2.93	-2.1	-6.9	4.8
Dec	106	16	1	15.90	-2.40	-59.56	-73.2	-10.6	-62.6
Annual				3.38	-0.34	-19.45			

In the Sacca di Goro Lagoon, growth and decay of macroalgae seemed to affect organic and inorganic dissolved N and P budgets although ΔDIP was not only related to the balance between production and respiration processes but also depended on water-sediment fluxes, as observed in real and simulated dystrophic crises (Giordani *et al.* 1996; Viaroli *et al.* 1996a).

From stoichiometric arguments, the Sacca di Goro can be considered as having been slightly autotrophic in 1992, with a NEM annual weighted mean of 3.4 mmol m^{-2} d^{-1}.

ΔDIN_{exp} is the DIN variation expected on the basis of organic matter production and mineralisation and was calculated as the product of ΔDIP by the N:P ratio of the dominant primary producer. Net nitrogen fixation minus the denitrification (*nfix-denit*) was calculated from the difference between the observed and expected ΔDIN values. Either the LOICZ concept of (*nfix-denit*) does not seems to be applicable for the Sacca di Goro, or perhaps an important process affecting the N cycle has not been considered, because (*nfix-denit*) values are an order of magnitude higher than the upper values expected for coastal systems (Table 2.24)- they range from -62 to +16 mmol m^{-2} d^{-1}. These values are in agreement with those estimated by Cattaneo *et al.* (2001) for a ten-year period for the Sacca di Goro. Even when the dissolved organic nitrogen fraction is included (see, for example, the budget of Tomales Bay, USA: http://data.ecology.su.se/MNODE/North%20America/ TOMALES.HTM, the problem remains, in that the observed non-conservative flux of total dissolved N ($\Delta DN = \Delta DIN + \Delta DON$) is still high, ranging from -43 to +2 mmol m^{-2} d^{-1} (Table 2.24). The non-conservative N flux which can be calculated from the N:P ratio of the non-conservative P flux ($\Delta DN_{exp} = (\Delta DIP + \Delta DOP)$ x N/P ratio) ranged from -20 to 24 mmol m^{-2} d^{-1}. According to the stoichiometric arguments, the discrepancy between observed and expected DN would be a measure of apparent (*nfix-denit*) but range from -62 to 20 mmol m^{-2} d^{-1} which is a very wide interval. Even if no measurement of N fixation were made in Sacca di Goro we can consider this process quite slow in a marine system (lower than 1 mmol m^{-2} d^{-1}) and direct measures of denitrification found values around 2.5 mmol m^{-2} d^{-1} even with peaks of 35 mmol m^{-2} d^{-1} in some spots (Bartoli *et al*. 2001).

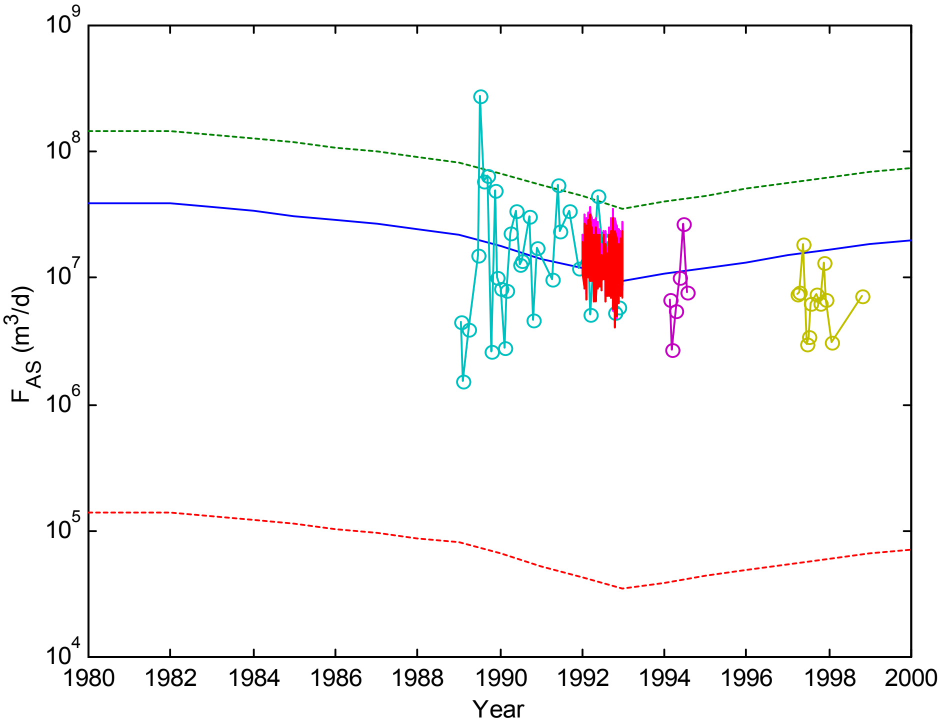

Figure 2.9. Exchange fluxes calculated following three different procedures. Hollow points represent the calculations based on the salt budgets (LOICZ), continuous blue line represent the calculation based on Yanagi's equation (Yanagi 2000b) using U_{mean} value from Ciavola *at al.* (2000), discontinuous lines represent the calculation using standard deviation, i.e. $U=U_{mean} \pm \Delta U$; continuous red line represent the daily exchange flows based on COHERENS 3D model (Marinov *et al.* 2004).

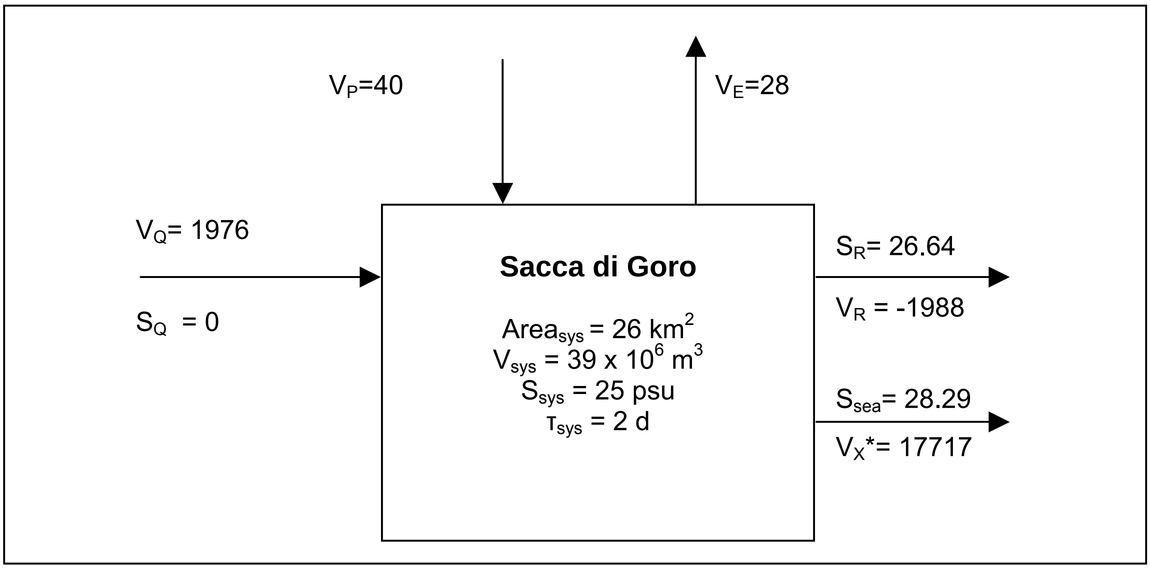

Figure 2.10. Water and salt budgets for the Sacca di Goro for 1992. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in PSU. V_X* is estimated from Marinov *et al.* (2004).

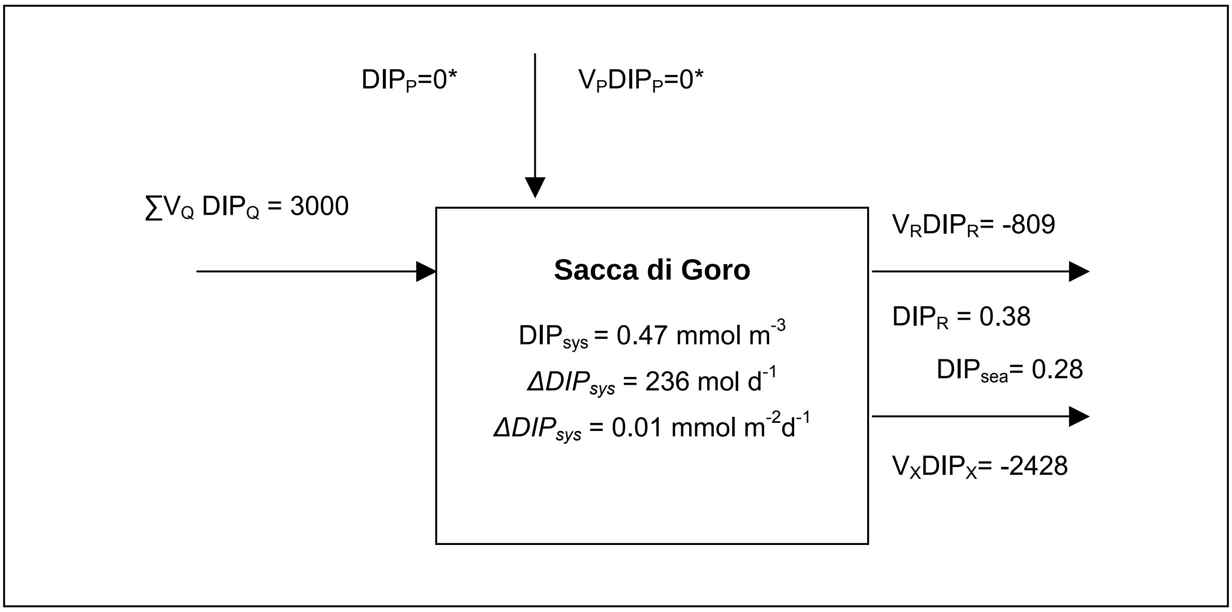

Figure 2.11. **DIP budget for the Sacca di Goro.** Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. * assumed.

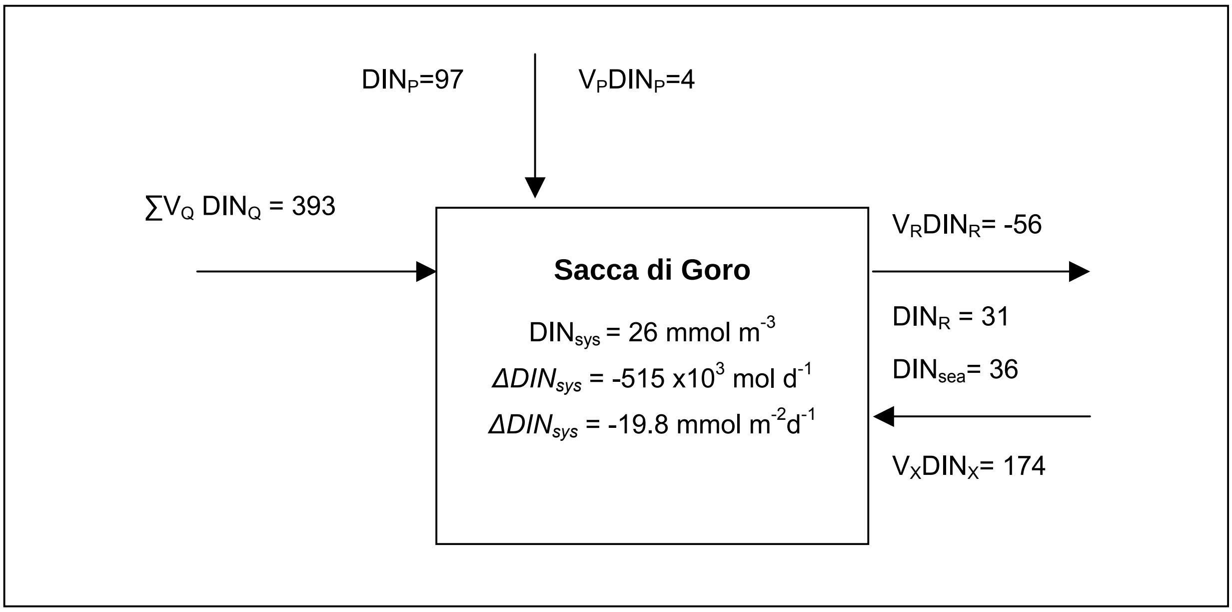

Figure 2.12. DIN budget for the Sacca di Goro. Concentrations are in mmol m^{-3} and fluxes in 10^3 mol d^{-1}.

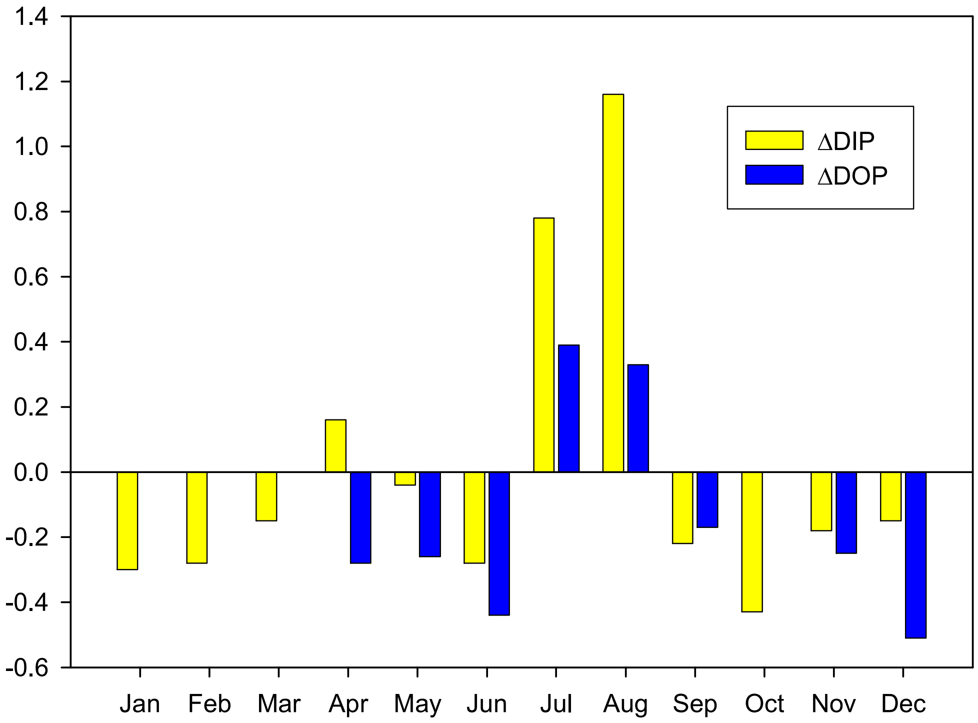

Figure 2.13. **Δ*DIP* and Δ*DOP* estimates in mmol m^{-2} d^{-1} for the Sacca di Goro in 1992.** Values of Δ*DOP* for January, February, March and October are not available.

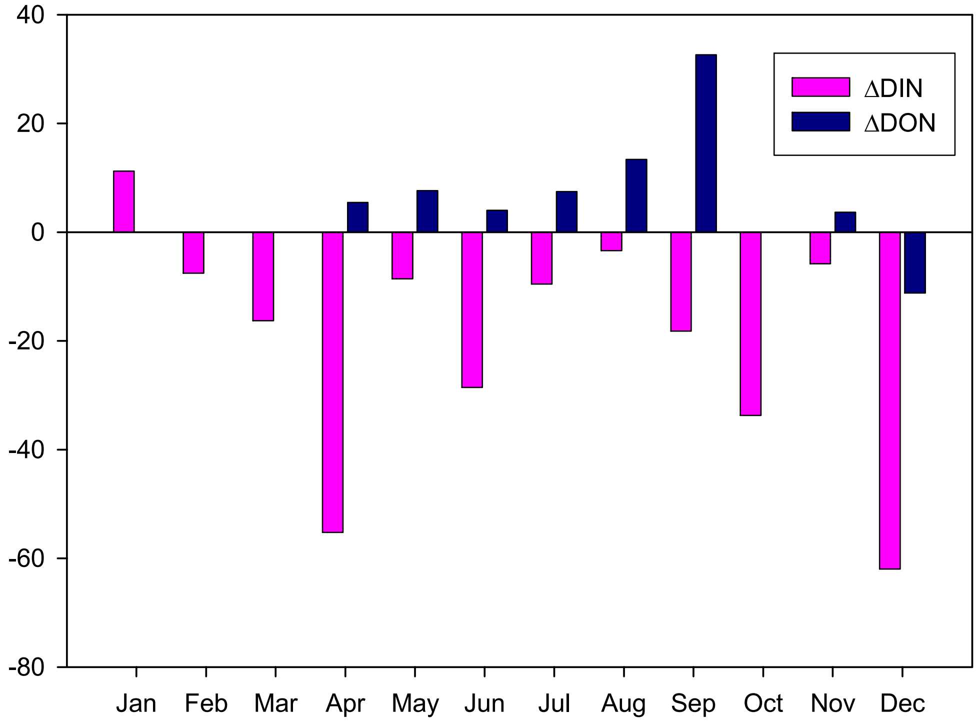

Figure 2.14. Δ*DIN* and Δ*DON* estimates in mmol m^{-2} d^{-1} for the Sacca di Goro for 1992. Values of Δ*DON* for January, February, March and October are not available.

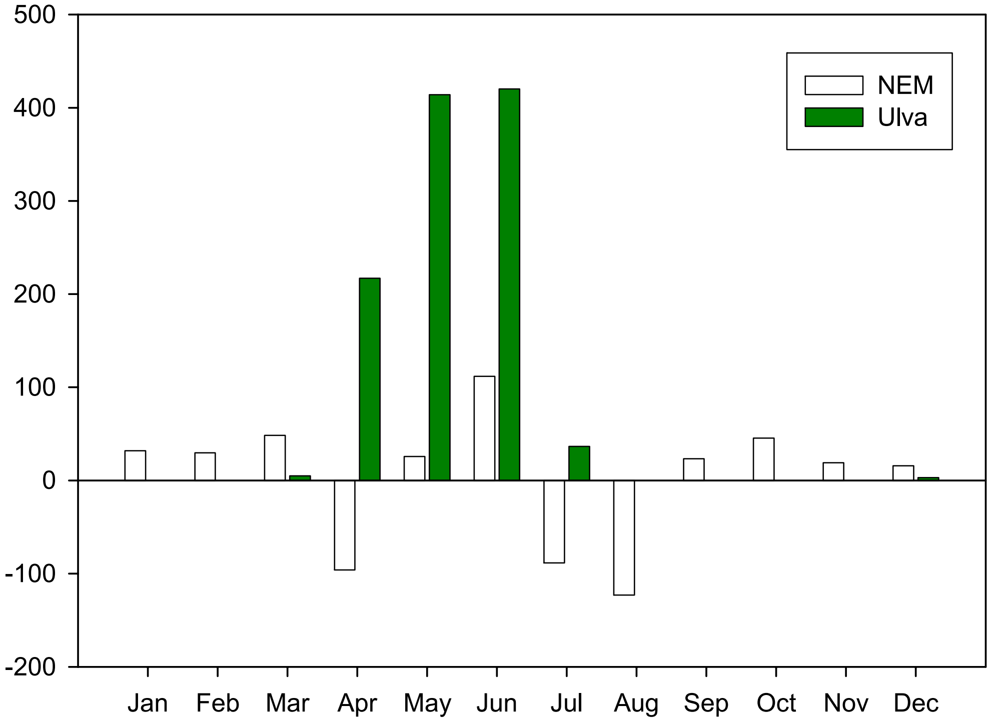

Figure 2.15. Density of *Ulva* spp. (g dw m^{-2}) and NEM (mmol m^{-2} d^{-1}) in the Sacca di Goro in 1992.

2.3 Pialassa Baiona Lagoon, Ravenna

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Summary

The Pialassa Baiona is an eutrophic lagoon located along the Adriatic coast of Italy. A single-box, single-layer LOICZ model was applied to data from the year 2000 to estimate the biogeochemical budget of the Pialassa Baiona. Water turnover time in the lagoon was estimated at 3 days. Both annual mean ΔDIP and ΔDIN were negative, indicating that the system acts as sink of both DIP and DIN. Stoichiometric calculations assumed nutrient rations in both Redfield proportions (C:N:P=106:16:1) and in proportions appropriate for macroalgae (C:N:P=335:35:1). The latter seems more appropriate for the Pialassa Baiona, which is affected by seasonal blooms of macroalgae. Overall the lagoon can be considered as "autotrophic", with a net ecosystem metabolism (*p-r*) varying from 1.0 to 3.0 mmol C m^{-2} d^{-1} considering Redfield or macroalgal ratios respectively. Denitrification dominated over nitrogen fixation since (*nfix-denit*) was negative in both cases.

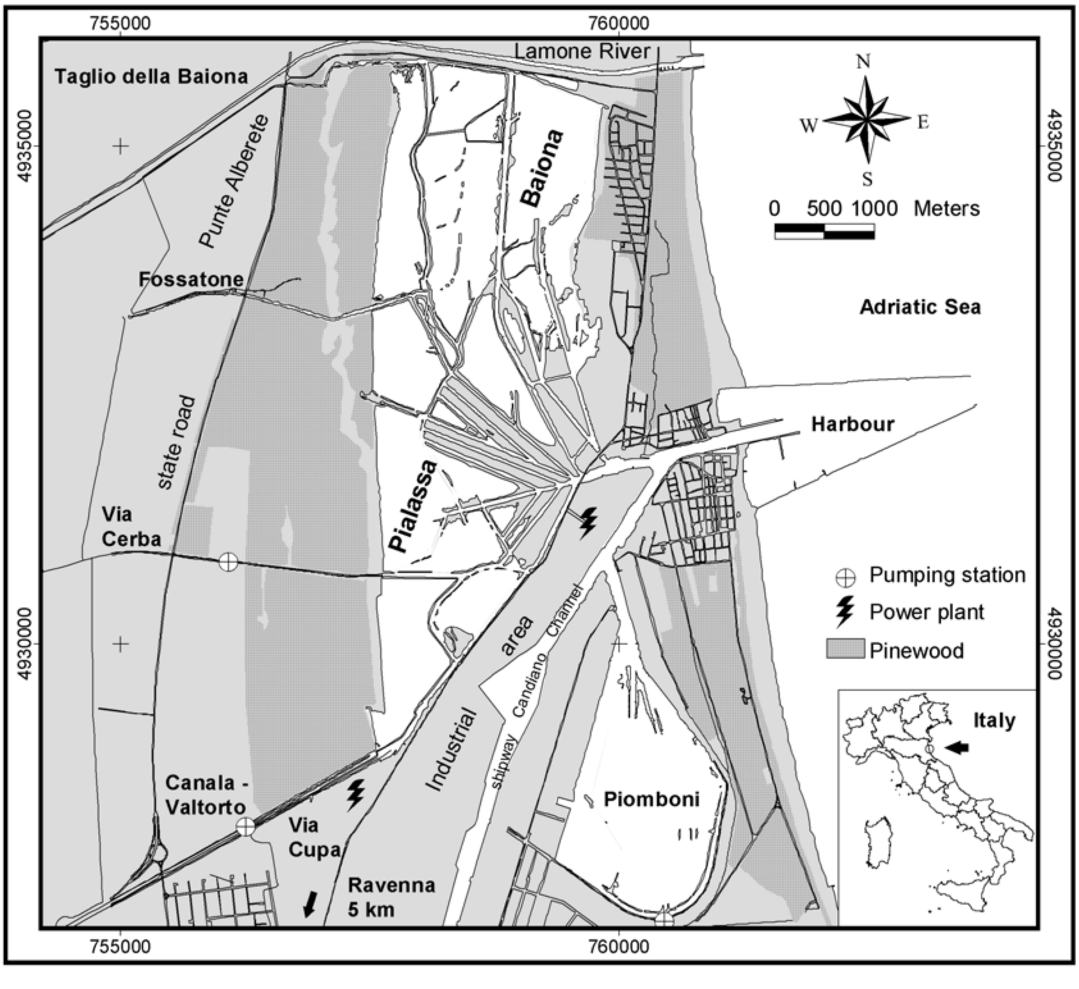

Figure 2.16. Map of the Pialassa Baiona Lagoon with the major water inputs, main inner channels and ponds, power plants and industrial area indicated (coordinate system: UTM32T ED50).

Study area description

The Pialassa Baiona Lagoon is located along the northern Adriatic Italian coast, between Ravenna Harbour and the mouth of the Lamone River (44.47°-44.53°N 12.24°-12.27°E, European Datum 1950; Figures 2.16 and 2.17). Artificial embankments divide the lagoon into several shallow water ponds connected by channels. Water exchange of some ponds is controlled by adjustable dams. The inner channels converge into a main channel connected to the sea through the shipway Candiano Channel (Ravenna Harbour). Total area is 11.80 km^2, including the embankments. The average depth varies from 0.5 m in the shallow areas to 3 m in the channels with a tidal range varying from 0.3 to 1 m, excluding extreme events. Tides cause large variations in water levels and vast shallow areas emerge during low tides. On average, the water covers an area of 9.862×10^6 m^2 and the total water volume is approximately 8.893×10^6 m^3, shared equally between ponds and channels.

The climate of the region is mediterranean with a continental influence. Precipitation is approximately 600 mm per year, with late spring and autumn peaks. The lagoon receives freshwater inputs from five main channels (Figure 2.16). Taglio della Baiona and Fossatone collect the water released from the wet woodland Punte Alberete originated from Lamone River. Via Cerba, Canala – Valtorto and Via Cupa drain a watershed of 264 km^2, including urban (9%) and agricultural (87%) areas. The water flow in two channels is controlled by pumping stations. Furthermore, the lagoon receives freshwater inputs from treatment plants of urban and industrial wastewater and also saltwater inputs from two power plants that draw water as coolant from the Candiano Channel to the lagoon. Sewage treatment facilities and power plants are located in the last part of Via Cupa channel and along the south side of the lagoon.

The lagoon is characterized by large areas of muddy bottom with variable proportions of clay/silt and organic matter. A pinewood stretches all along the western edge of the lagoon. Sandy sediments are abundant close to the relict dunes. The dunes are covered with halophile vegetation of *Salicornia* and *Arthrocnemum*. Embankments are covered with halophile herbaceous vegetation such as *Agropyron pungens*, with submerged meadows of *Ruppia cirrhosa* and *Potamogeton pectinatus*. There are reedbeds of *Phragmites australis*, marginal areas with *Juncus maritimus* and *J. acutus* wet meadows (Corbetta 1990; Corticelli *et al*. 1999). The most abundant species in the phytoplankton is the diatom *Skeletonema costatum*. Diatoms prevail from autumn to spring while the abundance of dinoflagellates rises in summer. Occasionally blooms of diatoms or cyanobacteria occur. The lagoon is affected by anthropogenic eutrophication, which causes extensive growth of seaweeds, especially the chlorophyceans *Ulva*, *Enteromorpha* and the rhodophyceans *Gracilaria*. Macroalgal growth and phytoplankton blooms are responsible for the events of anoxia and dystrophy that occasionally occur in summer (Boni 1990).

The prevalent human activities in the area include recreational and professional fishing, mollusc harvesting (mainly of the Manila clam, *Tapes philippinarum*), hunting, hiking and canoeing (Figure 2.18).

Following the LOICZ guidelines (Gordon *et al.* 1996), an annual single-box, single-layer model was applied to the data collected in the year 2000. A single box model was adopted despite the apparent complexity of the Pialassa Baiona lagoon because the inner dynamics of water and nutrients are not well defined. Meteorological data for the study period were supplied by the Regional Agency for Environmental Protection (ARPA Emilia-Romagna 2001). Flux of potential evaporation was estimated by Hargreaves' equation (Hargreaves 1975) as recommended by Shuttleworth (1993). Data concerning freshwater flow and nutrient concentration were obtained from Angelini and Strumìa (1994) and Giaquinta (2001). Direct measures of flows and nutrient concentrations were compared to theoretical loads based on watershed characteristics (e.g., surface, inhabitants, human activities, industrial plants), load coefficients and rainfall. Measured and theoretical loads were in good agreement. Salinity and nutrient concentrations of adjacent coastal waters were obtained from the annual report of the Struttura Oceanografica Daphne (ARPA Emilia-Romagna 2001). Salinity and nutrient concentrations of the system were provided by the Department of Public Health of the Local Health Service Agency (AUSL, Ravenna).

Water and salt balance

Water inputs and outputs are summarized in Table 2.25. The main freshwater input is due to runoff from the watershed. Its volume is comparable to the sewage inputs. The contribution of the channels is reported in Table 2.26 while the different types of sewage are reported in Table 2.27. Groundwater flow was negligible compared to the other freshwater inputs and was assumed to be zero in the budget. Direct precipitation during the study period was estimated to be 574 mm, equivalent to 18.5×10^3 m^3 d^{-1} over the whole area. Evaporative loss is about twice the inflow from direct precipitation. A high unidirectional input of saltwater was provided by cooling water from two power plants. To balance the water inputs a net water output of 1292×10^3 m^3 d^{-1} to the sea was calculated (V_R).

Table 2.25. Mean flow (V) and salinity (S) of the different water sources.

Sources	V (10^3 m^3 d^{-1})	S (psu)
Runoff	113	0
Sewages	97	0
Atmosphere	18.5	0
Evaporation	-36	0
Power plants	1,099	30.32
System		27.96
Sea (residual)	-1292	29.14
Sea (exchange)	1828	
Sea		30.32

In the lagoon, the salinity varies from 0 psu in areas close to the pinewood to 37 psu in the areas with reduced water exchange during the summer. Average salinity during the study period, taking into account the water volumes of the different areas, was about 27.96 psu. Salinity of the seawater in front of the lagoon is low (average during study the period 30.32 psu) due to the Po River influence. Salinity of the saltwater provided by the power plant was assumed equal to seawater. Using the salinity gradient between the lagoon system and the sea and other inputs of saltwater, the exchange flux (V_X) was calculated at $1,828 \times 10^3$ m^3 d^{-1} and the estimated average water residence time was about 3 days (Figure 2.19). This average time does not consider the water circulation within the ponds and channels; water turnover time is much longer in areas with reduced water exchange and only a tidal cycle (about 12 hours) in the main channels.

Budgets of non-conservative materials

The relative contributions of the various water flows providing loads of dissolved phosphorus and nitrogen as runoff and sewage are reported in Tables 2.26 and 2.27 respectively. All the estimated loads of dissolved inorganic phosphorus (DIP) and nitrogen (DIN) to the system are summarized in Table 2.28.

DIP balance

Sewage represents the main phosphorus input, followed by cooling water from power plants and then by runoff from the watershed (Figure 2.20). Atmospheric phosphorus inputs were assumed to be zero as no data on dry and wet deposition were available. The net phosphorus budget (ΔDIP) was low and reached values of -9 µmol m^{-2} d^{-1}, equivalent to -90 mol d^{-1} overall (Figure 2.19). Negative ΔDIP indicates that the lagoon acts as a net sink of DIP.

Table 2.26 Mean runoff (V; 10^3 m^3 d^{-1}) and nutrients flow (V_{DIP}, V_{DIN}; mol d^{-1}) from western channels, excluding sewages located in the last part of Via Cupa channel.
* approximated to the closest 10 mol d^{-1} step.

Channels	V	V_{DIP}	V_{DIN}
Taglio della Baiona	9	49	277
Fossatone	9	29	1215
Via Cerba	18	65	3016
Canala/Valtorto	26	244	12309
Via Cupa	51	830	39836
Total	113	1220*	56650*

Table 2.27 Mean sewage flow (V; 10^3 m^3 d^{-1}) and nutrient loads (V_{DIP}, V_{DIN}; mol d^{-1}) from treatment plants of urban, industrial and cottage wastewaters.
* approximated to the closest 10 mol d^{-1} step.

Sewage	V	V_{DIP}	V_{DIN}
Civil (treated)	47	1130	24043
Industrial (treated)	49	2660	47986
Fishing cottage	~ 0	18	195
Total	97	3810*	72220*

Table 2.28 Average nutrient concentrations (DIP, DIN; mmol m^{-3}) and loads (V_{DIP}, V_{DIN}; mol d^{-1}) for the various sources. According to the LOICZ guidelines, residual sea DIP and DIN concentrations are assumed as average between sea and lagoon concentrations.
* approximated to the closest 10 mol d^{-1} step.

Sources	DIP	DIN	V_{DIP}	V_{DIN}
Runoff	10.74	499.87	1220	56650
Sewage	39.38	746.78	3810	72220
Atmosphere	0	97.00	0	1790
Evaporation	0	0	0	0
Power plants	2.58	49.97	2840	54920
Sea (residual)	1.70	35.07	-2200	-45300
Sea (exchange)			-5580	-46820
Lagoon system	3.22	47.88		
Sea	0.17	22.26		

DIN balance
Sewage is also the main nitrogen input, followed by runoff from the watershed and cooling water from power plants (Figure 2.20). Atmospheric nitrogen inputs were estimated from the average DIN concentration in the rainwater (97 mmol m^{-3}) reported by Mosello (1993). The net nitrogen budget (*ΔDIN*) was high and reached values of -9.48 mmol m^{-2} d^{-1} equivalent to -93,500 mol d^{-1} (Figure 2.21). Negative *ΔDIN* indicates that the lagoon acts as a net sink of DIN.

Despite the function of the lagoon as a sink of DIP and DIN, a surplus of nutrient terrestrial inputs is exported to the sea. These flows can be estimated by summing residual and exchange flows reported in Table 2.28. Overall, the exports accounts for 7,780 mol d^{-1} of DIP and 92,120 mol d^{-1} of DIN, corresponding to 88 tonnes y^{-1} and 472 tonnes y^{-1}, respectively. These values agree with estimates on theoretical bases by Marchetti and Verna (1992) for the contribution to the northern Adriatic eutrophication from the whole Candiano basin (including the harbour channels, the connected small Piomboni Lagoon and their watersheds).

Stoichiometric calculations of aspects of net system metabolism

On an annual basis and in accordance with the assumptions of the model, the lagoon can be considered an autotrophic system because the negative *ΔDIP* values calculated can be considered as an estimate of net DIP assimilation associated with organic matter production. This production could be related to the development of dense beds of floating macroalgae during the summertime and the recurring phytoplankton blooms. To consider these phenomena, both the phytoplankton Redfield ratio (C:N:P=106:16:1) and the ratio for macroalgae (C:N:P=335:35:1) reported by Atkinson and Smith (1983) were used in the stoichiometric calculations (Table 2.29). Under these assumptions the net ecosystem metabolism (NEM) can be estimated to be in the range between 0.97 and 3.06 mmol C m^{-2} d^{-1}, depending on whether calculations are based on phytoplankton or macroalgae as dominant primary producers. The latter seems more appropriate for the Pialassa Baiona, which is affected by seasonal blooms of macroalgae, especially in the south side of the lagoon due to the location of the major nutrient inputs.

Table 2.29. Results of the stoichiometric calculations (mmol m^{-2} d^{-1}).

Hypothesis	**NEM**	ΔDIN_{exp}	***(nfix-denit)***
Phytoplankton	0.97	-0.15	-9.33
Macroalgae	3.06	-0.32	-9.16

The difference between the observed and expected *ΔDIN*, based on the N:P ratio, was considered to be the net ecosystem nitrogen fixation minus denitrification (*nfix-denit*). Negative values using either phytoplankton or macroalgae nutrient ratios suggest that denitrification losses dominate over nitrogen fixation inputs (Table 2.29). The relatively high values obtained can be explained by high benthic respiration rates. However, these results should be considered with caution since they not take into account the heterogeneity of the lagoon system.

Figure 2.17. View of the Pialassa Baiona Lagoon (photo by Biserni).

Figure 2.18. Fishing activities in the Pialassa Baiona Lagoon.

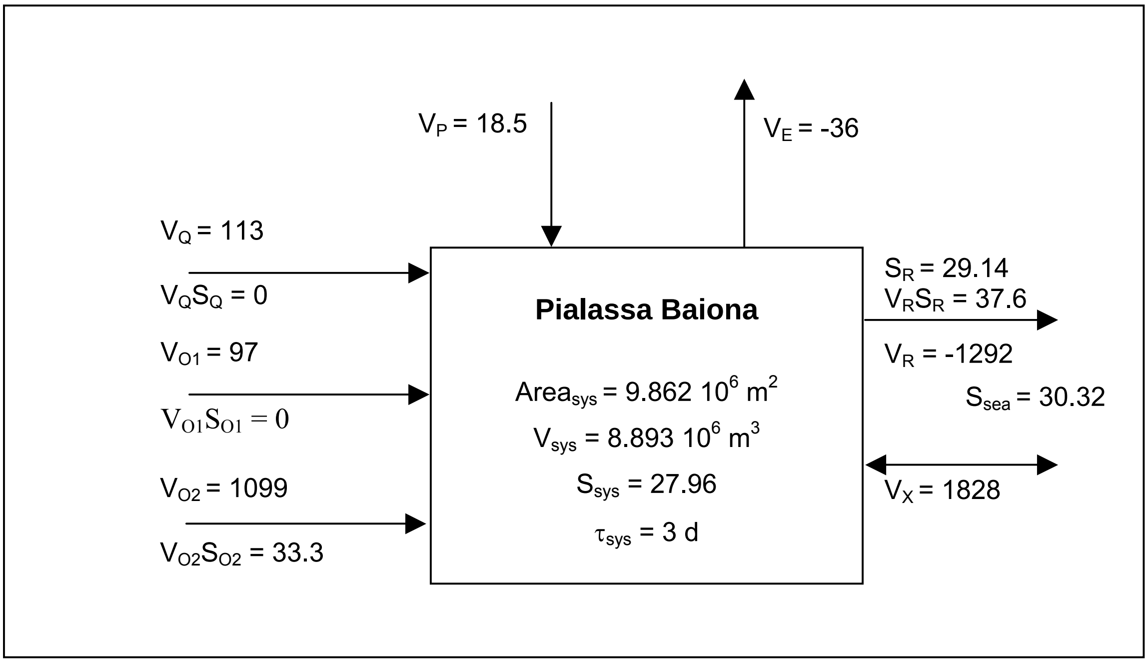

Figure 2.19. Steady-state water and salt budgets for the Pialassa Baiona Lagoon. P = precipitation; E = evaporation; O1 = sewage; O2 = power plants; Q = runoff; X = exchange; R = residual. Units: water fluxes in 10^3 m^3 d^{-1}; salt fluxes in 10^6 psu m^3 d^{-1}; salinity in psu.

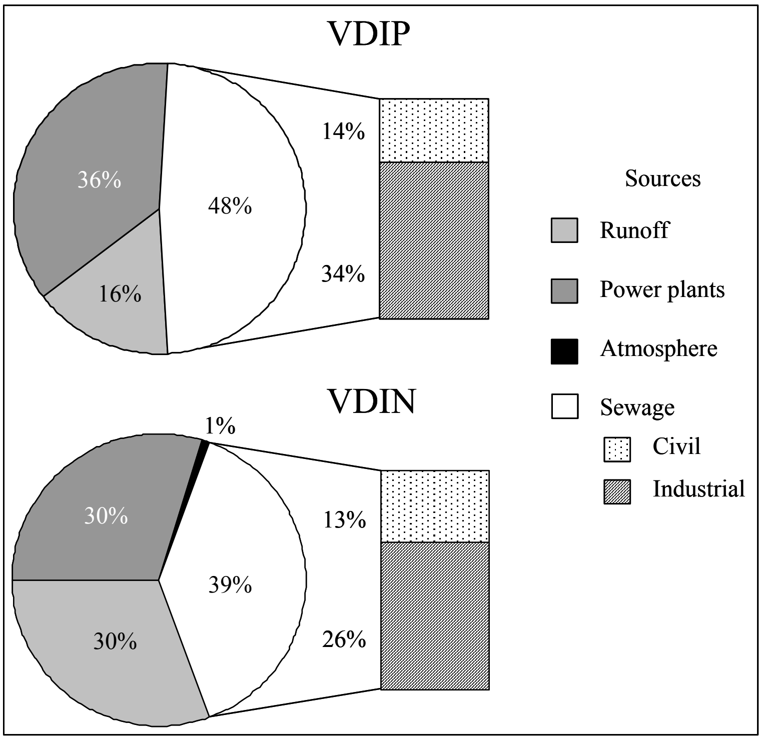

Figure 2.20. Relative contribution of the different water inputs to the Pialassa Baiona Lagoon budgets of DIP and DIN.

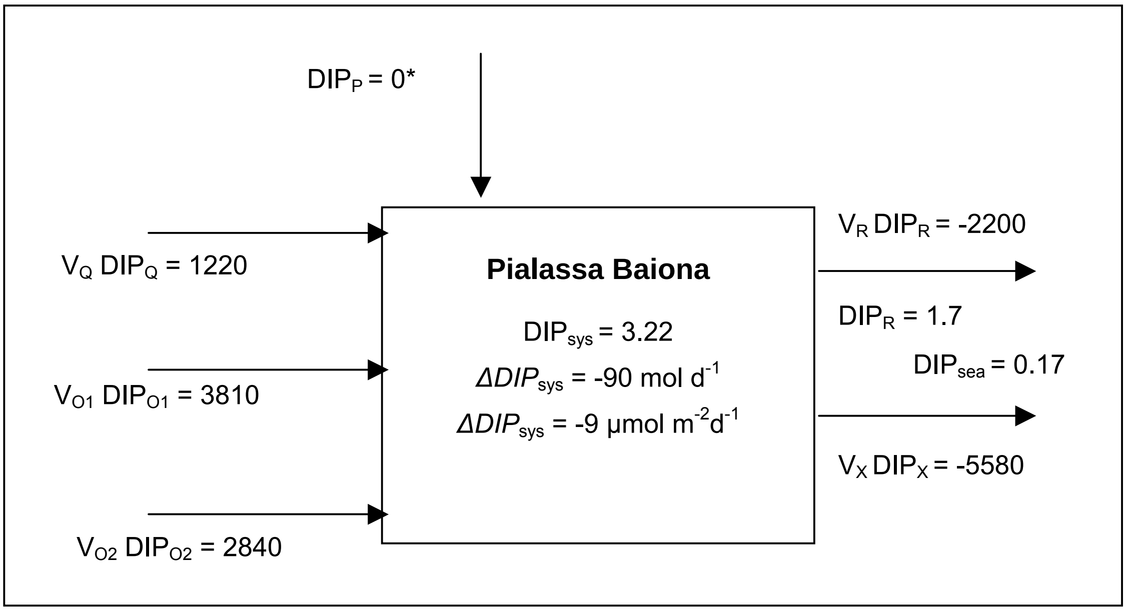

Figure 2.21. Steady-state DIP budget for the Pialassa Baiona Lagoon. O1 = sewage; O2 = power plants; Q = runoff; X = exchange; R = residual. Units: concentrations in mmol m^{-3}, loads in mmol d^{-1}. * = assumed.

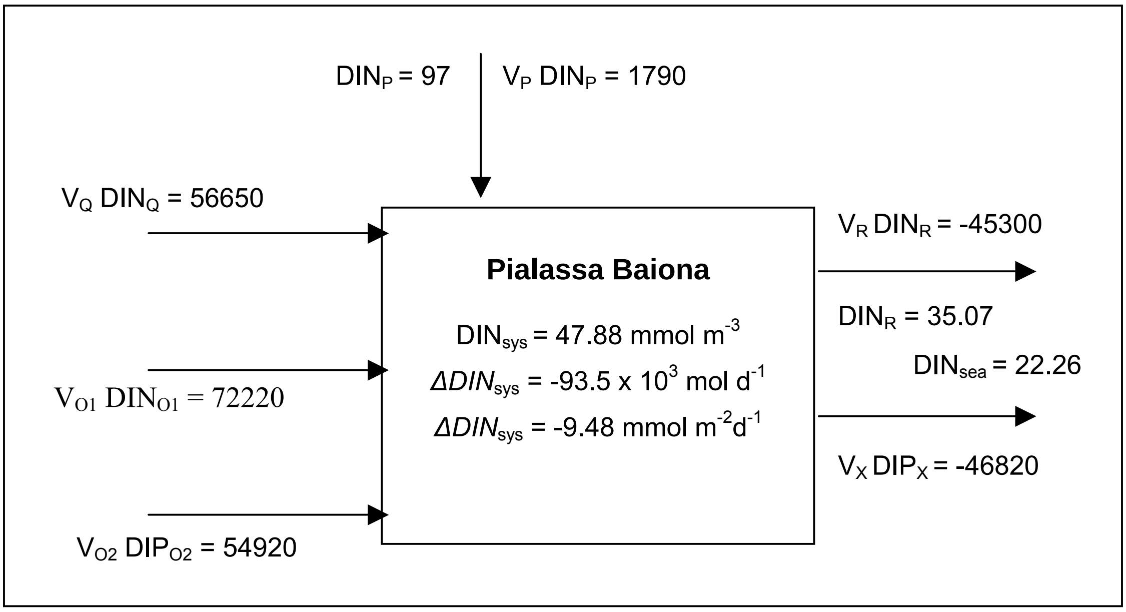

Figure 2.22. Steady-state DIN budget for the Pialassa Baiona Lagoon. O1 = sewage; O2 = power plants; Q = runoff; X = exchange; R = residual. Units: concentrations in mmol m^{-3}, loads in mmol d^{-1}.

3. SOUTH-EASTERN ITALIAN COASTAL SYSTEMS

3.1 Lagoon of Lesina

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Study area description

The Lagoon of Lesina is located along the southern Adriatic coast (Puglia region, Italy) on the northern side of the Gargano promontory (41.88° N; 15.45°'E) between the Fortore River and Rodi Garganico (Figure 3.1). This lagoon has an extended and narrow shape, elongated in the east-west direction and is connected with the Adriatic Sea by means of natural and artificial channels interspersed with sand-dunes. The economic relevance of this lagoon is mostly related to extensive fish farming. It is also internationally known as a breeding area for many migratory bird species. The ecosystem covers an area of 51.5 km^2 with an average depth of 0.8 m and a volume of 41.2x10^6 m^3. The lagoon communicates with the sea through two canals: Schiapparo on the eastern side and Acquarotta on the western side. The western area of the lagoon is characterized by freshwater inputs receiving both domestic and agricultural effluents.

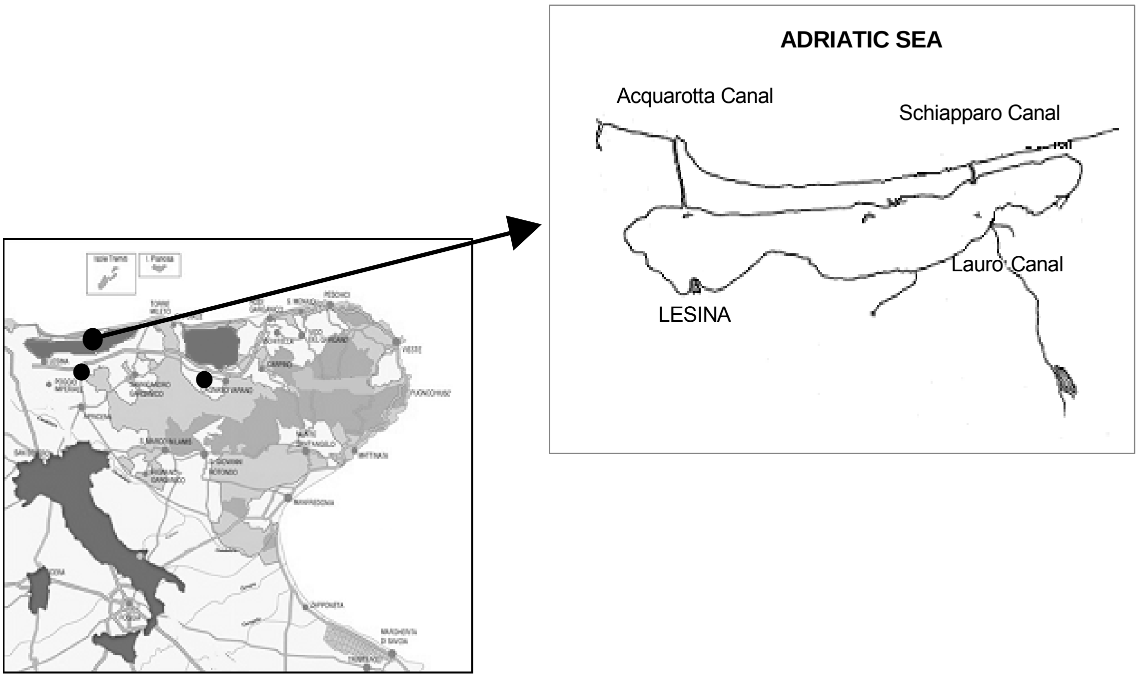

Figure 3.1. Location and sketchmap of the Lagoon of Lesina.

Since 1997, the flow of the Schiapparo canal has been partially reduced by wooden barriers, while the Acquarotta canal has been completely closed by a sand barrier. These barriers prevented adequate water exchange and the free passage of fishfry within and into the lagoon until they were removed in April 2000. Protective grids (10 mm) were deployed to retain fish within the lagoon. Numerous small fish and larvae of other species are now visible near these structures indicating a massive immigration from the sea.

The south-eastern side of the lagoon receives freshwater inputs, with seasonal peaks during the winter rainfall period. The canals collect agricultural drainage water from two pumping stations located south of Lesina where the land is lower than mean sea level. No freshwater inputs occur in the south-western part of the lagoon, which only receives water from an intensive aquaculture farm (3 km from the lagoon), in which both freshwater (*Cyprinus* sp.) and marine (*Anguilla anguilla*) fish are reared. The moderate freshwater inputs and water exchanges with the sea suggest that the hydrological balance in the Lagoon of Lesina is strongly affected by atmospheric inputs.

The Lagoon of Lesina is eutrophic; nutrient concentrations were influenced by the reduced water exchange after the closure of the canals, which were re-opened after April 2000. The lagoon exhibits strong seasonal variations of physical factors such as temperature (ranging from 7°C in winter to 26°C in summer) and salinity (between 11 and 34 psu); moreover, the western part of the lagoon generally exhibits higher salinity values than the eastern area.

Values of physical and chemical parameters of the lagoon were used to estimate seasonal and annual budgets, applying the one-box one-layer LOICZ model for the period from July 1998 to June 1999. Water samples were collected at 29 stations during the POP Project (Progetto Operativo Plurifondo, a programme for the reintroduction of the algae *Gracilaria verrucosa*). Station locations were defined to cover the entire lagoon. Data on freshwater inputs and water flows were obtained from from Nista (1994), and data on nutrient concentrations were obtained from ASL FG-3 (Azienda Sanitaria Locale, Foggia 3). Rainfall measurements were obtained from the meteorological station of Lesina (Consorzio Bonifica Capitanata, Foggia) and evaporation was calculated using the Hargreaves equation (Hargreaves 1975). In 1998-99, precipitation was very low, particularly in the summer period (0.5 mm d^{-1}); in these months, the closure of the canals also caused elevated evaporation rates (3.7 mm d^{-1}), with consequent hypersalinity of the western area of the lagoon (up to 44 psu) and reduced water depth. This caused a massive growth of the macroalga *Valonia utricularis*. Nutrient concentrations were influenced by the freshwater input, resulting in particularly high concentrations during the rainy period (0.17 and 29.3 µM DIP and DIN, respectively); lower values were measured in the summer period (0.09 and 4.3 µM DIP and DIN, respectively).

Primary producers include phytoplankton and the littoral macrophytes *Valonia utricularis, Zostera noltii,* and *Ruppia* sp. Data collected in this study for the Lagoon of Lesina indicated the presence of a primary production strongly phosphorus-limited, as suggested by the very high N/P ratios (N:P=199 on annual average). Therefore the lagoon acts as a sink for dissolved inorganic nitrogen (DIN).

Water and salt balance

For the Lagoon of Lesina, the major freshwater inputs are: five canals (Lauro, S. Nazzario, Caldoli, Mascolo and Mascione; V_Q), two pumping stations (Palude Grande and Lauro; V_O) and direct precipitation into the system (V_P). Evaporation (V_E) was the only freshwater output from the lagoon.

In the period investigated, direct rainfall to the lagoon was 427 mm y^{-1} with a strong seasonal pattern with minima in the summer period when evaporation largely exceeded precipitation (Table 3.1). Figure 3.2 illustrates the annual water and salt budgets of the lagoon. Net export of water from the lagoon to the sea, indicated by the negative residual flow (V_R), was observed during the entire period. The highest negative residual flow values were obtained in winter and in autumn during the rainy period. The V_x values, which indicate the mixing volume between the lagoon and the sea also showed a maximum in the autumn season. The mean salinity of the system remained low due to moderate mixing between seawater and freshwater, especially in the eastern parts of the lagoon. The estimated water residence time was 100 days.

Table 3.1. Water flux (precipitation V_P, evaporation V_E, runoff input V_Q, pumping machine input V_O), residual flow (V_R), salinity of the lagoon and adjacent sea (S_{SYST}, S_{SEA}), mixing water volumes between lagoon and sea (V_X) and water exchange time (τ) in the Lagoon of Lesina in the period 1998-1999 (*seasonal data are not available thus mean values were used).

Season	V_P	V_E	V_Q	V_O	V_R	S_{SYST}	S_{SEA}	V_X	τ
	(10^3 m^3 d^{-1})					(psu)		(10^3 m^3 d^{-1})	(days)
Summer 1998	27.7	187.9	98.1*	87.5*	-25.4	30.2	36.8	128.9	267
Autumn 1998	150.5	84.0	98.1*	87.5*	-252.1	28.6	36.1	1089.1	31
Winter 1998-99	49.1	40.1	98.1*	87.5*	-194.6	19.2	37.1	306.6	82
Spring 1999	65.1	200.5	98.1*	87.5*	-50.2	19.9	36.8	84.4	306
Annual average	66.1	128.1	98.1*	87.5*	-123.6	23.7	36.7	287.1	100

Budgets of non-conservative materials

DIP balance

The DIP budget for the year 1998-99 is shown in Figure 3.3. On an annual basis, the DIP exchanges were low, and non-conservative flux of DIP (Δ*DIP*) was approximately -0.12 mmol m^{-2} d^{-1}. The main DIP sources were the moderate inputs from V_O that correspond to the two water pumping machines (Palude Grande and Lauro). DIP concentrations in the system were very low (0.10 µM) for most of the time (Table 3.2). Another reason for low concentration, apart from the low inputs, is that this element is also sequestered by macrophytes and phytoplankton. Δ*DIP* values ranged from -0.07 to -0.19 mmol m^{-2} d^{-1} in autumn and summer respectively, when DIP inputs were close to 3400 and 9800 mol d^{-1}. Δ*DIP* was negative for the whole investigated period, indicating that the lagoon acts as a net DIP sink (Table 3.3).

Table 3.2. Nutrient concentrations in the freshwater input, in the Lagoon of Lesina and in the adjacent sea, 1998-99. Unit: mmol m^{-3}.

*seasonal data are not available thus mean values were used.

Season	DIP_Q	DIP_O	DIP_{SYST}	DIP_{SEA}	DIN_Q	DIN_O	DIN_{SYST}	DIN_{SEA}
Summer 1998	44.7	61.5	0.09	0.07	444	1150	4.3	1.5
Autumn 1998	5.0	33.2	0.10	0.13	67	3030	13.6	14.4
Winter 1998-99	17.0	52.0*	0.17	0.10	378	100	29.3	8.0
Spring 1999	12.8	52.0*	0.06	0.03	47	1600	28.6	2.0
Annual average	15.9	52.0	0.10	0.08	156	1363	20.9	5.8

Table 3.3. Seasonal variation of *ΔDIP, ΔDIN, ΔDIN*

Season	*ΔDIP*	*ΔDIN*	*$ΔDIN_{exp}$*	*(nfix-denit)*	*(p-r)*
Summer 1998	-0.19	-2.79	-3.04	+0.25	+20.1
Autumn 1998	-0.07	-5.23	-1.12	-4.11	+7.4
Winter 1998-99	-0.12	-0.69	-1.92	+1.23	+12.7
Spring 1999	-0.11	-2.75	-1.76	-0.99	+11.7
Annual average	-0.12	-2.50	-1.92	-0.58	+12.7

DIN balance
The DIN budget for the year 1998-99 is shown in Figure 3.4. The overall DIN input to the Lagoon of Lesina was about 20-fold higher than DIP, resulting in a strong imbalance of the N/P ratios. Ammonium was the dominant form of dissolved inorganic nitrogen in all seasons except winter, when nitrates were dominant. The lagoon appeared to be a sink for DIN in all seasons (Table 3.3).

Stoichiometric calculations of aspects of net system metabolism
According to the assumptions of the LOICZ biogeochemical model, ΔDIP values allow a direct estimate of the net energy budget of the system, determining whether the system is a net consumer ($\Delta DIP>0$ and $(p\text{-}r)<0$) or a net producer ($\Delta DIP<0$ and $(p\text{-}r)>0$) of organic matter. With the assumption that the system is dominated by phytoplankton and using the Redfield ratio of C:P (106:1) (Redfield *et al.* 1963), the system seems to be a net producer of organic matter (Table 3.3).

Using the Redfield ratio of N:P (16:1), the values for (*nfix-denit*) were positive for summer and winter and negative for the rest of the year. Considering average behaviour over the whole period, a more accurate estimation, (*nfix-denit*) is negative (-0.58 mmol m^{-2} d^{-1}) indicating that denitrification prevails over nitrogen fixation processes. The Lagoon of Lesina appeared to be a sink of nitrogen available to bacterial degradation, re-mineralization and ammonium production. The lagoon also appears to be an autotrophic system, as indicated by NEM values of +12.7 mmol m^{-2} d^{-1} (Table 3.3).

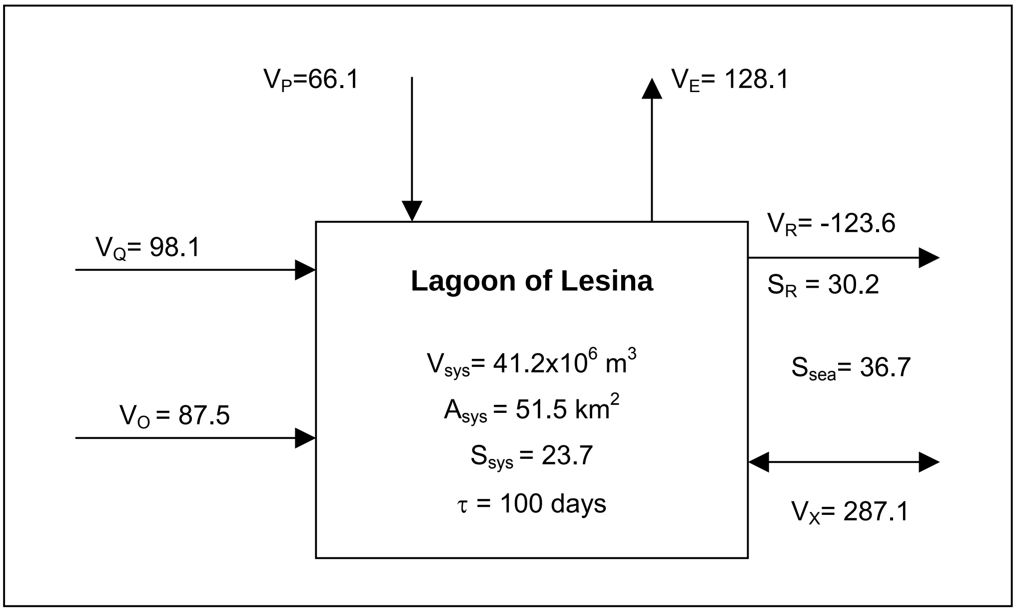

Figure 3.2. Water and salt budgets for the Lagoon of Lesina in 1998-99. Water fluxes are expressed as 1000 m^3 d^{-1} and salinity in psu.

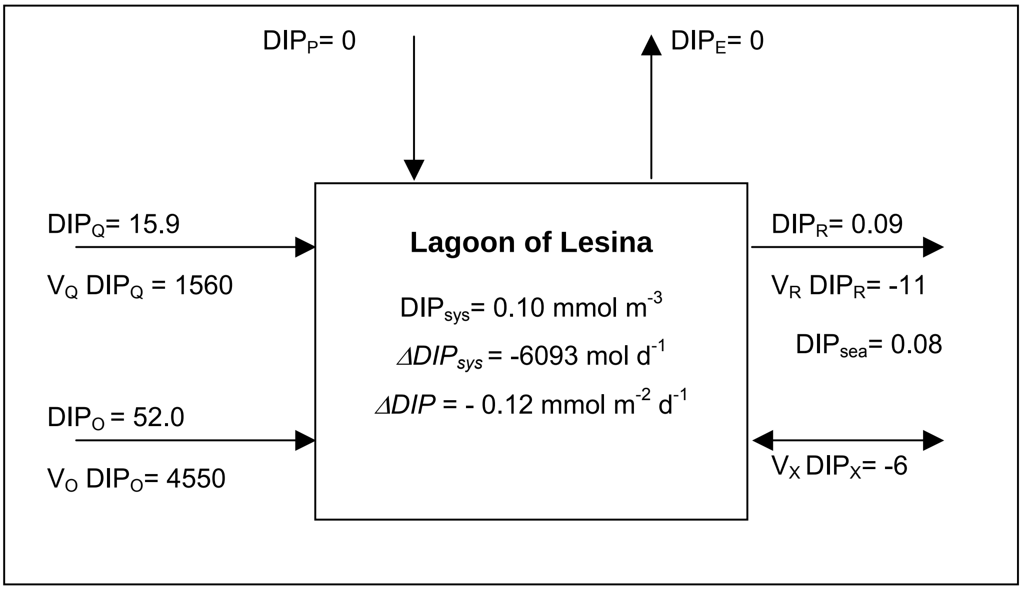

Figure 3.3. DIP budget for the Lagoon of Lesina in the period 1998-99. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

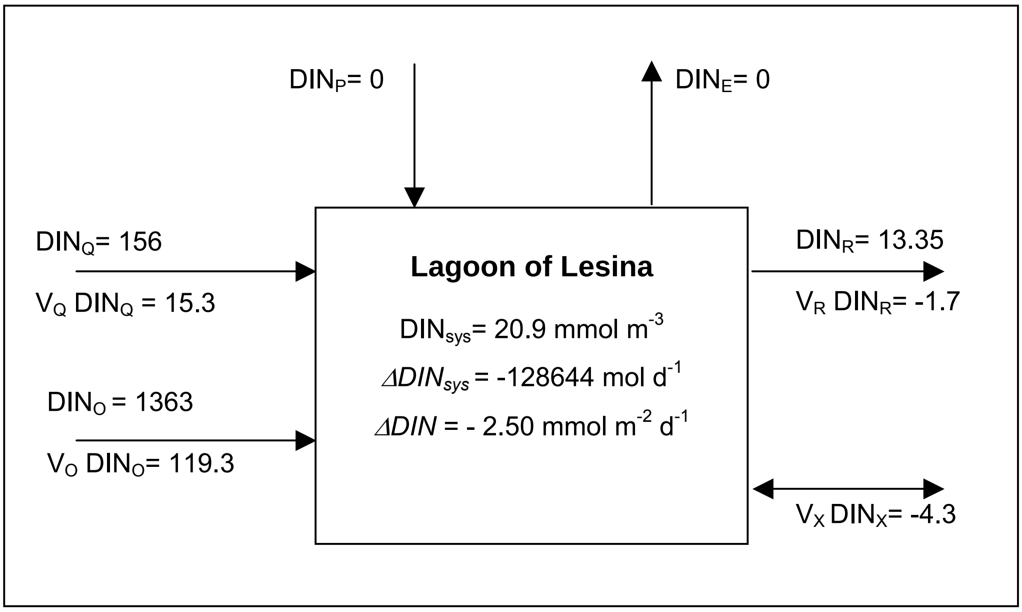

Figure 3.4. DIN budget for the Lagoon of Lesina in the period 1998-99. Concentrations are in mmol m^{-3} and fluxes in 10^3 mol d^{-1}.

Figure 3.5. Fishing is an important economic activity of the lagoon.

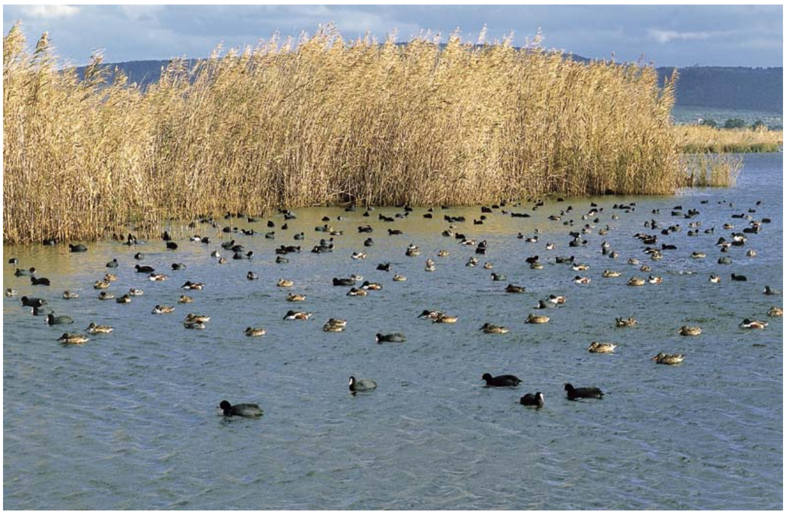

Figure 3.6. Many migratory bird species breed in the lagoon.

Figure 3.7. View of the village of Lesina.

3.2 Lagoon of Varano

Elena Manini[1], Paolo Breber[1], Raffaele D'Adamo[1], Federico Spagnoli[1], Roberto Danovaro[2]

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Study area description

The Lagoon of Varano is located along the southern Adriatic coast (Puglia region, Italy) on the northern coast of the Gargano promontory (41.88 °N; 15.75 °E; Figures 3.8 and 3.12). It has a rounded shape and is connected with the Adriatic Sea by means of natural and artificial channels interspersed with sand dunes. The economic relevance of this lagoon is mostly related to intensive fish and mussel farming, although recently mussel farming declined and fish became the most intensively exploited resource (Figure 3.13). The lagoon is an internationally known breeding area for many migratory bird species. It covers an area of 64 km^2, with a perimeter of 33 km. The average depth is 4 m, with maximum depths of 5 m in the central zone.

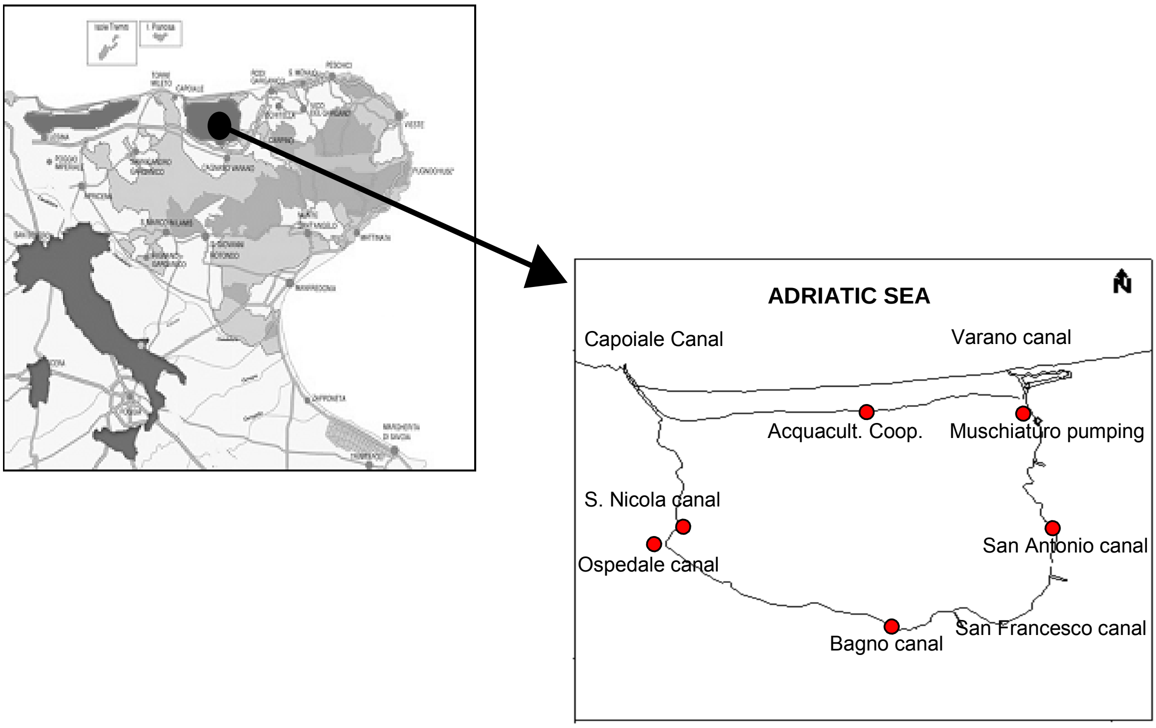

Figure 3.8. Location and map of the Varano coastal lagoon.

In the last few years, salinity has increased progressively from 21 to 27 psu after a series of mouths were opened to the sea. The complete hydrological system consists of the lagoon, two artificial canals connecting the lagoon with the sea (Capoiale and Varano canals located at the north-western and eastern corner respectively), some freshwater inputs (the main ones are S. Antonino and S. Francesco Canals and the Muschiaturo drainage pumping station) and some small catchment basins (Bagno, Irchio, Ospedale and S. Nicola).

Hydrological investigations of the water balance of the lagoon (based on 20 sampling sites) estimated a freshwater input of approximately 87,000 m^3 d^{-1} with an organic nutrient load mostly originating from urban and agricultural runoff, fish-farming and livestock rearing activities. The water budget, salinity and nutrient data were determined in the framework of an integrated project for protection and development of the lagoon (carried out from 1997 to 1999). Data for the total freshwater inputs were based on the study of Consortium ELTCON (Environmental Characterization of the Lagoon of Varano, March 1995; see Villani *et al.* 1999). Rainfall data were collected from a local meteorological station (Consorzio Bonifica Capitanata, Foggia); and evaporation was calculated using Hargreaves' equation (Hargreaves 1975).

The trophic conditions of the system are highlighted by relatively low annual mean phosphorus and nitrogen concentrations (0.16 and 4.60 mmol m^{-3}, respectively), with values comparable to those typical of oligo-mesotrophic waters.

Water and salt balance

Figure 3.9 shows the water and salt budget for Lagoon of Varano from 1997 to 1999. Because the lagoon is well-mixed, it was treated as single-box, single-layer system. V_Q is the freshwater load from the canals and V_O from the pumping station. Mean annual precipitation was estimated as 138.9×10^3 m^3 d^{-1}, while evaporation was 159.9×10^3 m^3 d^{-1}. The calculated residual outflow, V_R, was -65.1×10^3 m^3 d^{-1} (the negative sign indicating a loss from the system).

S_Q and S_O were 1.8 and 18.0 psu respectively and the mean salinity of the lagoon was 27.0 psu. This is lower than the salinity of the adjacent sea (36.1 psu) and mixing exchange flow (Vx) was estimated as 183.0×10^3 m^3 d^{-1}. The salt exported through the residual flow must be replaced through the mixing volume with the adjacent sea. Due to the low tidal excursion and to the reduced exchange with the adjacent coastal area, the estimated water residence time was very long: close to 3 years (1032 days).

Budgets of non-conservative materials

DIP balance

Figure 3.10 illustrates the dissolved inorganic phosphorus (DIP) budget from 1997 to 1999, considering that nutrient loads are delivered largely through the freshwater input (4 and 68 t y^{-1} of P and N respectively). The non-conservative DIP flux (ΔDIP) was estimated as the difference between total inputs and total outputs (residual and exchange fluxes). ΔDIP of the system was -365×10^3 mmol d^{-1} (equivalent to -0.006 mmol m^{-2} d^{-1}), therefore the system appears to be a net sink for DIP.

DIN balance

Figure 3.11 illustrates the dissolved inorganic nitrogen (DIN) budget from 1997 to 1999. The non-conservative DIN flux (ΔDIN) of the system was approximately -12.7×10^3 mol d^{-1} (equivalent to -0.20 mmol m^{-2} d^{-1}). Therefore the system also can be considered a net sink for DIN.

Stoichiometric calculations of aspects of net system metabolism

Stoichiometric estimates of system metabolism can be based on the molar C:N:P ratio of the reactive organic material of the system. For our estimates, we assumed that this material was plankton, with a Redfield C:N:P molar ratio of 106:16:1. Stoichiometric analyses of the non-conservative fluxes indicate that the lagoon can be considered a net producer of organic matter with NEM = +0.64 mmol m^{-2} d^{-1} and also a net denitrifying system with (*nfix-denit*) = -0.10 mmol m^{-2} d^{-1} (Table 3.4).

Table 3.4. ΔDIN_{exp}, (*nfix-denit*) and net ecosystem metabolism (*p-r*) in Lagoon of Varano for the period 1997-99.

Parameters	Lagoon of Varano
ΔDIN_{exp} (mmol m^{-2} d^{-1})	-0.10
(*nfix-denit*) (mmol m^{-2} d^{-1})	-0.10
(*p-r*) (mmol m^{-2} d^{-1})	+0.64

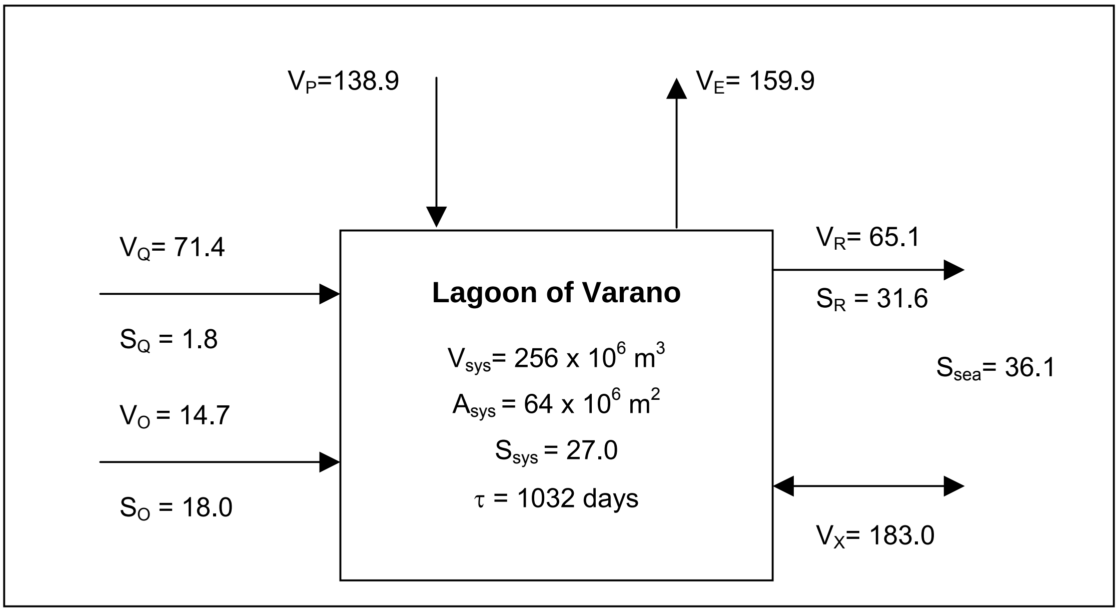

Figure 3.9. Water and salt budgets for the Lagoon of Varano in 1997-99. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in psu.

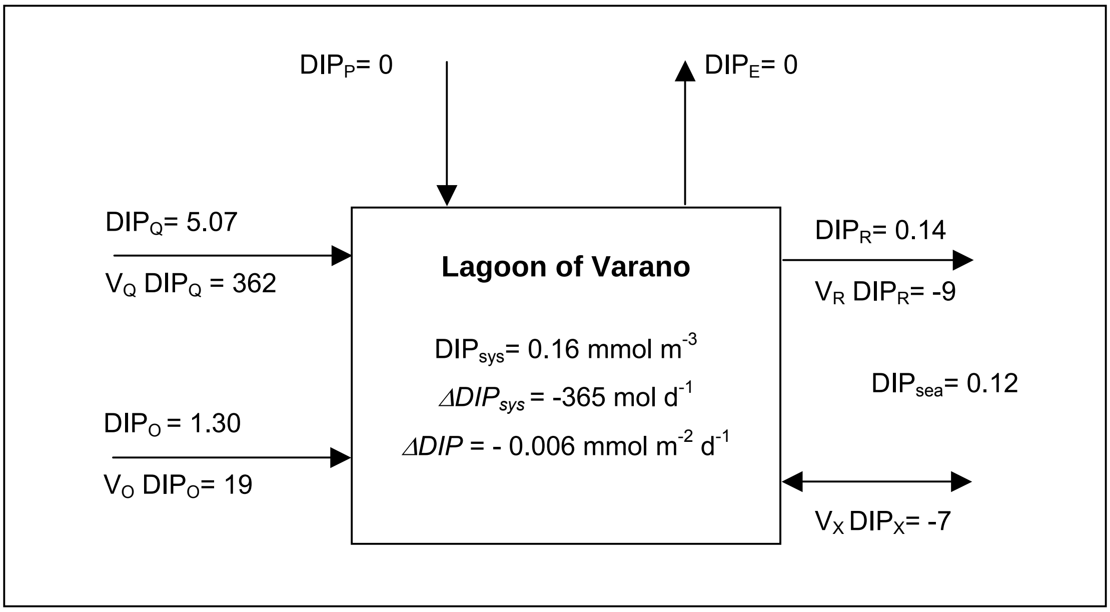

Figure 3.10. DIP budget for the Lagoon of Varano in the period 1997-99. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

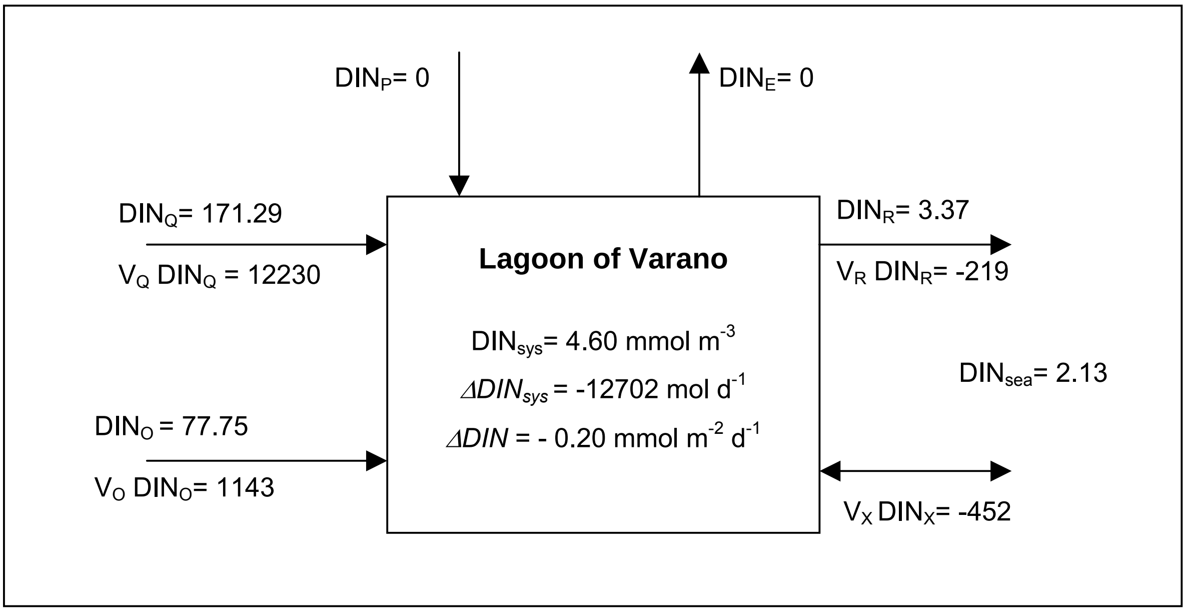

Figure 3.11. DIN budget for the Lagoon of Varano in the period 1997-99. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

Figure 3.12. Views of the Lagoon of Varano.

Figure 3.13. Fishing is an important economic activity of the lagoon.

3.3 Torre Guaceto wetland

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Summary

In this paper, we report a study of the water, salt and nutrients budgets of the wetland part of the Torre Guaceto Nature Reserve, in which the LOICZ Biogeochemical Budget Model (Gordon *et al.* 1996) was applied to estimate the net system metabolism. The reserve is located in the Apulia region of Italy, on the Adriatic coast, about 15 km north of the city of Brindisi (Figure 3.12 and 3.19). The region is characterized by Mediterranean-type climatic variations, with meteorologically stable summers and unstable winters. The study took place between July 2001 and May 2002. The wetland area of the reserve was treated as a single-box, single-layer system with seasonal variation, following LOICZ guidelines.

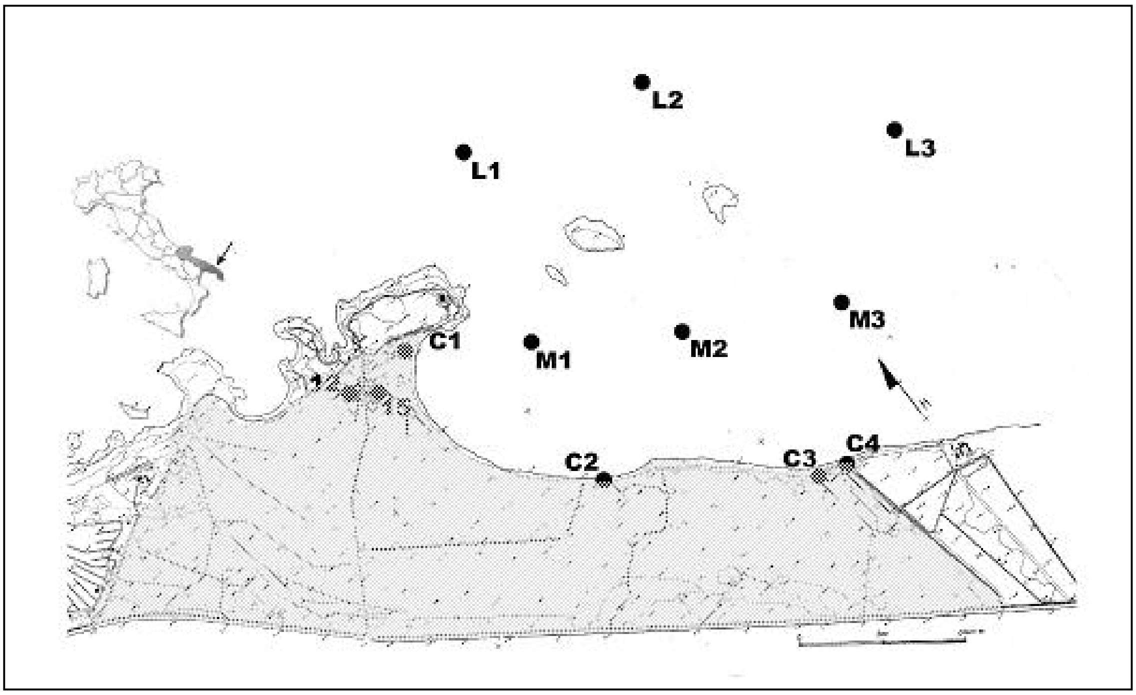

Figure 3.12. Location of Torre Guaceto Nature Reserve and sampling stations. The grey part is the area considered in this study.

The entire system, consisting of a marine area and the salt marsh, can be considered to be in an oligo-mesotrophic state on the basis of the classification proposed by Håkanson (1994), Nürnberg (1996), Dodds *et al.* (1998) and the measured dissolved inorganic phosphorus and chlorophyll *a* concentrations (0.43÷28.90 and 0.088÷1.06 mg m^{-3} respectively).

The water volume of the brackish wetland cannot be considered constant (it varies from 2.39 to 4.54x10^5 m^3) so the formulas of the standard LOICZ approach were modified to account for the seasonal variability of water volume and the characteristics of the system. Water inputs to the system are only precipitation and groundwater while outputs are evaporation and transport to sea via numerous small streams. The main inputs of dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) are from groundwater.

The estimated water turnover time in the system ranges between 21 and 69 days. Judging from the *ΔDIP* and *ΔDIN* values obtained with the model application, the system acts as a source for DIP and a *sink* for DIN; moreover, it seems to be slightly heterotrophic with denitrification processes prevailing over nitrogen fixation.

The seasonal variations of ecosystem functions appear to be in agreement with vegetative growth and ageing of the reeds (*Phragmites australis* (Cav.) Trin ex Steud.), which constitute the predominant vegetation in the area.

Study area description

The Torre Guaceto Nature Reserve (40.71°N-17.80°E) is located in the Apulia region (Italy), on the Adriatic coast, about 15 km north of the city of Brindisi and consists of a brackish wetland and a marine area (Figure 3.12, 3.19, 3.20, 3.21). The LOICZ biogeochemical budget approach was applied to the wetland, which covers a surface area of 1.19 km^2. This wetland is crossed by a network of canals which were built in an attempt to reclaim the marshy area, and which delineate areas of varying size. In the dry season, an unsealed road (submerged in the autumn-winter season) divides the wetland ecosystem into two distinct compartments.

The mean depth of the marshy area is about 20 cm in the summer and 40-45 cm in winter. During the year of study, the total volume ranged between 2.39×10^5 m^3 and 4.54×10^5 m^3, which means that the system is not in hydraulic equilibrium during the year. At present, the marshy ecosystem has no localized surface water inputs and only negligible atmospheric and groundwater inputs.

The system is located in the Canale Reale watershed (surface area 383 km^2). The Canale Reale flows into the protected marine area, to the south of Zone A (the part of the reserve enjoying maximum protection). However, the Canale Reale is physically separated from the marshy ecosystem by concrete dykes and a concrete river bed near the canal mouth. The watershed feeds the water-bearing stratum present under the wetland, delivering considerable freshwater input from precipitation. Tidal variation in sea levels in the area, according to regional sea charts, is very low and, due to the shallow coastal dunes, tide does not affect the hydrological budget of the Torre Guaceto marsh. The system is covered by dense reeds, which probably form the dominant biological element of the system.

Within the marine reserve it is possible to identify an area of about 1.44 km^2 with a total volume of 5.73×10^6 m^3 that receives freshwater from the Canale Reale and brackish water from the outflow of the brackish ecosystem and the groundwater layer. The area, protected to the north by a promontory and to the east by two islets, consists of a sandy, shallow bay.

For the analysis of the hydrological and nutrient budget of the Torre Guaceto wetland system, an experimental design was set up with 12 sampling stations: two in the wetland, four corresponding to the streams flowing into the Nature Reserve and six in the bay. There are thus three transects with a coast-offshore gradient. At all the stations, samplings were done seasonally and in every sample the following parameters were determined: salinity, temperature, nitrate, nitrite, ammonium, phosphorus and chlorophyll (chl_*a*). In addition, the input of every stream was periodically calculated, with special attention paid to heavy rains. All the parameters were determined using standard procedures. The dissolved phosphorus absorbance was measured with a 10 cm cell, in order to increase the standard sensitivity of the method, the phosphorus concentration being very low both in the system and in the marine area. Atmospheric temperature and precipitation were obtained from the meteorological station in the area and from historical data. Evaporation was calculated using Hargreaves' equation (Hargreaves 1975). Data of temperature and precipitation presented here are averages from twenty and forty years data sets, respectively.

Water and salt balance

For the water and salt balance estimates, the equations proposed by Gordon *et al.* (1996) were used, adapting them on the basis of data availability and morphology of the site.

The principal equation, which establishes the relationship between the variation in mass of the water body and the input and output fluxes for the system, is:

$$\frac{dV_{sys}}{dt} = V_Q + V_P + V_G + V_O - V_E + V_{in} - V_{out}$$

where V_{sys} is the volume of the system and V_Q is the input flux for the system representing streams flowing into the body of water under consideration. In the salt marsh of the Torre Guaceto reserve this input is negligible, because the banks and bed of the only stream that crosses the system are completely cemented, preventing any influence on the water and salt balance.

V_P represents the input deriving from direct precipitation, and V_E is the quantity of water evaporating corrected for evapotranspiration. V_E constitutes an output for the system, so in the formula it assumes a negative sign.

V_O is made up of all the water input not included in the preceding factors, i.e. not canalized or surface flowing. This quantity is considered negligible.

V_G is the flow of groundwater from the water layer underlying the body of water under study. It has not been possible to collect data on groundwater characteristics, so this flux, which is not negligible, is unknown.

V_{in} and V_{out} are hydrographically driven advective inflow and outflow of water between wetland and sea. In our model we considered the negligible inflow, because there is no visible input of seawater into the marsh system. The only exchange flux between system and sea is given by the few streams that carry the marsh water into the sea; so we substituted the model value of V_{out} with the total output of the streams.

In the classical applications of the model, the term $\frac{dV_{sys}}{dt}$ is considered zero, indicating that the variations of the water volume of the system are, at least approximately, constant during the period under consideration. In the case of Torre Guaceto this assumption is not valid, since the saltmarsh water volume almost doubled from summer to winter in the studied year. Therefore, we needed to take into consideration the variations of the system volume in the model. This was obtained by describing the system volume, only for the year studied, through a polynomial function, produced with *best fit* techniques, since further observations demonstrate that the system volume variation was not periodic:

$$y = 61.582x^4 - 3495.8x^3 + 69262x^2 - 551159x + 2*10^6 \qquad R = 0.852 \quad p < 0.001$$

where y is the system volume, and
x is the time, expressed as the rank of each month in a solar year.

We calculated the derivative of this function and we expressed V_G as follows using Gordon's equation:

$$V_G = \frac{dV_{sys}}{dt} - V_P + V_E + V_{out}$$

In the LOICZ budget method, the salt budget is used to estimate V_X, the volume of sea water exchanged with the marsh ecosystem. In the present study, V_X could not be calculated because, apparently, there is no direct input of saltwater from the sea into the system.

According to the water balance described above, the Torre Guaceto wetland system should be a freshwater marsh, with a negligible salt budget. However, water sampling and analyses demonstrated that the system salinity varied between 5.8 and 13.3 psu (Table 3.5); therefore, a marine input has to occur in the system. We hypothesized that the marine input occurred via groundwater as a saltwater infiltration into the groundwater layer (Figure 3.13), and we verified this assumption through analysis of the groundwater salinity.

Table 3.5. Salinity in the Torre Guaceto wetland. S_{sys} = Salinity of the system; S_{out} = average salinity in the streams; S_G is the salinity estimated for groundwater, S_{sea} = salinity of the adjacent sea.

	Salinity (psu)			
	S_{sys}	S_{out}	S_G	S_{sea}
winter	6.3	5.3	5.6	39.7
spring	5.8	3.3	2.9	38.0
summer	13.3	5.7	2.1	40.0
autumn	12.0	7.0	7.0	40.0
annual	9.4	5.3	4.4	39.4

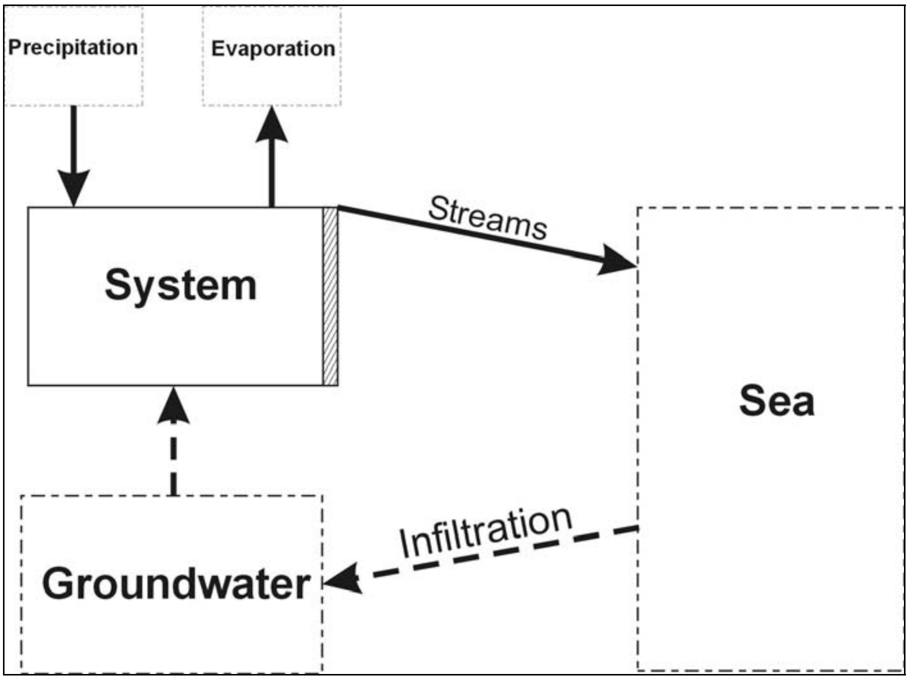

Figure 3.13. Scheme of input and output flows in Torre Guaceto wetland system.

According to Gordon's equations (Gordon *et al.* 1996) it is possible to calculate the groundwater salinity. The salt balance may be described with the formula:

$$\frac{d(V_{sys}S_{sys})}{dt} = V_P S_P + V_G S_G - V_E S_E - V_{out} S_{out}$$

In the model, the salinity associated with V_{out} is the system salinity: in this case, we can provide the flux salinity, S_{out}, calculated as the average salinity of the streams. We considered the salt input and output by precipitation and evaporation to be negligible, thus the salinity of the system is a function of S_G and S_{out} and it is possible to calculate S_G:

$$S_G = \frac{1}{V_G}\left(\frac{dV_{sys}}{dt}S_{sys} + V_{sys}\frac{dS_{sys}}{dt} + V_{out}S_{out}\right)$$

The term $\frac{dS_{sys}}{dt}$ can be considered negligible, compared with the other terms, and the groundwater salinity calculated with the formula ranged between 2.1 and 7.0 psu throughout the year. The minimum value, 2.1 psu, was calculated for the summer period, which was rather unexpected. However, the marine input may actually be reduced during summer since the groundwater layer position and shape do not seem to guarantee a regular groundwater flux into the system during the dry season.

A number of hydro-geological analyses were performed in the winter period in order to verify this hypothesis. The analyses were performed at four study sites and showed a groundwater salinity which ranged between 4.2-5.1 psu in the winter period, very close to the 5.6 psu value calculated with the Gordon's equation. Moreover, the analysis of the elements in the groundwater supported the marine infiltration. In fact, at the study sites the water salinity was due to Cl^-, Na^+ and K^+. By comparing the data with 1950 data on the groundwater it seems that the marine infiltration is increasing in importance in recent years, probably due to the water management in the area.

According to both calculated and observed groundwater salinity, the groundwater input can be divided into two parts: one saline, V_{sea}, of marine origin, and one, $V_{freshwater}$, from the freshwater-bearing stratum present under the area ($V_{freshwater} = V_G - V_{sea}$). Consequently, the groundwater salinity will be a weighted average of the salinity values of the two parts:

$$S_G = \frac{(V_G - V_{sea})S_{freshwater} + V_{sea}S_{sea}}{V_G}$$

This formula permits the calculation of V_{sea}: considering the preceding equation for S_G, we can write (the freshwater salinity is negligible):

$$V_{sea} = \frac{S_G}{S_{sea}}V_G$$

Therefore, marine input into the Torre Guaceto wetland occurs through the groundwater and can be estimated by the LOICZ model. This input cannot be considered as V_{in} in the model, but it actually represents an exchange flux between marine and wetland ecosystems (Figure 3.13).

Finally, an estimate of the wetland system water exchange time is calculable with the formula (similar to the hydraulic residence time equation):

$$\tau = \frac{V_{sys}}{V_{out}}$$

Table 3.6 shows the values of all water fluxes considered in the model.

Table 3.6 Seasonal and annual system volume, water fluxes and turnover time for the Torre Guaceto wetland system.

	V_{sys}	dV_{sys}/dt	V_P	V_E	V_G	$V_{freshwater}$	V_{out}	V_{sea}	τ
	m^3	$m^3\ d^{-1}$	$m^3\ d^{-1}$	$m^3\ d^{-1}$	$m^3\ d^{-1}$	$m^3\ d^{-1}$	$m^3\ d^{-1}$	$m^3\ d^{-1}$	days
winter	4.54E+05	5.76E+02	2.82E+03	1.85E+03	2.15E+04	1.85E+04	2.19E+04	3.01E+03	21
spring	4.51E+05	-3.27E+02	1.85E+03	4.32E+03	2.15E+04	1.99E+04	1.94E+04	1.63E+03	23
summer	2.39E+05	-2.20E+00	7.66E+02	6.59E+03	9.28E+03	8.79E+03	3.46E+03	4.92E+02	69
autumn	3.94E+05	9.59E+02	2.68E+03	3.33E+03	1.72E+04	1.42E+04	1.56E+04	3.02E+03	25
annual	3.90E+05	2.47E+02	2.04E+03	5.32E+03	1.86E+04	1.65E+04	1.51E+04	2.09E+03	26

Budgets of non-conservative materials

The nutrient budget of the wetland system has been calculated for all seasons to produce an annual budget model. The equations used for the calculation of the nitrogen and phosphorus budgets are as follows:

$$V\frac{dY}{dt}+Y\frac{dV}{dt}=\Sigma V_{input}Y_{input}-\Sigma V_{output}Y_{output}+\Delta Y=0$$

where Y refers to the concentration of a nutrient, *ΔY* is the net non-conservative flux, $\Sigma V_{input}Y_{input}=V_PY_P+V_GY_G$ and $\Sigma V_{output}Y_{output}=V_EY_E+V_{out}Y_{out}$. The nutrient concentrations for V_E and V_P are considered zero because data are not available.

Y_{out} is the average of nutrient concentrations in the streams that link the system to the sea; for V_GY_G the nutrient concentration was calculated with a formula derived from the preceding one for groundwater salinity:

$$Y_G=\frac{(V_G-V_{sea})Y_{freshwater}+V_{sea}Y_{sea}}{V_G}$$

The data for the nutrients of the freshwater-bearing stratum, considering sampling stations far from the coast, are obtained from the literature.

We calculated *ΔY* as follows, considering the term $V\frac{dY}{dt}$ negligible:

$$\Delta Y=V\frac{dY}{dt}+Y\frac{dV}{dt}-\Sigma V_{input}Y_{input}+\Sigma V_{output}Y_{output}$$

DIP balance

For the investigated period, the wetland system seems to be a *source* of DIP during the year, although, in area-specific units, *Δ DIP* is very low (Table 3.7).

DIN balance

ΔDIN was negative for the whole period investigated, especially in winter and spring, indicating that the system is a net *sink* for DIN. The *ΔDIN* values are reported in Table 3.8.

Table 3.7 Seasonal and annual values for *ΔDIP* in the Torre Guaceto wetland system.

	ΔDIP	*ΔDIP*
	(mol d^{-1})	(µmol m^{-2} d^{-1})
winter	3.99	3.34
spring	4.80	4.02
summer	0.38	0.32
autumn	0.57	0.48
annual	2.74	2.29

Table 3.8. Seasonal and annual values for *ΔDIN* in the Torre Guaceto wetland system.

	ΔDIN	*ΔDIN*
	(mol d^{-1})	(mmol m^{-2} d^{-1})
winter	-1.04E+04	-8.70
spring	-1.15E+04	-9.63
summer	-6.41E+03	-5.36
autumn	-7.81E+03	-6.54
annual	-1.02E+04	-8.58

Stoichiometric calculations of aspects of net system metabolism

The model assumes that positive *ΔDIP* values are an indication of net organic matter mineralisation and can be directly estimated from the DIP release. The difference between observed and expected *ΔDIN* indicates the balance between nitrogen fixation processes and denitrification (*nfix-denit*).

The expected *ΔDIN* value was calculated by multiplying the observed *ΔDIP* by the N:P ratio of the mineralized organic matter. For the Torre Guaceto wetland, the Redfield C:N:P ratio (106:16:1) was used for the stoichiometric calculations.

The net ecosystem metabolism *NEM* or (*p-r)* was calculated from *ΔDIP* values utilising a C:P ratio of the mineralized matter of 106:1.

During the investigated period *NEM* was negative, indicating a net mineralisation of organic matter and a slightly heterotrophic state, with consequent release of DIP in the water column. As shown in Table 3.9, the calculated values are very low, so it may be asserted that the system is substantially in equilibrium.

The water, salt and nutrient budgets for all seasons are shown in Figures 3.14-3.18.

The Torre Guaceto wetland can be compared with other Apulian wetlands such as Alimini Lake and Acquatina Lake. Alimini Lake is a brackish lake located in southern Apulia. It consists of two basins, Alimini Grande and Alimini Piccolo, connected through a natural channel 1.5 km long. Previous studies have established that the system is a source for DIP in spring and a sink in the other seasons. Since the *ΔDIP* value is 0, nitrogen fixation minus denitrifications (*nfix-denit*) is equal to *ΔDIN*. For all seasons except summer in Alimini Lake, denitrification prevailed over nitrogen fixation. The annual (*nfix-denit*) for Alimini Lake was negative, so the system is net denitrifying (Vadrucci *et al.* 2001). Acquatina Lake, 15 km from Lecce, Apulia, is an artificial basin created in the 1930s. Previous studies have established that the system is a sink for N and P (Cappello *et al.* unpublished data). Systematic investigations carried out in Acquatina Lake confirmed that primary production and the phytoplanktonic biomass of the system are limited by phosphorus. The rate at which nutrients are renewed in the water column suggested meso-oligotrophic conditions for the system (Vadrucci *et al.* 1995, Vadrucci *et al.* 1996).

Because of its low anthropogenic impact, the Torre Guaceto wetland system seems to be very similar to these other Apulian systems.

Table 3.9. Seasonal and annual values for NEM. DIN_{exp} and (*nfix-denit*). (C:N:P =106:16:1)

	(p-r)	DIN_{exp}	(*nfix-denit*)
	(mmol m^{-2} d^{-1})		
winter	-0.35	0.05	-8.75
spring	-0.43	0.06	-9.70
summer	-0.03	0.01	-5.37
autumn	-0.05	0.01	-6.55
annual	-0.24	0.04	-8.62

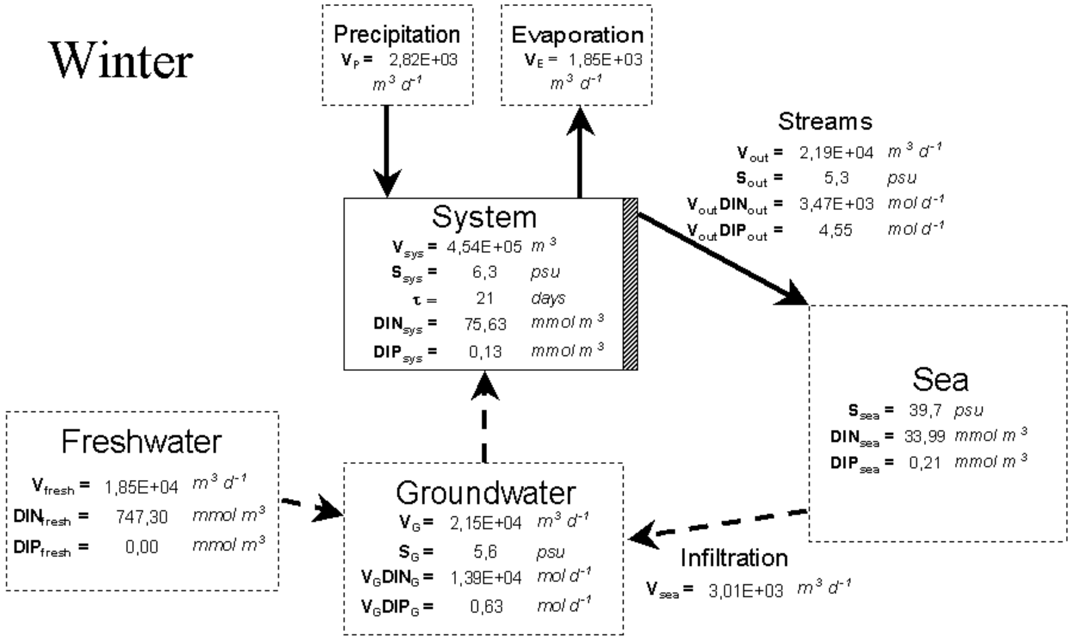

Figure 3.14. Steady-state water, salt and non-conservative (phosphorus and nitrogen) budget for winter in the Torre Guaceto wetland system.

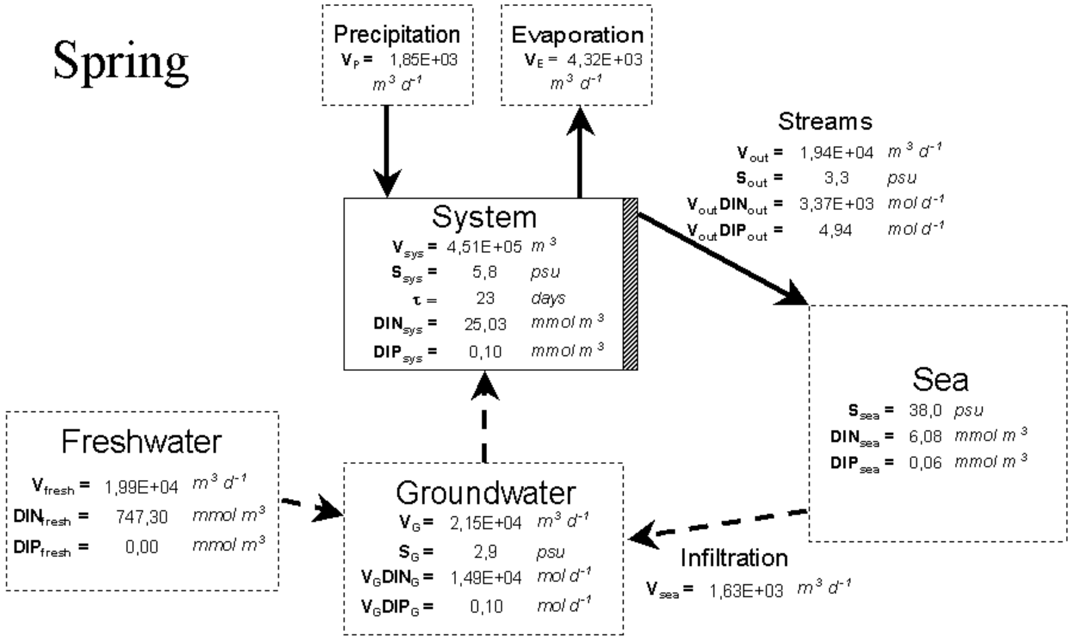

Figure 3.15. Steady-state water, salt and non-conservative (phosphorus and nitrogen) budget for spring in the Torre Guaceto wetland system.

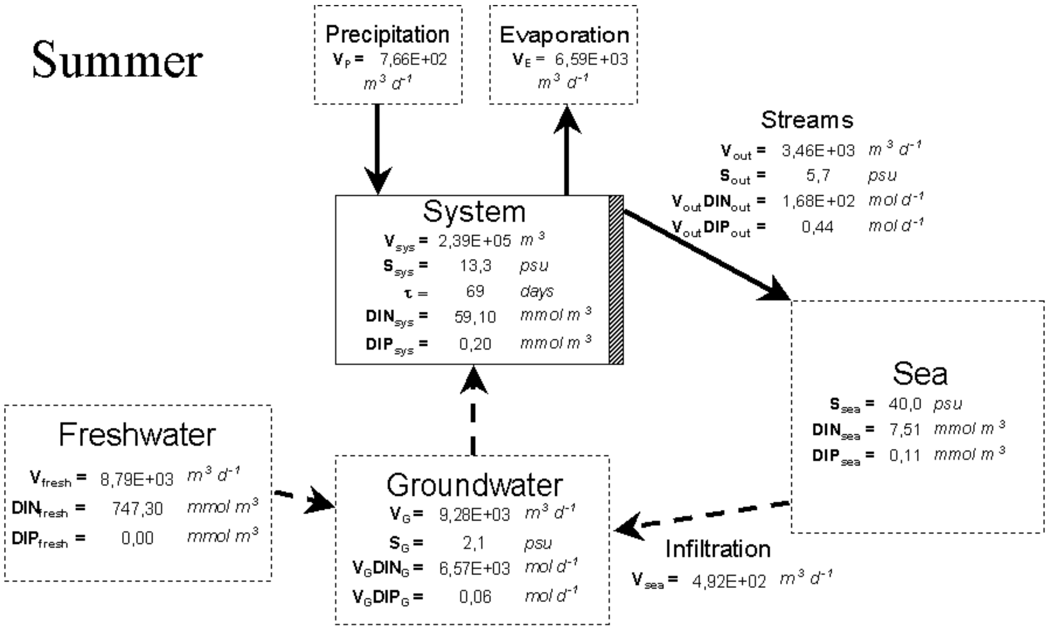

Figure 3.16. Steady-state water, salt and non-conservative (phosphorus and nitrogen) budget for summer in the Torre Guaceto wetland system.

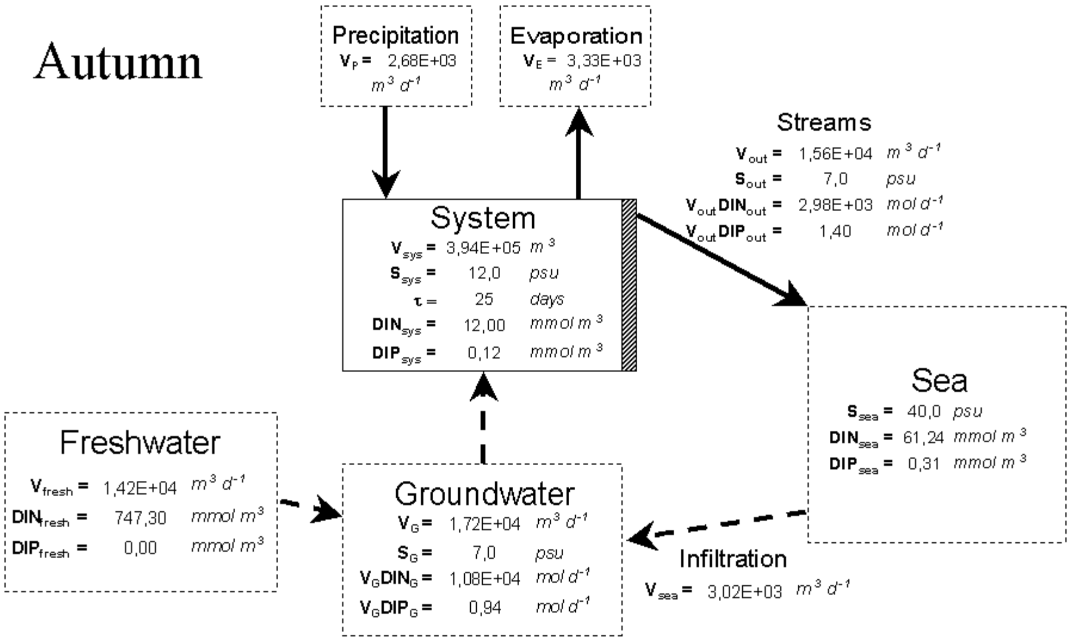

Figure 3.17. Steady-state water, salt and non-conservative (phosphorus and nitrogen) budget for autumn in the Torre Guaceto wetland system.

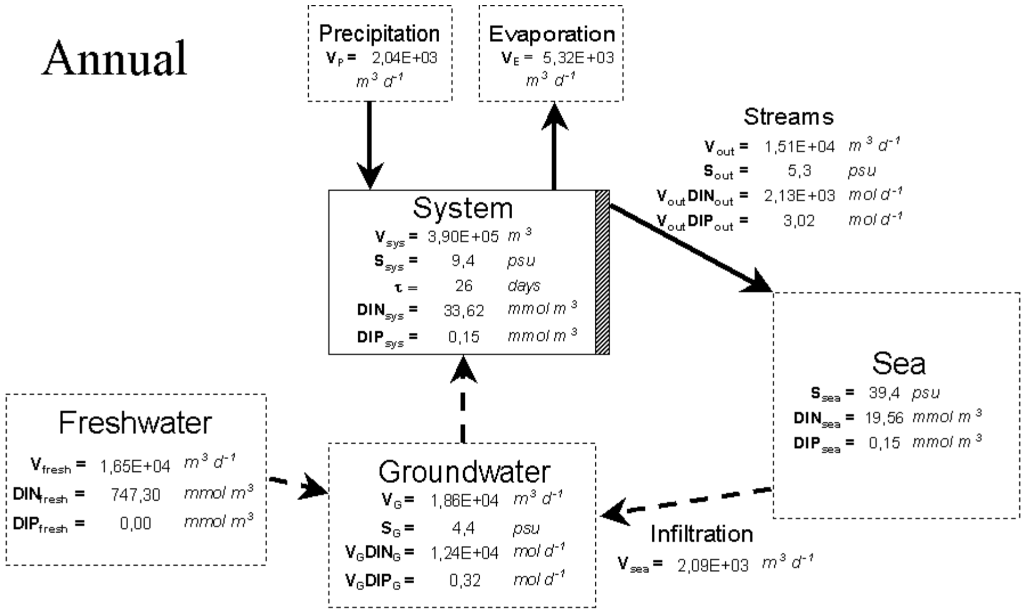

Figure 3.18. Steady-state water, salt and non-conservative (phosphorus and nitrogen) annual budget for the Torre Guaceto wetland system.

Figure 3.19. Torre Guaceto Nature Reserve.

Figure 3.20. Torre Guaceto wetland system.

Figure 3.21. View of Torre Guaceto.

3.4 Torre Guaceto Bay

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Summary

We applied the one-box LOICZ Biogeochemical Budget Model to a marine area in the Torre Guaceto Nature Reserve, comparing a version of Knudsen's method (Gordon *et al*. 1996) with Yanagi's method for V_X estimation (Yanagi 2000b). The reserve is located in the Apulia region of Italy, on the Adriatic coast, about 15 km north of the city of Brindisi. The region is characterized by mediterranean-type climatic variations, with meteorologically stable summers and unstable winters. The data reported refer to a marine area of 1.44 km^2 which was studied for a period of about two years, from summer 2001 to spring 2003.

The two calculated values of V_X differ by about an order of magnitude, which affects the ecological characteristics estimated with the LOICZ method. The estimated water turnover time in the system varies from 11 hours using Yanagi's method to 83 hours calculated according to LOICZ guidelines. Neither methods operates properly in the area. The V_X estimation through the salinity budget (Gordon *et al.* 1996) gives reasonable results but is based on minimal differences of salinity between the system and the open sea (0.6 psu) and can be affected by high uncertainty. While the result obtained with Yanagi's (2000b) application do not seem reasonable (V_X is ten times bigger and τ is only 11 hours), this may be due to the W/H ratio which is borderline between wide-and-shallow and deep-and-narrow systems and to the relatively small volume of the system. Further investigations are needed to estimate V_X fluxes in this system. Discussion about this application is welcomed (email: loiczmail@virgilio.it).

According to the *ΔDIP* and *ΔDIN* values, the system acts as a source for DIP and DIN with the first approach, and as a sink for DIP and a source for DIN with the second, implying respectively a negative and a positive NEM value; denitrification processes always prevail.

Values of NEM and *(nfix-denit*) obtained with Yanagi's estimation of V_X are not reasonable for a system such as this one.

Study area description

The Torre Guaceto Nature Reserve (40.71°N-17.80°E) is located in the Apulia region, on the Adriatic coast of Italy, about 15 km north of the city of Brindisi and consists of a wetland and a marine area. The system is located in the Canale Reale watershed (surface area 383 km^2). Within the marine part of the reserve, an area of about 1.44 km^2 with a total volume of 5.73x10^6 m^3 receives freshwater from the Canale Reale, which is affected by wastewater at least in some seasons; it also receives brackish water from the outflow of the brackish ecosystem and from groundwater. The area consists of a sandy, shallow bay protected to the north by a promontory and to the east by two islets.

For the analysis of the hydrological and nutrient budget of the Torre Guaceto Bay ecosystem, an experimental design was set up with eight sampling stations (Figure 3.22), with stations sited at the mouth of each of four streams flowing into the marine reserve, two in the bay and two in open sea. At all the stations water sampling was organized on a seasonal basis and from every sample the following parameters were determined: salinity, temperature, nitrate, nitrite, ammonium, phosphorus and chlorophyll (chl_*a*). Freshwater input to the bay was also evaluated by measuring the discharge of every stream. All the parameters were determined using standard procedures. Dissolved phosphorus absorbance was measured with a 10 cm cell, in order to increase the standard sensitivity of the method, as phosphorus concentration was very low. Temperature of the atmosphere and precipitation were obtained from the meteorological station present in the area and from historical data. Evaporation was calculated using Hargreaves' equation (Hargreaves 1975). Data of temperature and precipitation presented here are averages from twenty and forty years data sets, respectively.

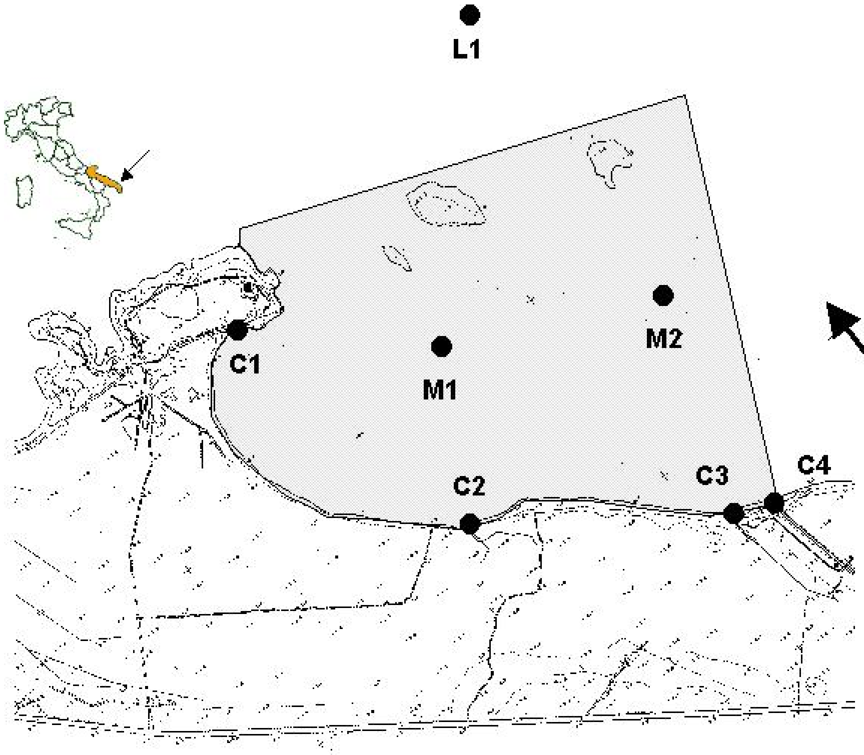

Figure 3.22. Location of Torre Guaceto Bay and the sampling stations. The grey shaded part is the area considered in this study.

The analyses performed have underlined the existence of significant differences between the delimited marine area and the open sea, mostly for DIN (Table 3.10, Figure 3.23), which is always significantly higher in the bay than in the open sea (t Student test = 2,99 df = 91 p<0,05), as a result of the high DIN input from the freshwater and brackish channels.

Table 3.10. Seasonal values of DIN and DIP for the channel (C, in mol d^{-1}), the bay (M, in µM) and the adjacent sea (L, in µM).

		DIN	DIP	
Winter	**C**	6193	202	mol d^{-1}
	M	64.37	0.81	µM
	L	23.48	0.14	µM
Spring	**C**	6205	331	mol d^{-1}
	M	26.25	0.03	µM
	L	11.73	0.05	µM
Summer	**C**	1394	37	mol d^{-1}
	M	28.07	0.06	µM
	L	4.98	0.11	µM
Autumn	**C**	5508	446	mol d^{-1}
	M	60.65	0.04	µM
	L	33.65	0.17	µM

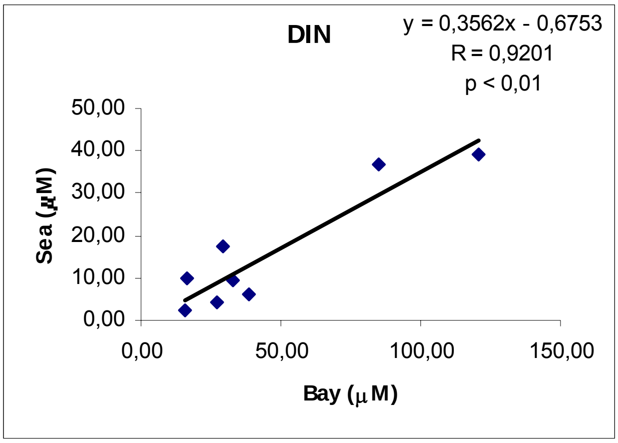

Figure 3.23. Relationship between bay and open sea DIN concentrations.

Water and salt balance

To estimate the water and salt balance, the Gordon *et al.* (1996) equations were used:

$$\frac{dV_{sys}}{dt} = V_Q + V_P + V_G + V_O - V_E + V_R$$

The system is considered in steady-state and the volume (V_{sys}) is approximately constant. V_Q is the water flux input to the system from four channels flowing out into the bay. V_P is the direct precipitation, with a mean value of 600 mm per year. V_E is the output caused by the evaporation of water, calculated using Hargreaves' equation. V_O represents water input not included in the preceding definitions, considered negligible. V_G is the groundwater input, which is not considered in this work although other investigations have shown a considerable exchange flux between the groundwater layer and the marine area (Pomes et al., in this volume).

V_R is the residual flux of the system, directed from the bay to the open sea or *vice versa*, required to balance water input and output. The salinity of this flux, S_R, is the average between the salinity of the open sea, S_{sea}, and the salinity of the system, S_{sys}. Annual values for the system are given in Table 3.11.

Table 3.11. Annual values for precipitation, evaporation and freshwater inputs in Torre Guaceto Bay.

V_Q	V_P	V_E	V_R
10^3 m^{3}d^{-1}	10^3 m^{3}d^{-1}	10^3 m^{3}d^{-1}	10^3 m^{3}d^{-1}
28.7	1.9	-3.8	-26.8

Finally, V_X, the exchange flux between the bay and the open sea, is estimated with the salt budget:

$$V_X S_{sea} + V_Q S_Q + V_R S_R - V_X S_{sys} = 0$$

$$V_X = \frac{V_R S_R + V_Q S_Q}{S_{sys} - S_{sea}}$$

where every flux is multiplied for its salinity (S_Q is the mean salinity of the channels input).

An estimate of the water residence time, τ, is given by:

$$\tau = \frac{V_{sys}}{V_X + |V_R|}$$

The estimated V_X flux, water time residence and the salinities used for the calculations are given in Table 3.12 and Figure 3.24.

Table 3.12. Annual exchange flux (V_X), residence time (τ) and salinity (S) of Torre Guaceto Bay and the open sea according to LOICZ guidelines based on the salinity budget.

S_Q	S_{sys}	S_{sea}	V_X	τ
psu	psu	psu	$10^6 m^3 d^{-1}$	h
3.86	38.09	38.65	1.64	83

The reduced difference between system and open sea salinities (less than 1 psu) is a weakness of the application of the Gordon guidelines (Gordon et al. 1996), in that V_X is estimated without sufficient precision. Therefore, we also used an alternative method to evaluate the exchange flux, described by Yanagi (Yanagi 2000b). His formula expresses the exchange flux V_X across the open boundary of the system as a function of the magnitude of the horizontal dispersion coefficient D_H ($m^2 d^{-1}$), estimated by the following expression (Taylor 1953), which is applicable to wide and shallow systems:

$$D_H = \frac{1}{120}\left(\frac{W^4}{K_h}\right)\left(\frac{U}{W}\right)^2 \qquad with \quad \frac{L}{W} < 2 \quad \frac{W}{H} > 500$$

or, for deep and narrow systems:

$$D_H = \frac{1}{120}\left(\frac{H^4}{K_v}\right)\left(\frac{U}{H}\right)^2 \qquad with \quad \frac{L}{W} > 2 \quad \frac{W}{H} < 500$$

where:
W (in m) is the length of the open boundary between the bay and the open sea;
L (in m) is the distance from the center of the system to its mouth;
H (in m) is the average depth of the open boundary of the system;
K_h (in $m^2 d^{-1}$) is the horizontal diffusivity;
K_v (in $m^2 d^{-1}$) is the vertical diffusivity;
U (in $m d^{-1}$) is the residual flow velocity at the surface layer of the open boundary.

The marine part of the Torre Guaceto Nature Reserve is a shallow and wide bay, so that the first of the two equations is the appropriate one to use, although the ratio W/H is technically below the specified limit of 500 recommended for shallow and wide systems. K_h can be determined using Okubo's equation (Okubo 1971):

$$K_h = 18W^{1.15}$$

while U, measured in Torre Guaceto Bay (Petretti 1988), is 0.039 m s^{-1}.

The resulting expression for V_X is a function of the D_H coefficient, the area of the open boundary (A, in m^2) and the distance between the geographic centre of the system and the observation point for the open sea salinity (F, in m):

$$V_X = D_H \frac{A}{F} \quad with \quad A = W * H$$

The calculated value of V_X (Table3.13) is about $1.2*10^7$ m^3d^{-1}; this implies a residence time for the system water volume is less than a day, about 11 hours.

Table 3.13. Data for the calculation of V_X and residence time for Torre Guaceto Bay using Yanagi's method (Yanagi 2000b).

Variable/system	Torre Guaceto
L (m)	600
W (m)	1900
H (m)	4
A (m^2)	7600
L/W	0.3
W/H	475
Classification	Wide and shallow
U ($m\ s^{-1}$)	0.039 (Petretti 1988)
K_v, K_h ($m^2\ d^{-1}$)	$K_h = 106x10^3$
D_H ($m^2\ d^{-1}$)	3.2×10^6
F (m)	2000
V_X ($m^3\ d^{-1}$) - Yanagi	$1.22x10^7$
V_X ($m^3\ d^{-1}$) - Gordon	$1.64x10^6$
Residence time τ (h)	11

Budgets of non-conservative materials

With these results, we proceeded to evaluating the non conservative budget, following Gordon (Gordon *et al.* 1996), from the 2001 summer to 2003 spring:

$$\Delta Y = -\left(V_Q Y_Q + V_P Y_P + V_G Y_G + V_O Y_O + V_E Y_E + V_R Y_R + V_X \left(Y_{sea} + Y_{sys}\right)\right)$$

where Y is the nutrient concentration of DIN and DIP and *ΔY* represents the non conservative behaviour of the nutrients (Table 3.14). Y_P and Y_E, the nutrient concentration of the precipitation and evaporation, are considered negligible.

Table 3.14. Annual values of DIN, DIP and *ΔDIP, ΔDIN* for Torre Guaceto Bay using Yanagi's estimate of V_X. values with (*) refer to standard LOICZ calculation of Vx based on salinity budget.

DIP_Q	DIP_{sys}	DIP_{sea}	V_QDIP_Q	V_RDIP_R	V_XDIP_X	*ΔDIP*	*ΔDIP*
mmol m^{-3}	mmol m^{-3}	mmol m^{-3}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mmol $m^{-2}\ d^{-1}$
6.72	0.23	0.12	193	-5	-1342	1154	0,80
					-180*	-8*	-0.006*

DIN_Q	DIN_{sys}	DIN_{sea}	V_QDIN_Q	V_RDIN_R	V_XDIN_X	*ΔDIN*	*ΔDIN*
mmol m^{-3}	mmol m^{-3}	mmol m^{-3}	mol d^{-1}	mol d^{-1}	10^3 mol d^{-1}	10^3 mol d^{-1}	mmol $m^{-2}\ d^{-1}$
168.31	44.84	18.46	4830	-848	-322	317	221
					-43*	39*	27*

Stoichiometric calculations of aspects of net system metabolism

For the estimates of *NEM* and (*nfix–denit)* we considered the Redfield ratio 106:16:1 suitable for phytoplankton (Table 3.15). The values obtained with the two approaches result to be different: the system seems to be highly heterotrophic with the Yanagi estimation of V_X (-85 mmol $m^{-2}\ d^{-1}$ which is too high for a system like Torre Guaceto Bay), while, following Gordon's guidelines, it is slightly autotrophic (0.6 mmol m^{-2} d^{-1}). Nitrogen fixation processes always prevail over denitrification but with values which are not realistic.

Table 3.15. Differences between Yanagi and Gordon estimations of net ecosystem metabolism and nitrogen fixation processes in Torre Guaceto Bay.

	NEM (*p-r*)	***ΔDIN*$_{exp}$**	***(nfix-denit)***
	mmol C m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}
Yanagi	-85	13	208
Gordon	0.6	-0.1	34.5

The small volume of the marine area relative to the area of the open boundary represents a major problem with Yanagi's estimation of V_X in Torre Guaceto Bay, even when compared with other systems to which the method was applied, such as Dokai Bay (Yanagi 2000a, 2000b), Hakata Bay (Yanagi 1999, 2000b) and Sacca di Goro Lagoon (Viaroli *et al.* 2001b); thus, the higher water exchange flux is likely to be due to a high efficiency in water circulation between the bay and the open sea.

Acknowledgements
We thank G. Giordani and D. Swaney for their useful comments and suggestions on a previous draft of this paper.

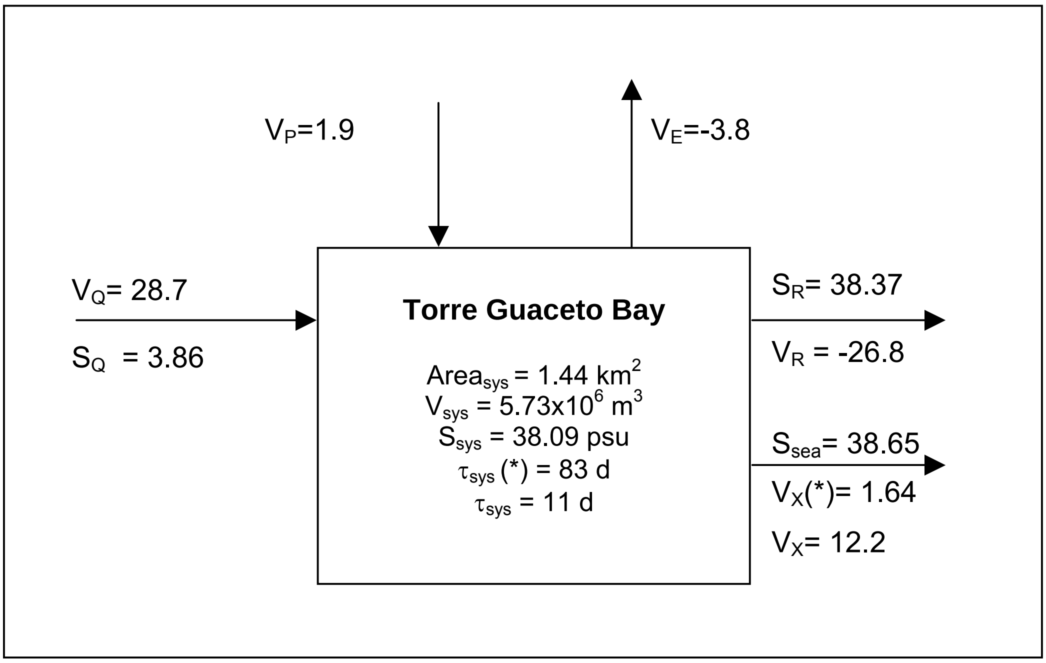

Figure 3.24. Water and salt budgets for Torre Guaceto Bay. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in PSU. Values with (*) refer to standard LOICZ calculation based on salinity budget.

3.5 Acquatina Lake

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Summary

Here, we report a study on the water, salt and nutrient balance of a saltmarsh lake: Acquatina Lake, with a view to the application and implementation of the LOICZ Biogeochemical Model. Acquatina Lake is located in the South Apulia region of Italy on the Adriatic Sea shore and is a small, meso-oligotrophic, artificial basin used for scientific experiments and aquaculture. In the lake, two areas with different salinity have been identified. The main freshwater inputs are from precipitation and from a diversion of the Giammatteo Canal; the outputs from the system are a canal subject to tidal influence and fairly intense evaporation. A LOICZ budget was done on data collected from literature and on unpublished data collected in 1995.

Study area description

The Acquatina Lake area (Figure 3.25) is a coastal marsh lake located on the Adriatic Sea shore of the Salento Peninsula (40.44°N, 18.24°E). It is connected to the sea by a channel 15 m wide and 400 m long. The principal freshwater inputs are a lateral ramification of the Giammatteo Canal (on the northern boundary of the lake) and rainfall. Long ago, the area was part of a system of marsh areas periodically flooded by the sea. In the 1930s, during reclamation works in the coastal marsh areas, the perimeter was embanked with brickwork which is still present. Underlying the region is a thick sedimentary carbonaceous layer of the Jurassic-Cretaceous Age (200-65 million years bp), covered by quaternary sediments (2 million years bp) known as the *Calcareniti del Salento* formation.

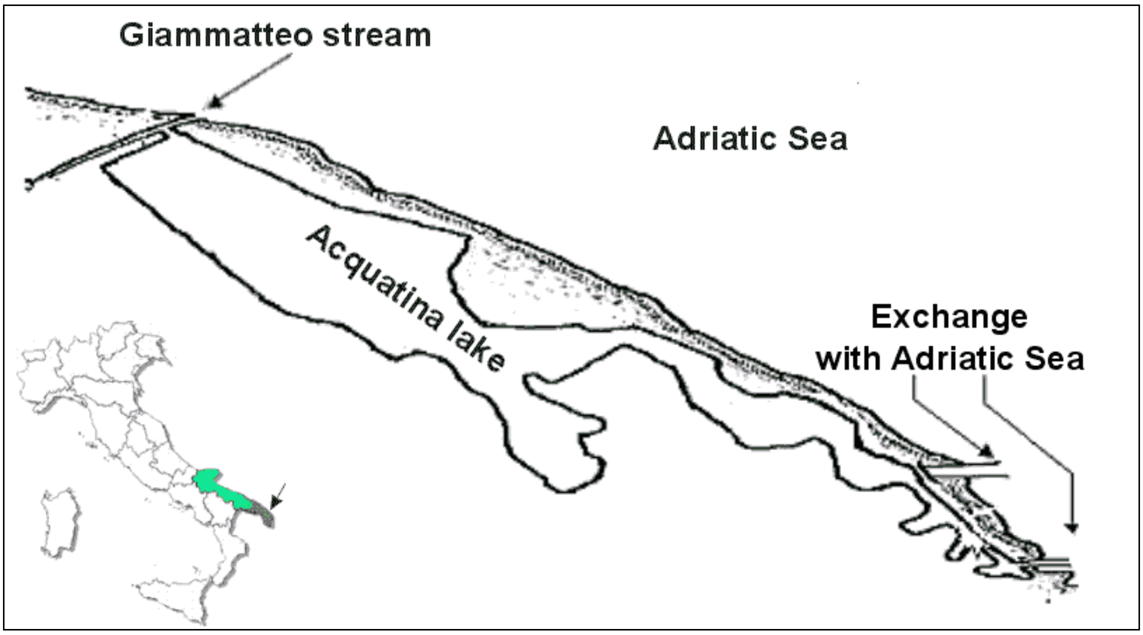

Figure 3.25. Location and map of Acquatina Lake.

The lake is about 2 km long with a surface area of about 0.45 km^2. The maximum depth of the water barely exceeds 2 m, with a mean value of 1 m. Tidal variation of sea level does not usually exceed 35 cm. The Giammatteo canal is fed by precipitation and groundwater. Input from the canal is highly variable, depending on seasonal rainfall and agricultural use, which can be intensive. The Acquatina area is characterized by a superficial saltwater-bearing stratum, whose relatively low depth causes its emergence in depressed areas.

Water and salt balance

The lake comprises two large areas with different salinity, between about 15 and 35 psu (Scalzo *et al.* 1994; Calò *et al.* 1996). The area of lowest salinity is near the Giammatteo canal, while the most saline water is close to the sea connection. Communication with the sea allows the lake to receive seawater twice a day with the incoming tides and to drain water to the sea during the outgoing tide phases. Rainfall is about 700 mm per year (data from meteorological station of Lecce, Aeronautica Militare), and is particularly low in summer. Sudden storms may cause a rise in the mean level of the water and, when this happens during high tide, the water in the lake may rise over its embankments.

The mean annual atmospheric temperature is about 16°C (Calò *et al.* 1996). Acquatina Lake is subject to intense evaporation, especially in the summer period.

To estimate the water and salt balance, the Gordon *et al.* (1996) equations were used:
In Acquatina V_Q. is represented by the deviation from the Giammatteo canal that flows into the lake(Vadrucci, unpublished data), V_E is calculated using Hargreaves equation and V_O and V_G are considered negligible;

The estimated values for V_R indicates that the system exports water to the sea during the whole of the investigated period, with minimum values in summer (8700 m^3 d^{-1}). In this season also the exchange flux (V_X) with the sea is scarce (47900 m^3 d^{-1}) and the water turnover time is long (8 days) (Table 3.16). The annual water and salt budget is represented in Figure 3.26.

Table 3.16 Water and salt balance of Acquatina Lake. *Annual values are calculated as the time-weighted average of seasonal values.

	V_Q	V_P	V_E	V_R	S_Q	S_{sys}	S_{sea}	V_X	τ
	10^3 m^3d^{-1}	10^3 m^3d^{-1}	10^3 m^3d^{-1}	10^3 m^3d^{-1}	psu	psu	psu	10^3 m^3d^{-1}	d
Winter	76.6	0.9	-0.8	-76.7	2.10	23.44	37.43	155.4	2
Spring	44.8	0.7	-2.1	-43.4	2.05	27.99	38.18	131.9	3
Summer	11.7	0.4	-3.4	-8.7	1.59	32.09	38.06	47.9	8
Autumn	39.7	1.3	-1.7	-39.3	2.02	29.27	37.81	144.8	2
Annual*	*43.2*	*0.8*	*-2.0*	*-42.0*	*1.94*	*28.20*	*37.87*	*119.7*	*3*

Budgets of non-conservative materials

The nutrient concentrations in the flows due to direct precipitation and evaporation are considered zero. The nutrient data for the sea are taken from Fiocca *et al.* 1998.

DIP balance
Comparison of these results with those of previous studies (Vadrucci *et al.* 1995, Calò *et al.* 1996, Giacobbe *et al.* 1996; Vadrucci *et al.* 1996) carried out on Acquatina Lake have confirmed that the primary production and phytoplankton biomass of the system are limited by the availability of phosphorus (Table 3.17, Figure 3.27) and that the system seems to be meso-oligotrophic. The largest

DIP inputs were observed in winter and spring, due to freshwater fluxes. During the period studied, Acquatina Lake was a DIP sink, particularly during autumn and winter. The results obtained are likely to be due to primary production in autumn, while in winter, DIP loss processes were not related to algal metabolism, but probably to absorption on decaying detritus (Vadrucci *et al.* 1996).

Table 3.17. DIP budget of Acquatina Lake.

Season	DIP_Q	DIP_{sys}	DIP_{sea}	V_QDIP_Q	V_RDIP_R	V_XDIP_X	ΔDIP	ΔDIP
	mmol m^{-3}	mmol m^{-3}	Mmol m^{-3}	Mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mmol m^{-2} d^{-1}
Winter	0.22	0.06	0.09	17	-6	5	-16	-0.035
Spring	0.34	0.13	0.05	15	-4	-10	-1	-0.002
Summer	0.25	0.05	0.05	3	0	0	-2	-0.005
Autumn	0.24	0.08	0.18	10	-5	14	-19	-0.041
Annual	*0.26*	*0.08*	*0.09*	*11*	*-4*	*2*	*-9*	*-0.021*

DIN balance

The overall DIN input into Acquatina Lake was about two orders of magnitude larger than the DIP input. Nitrate was the dominant form of nitrogen in all seasons. *ΔDIN* values show that the area under study was, overall, a DIN sink on an annual scale. *ΔDIN* values were lower during summer than in the other seasonal periods (Table 3.18, Figure 3.28), probably due to the summer decrease of freshwater inputs to the lake.

Table 3.18. DIN budget of Acquatina Lake.

Season	DIN_Q	DIN_{sys}	DIN_{sea}	V_QDIN_Q	V_RDIN_R	V_XDIN_X	ΔDIN	ΔDIN
	mmol m^{-3}	mmol m^{-3}	mmol m^{-3}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mmol m^{-2} d^{-1}
Winter	57.33	19.87	2.85	4392	-871	-2644	-877	-1.95
Spring	81.93	12.36	1.78	3673	-307	-1396	-1971	-4.38
Summer	64.54	13.32	1.32	754	-64	-575	-116	-0.26
Autumn	64.33	15.82	2.33	2552	-356	-1953	-243	-0.54
Annual	*67.09*	*15.32*	*2.07*	*2835*	*-397*	*-1636*	*-802*	*-1.78*

Stoichiometric calculations of aspects of net system metabolism

The difference between the observed and expected *ΔDIN* was considered to be the net ecosystem nitrogen fixation minus denitrification *(nfix-denit)*. The expected *ΔDIN* value was calculated by multiplying the observed *ΔDIP* by the N:P ratio of the mineralized organic matter. The Redfield C:N:P ratio (106:16:1) was used for the stoichiometric calculations.

The net ecosystem metabolism, NEM or (*p-r*), is always positive (Table 3.19), indicating a greater productivity in winter and autumn than in spring and summer, when the values are lower than 1 mmol C m^{-2} d^{-1}.

In the area the annual value for (*nfix-denit*) was -1.45 mmol m^{-2} d^{-1}, indicating that denitrification processes dominate over nitrogen fixation inputs. The higher value of (*nfix-denit*) observed in spring seems to be related to a decrease of oxygen concentration linked to an increase of respiration processes as demonstrated also by the spring NEM value, that was approximately zero, and the higher spring DIP value observed in the system with respect to the other seasons.

Table 3.19. Values of net ecosystem metabolism (*p-r*), *ΔDIN*$_{exp}$ and (*nfix-denit*).

	NEM (*p-r*)	***ΔDIN***$_{exp}$	**(*nfix-denit*)**
	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}
Winter	3.8	-0.57	-1.38
Spring	0.2	-0.03	-4.35
Summer	0.5	-0.07	-0.18
Autumn	4.4	-0.66	0.12
Annual	*2.2*	*-0.33*	*-1.45*

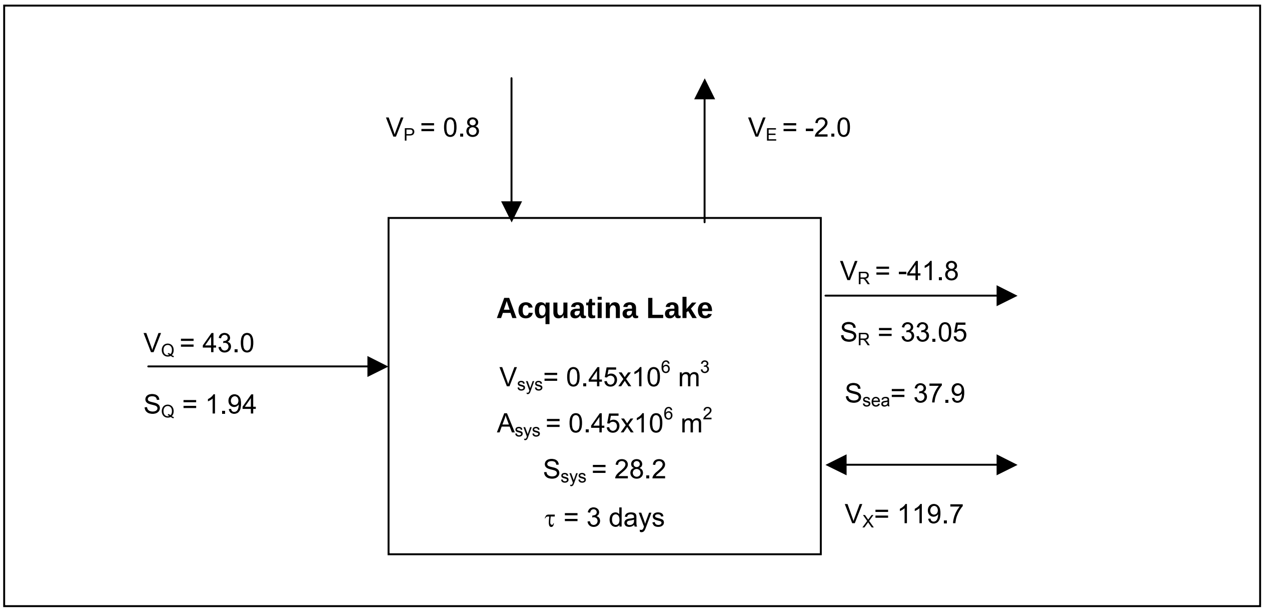

Figure 3.26. Water and salt budgets for Acquatina Lake. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in PSU. Annual values are calculated as the time-weighted average of seasonal values.

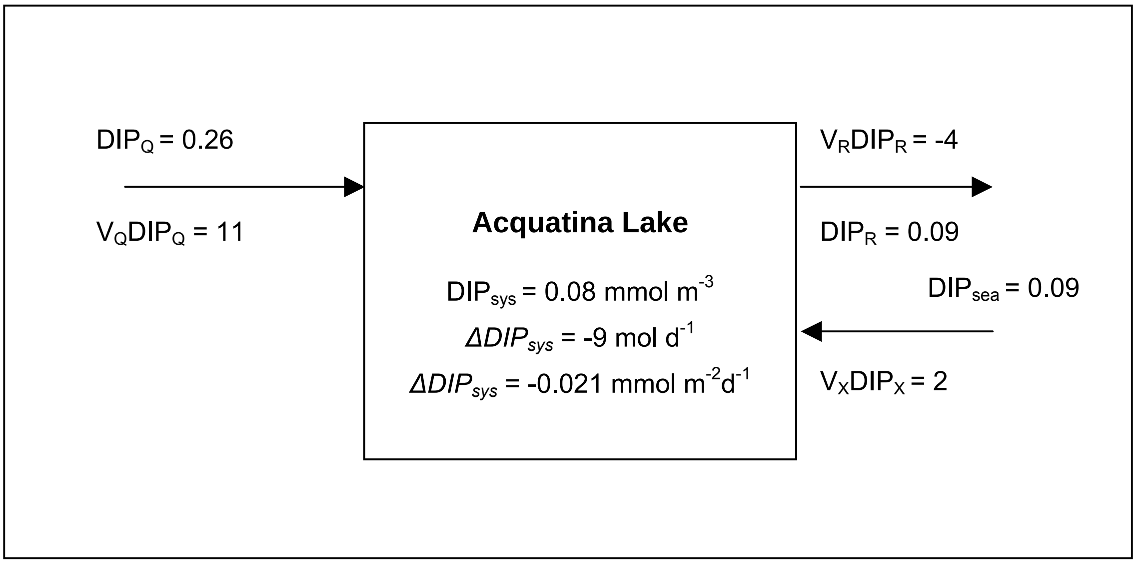

Figure 3.27. **DIP budget for Acquatina Lake.** Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

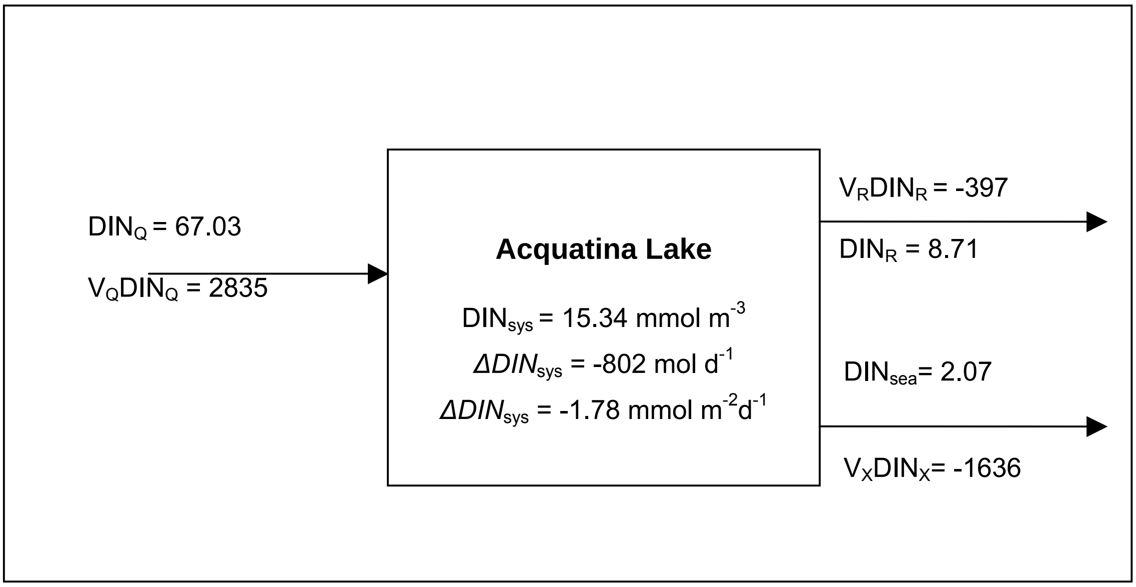

Figure 3.28. DIN budget for Acquatina Lake. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

4 COASTAL SYSTEMS OF SICILY AND SARDINIA

4.1 Rada di Augusta, eastern coast of Sicily

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Study area description

The Rada di Augusta is a wide natural bay which occupies about 30 km of the eastern coast of Sicily. The bay (37.21°N, 15.23°E) is located between Cape Santa Croce and Peninsula Magnisi. In recent years, the bay has been almost completely enclosed with breakwaters to form a vast harbour basin communicating with the sea through two narrow inlets (east and south, Figure 4.1). The bay is about 6.4 km long and 10.25 km wide. The surface area is 23.5 km^2 and the total volume is approximately 3.5×10^8 m^3.

As a coastal marine environment with a low water turnover, and with intensive human activities in the area, the Rada di Augusta is a complex environmental system with a very high state of degradation which can be ascribed primarily to heavy industrialization and dense urbanization (Figure 4.2).

The main sources of pollution are hydrocarbons deriving from the petrochemical refining plants (Sciacca and Fallico 1978; De Domenico *et al*. 1994) and urban wastewaters (70,000 inhabitants) reaching the bay after only a partial treatment, which lead to a semipermanent condition of eutrophication. High inputs of N and P come also from industrial (fertilizer production) and agricultural activities (Azzaro 1993). The basin has been studied for several years because of various eutrophication phenomena (Andreoli *et al*. 1987; Decembrini *et al*. 1993; Magazzù *et al*. 1995).

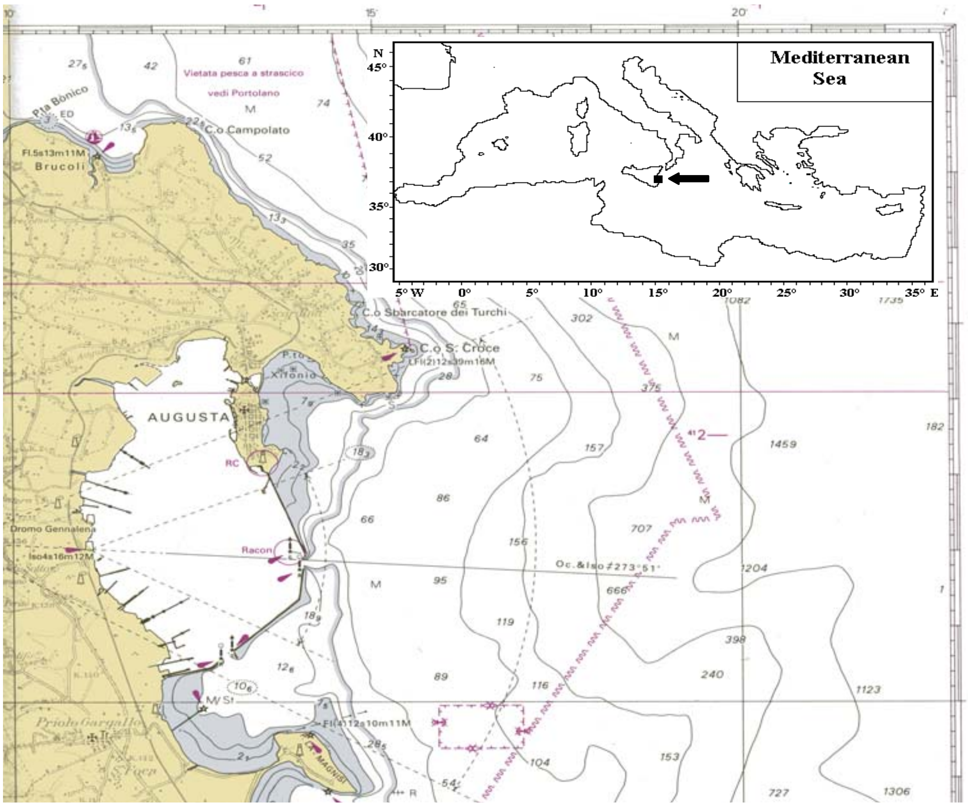

Figure 4.1. Map showing the location of the Rada di Augusta and the area studied.

In this paper a budgetary analysis was conducted using the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al*. 1996). Data were collected from November 1989 to October 1990.

Water and salt balance

The water budget for Rada di Augusta was calculated for three periods: November-March, April-June and July-October and for the whole year, using a single-box single-layer model. In the Rada di Augusta, the major freshwater inputs are civil, agricultural and industrial discharges (V_O) and direct precipitation (V_P).

Riverine (V_Q), underground (V_G) and other (V_O) inputs have been inferred from a Talassographic Report (1992). Precipitation data (V_P) were obtained from a Meteorological Station and evaporation (V_E) was calculated using the Hargreaves' equation (Hargreaves 1975).

In the study area, direct rainfall was 450 mm. The highest values were registered in the first period (November-March), the lowest in the third period (July-October). Evaporation exceeded precipitation in the second and third periods, while in the first, they were in balance. The water and salt budgets during the three periods are shown in Table 4.1 and Figure 4.3.

A net export of water from Rada di Augusta to the sea, indicated by negative residual flows (V_R), was obtained for the three periods, with highest values during the first period. The V_X values, which indicate the mixing volume between the system and the sea, also showed a maximum in the first period.

The estimate of water residence time (τ) was four months for the first period (winter) and six months for the second one (spring). During summer (the third period) the estimated exchange time was about twice that of the spring period. The annual average estimated water residence time was longer than 4 months (Figure 4.2).

Table 4.1. Water fluxes, salinity and water exchange time (τ) in the Rada di Augusta.
*Annual values are calculated as the time-weighted average of seasonal values

Period	**V_Q**	**V_G**	**V_P**	**V_O**	**V_E**	**V_R**	**S_{syst}**	**S_{sea}**	V_X	τ
	(10^3 m^3 d^{-1})						(psu)		(10^3 m^3 d^{-1})	(days)
Nov-Mar	6.0	5.0	40.5	100.0	-44.2	-107.3	36.65	38.07	2823.0	119
Apr-Jun	2.4	3.0	18.5	90.0	-105.0	-8.9	38.03	38.20	1995.7	175
Jul-Oct	1.0	0.5	28.8	60.0	-86.9	-3.4	38.03	38.15	1079.2	323
Annual *	3.4	3.0	31.1	84.0	-73.7	-47.8	37.46	38.13	2029.1	169

Budgets of non-conservative materials

The data considered refer to twenty-five stations located in the Rada di Augusta and to ten stations located in the open sea, which were sampled monthly from March 1989 until March 1990. The variations of nutrient concentrations during the three periods are reported in Tables 4.2 and 4.3. The concentrations of DIP_Q, DIP_G, DIP_O, DIN_Q, DIN_G and DIP_O have been calculated from data obtained from the Talassographic Report (1992).

Table 4.2. DIP concentrations (in mmol m^{-3}) in the Rada di Augusta.
*Annual values are calculated as the time-weighted average of seasonal values.

Period	DIP_Q	DIP_G	DIP_O	DIP_{syst}	DIP_{sea}
Nov.-Mar.	0.50	0.50	3.00	0.34	0.09
Apr-Jun	0.50	0.50	3.00	0.29	0.33
Jul-Oct	0.50	0.50	3.00	0.04	0.19
Annual*	0.50	0.50	3.00	0.23	0.18

Table 4.3. DIN concentration (in mmol m^{-3}) in the Rada di Augusta.
*Annual values are calculated as the time-weighted average of seasonal values.

Period	DIN_Q	DIN_G	DIN_O	DIN_{syst}	DIN_{sea}
Nov.-Mar.	6.00	6.00	700	5.59	1.33
Apr-Jun	6.00	6.00	700	2.37	1.80
Jul-Oct	6.00	6.00	700	2.52	2.00
*Annual**	6.00	6.00	700	3.75	1.67

DIP balance
Data for the DIP budgets in the three examined periods are reported in Table 4.4 and the annual budget in Figure 4.4. The system acted as a source for the first period *(ΔDIP* was positive) and as a sink in the same range of values in the remaining periods. On an annual basis, the system can be considered as a sink of DIP (Figure 4.3).

Table 4.4. DIP budgets for the Rada di Augusta in 1989-90.
*Annual values are calculated as the time-weighted average of seasonal values.

Period	V_QDIP_Q	V_GDIP_G	V_ODIP_O	V_RDIP_R	V_XDIP_X	*ΔDIP*	
	(mol d^{-1})					(mol d^{-1})	(µmol m^{-2} d^{-1})
Nov.-Mar.	3.0	2.5	300.0	-23.6	-705.8	423.9	18.04
Apr-Jun	1.2	1.5	270.0	-2.8	79.8	-349.7	-14.88
Jul-Oct	0.5	0.3	180.0	-0.4	161.9	-342.3	-14.57
*Annual**	1.7	1.5	252.1	-10.6	-217.5	-27.2	-1.16

DIN balance
Non-conservative fluxes of DIN (Δ*DIN*) were negative for all of the periods investigated, indicating a dominance of DIN removal processes (mainly assimilation); the system acts therefore as a net sink for DIN. Maximal negative values were measured in the spring period (Table 4.5). The annual DIN budget is shown in Figure 4.5.

Table 4.5. DIN budgets for the Rada di Augusta in 1989-90.
*Annual values are calculated as the time-weighted average of seasonal values.

Period	V_QDIN_Q	V_GDIN_G	V_ODIN_O	V_RDIN_R	V_XDIN_X	*ΔDIN*	
	(mol d^{-1})					(mol d^{-1})	(mmol m^{-2} d^{-1})
Nov.-Mar.	36.0	30.0	70000	-371.3	-12026.0	-57669	-2.45
Apr-Jun	14.4	18.0	63000	-18.6	-1137.5	-61876	-2.63
Jul-Oct	6.0	3.0	42000	-7.7	-561.2	-41440	-1.76
*Annual**	20.5	17.9	58820	-160.8	-5448	-53249	-2.26

Stoichiometric calculations of aspects of net system metabolism
According to the assumption of the LOICZ biogeochemical model, the Δ*DIP* values and the C:N:P ratio of primary producers (in this case phytoplankton, thus the Redfield ratio was used) allow a direct estimate of the net energy budget of the system, determining whether the system is a net consumer *(*Δ*DIP* > 0 and *p-r* < 0) or a net producer ((Δ*DIP* < 0 and *p-r* > 0) of organic matter.

As indicated in Table 4.6, the Rada di Augusta act as a net consumer in the first period (-1.91 mmol m-2 d-1) and as net producer (1.58 and 1.54 mmol m^{-2} d^{-1}) in the remaining periods.

In all periods denitrification prevailed over nitrogen fixation (i.e., (*nfix-denit*) <0) especially in the cold months. On an annual basis, the Rada di Augusta system can be considered as an autotrophic system with an estimated net production of organic matter of 0.12 mmol C m^{-2} d^{-1} and denitrification processes lead to a net removal of 2.24 mmol m^{-2} d^{-1} of DIN.

Table 4.6. Net ecosystem metabolism (*p-r*), expected *ΔDIN* and (*nfix-denit*) for the Rada di Augusta in 1989-90.
*Annual values are calculated as the time-weighted average of seasonal values.

Period	**(*p-r*)**	**ΔDIN_{exp}**	**(*nfix-denit*)**
	(mmol m^{-2} d^{-1})		
Nov.-Mar.	-1.91	0.29	-2.74
Apr-Jun	1.58	-0.24	-2.39
Jul-Oct	1.54	-0.23	-1.53
Annual*	0.12	-0.02	-2.24

Figure 4.2. View of the Rada di Augusta.

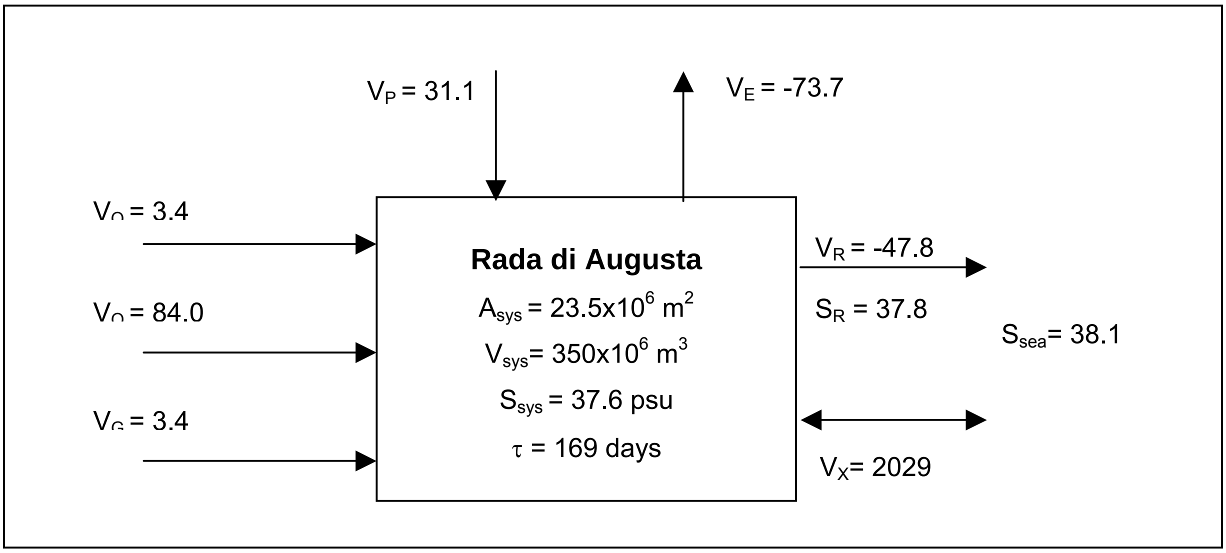

Figure 4.3. Water and salt budgets for the Rada di Augusta. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in PSU. Annual values are calculated as the time-weighted average of seasonal values.

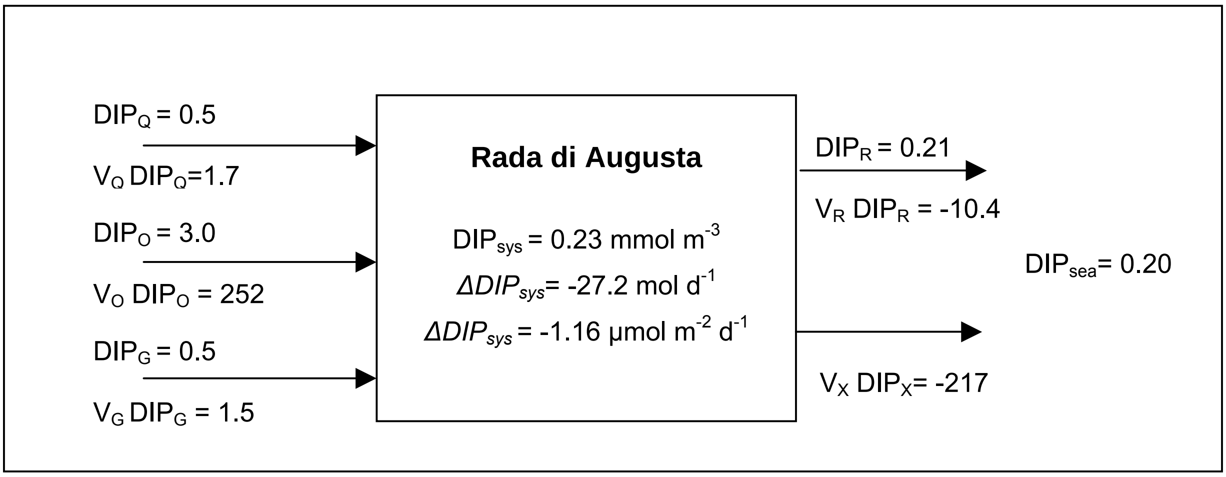

Figure 4.4. DIP budget for the Rada di Augusta. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

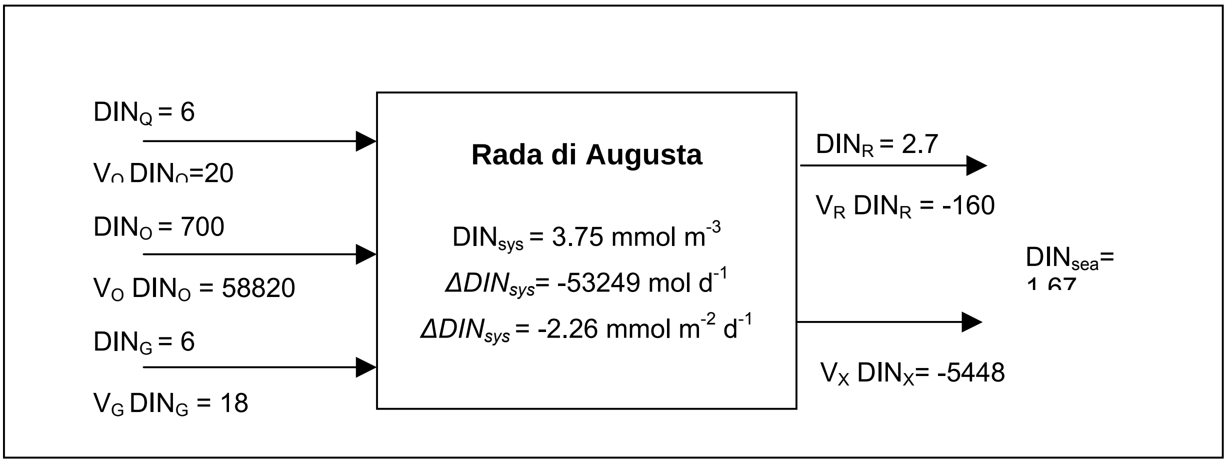

Figure 4.5. DIN budget for the Rada di Augusta. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

4.2 Capo Feto marshland, south-west Sicily

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Introduction

Capo Feto is a typical marshland located on the south-western coast of Sicily, 5 km west of Mazara del Vallo (37.68° N, 12.48° E). Physical and chemical features of the Capo Feto area were studied from summer 2000 to summer 2002. Data from 2001 were used to calculate seasonal and annual budgets using a single-box, single-layer LOICZ Biogeochemical Model (Gordon *et al.* 1996). Rainfall data were recorded at a field station near the study area and compared with the long-term time-series data of E.S.A. (Sicilian Agency of Agricultural Development). Freshwater inputs showed a strong seasonal variability, and the estimated water exchange time (τ) varied from 77 days during the first quarter of the year to 115 days during the last quarter of the year. On an annual basis the estimated value of τ was 105 days, Concerning the nutrient balance, ΔDIP and ΔDIN were positive for all seasons and, on an annual basis, ΔDIP is 0.024 mmol m^{-2} d^{-1} and ΔDIN is 0.09 mmol m^{-2} d^{-1}. Net ecosystem metabolism [NEM or (p-r)] is -2.5 mmol C m^{-2} d^{-1} on an annual basis, suggesting a prevalence of respiration processes. Denitrification prevailed over nitrogen fixation [(*nfix-denit*)<0].

Study area description

The study area is included in the inner area of the Life-Nature project of protection funded by the European Union. The marshland has a total extent of 1.4 km^2 and an average depth of 1.75 m. The catchment area of the Capo Feto coastal zone (Figure 4.6) shows typical features of a southern European wetland habitat (Figure 4.7): in summer it is dry except for the network of reclamation channels and a few ponds, while in winter the Capo Feto area appears to be a typical wetland (Pernice *et al.* 2001). Many ponds and marsh areas are filled with the characteristic wildlife of migratory and sedentary birds. All drainage of the wetland is currently maintained by a network of 10 artificial channels: the main channel is oriented east-west with perpendicular secondary channels, assuring the drainage of groundwater and rainwater.

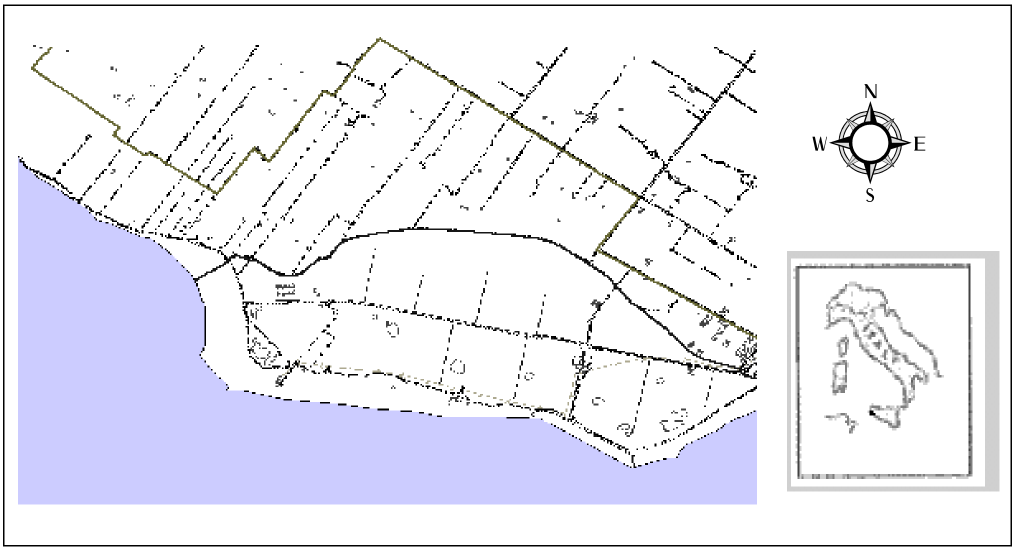

Figure 4.6. Location and map of Capo Feto.

In the 1970s, parts of Capo Feto were subjected to anthropic development related to agriculture, tourism and urbanization. In the eighties, construction of the underground Italian–Algerian methane pipeline, which crosses the Capo Feto (Assessorato Territorio Ambiente Relazione 1984-85), strongly changed the original features of the area. In addition, effects of recent global climate changes have caused further modifications of the natural habitat.

Capo Feto has a typical mediterranean climate, characterized by high temperatures in summer and mild conditions in winter. Because of its geographic position on the western coast of Sicily and its geomorphology, Capo Feto, is exposed to strong and persistent winds (annual average is approximately 6.8 m sec^{-1}) which have a strong influence on the climate (Pusceddu *et al.* 1997). In winter, winds mainly blow from the west or north-west, while in spring-summer they are characterized by continuous changes of direction and force. North winds are the steadiest, coldest and most persistent in duration, while the “sirocco” is a typical muggy wind from the south-east which lasts 3-5 days and is strongest in April-June. The wind from the north-west, locally called the “marascata”, is cold, intense and has high salt content. It causes damages to the plants of the coastal landscape. In autumn, the wind blows mainly from the west (“ponente”).

The annual average temperature is approximately 17.1°C; the highest annual temperature is usually recorded in August or, less frequently, in July with values of 30-32°C or as high as 37-38°C. Minimum annual temperatures, on some January and February nights, rarely reach zero.

The average annual rainfall in the last ten years has been 415 mm, distributed over a period of 75 days. This index of rainfall is among the lowest in Sicily. Moreover, most of the rain often occurs within a few days, and it is not rare that in a single day 10% of the annual rainfall occurs. The precipitation in autumn-winter is frequently of stormy origin with high intensity. In spring and summer, precipitation is quite modest and less frequent.

The watershed of Capo Feto is about 45 km^2, and contains an estimated population of about 6000. The main activity is agriculture, in particular olives and vineyards but also some vegetables and fruit cultivation. Few industrial activities are present, and these are mainly related to wine production. Due to its touristic value, there are a lot of summer houses in the area.

For Capo Feto, water and nutrient budgets were estimated for 2001, before the beginning of the Life Nature reclamation and environmental remediation works.

Water and salt balance

The study area has a long-term annual average rainfall of 124 mm, decreasing in the last fifty years. Overexploitation of groundwater by agricultural and domestic wells has caused a drop in the average level of groundwater and salt intrusion into the water table. The entire catchment area is dry in summer except the network of reclamation channels and a few ponds.

The principal channel is about 5 m wide, with depths from 0.4 to 1.1 m. This channel contains water in all seasons but while in winter, rainwater flows to the sea, in summer it’s dry in the latter part.

The basin of a disused water-scooping machine located at the end of the channels network is full all year round, and its depth is approximately 0.8 m. This water body collects the water of the channel network which is not connected to the sea.

The water volume of the system was calculated by utilising the following experimental data: on the calcareous stratum there are 5 m of palustrine sediments with a porosity average of 0.47 and an average saturation index of about 70% (Life-Nature Project No. B34/006270/99, 2002). The water column in the sediment is calculated as 1.65 m high which added to the mean surficial water layer (0.10 m) yields a value for the mean depth of the system of 1.75 m.

The water inputs (∑ inputs) of the system are:

a) precipitation (V_P)
b) groundwater (V_G)

The water outputs (∑outputs) of the system are:

a) evaporation (V_E)
b) residual and exchange flows with the sea (V_R and V_X).

The river input, V_Q, and other water inputs, V_0, are negligible.

The water budget was calculated on annual and seasonal bases for the year 2001, considering the system in steady-state.

The precipitation data (V_P) was collected by the meteorological station "Contrada Ramisella" located near the Capo Feto wetland. Direct evaporation (V_E) was calculated using Hargreaves' equation (Shuttleworth 1993) and compared to experimental data.

The groundwater inputs (V_G) were calculated by estimating seepage into the catchment basin.

The salt mass balance was calculated with data collected during a 4-season survey conducted in 2001 in which the sampling stations were located along three transects in the inner area (Badour 1987). In summer, the salinity of the system is very high due to evaporation. Salinity of precipitation and evaporation fluxes are considered zero.

The seasonal and annual budgets of water and salt are summarized in Table 4.7 and Figure 4.8, along with the estimated water turnover time (τ) of the Capo Feto marshland.

Table 4.7. Seasonal water budgets, salinity and water exchange time in Capo Feto in 2001. *Annual Vx value is calculated as the time-weighted average of seasonal values.

Season	V_G	V_P	V_E	V_R	V_X	S_G	S_{syst}	S_{sea}	τ
	(10^3 m^3 d^{-1})					(psu)			(days)
Jan-Feb-Mar	2.8	2.9	-2.1	-3.6	28.1	8.4	33.6	37.3	77
Apr-May-Jun	2.6	1.5	-3.1	-1.0	21.8	8.6	37.3	38.0	107
Jul-Aug-Sep	2.2	0.5	-6.5	3.8	22.5	9.8	46.3	38.2	93
Oct-Nov-Dec	2.4	1.9	-5.5	1.2	20.1	9.6	41.2	37.7	115
Annual	2.5	1.7	-4.3	0.1	23.1*	9.1	39.6	37.8	105

During the first six months of the year and especially in the first part, a net water export from the wetland to the sea (V_R negative) was estimated; this is because the input of rainfall and groundwater of the system were greater than evaporation. In summer and in autumn, a net water import from the sea to the wetland (V_R >0) was observed; in fact, rainfall and groundwater inputs are lower than evaporation. On an annual basis, V_R is slightly positive indicating that evaporation prevails over water inputs and a net water import from the sea are necessary to maintain the water volume of the system.

On an annual basis, the estimated water exchange time (τ) is 105 days.

Budgets of non-conservative materials

The inorganic nutrient amounts for the analysis with the LOICZ budgeting of the Capo Feto wetland has been determined by executing a series of samplings in the study area and the results of analysis are summarized in Table 4.8.

Table 4.8. Nutrient concentrations in Capo Feto marshland (2001).

Season	DIP_G	DIP_{syst}	DIP_{sea}	DIN_G	DIN_{syst}	DIN_{sea}
	(mmol m^{-3})					
Jan-Feb-Mar	0.56	1.53	0.03	11.8	8.7	2.00
Apr-May-Jun	0.56	1.50	0.03	11.6	8.8	2.03
Jul-Aug-Sep	0.56	1.47	0.03	11.4	8.7	2.05
Oct-Nov-Dec	0.56	1.50	0.03	11.6	9.0	2.08
Annual	0.56	1.50	0.03	11.6	8.8	2.04

The main income of nutrient in the system has been to the flow of groundwater, because the territory bordering with the wetland turns out cultivated in vineyard cultivation (European Environment Agency report, 7/2001), that annually comes fertilized with nitrogen and phosphorus fertilizers. The amount of inorganic phosphorus and nitrogen due incoming rainwater has bean considered null.

DIP balance

Annual and seasonal budgets for DIP are reported in Table 4.9and Figure 4.9.

Table 4.9. DIP budgets in Capo Feto marshland (2001).

Season	V_GDIP_G	V_RDIP_R	V_XDIP_X	*ΔDIP*	
	(mol d^{-1})			(mol d^{-1})	(mmol m^{-2} d^{-1})
Jan-Feb-Mar	2	-3	-42	43	0.031
Apr-May-Jun	1	-1	-32	32	0.023
Jul-Aug-Sep	1	3	-32	28	0.020
Oct-Nov-Dec	1	1	-30	28	0.020
Annual	1	0	-34	33	0.024

The input of DIP to Capo Feto is assumed to come from groundwater since no data on precipitation are available. The largest input was observed during the first three months of the year in parallel to the higher input of groundwater and the agricultural fertilization period.

DIN balance

Annual and seasonal budgets for DIN are reported in Table 4.10 and Figure 4.10.

Table 4.10. DIN budgets for Capo Feto marshland in 2001.

Season	V_GDIN_G	V_RDIN_R	V_XDIN_X	*ΔDIN*	
	(mol d^{-1})			(mol d^{-1})	(mmol m^{-2} d^{-1})
Jan-Feb-Mar	33	-19	-188	174	0.12
Apr-May-Jun	30	-5	-148	123	0.09
Jul-Aug-Sep	25	20	-150	105	0.08
Oct-Nov-Dec	28	7	-139	104	0.07
Annual	29	1	-156	127	0.09

The DIN input to Capo Feto comes from groundwater since no data on precipitation are available. As for DIP, the higher DIN input was observed in the rainy season along with the highest input of groundwater and the fertilisation activities in the agricultural land. DIN inputs are dominated by nitrate as for the nitrogen species in the water column of the wetland (Dallocchio *et al.* 1998).

Stoichiometric calculations and aspects of the net system metabolism

On an annual basis, Capo Feto can be considered as a source of DIP and DIN from positive ΔDIP (0.024 mmol m^{-2} d^{-1}) and ΔDIN (0.09 mmol m^{-2} d^{-1}) values calculated following the LOICZ procedure.

Assuming a production of organic matter with a Redfield C:N:P ratio, the annual net ecosystem metabolism (NEM), taken as the difference between ecosystem production and respiration *(p-r*), was -2.5 mmol C m^{-2} d^{-1} in 2001 indicating that the system can be considered as net heterotrophic. Results of the seasonal budgets are summarized in Table 4.10. The calculation of (*nfix-denit*) was negative for all seasons indicating a dominance of denitrification processes over nitrogen fixation (-0.29 mmol m^{-2} d^{-1} on annual basis).

Table 4.10. Seasonal variations of ΔDIN_{exp}, (*nfix-denit*) and net ecosystem metabolism (*p-r*) in Capo Feto marshland in 2001 (unit: mmol m^{-2} d^{-1}).

Season	ΔDIN_{exp}	**(*nfix-denit*)**	**NEM (*p-r*)**
Jan-Feb-Mar	0.50	-0.38	-3.3
Apr-May-Jun	0.37	-0.28	-2.4
Jul-Aug-Sep	0.32	-0.24	-2.1
Oct-Nov-Dec	0.32	-0.25	-2.1
Annual	0.38	-0.29	-2.5

Figure 4.7. View of Capo Feto marshland.

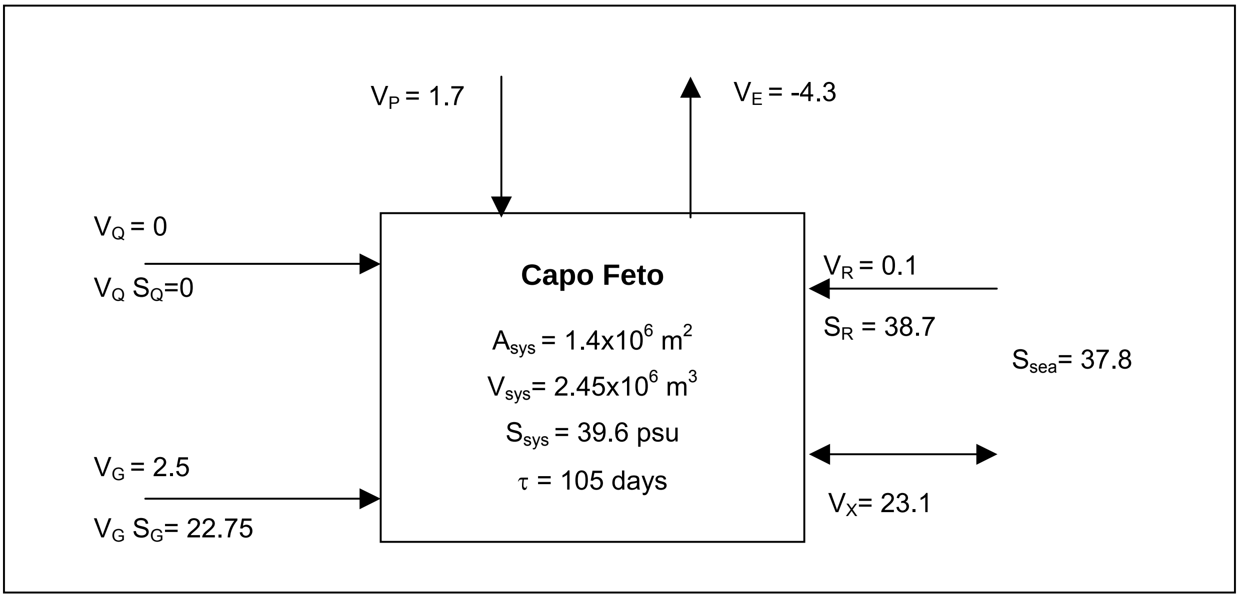

Figure 4.8. Water and salt budgets for Capo Feto marshland. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in psu. Annual V_x value is the time-weighted average of seasonal values.

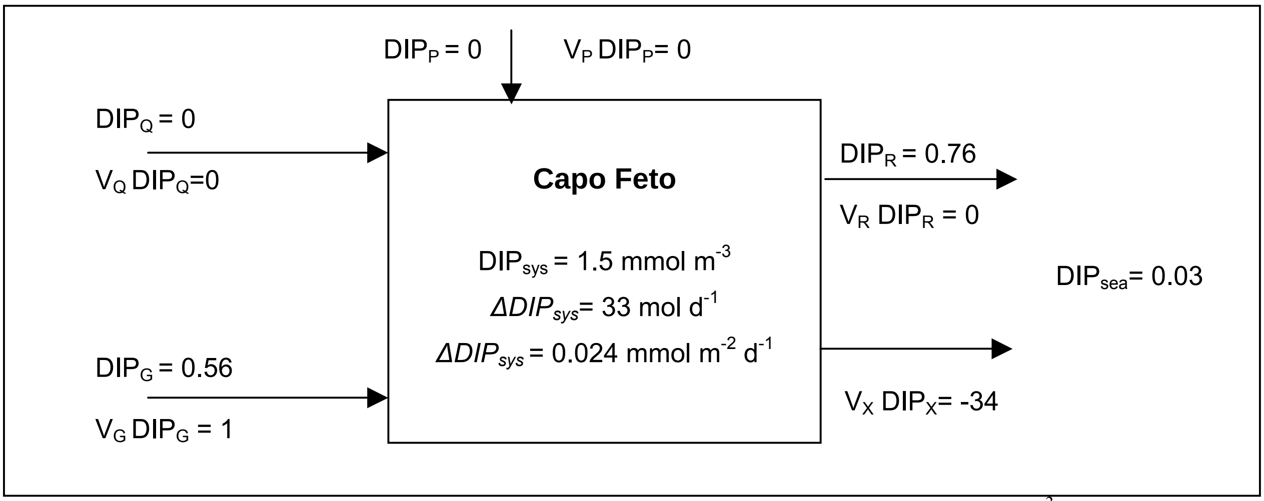

Figure 4.9. DIP budget for Capo Feto marshland. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

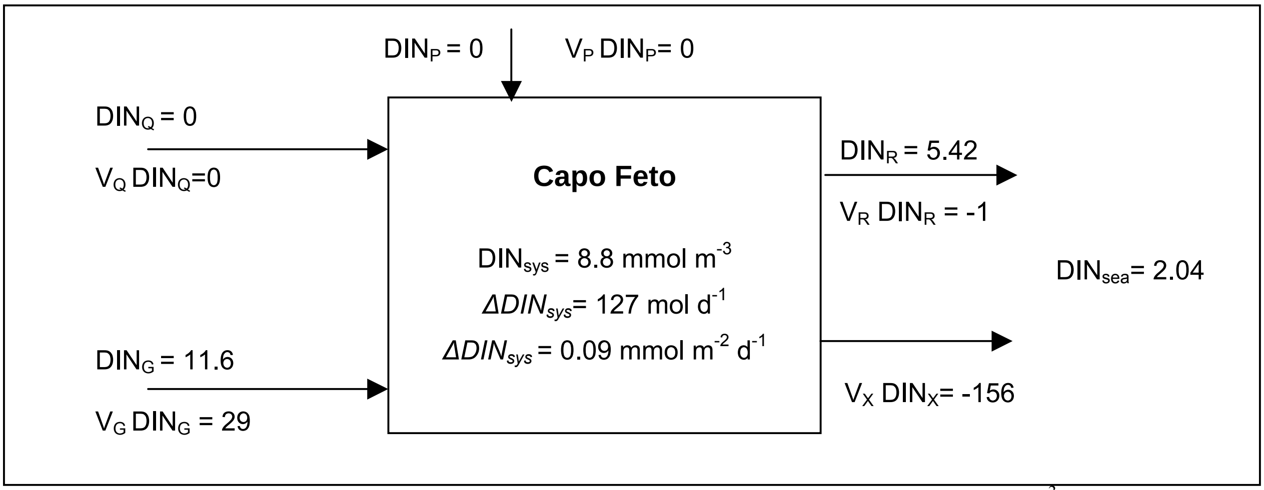

Figure 4.10. DIN budget for Capo Feto marshland. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Annual values are calculated as the time-weighted average of seasonal values.

4.3 Stagnone di Marsala Lagoon, western Sicily

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Summary

The Stagnone di Marsala is a large oligotrophic brackish lagoon situated on the west coast of Sicily, Italy. It was studied in 1996, applying a single-box-single-layer LOICZ Biogeochemical Model. The high salinity difference between the open sea and the system indicates that the water exchange was low even if the two openings, positioned at the north and south, allow seawater inputs to cross the system. An unexpectedly long water exchange time was calculated (about 65 days). The nutrient inputs were from the sea and very low non-conservative fluxes were calculated for both DIN and DIP. The Stagnone di Marsala seems to act as a net sink for DIN and as a source for DIP. NEM is very low (-0.05 mmol m^{-2} d^{-1}) and denitrification appears to prevail over N-fixation.

Study area description

The Stagnone di Marsala (37.83°N, 12.45°E) is a 21.35 km^2 long lagoon (about 1.8 km wide and 11 km long) on the north-western coast of Sicily (Italy). The lagoon has a northern narrow and shallow mouth to the sea (400 m wide, 0.3-0.4 m deep) and another wider and deeper mouth to the south (1200 m wide, 1.0-1.5 m deep). At the western end of the northern opening a 20 m wide, 1 m deep channel was dredged, enhancing the local flushing capability. Inside the lagoon, next to the islands of Motia and Santa Maria, there is a slightly submerged relict of a Phoenician road which is effective in reducing flow, thus creating a low-flushing sub-basin to the north-east (Figure 4.11). Because of the small tidal range (about 0.3 m of astronomical component at spring tide), lagoonal flushing is expected to be mainly wind- driven.

The climate of the region is mediterranean. Precipitation is approximately 600 mm yr^{-1}, with early spring and late autumn peaks.

The basin is oligotrophic with chlorophyll-*a* concentrations of about 1.0 µg l^{-1} (Sarà *et al.* 1999). No freshwater input is present. Seagrasses (*Posidonia oceanica* in the central-southern area and *Cymodocea nodosa* in the northern) cover the sand-mud bottom. *C. nodosa* and *Caulerpa prolifera* prairies are probably related to both low hydrodynamic conditions and different sedimentological regimes, i.e. muddy bottoms. Indeed, on an empirical basis, such physical conditions are known to be effective in determining the prevailing aquatic plant species. In particular, in the northern basin of the lagoon a discontinuous *P. oceanica* meadow shows surfacing reef formations ~2-3 m wide and atolls (10-20 m diameter), both representing about 12% of the total coverage (Calvo *et al.* 1996).

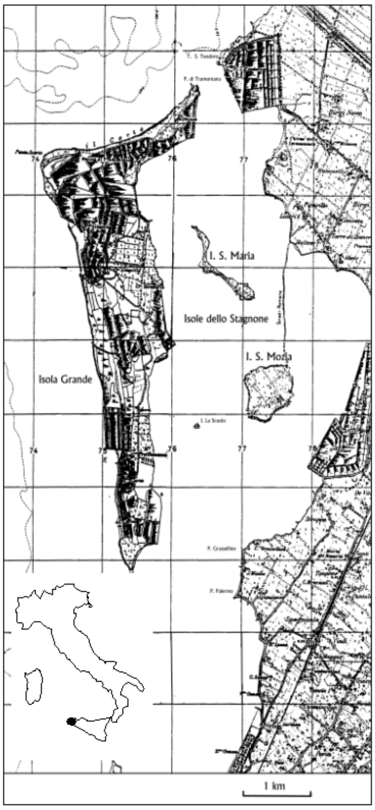

Figure 4.11. Stagnone di Marsala.

The lagoon represents a biotype of great natural importance in the Mediterranean area, due to the characteristics of the plant and animal species living in it. In particular, of utmost importance from an ecological point of view are the *P. oceanica* meadows (plateau reef and barrier reef) located in the vicinity of the coastal zone, which contribute to the maintenance of natural lagoon ecosystems (Calvo *et al.* 1980). The importance of the bio-hydrodynamic equilibrium of the lagoon should be further stressed. Qualitative hypotheses based on *in situ* observations have so far given indications about the lagoon circulation (Mazzola and Sarà 1995). Recently a slow but progressive increase in the level of sedimentation has been detected in the openings between the lagoon and the sea (Agnesi *et al.* 1993) due to both natural events (littoral drift and subsidence phenomena) and human interventions (waste material along the shoreline). The dependence of the extent of coverage of *P. oceanica* on different flushing capabilities of the lagoon has also been confirmed by a previous numerical investigation carried out using a 2-dimensional depth-averaged model (Balzano *et al.* 2000).

The objective of this paper was to determine the water, salt and nutrient budgets of the Stagnone di Marsala by applying the LOICZ budget modelling approach (Gordon *et al.* 1996).

From January to December 1996, temperature and salinity data were recorded within the Stagnone di Marsala and the open sea. Water samples were collected in the lagoon and open sea and analysed for nitrate, nitrite, ammonium and phosphorus concentrations using standard procedures (see respectively Bendschneider and Robinson 1952; Wood *et al.* 1967; Catalano 1987; Murphy and Riley 1962). Air temperature data were obtained from the local meteorological station (Areonautica Militare di Birgi, Trapani). Data on the nutrient concentration of precipitation were not available. Evaporation was calculated using the Hargreaves equation (Hargreaves 1975).

Water and salt balance

The water and salt budget of Stagnone di Marsala is shown in Figure 4.12. Freshwater inputs to the lagoon from land are considered negligible since *the Birgi River collects continental inputs and flows into the open sea north, outside the Stagnone di Marsala.* Precipitation data (V_P) were obtained from the National Hydrological Service database and evaporation losses (V_E) were calculated according to Hargreaves' equation.

To balance the water losses in evaporation, a net water input of about 19×10^3 m^3 d^{-1} from the sea was estimated (V_R). Considering the salinity gradient between the lagoon system and the sea, the exchange flux (V_X) was calculated at about 300×10^3 m^3 d^{-1}. Salinity of the seawater connected with the lagoon is 36.80 psu. The estimated water residence time was about 65 days.

These calculated water fluxes are somewhat larger than, but of the same order of magnitude as previous numerical simulations carried out in the same area (Balzano *et al.* 2000).

Budgets of non-conservative materials

The Stagnone di Marsala is an oligotrophic system with low nutrient concentrations, similar to those of the open sea (Table 4.12). Throughout the study year the dominant form of DIN was nitrate, while ammonium and nitrite concentrations were very low. The inputs of DIP and DIN to the lagoon were from net water inputs from the open sea (V_RDIP_R, V_RDIN_R), while outputs were from the water exchanges between the sea and the lagoon system (V_XDIP_X, V_XDIN_X). No data on dry deposition were available, but is probable that atmospheric DIP and DIN inputs are very low in the Stagnone di Marsala. For this reason these variables were assumed to be zero. Very low non-conservative fluxes were obtained for both DIN and DIP.

Table 4.12. Nutrient concentrations (mmol m^{-3}) in the Stagnone di Marsala and the open sea.

Year	**DIP_{sys}**	**DIP_{sea}**	**DIN_{sys}**	**DIN_{sea}**
1996	0.03	0.02	2.66	2.60

DIP balance
The annual dissolved inorganic phosphorus budgets are reported in Table 4.13 and the mass balance of DIP are shown in Figure 4.13.

On an annual basis, ΔDIP (non-conservative DIP fluxes) were positive, though very low, close to zero, when referred to the surface area of the system. Outputs tend to be greater than inputs suggesting that the Stagnone di Marsala acts as a source of DIP. DIP mobilization processes (DIP release) seem to prevail over storage (DIP assimilation).

Table 4.13. DIP budget of the Stagnone di Marsala.

Year	**V_RDIP_R**	**V_XDIP_X**	**ΔDIP**	
	mol d^{-1}		mol d^{-1}	µmol m^{-2} d^{-1}
1996	0.47	-2.96	2.49	0.11

DIN balance
The data for the ΔDIN budgets relative to the investigated period are summarized in Table 4.14 *and the mass balance of DIN are shown in Figure 4.14.*

As with DIP, the nonconservative flux of DIN (ΔDIN) *calculated on surface basis was very low*. The negative value of ΔDIN suggests a slight prevalence of DIN internal removal processes, mainly assimilation by primary producers. Inputs are prevalent over outputs and the Stagnone di Marsala tends to act as a net sink of DIN.

Table 4.14. DIN budget of the Stagnone di Marsala.

Year	**V_RDIN_R**	**V_XDIN_X**	**ΔDIN**	
	mol d^{-1}		mol d^{-1}	µmol m^{-2} d^{-1}
1996	49.10	-17.74	-31.36	-1.47

Stoichiometric calculations of aspects of net system metabolism
The primary producers community of the lagoon is mainly represented by *C. nodosa* dense prairies. The C:N:P ratio of this seagrass (Atkinson and Smith, 1993) was used for following stoichiometric calculations, since no large variations of phytobenthic populations were observed during the last decade.

Table 4.15. Net ecosystem metabolism (p-r) and (nfix-denit) of the Stagnone di Marsala.

Year	**NEM (*p-r*)**	**ΔDIN_{exp}**	**(*nfix-denit*)**
	mmol m^{-2} d^{-1}		
1996	-0.046	0.002	-0.003
	***Cymodocea nodosa* (C:N:P = 408:15:1)**		

The net ecosystem metabolism (NEM) or (*p-r*) was estimated by the ΔDIP value, using the C:P ratio reported in Table 4.15. The difference between production and respiration was -0.046 mmol m^{-2} d^{-1} for the year under investigation. On the basis of these results, it may be inferred that the lagoon metabolism is slightly heterotrophic.

The expected *ΔDIN* was obtained by multiplying the *ΔDIP* by the N:P ratio reported in Tables 4.13 and 4.15. Net nitrogen fixation minus denitrification (*nfix-denit*) was negative with -0.003 mmol m^{-2} d^{-1}. During the year studied, the gap between the observed and expected *ΔDIN* (*nfix-denit*) indicates that the denitrification losses dominated over nitrogen fixation.

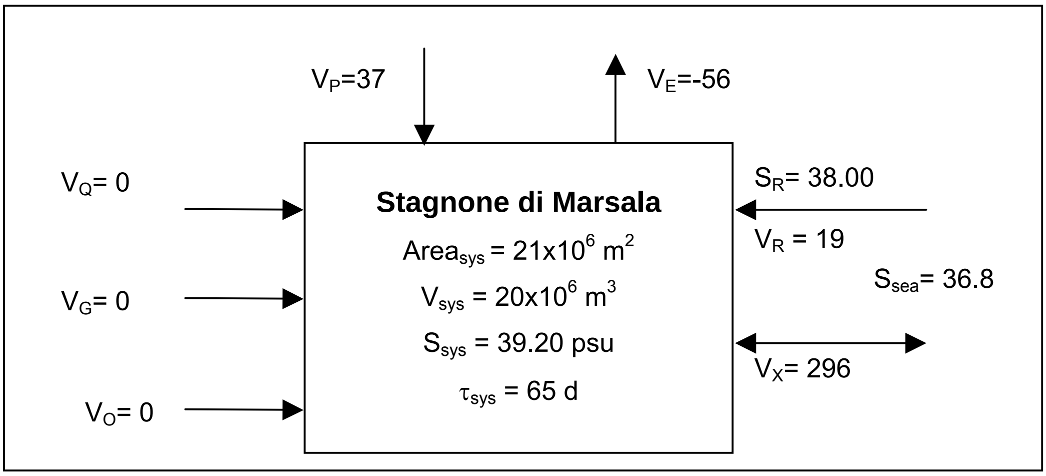

Figure 4.12. Water and salt budgets for Stagnone di Marsala Lagoon for 1996. Water flux units are 10^3 m^3 d^{-1} .

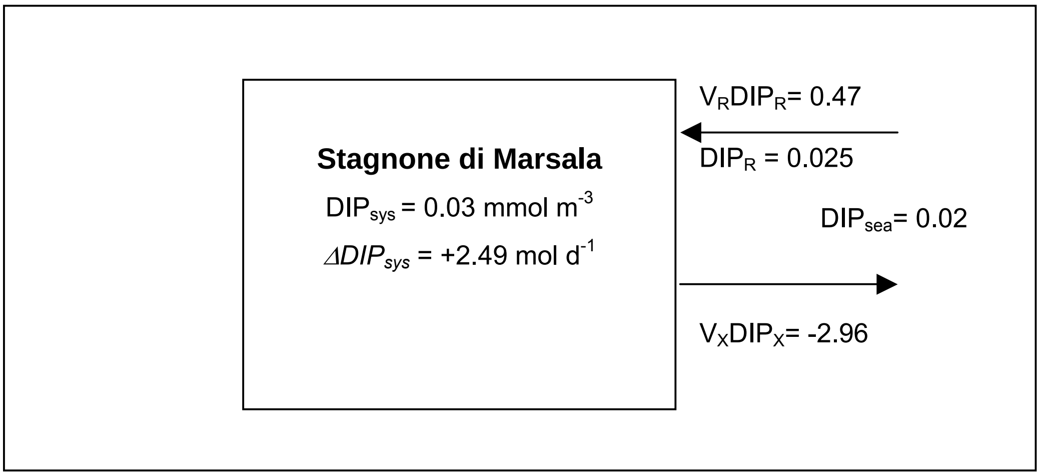

Figure 4.13. Mass balance of DIP. Fluxes are mol d^{-1}. Concentrations in mmol m^{-3}.

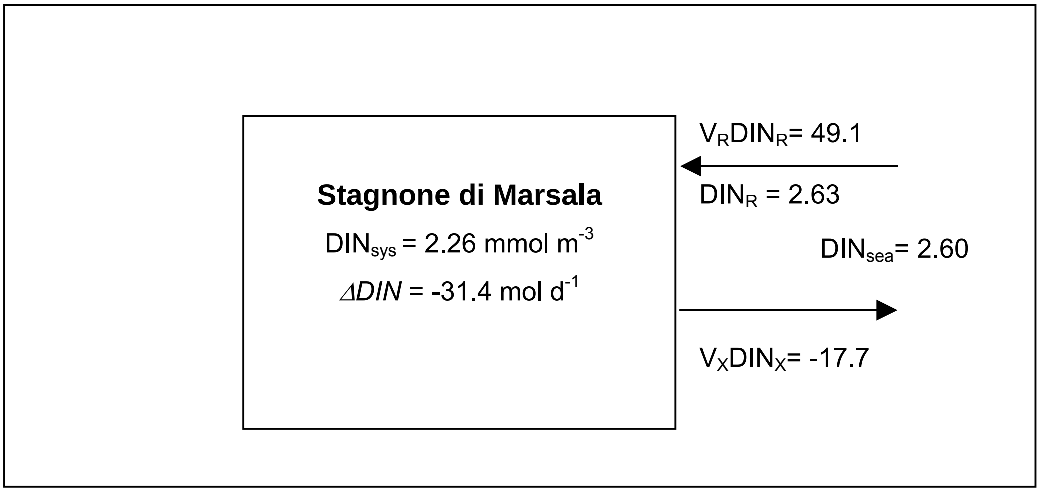

Figure 4.14. Mass balance of DIN in Stagnone di Marsala. Fluxes are mol d^{-1}. Concentrations in mmol m^{-3}.

4.4 Marinello coastal system, north-eastern Sicily

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Summary

The Marinello coastal system is located on the Tyrrhenian coast of Messina province, Sicily (Italy) and includes five ponds. Physical and chemical features of two of them were studied from April 1997 to March 1998 in order to evaluate water and nutrient budgets using a single-box, single-layer LOICZ biogeochemical model. Air temperature and rainfall records were obtained from the meteorological station in Tindari. Estimated water exchange time varied from approximately two months for the outer basin (Fondo Porto) in the wet period (October-March) to about one year for the inner basin (Verde) in the dry period (April-September) depending on the variability of the inputs.

The ponds are net exporters of DIP to the sea in both periods, and appear to act as net sinks for DIP ($\Delta DIP < 0$). High DIN concentrations were measured in both ponds during the wet season with values four to five times higher than in the dry season.

The system is a net producer of organic matter ($\Delta DIP<0$ and NEM>0); this applies to both periods and particularly to Verde pond. Nitrogen removal is generally balanced by nitrogen storage processes during summer, while N-fixation prevails in the wet season.

Study area description

The Marinello coastal system (38.13°N, 15.05°E) is a small littoral area located behind the Tindari Cliff in Patti Gulf (Messina, Italy), and currently comprises five small, deep ponds whose shape, number and dimensions are continuously changing due to the rapid evolution of coastal morphology. At present, the system covers an area of approximately 697,000 m^2 (Figure 4.15).

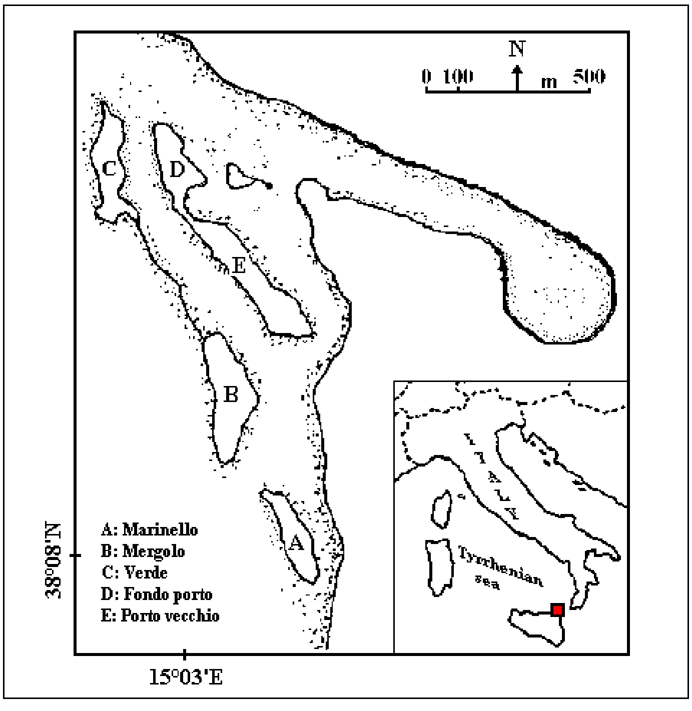

Figure 4.15. Location and map of the Marinello coastal system.

Direct urban discharges are completely absent, but in summer the bay is subject to variable levels of human pressure.

Each basin is affected by different kinds of water inflows. The outermost ponds are mainly influenced by sea water inflows, through infiltration mechanisms or direct contribution during storms. Conversely, the most important input to the three inner ponds is surface runoff, carrying dissolved and particulate matter from the surrounding lands (often used for pasture or agricultural exploitation). The heterogeneity of allochthonous inputs and inorganic enrichment (Azzaro 1995; Leonardi *et al.* 2000), emphasized by the morphologic dynamism of this ecosystem (Leonardi and Giacobbe 2001; Leonardi *et al.* 2001) determines the differentiation of trophic levels and salinity values among ponds.

In this paper we compare two very different basins of this coastal system: Fondo Porto pond and Verde pond. The first features an area of 13,000 m^2, a volume of 19,500 m^3 and a mean depth of about 1.5 m. Fondo Porto is a typical coastal pond with high salinity and low nutrient concentrations, its water balance being strongly conditioned by seawater. Conversely, Verde pond exhibits an area of 17,000 m^2, a volume of 27,200 m^3 and a mean depth of 1.6 m. It is characterized by lower salinity and higher nutrient loads from terrestrial and atmospheric sources. Water sources to the Verde pond become enriched in organic and inorganic compounds due to their passage across the overhanging cliff, which is heavily colonized by seagulls. This loading scenario combined with specific climatic conditions (e.g., high summer temperatures) has occasionally resulted in dystrophic crises with anoxia and fish mortality.

The water budgets were calculated for two periods: the dry one from April to September 1997 and the wet one from October 1997 to March 1998, using a single-box, single-layer model. The budgetary analysis was performed according to LOICZ Biogeochemical Budgeting Guidelines (Gordon *et al.* 1996).

The hydrological data used in the model were collected monthly from April 1997 to March 1998 in the framework of the Finalized Project Cultural Heritage of the CNR, Italy. Since no water stratification was observed and because of the shallowness of the basins (maximum depth 4.20 m), water samples were collected at 0.25 m and assumed to be representative of the whole water column. Air temperature and wet deposition data were obtained from the Tindari meteorological station (Regione Siciliana 2001). Evaporation was calculated using Hargreaves' equation (Hargreaves 1975).

Water and salt balances

The estimated budgets are shown in Table 4.16, annual budgets are shown in Figures 4.17 and 4.18 for Verde and Fondo Porto ponds respectively.

The ponds do not receive direct fluvial inputs, so runoff inputs constitute the major contribution to V_Q. Highest values were calculated for the wet period in the Verde pond (V_Q= 90 m^3 d^{-1}), which has a wider drainage basin receiving surface runoff from the Tindari cliff (290 m).

Because of the small surface area of the systems, direct rainfall contribution was very low even in the wet period (V_P max= 8 m^3 d^{-1} in the Verde pond).

In the Verde pond, freshwater inflows exceeded evaporation outflow and a net export of water from the ponds was observed in both periods studied. The residual water flow was higher during October-March (V_R= -93 m^3 d^{-1}). In this basin water exchange times varied from three months (wet period), to a little less than one year (dry period).

In the Fondo Porto pond, the inflow-outflow balance was in equilibrium during the dry period, while a low outflow was estimated for the wet period. The water exchange times were shorter there than in Verde pond, ranging between 2 and 8 months.

Table 4.16. Water fluxes, salinity and water exchange times for the Verde and Fondo Porto ponds in the dry (April-September) and wet (October-March) periods (1997-98).

	Period	V_Q	V_G	V_P	V_E	V_R	S_Q	S_{syst}	S_{sea}	V_X	τ
		(m^3 d^{-1})						(psu)		(m^3 d^{-1})	(days)
Verde	*Apr-Sept*	65	10	3	-50	-28	2.00	24.07	37.37	55	328
	Oct-Mar	90	20	8	-25	-93	2.00	22.07	36.88	173	102
	Annual	78	15	5.5	-38	-61	2.00	23.07	37.12	114	156
Fondo Porto	*Apr-Sept*	30	10	3	-40	-3	2.00	36.73	37.37	80	235
	Oct-Mar	40	20	6	-20	-46	2.00	31.56	36.88	281	60
	Annual	35	15	4.5	-30	-25	2.00	34.15	37.12	181	95

Balance of non-conservative materials

The DIP and DIN of the systems and their input and output environments are reported in Table 4.17. DIP system concentrations were different for the two ponds, with highest concentrations in the Verde pond during dry season. The values measured in Fondo Porto seemed to be close to that of the sea and approximately half of those observed in the Verde Pond.

High values of DIN are found in both ponds during the wet season with concentrations four to five times higher than in the dry season.

This contrasting behaviour of DIP and DIN in the two seasons for both ponds resulted in an unbalanced N_{tot}/P_{tot} molar ratio relative to Redfield, with values of 5-7 in the dry period and values of about 36 in the wet season. Nutrient ratios suggestive of N-limitation were recorded for the sea in both dry (6.6) and wet (10) periods, but in the ponds the high value during the wet season suggests a switch to a N-excess condition.

Table 4.17. Nutrient concentrations in mmol m^{-3} for input waters, in Verde and Fondo Porto ponds and the adjacent sea in the dry (April-September) and wet (October-March) periods (1997-98).

Verde Pond

Period	DIP_Q	DIP_G	DIP_{syst}	DIP_{sea}	DIN_Q	DIN_G	DIN_{syst}	DIN_{sea}
Apr-Sept	3.00	0.10	0.70	0.24	50	1.00	3.73	1.59
Oct-Mar	3.00	0.10	0.44	0.24	50	1.00	16.14	2.43
Annual	3.00	0.10	0.57	0.24	50	1.00	9.94	2.01

Fondo Porto pond

Period	DIP_Q	DIP_G	DIP_{syst}	DIP_{sea}	DIN_Q	DIN_G	DIN_{syst}	DIN_{sea}
Apr-Sept	0.60	0.10	0.31	0.24	10	1.00	2.29	1.59
Oct-Mar	0.60	0.10	0.22	0.24	10	1.00	8.03	2.43
Annual	0.60	0.10	0.27	0.24	10	1.00	5.16	2.01

On the basis of the available data, a first attempt was made to quantify the nutrient loads to the system. Results are presented in Table 4.18. An annual load of about 20 kg-N $year^{-1}$ was estimated for the Verde pond, which corresponds to a specific load of 1.17 g N m^{-2} $year^{-1}$; for phosphorus an annual load of 2.65 kg-P $year^{-1}$ was estimated, which corresponds to a specific load of 0.16 g-P m^{-2} $year^{-1}$.

An annual load of about 1.9 kg-N $year^{-1}$ was estimated for the Fondo Porto pond, which corresponds to a specific load of 0.14 g N m^{-2} $year^{-1}$; for phosphorus, an annual load of 0.25 kg-P $year^{-1}$ was estimated, which corresponds to a specific load of 0.02 g-P m^{-2} $year^{-1}$.

Table 4.18. Estimated nutrient loads to Verde and Fondo Porto ponds in the dry (April-September) and wet (October-March) periods (1997-98).

	Phosphorus			Nitrogen		
	mol d^{-1}		kg $year^{-1}$	mol d^{-1}		kg $year^{-1}$
	Apr-Sept	*Oct-Mar*	year	*Apr-Sept*	*Oct-Mar*	year
Verde	0.196	0.272	2.65	3.26	4.52	19.87
Fondo Porto	0.019	0.026	0.25	0.31	0.42	1.86
Total	0.215	0.298	2.90	3.57	4.94	21.73

DIP balance

The budgets for DIP are reported in Table 4.19. Annual values are reported in Figures 4.19 and 4.20 for Verde and Fondo Porto ponds respectively.

According to the assumptions of the LOICZ biogeochemical model, the *ΔDIP* values suggest that both ponds are moderate producers of organic matter in both periods. Verde pond had values of *ΔDIP* of an order of magnitude greater than Fondo Porto pond.

Table 4.19. DIP budgets for the Verde and Fondo Porto ponds in the dry (April-September) and wet (October-March) periods (1997-98).

	Period	**V_Q DIP_Q**	**V_G DIP_G**	**V_R DIP_R**	**V_X DIP_X**	***ΔDIP***	
		(mmol d^{-1})				(mmol d^{-1})	(mmol m^{-2} d^{-1})
Verde	*Apr-Sept*	195	1	-13	-25	-158	-0.009
	Oct-Mar	270	2	-32	-35	-205	-0.012
	Annual	234	1.5	-25	-30	-182	-0.011
Fondo Porto	*Apr-Sept*	18	1	-1	-6	-12	-0.001
	Oct-Mar	24	2	-11	6	- 21	-0.002
	Annual	21	1.5	-6	0	-17	-0.001

DIN balance

The budgets for DIN are reported in Table 4.20. Annual budgets are shown in Figures 4.21 and 4.22 for Verde and Fondo Porto ponds respectively. The DIN budgets generally show negative values of *ΔDIN* except in the wet season for Fondo Porto pond, when a net release of DIN from the system was detected. On an annual basis this system acts as a net source of DIN.

Table 4.20. DIN budgets for the Verde and Fondo Porto ponds in the dry (April-September) and wet (October-March) periods (1997-98).

	Period	**$V_Q DIN_Q$**	**$V_G DIN_G$**	**$V_R DIN_R$**	**$V_X DIN_X$**	***ΔDIN***	
		(mol d^{-1})				(mol d^{-1})	(mmol m^{-2} d^{-1})
Verde	*Apr-Sept*	3.25	0.01	-0.07	-0.12	-3.07	-0.18
	Oct-Mar	4.50	0.02	-0.86	-2.37	-1.29	-0.08
	Annual	3.88	0.015	-0.47	-1.25	-2.18	-0.13
Fondo Porto	*Apr-Sept*	0.30	0.01	-0.01	-0.06	-0.24	-0.02
	Oct-Mar	0.40	0.02	-0.24	-1.57	1.39	0.11
	Annual	0.35	0.015	-0.13	-0.82	0.58	0.04

Stoichiometric calculations of aspects of net system metabolism
Both systems are characterized by a net production of organic matter (NEM >0) especially in the wet period. Values of about 1.3 mmol m^{-2} d^{-1} found in Verde pond were an order of magnitude higher than those of Fondo Porto pond.

The annual (*nfix-denit*) is close to zero, indicating a balance between denitrification and N-fixation processes. In the dry season denitrification slightly prevails in Verde pond. In the wet season nitrogen fixation shows a slight prevalence in both ponds.

Table 4.21. Evaluation of the ecosystem metabolism for Verde and Fondo Porto ponds in the dry (April-September) and wet (October-March) periods (1997-98).

	Period	**NEM**	ΔDIN_{exp}	**(*nfix-denit*)**
		mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}
Verde	*Apr-Sept*	0.95	-0.14	-0.04
	Oct-Mar	1.27	-0.19	0.11
	Annual	1.11	-0.17	0.04
Fondo Porto	*Apr-Sept*	0.11	-0.02	0.00
	Oct-Mar	0.21	-0.03	0.14
	Annual	0.16	-0.03	0.07

Figure 4.16. Aerial image of the Marinello coastal system.

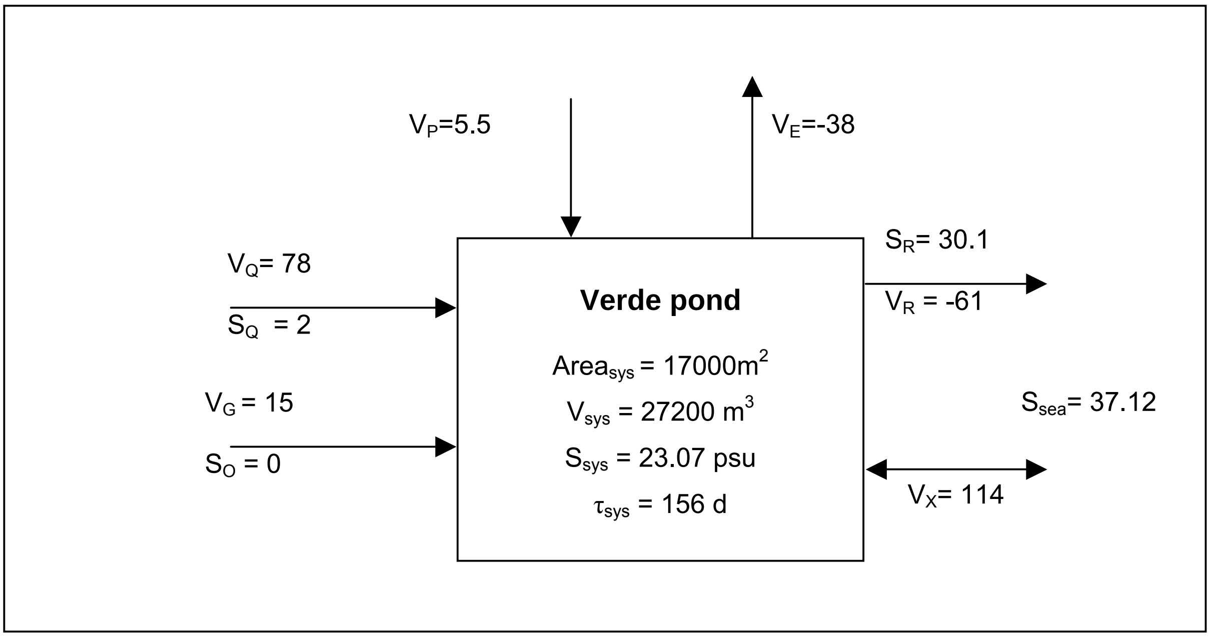

Figure 4.17. Water and salt budgets for Verde pond. Water fluxes are expressed in m^3 d^{-1} and salinity in psu.

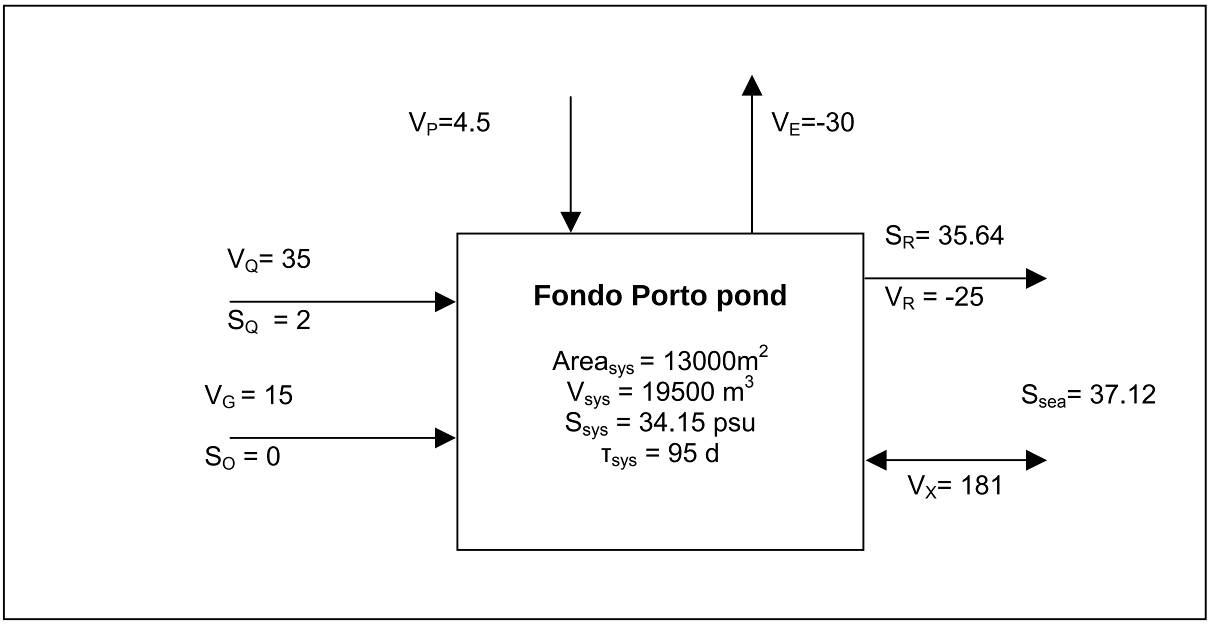

Figure 4.18. Water and salt budgets for Fondo Porto pond. Water fluxes are expressed in m^3 d^{-1} and salinity in psu.

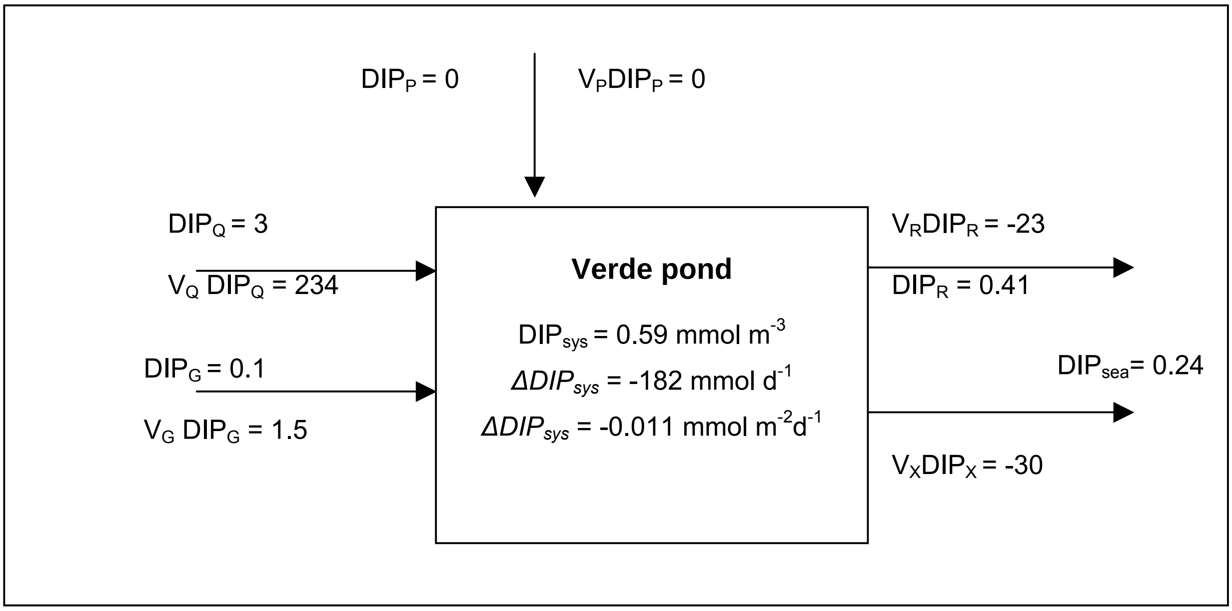

Figure 4.19. **DIP budget for Verde pond.** Concentrations are in mmol m^{-3} and fluxes in mmol d^{-1}.

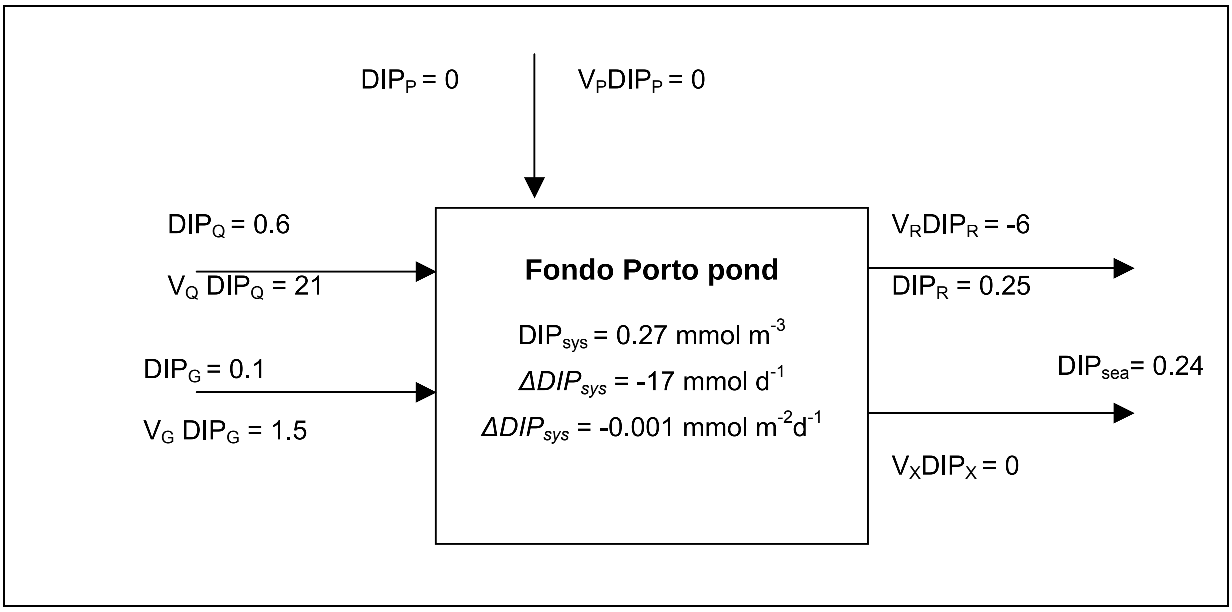

Figure 4.20. DIP budget for Fondo Porto pond. Concentrations are in mmol m^{-3} and fluxes in mmol d^{-1}.

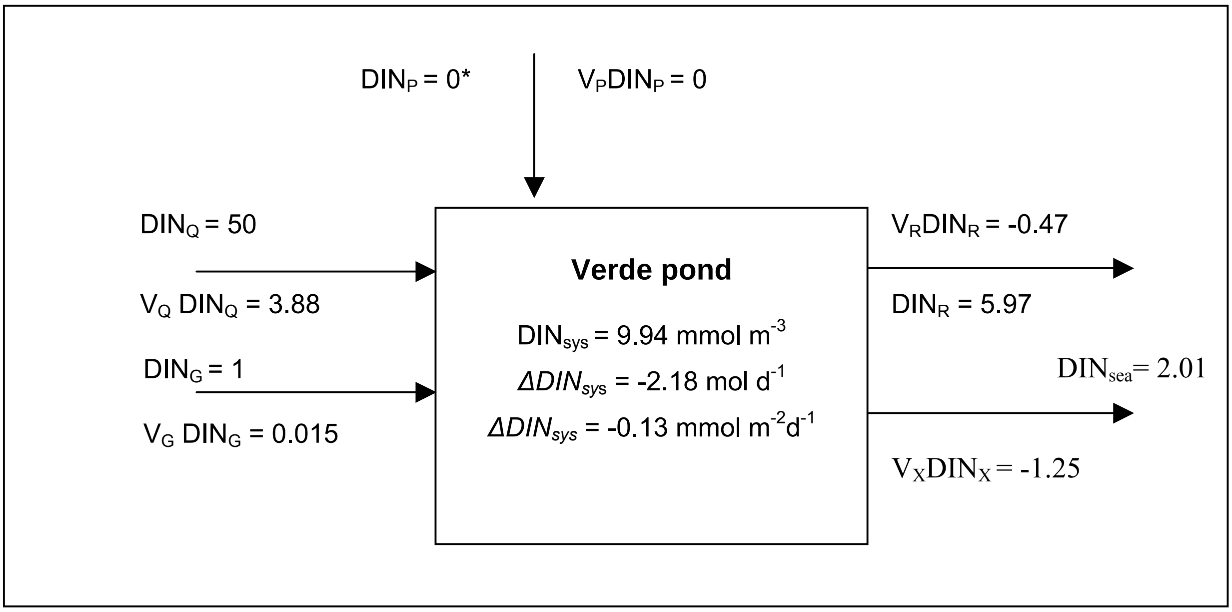

Figure 4.21. DIN budget for Verde pond. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. (* assumed)

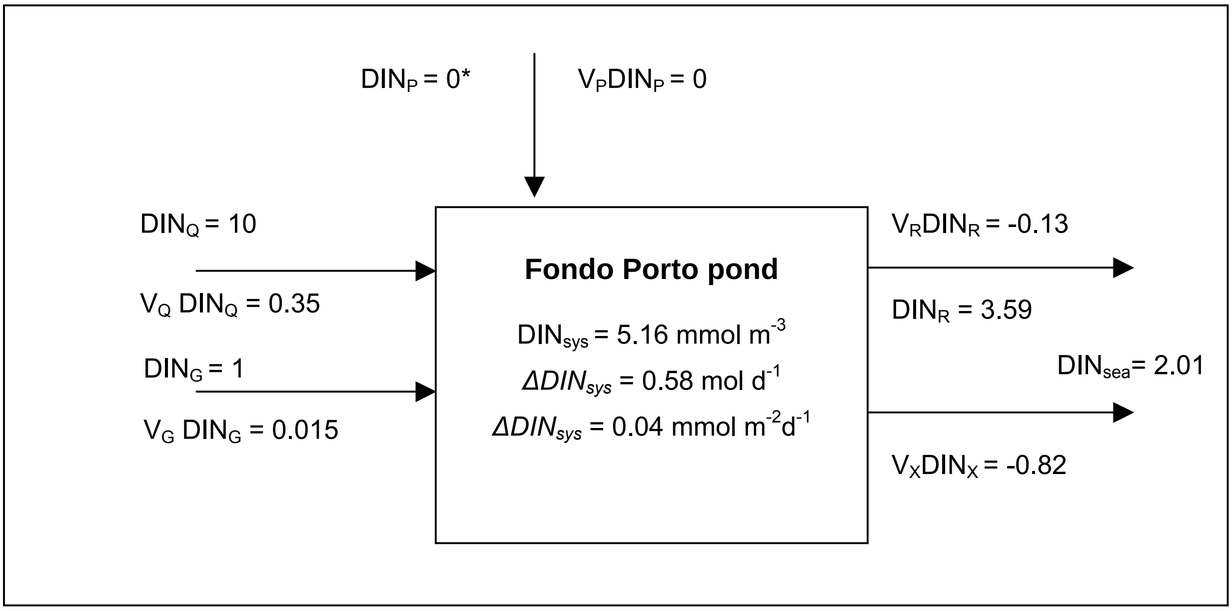

Figure 4.22. DIN budget for Fondo Porto pond. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. (* assumed)

4.5 Ganzirri Lake, north-eastern Sicily

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Study area description

The Capo Peloro (Figure 4.23) is a coastal brackish system located on the north-eastern corner of Sicily (Italy), 15 km north of Messina. It consists of two basins, Ganzirri Lake (or Pantano Grande) (Figure 4.24) and Faro Lake (or Pantano Piccolo), connected by a channel. Both of them communicate with the Ionian Sea, and Faro Lake occasionally also exchanges water with the Tyrrhenian Sea.

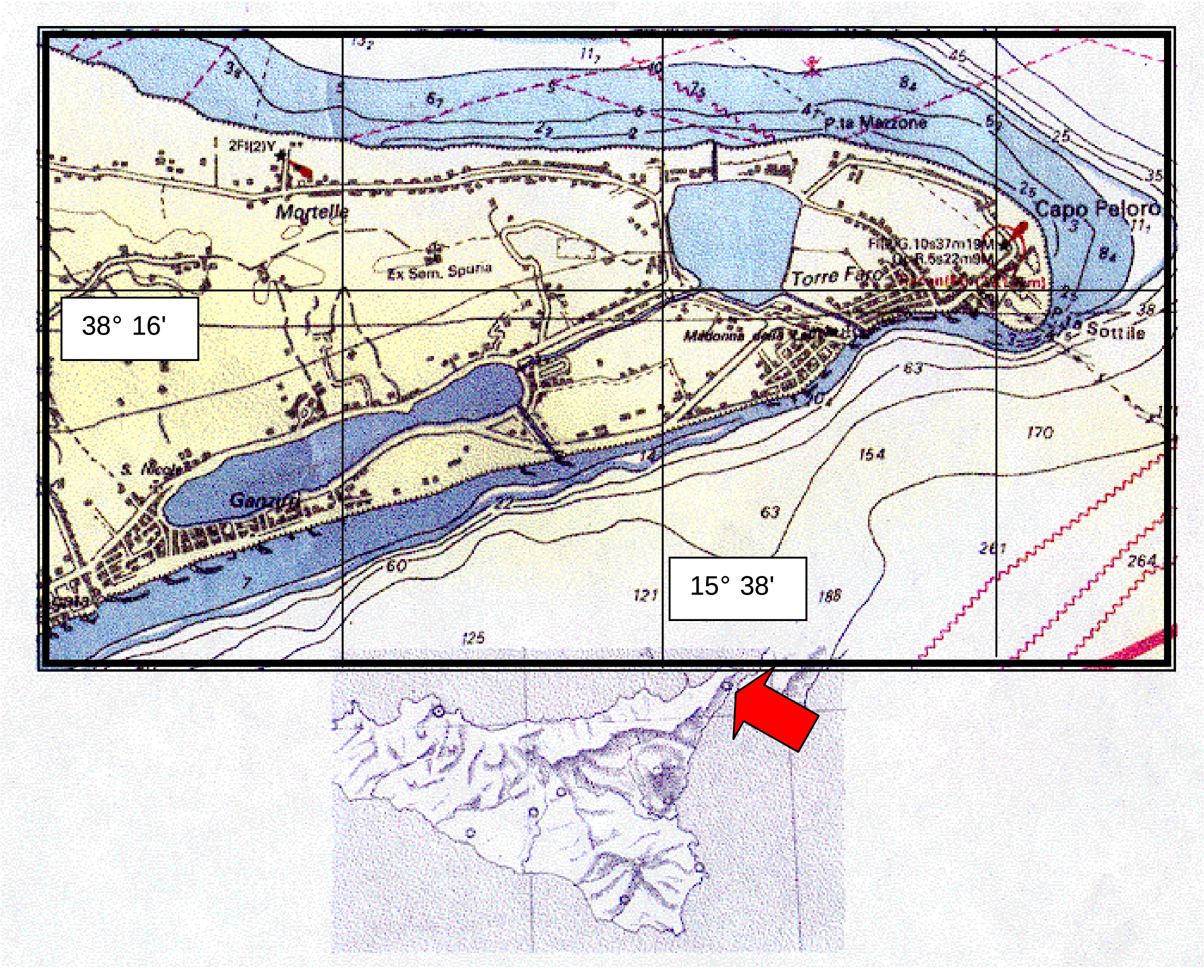

Figure 4.23. The Capo Peloro brackish system, Sicily (Italy). Ganzirri Lake is the southernmost basin.

Ganzirri Lake (38.26° N, 15.62° E) is the larger one, with a surface area of 0.338 km^2, a major axis of 1670 m and an average width of 200 m. Its maximum depth is 6.5 m and its estimated volume 0.975x10^6 m^3 (Abbruzzese and Genovese 1952). Due to its location, Ganzirri Lake gathers a considerable amount of freshwater from the land. As a consequence, and also due to its high surface to volume ratio, salinity and temperature variations induced by meteorological and climatic conditions are important.

The northern zone of the lake, which accounts for one quarter of the total surface area, is relatively shallow (maximum depth 1 m). It features a sandy bottom and large mats of the green alga *Chaetomorpha linum*, covered with dense tufts of epiphytes whose decomposition leads in summer to a significant oxygen uptake and hence to periodic dystrophic crises. Primary production in this zone is due to both phytoplankton and green and red macroalgae. In the southern zone, human impact is more direct due to the presence of the urban settlement of Ganzirri (population about 10,000). This zone has been extensively exploited for over a century for mussel culture. It is characterized by muddy sediments which become anoxic below the uppermost oxygenated layer. Primary production in the southern zone is primarily due to phytoplankton.

The objective of this study was to estimate the water, salt and nutrient budgets for Ganzirri Lake by applying the two-box, single-layer LOICZ budget modelling approach (Gordon *et al.* 1996). On the basis of previous investigations, two different steady states were considered which correspond to the warm and dry period (May-September) and to the cold and wet period (October-April). The data used in the model were collected from May 1998 to April 1999. Physical and chemical features of the lake were studied every two weeks in 10 sampling sites distributed throughout the lake and at the connections between the lake and its input and output environments (Cortese *et al.* 2000). Standard sampling and analytical procedures were applied (SIBM 1990). Air temperature and wet deposition data were obtained from a meteorological station located in Ganzirri at sealevel (Regione Siciliana 2001).

Figure 4.24. Ganzirri Lake (Pantano Grande).

<u>Water and salt balances</u>

From the morphological and bathymetric points of view, Ganzirri Lake can be divided in two sub-basins. The southernmost and inner basin has an average depth of 3.0 m and covers 0.253 km^2, approximately 75% of the total surface area. This inner basin can be assumed to be disconnected from the sea and communicates only with the northernmost and shallower part (Figure 4.25).

Ganzirri Lake has no fluvial inputs ($V_Q=0$). Major freshwater inputs in its inner part derive from direct nonpoint civil discharges ($V_{O\ inner}$) coming from urban settlements which are only partially sewered. These discharges are season-dependent due to the strong increase in population during the summer period. The outer basin (surface area 0.0846 km^2 and mean depth 1 m) exchanges water with Faro

Lake through the Canale Margi ($V_{O\ outer}$) and with the Ionian Sea through a narrow channel (Canale Due Torri). Geomorphological features of the drainage area suggests that surface runoff is also important and that groundwater inputs are present mainly in the inner part (V_G), though a precise evaluation of them is currently unavailable.

During the year considered in the study, direct rainfall to the lake was 705 mm, which is similar to the typical annual rainfall recorded for the area over the last three decades (734 mm, CV 23). The rainfall in the two periods was 160 mm in May-September (153 days) and 545 mm in October-April (212 days), a less extreme seasonal pattern than that of a typical year (129 mm and 612 mm in the two periods).

Evaporation (V_E) was estimated using Hargreaves' equation (Hargreaves 1975) and strongly exceeded precipitation (V_P) in the dry period.

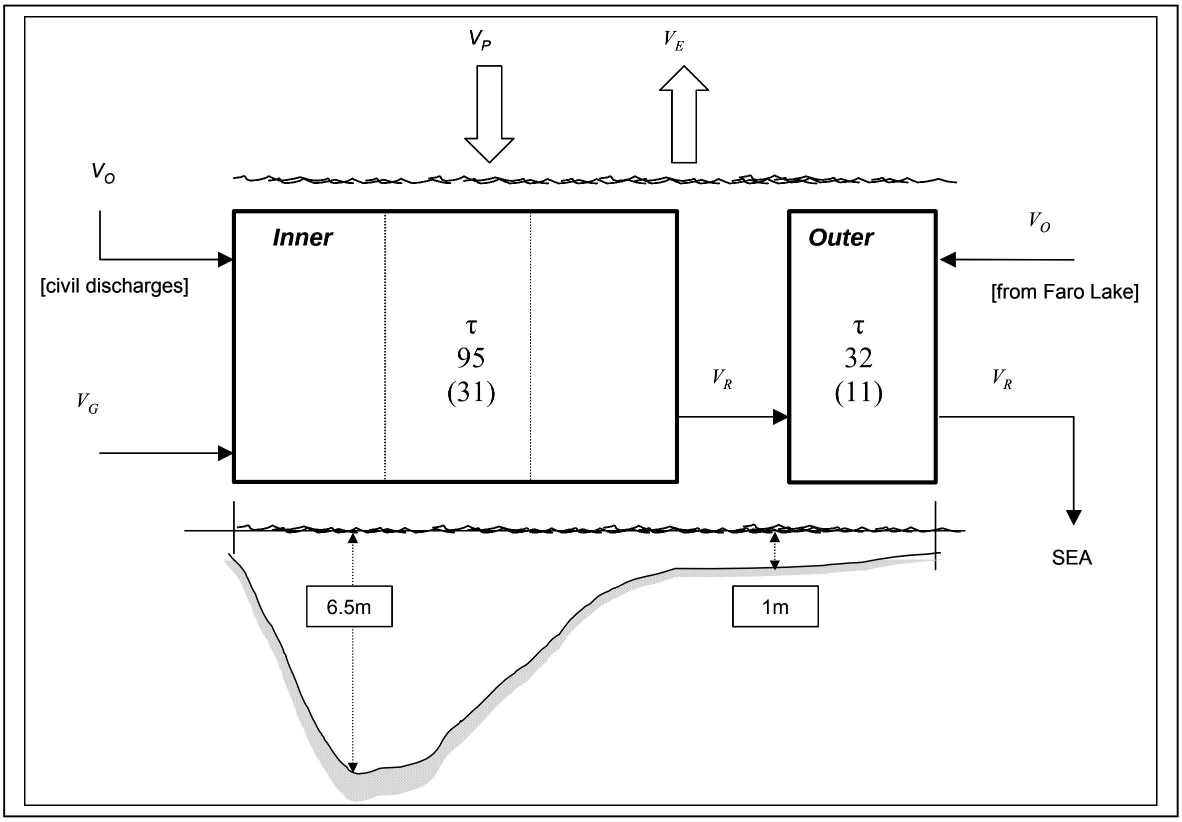

Figure 4.25. Schematic diagram of Ganzirri Lake showing main assumptions for modelling. Estimated water exchange times in dry (wet) period are indicated for the two sub-basins.

The estimated budgets are shown in Table 4.22. Net export of water from the lake to the sea, indicated by negative residual flow (V_R), was observed in both periods, with higher values in the wet period when the exchange flux V_X is maximum. The estimated water exchange times are in the order of 1 to 3 months for the inner basin in the wet and dry periods respectively. The water exchange times of the outer basin are of about 10 to 30 days in the same periods. As expected, the outer basin exhibits a more dynamic behaviour, with water exchange times three times shorter than those of the inner one. Time-weighted annual water budget are reported in Figure 4.26.

Table 4.22. Water fluxes, salinity and water exchange times for the two sub-basins of Ganzirri Lake in the two periods considered (1998-99). * time-weighted.

	Period	V_G	V_O	V_P	V_E	V_R	S_O	S_{syst}	S_{sea}	V_X	τ
		(10^3 m^3 d^{-1})					(psu)			(10^3 m^3 d^{-1})	(days)
Outer basin	*May-Sept (153 days)*	-	0.70	0.10	0.49	-0.92	32.90	32.60	38.00	1.75	32
	Oct-Apr (212 days)	-	0.70	0.19	0.25	-1.86	30.30	30.80	38.00	5.90	11
	*Annua*l*	-	0.70	0.15	0.35	-1.47	31.39	31.55	38.00	4.18	15
Inner basin	*May-Sept (153 days)*	1.00	0.80	0.29	1.48	-0.61	0.00	30.00	-	7.34	95
	Oct-Apr (212 days)	1.00	0.40	0.56	0.74	-1.22	0.00	29.20	-	22.88	31
	*Annual**	1.00	0.57	0.45	1.05	-0.96	0.00	29.54	-	16.37	44

Balance of non-conservative materials

Ganzirri Lake exhibits nutrient concentration patterns with features intermediate between the inflowing waters from the land and the open sea (Table 4.22) and shows evidence of nitrogen enrichment of a naturally oligotrophic ecosystem.

DIN_{syst} and DIP_{syst} concentrations are more or less similar for the two sub-basins, with DIN higher in wet season and DIP higher in dry season according to the input variations and the different consumption processes.

Table 4.23. Nutrient concentrations for the input waters, Ganzirri Lake and adjacent sea in the two periods considered (1998-99).

	Period	DIP_O	DIP_{syst}	DIP_{sea}	DIN_O	DIN_{syst}	DIN_{sea}
		(mmol m^{-3})					
Outer basin	*May-Sept*	3.00	0.29	0.21	50	6.26	4.00
	Oct-Apr	2.00	0.15	0.13	30	11.20	1.61
Inner basin	*May-Sept*	3.00	0.21	-	150	6.02	-
	Oct-Apr	2.00	0.13	-	100	14.76	-

On the basis of the available data, a first attempt was made to quantify the nutrient loads to the Lake. Results are presented in Table 4.24. For nitrogen, an annual load of 0.51 T yr^{-1} was estimated, which corresponds to a specific load of 1.5 g-N m^{-2} $year^{-1}$; for phosphorus a load of 0.04 T yr^{-1} was estimated, which corresponds to a specific load of 0.1 g-P m^{-2} $year^{-1}$.

Table 4.24. Estimated nutrient loads to Ganzirri Lake in the two periods considered (1998-99).

	Phosphorus				Nitrogen			
	mol d^{-1}			T yr^{-1}	mol d^{-1}			T yr^{-1}
	May-Sept	Oct-Apr	Annual	Annual	May-Sept	Oct-Apr	Annual	Annual
Outer basin	2.10	1.40	1.7	0.02	35	21	26.9	0.14
Inner basin	2.40	0.80	1.5	0.02	120	40	73.5	0.38
Total	4.50	2.20	3.17	0.04	155	61	100.5	0.51

DIP balance

The budgets for DIP are reported in Table 4.25. In both periods, *ΔDIP* (non-conservative DIP fluxes) are negative for both sub-basins with absolute values higher during the dry period, when DIP storage processes prevail (assimilation).

The lake acts as a net exporter of DIP to the sea in both dry and wet periods ($V_R DIP_R < 0$); in particular the outer basin seems to feed DIP also to the inner one ($V_X DIP_{X\ inner} > 0$ and $V_X DIP_{X\ outer} < 0$). Time-weighted DIP annual budget are reported in Figure 4.27.

Table 4.25 DIP budgets for the two sub-basins of Ganzirri Lake in the two periods considered (years 1998-99). * time-weighted

	Period	**$V_O\,DIP_O$**	**$V_R\,DIP_R$**	**$V_X\,DIP_X$**	***ΔDIP***	
		(mol d^{-1})			(mol d^{-1})	(mmol m^{-2} d^{-1})
Outer basin	*May-Sept*	2.10	-0.23	-0.14	-1.29	-0.015
	Oct-Apr	1.40	-0.26	-0.12	-0.73	-0.009
	*Annual**	1.69	-0.25	-0.13	-0.96	-0.011
Inner basin	*May-Sept*	2.40	-0.15	0.59	-2.84	-0.011
	Oct-Apr	0.80	-0.17	0.46	-1.09	-0.004
	*Annual**	1.47	-0.16	0.51	-1.82	-0.007

DIN balance

The budgets for DIN are reported in Table 4.26.

For the outer basin, *ΔDIN* (non-conservative DIN fluxes) are negative in both periods with absolute values higher during the wet period. This means that removal processes by primary producers are prevalent in that basin.

Values of opposite sign were found for the inner basin in the two periods. If compared to the yearly basis (weighed average) they are close to the balance, so that in the inner basin processes of storage and removal of DIN seem to balance each other during the year. Time-weighted DIN annual budget are reported in Figure 4.28.

Table 4.26. DIN budgets for the two sub-basins of Ganzirri Lake in the two periods considered (years 1998-99). * time-weighted

	Period	$V_O DIN_O$	$V_R DIN_R$	$V_X DIN_X$	ΔDIN	
		(mol d^{-1})			(mol d^{-1})	(mmol m^{-2} d^{-1})
Outer basin	*May-Sept*	35.0	-4.7	-4.0	-28.2	-0.33
	Oct-Apr	21.0	-11.9	-57.0	-49.4	-0.58
	*Annual**	26.9	-8.9	-34.8	-40.5	-0.48
Inner basin	*May-Sept*	120.0	-3.7	1.8	-118.1	-0.47
	Oct-Apr	40.0	-15.8	-81.5	57.3	0.23
	*Annual**	73.5	-10.7	-46.6	-16.2	-0.06

Stoichiometric calculations of aspects of net metabolism

The system is a net producer [$\Delta DIP<0$ and NEM>0] of organic matter; this seems valid for both sub-basins and particularly during summer periods (Table 4.27).

The term (*nfix-denit*) is generally negative. This indicates a prevalence of nitrogen removal processes (such as denitrification) over N-fixation. Processes of direct removal of algal biomass are also important, such as the natural export to the sea of free-floating algal sheets and biomass harvesting for management purposes.

Table 4.27. Evaluation of the ecosystem metabolism for the two sub-basins of Ganzirri Lake in the two periods considered (year 1998-99). * time-weighted

	Period	NEM	ΔDIN_{exp}	(*nfix-denit*)
		mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}
Outer basin	*May-Sept*	1.59	-0.24	-0.09
	Oct-Apr	0.95	-0.14	-0.44
	*Annual**	1.22	-0.18	-0.29
Inner basin	*May-Sept*	1.17	-0.18	-0.29
	Oct-Apr	0.42	-0.06	0.29
	*Annual**	0.73	-0.11	0.05

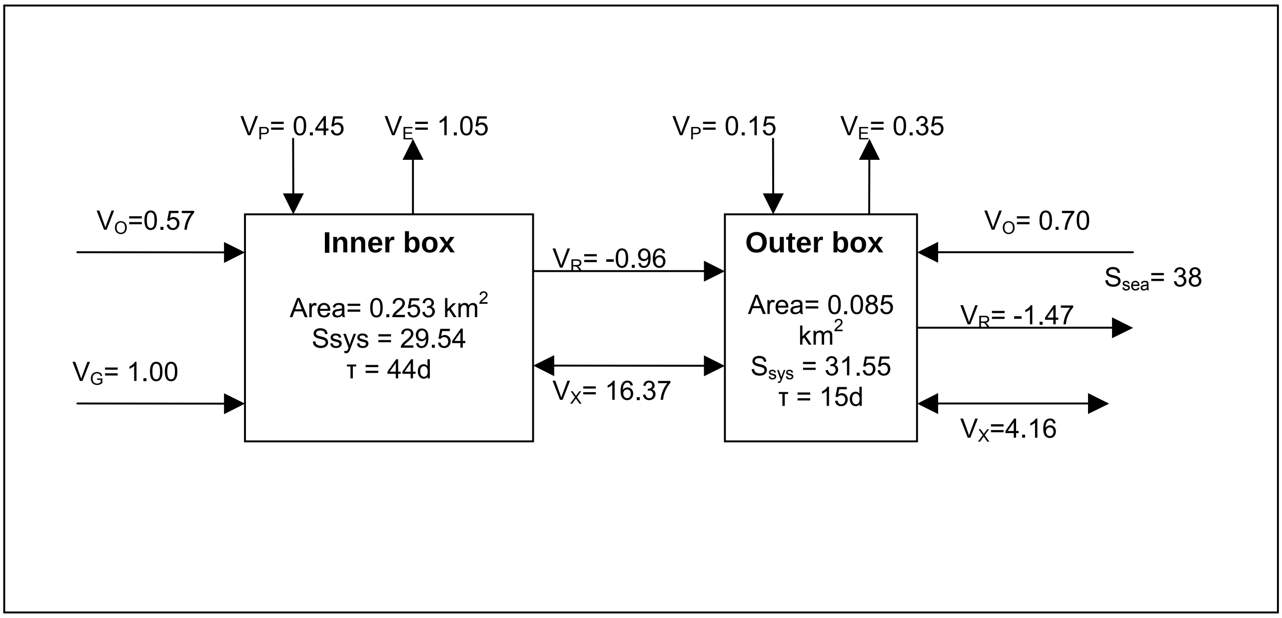

Figure 4.26. Water and salt budgets for Ganzirri Lake. Water fluxes are expressed in 10^3 m^3 d^{-1} and salinity in psu.

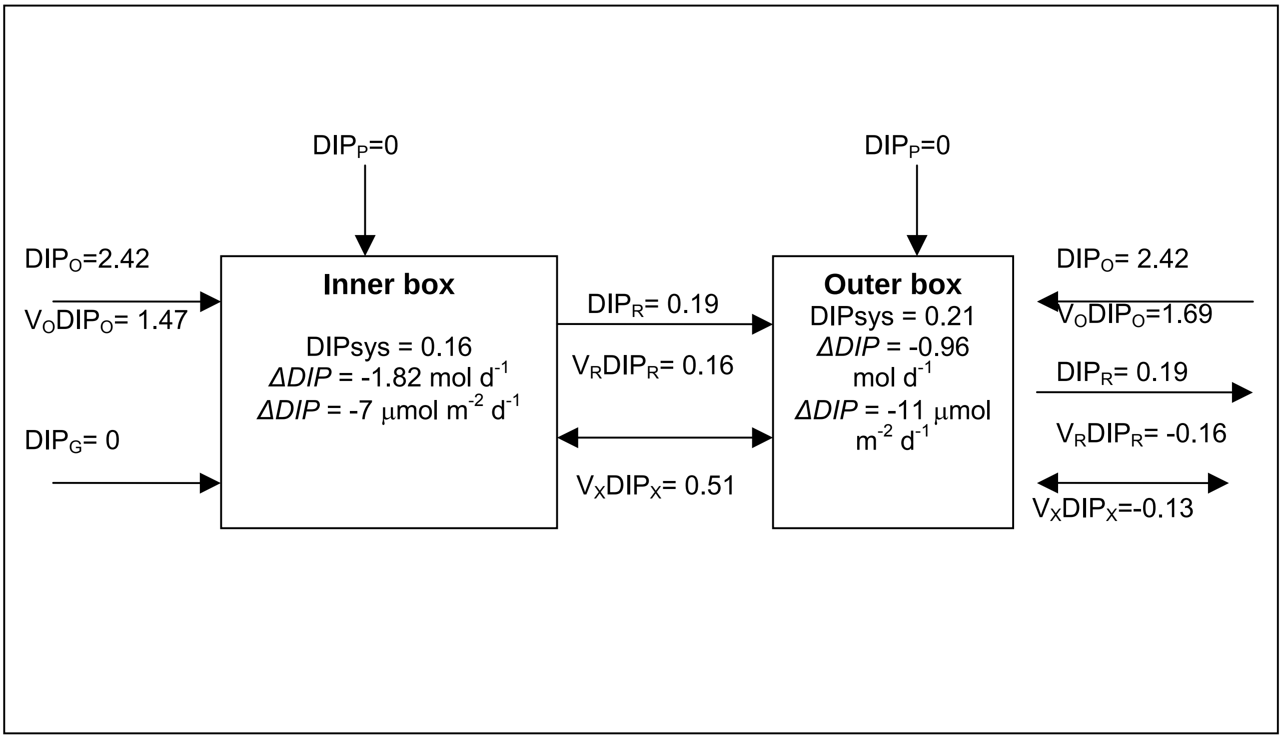

Figure 4.27. DIP budget for Ganzirri Lake. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

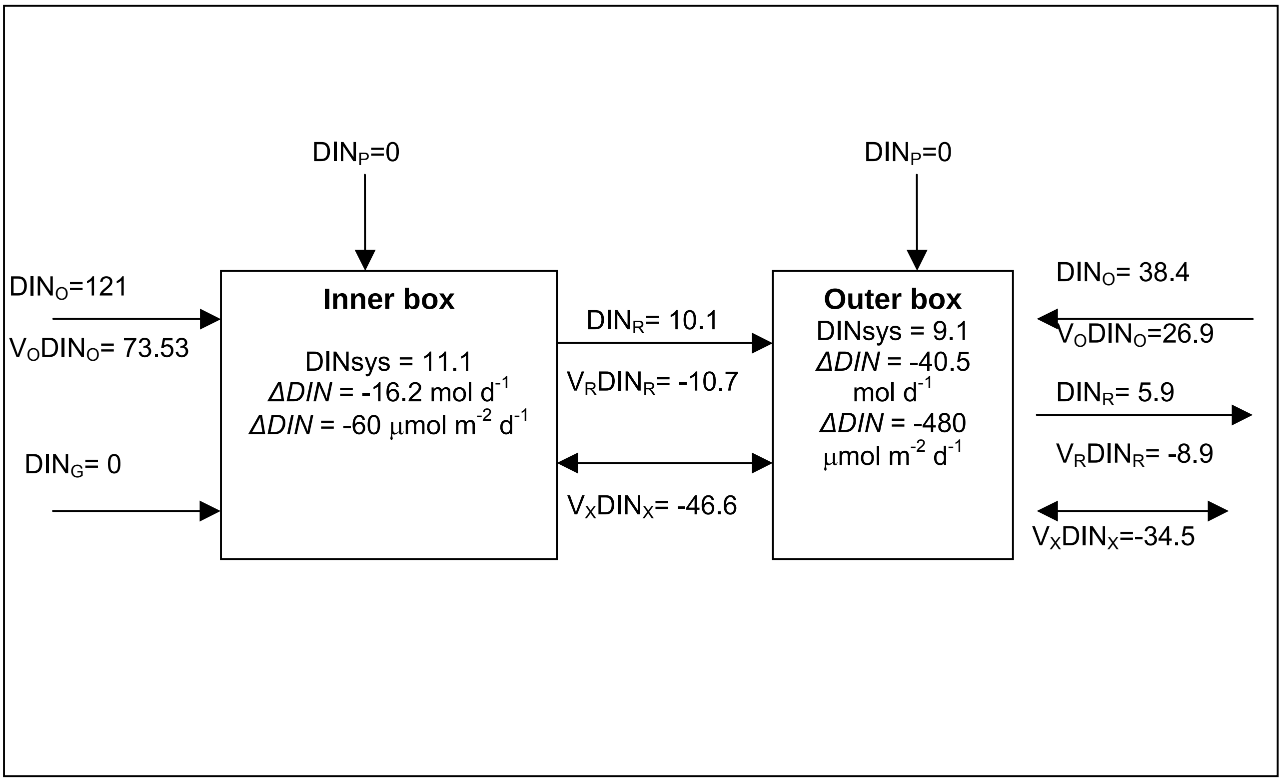

Figure 4.28. DIN budget for Ganzirri Lake. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

4.6 S'Ena Arrubia Lagoon, western Sardinia

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Study area

S'Ena Arrubia Lagoon (Figures 4.29 and 4.30) is located along the central western coast of Sardinia (39.83° N, 8.57° E); it is 1.2 km^2 in area and has a mean depth of 40 cm. Freshwater input is supplied from the watershed by two rivers: Rio Sant'Anna (also called Diversivo), which drains an area of 78.4 km^2 and showed no runoff from April 2001 to March 2002; and the Canale delle Acque Basse, (Figure 4.37) which drains 50 km^2 mostly originating from the drying up of a pond over 3000 ha wide and dedicated mainly to farming and cattle-breeding. This channel is below sea level and water is pumped from it into the lagoon. The lagoon communicates with the sea through a channel about 40 m wide, 230 m long and 1 m deep. The lagoon is very eutrophic (Sechi 1982; Fiocca *et al.* 1996) and dystrophic crises and fish kills occur occasionally. Anoxia and dystrophic crises were observed as early as the 1960s. Phytoplankton exhibit intense blooms in spring, especially due to *Cyclotella atomus* and *Chlorella* sp. The macroalgal component, mostly consisting of *Ulva* sp. and *Enteromorpha flexuosa* (Kützing) DeToni, becomes abundant in late spring-summer. Water characteristics show considerable variations. Salinity, for example, fluctuates greatly depending on the prevalent inputs (fresh or marine waters), while nitrogen and phosphorus can reach very high and abrupt peaks. The particular dynamics are determined by the quantity of input waters from the Canale delle Acque Basse, the source of most of the freshwater to the lagoon. The climate of the lagoon is Mediterranean, with a long hot summer and short mild rainy winter.

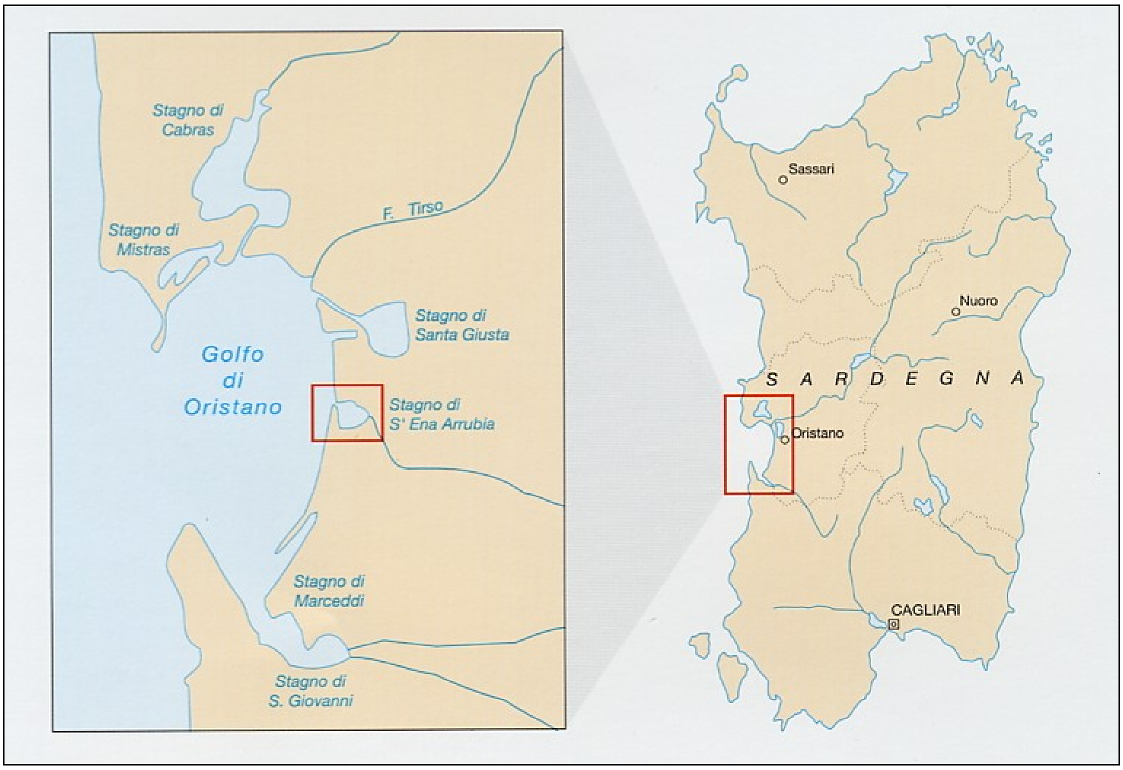

Figure 4.29. Location of S'Ena Arrubia Lagoon.

The LOICZ model was applied to data obtained between April 2001 and March 2002, during which an intensive investigation was carried out. In this period, precipitation and water inflows were lower than the average of the previous fifty-year period (360 mm versus 650 mm). Samples for phytoplankton and water chemical analyses were collected at weekly intervals from June to September and each month for the rest of the period; macroalgal samples were collected monthly in three areas of the lagoon and repeated three times for each area.

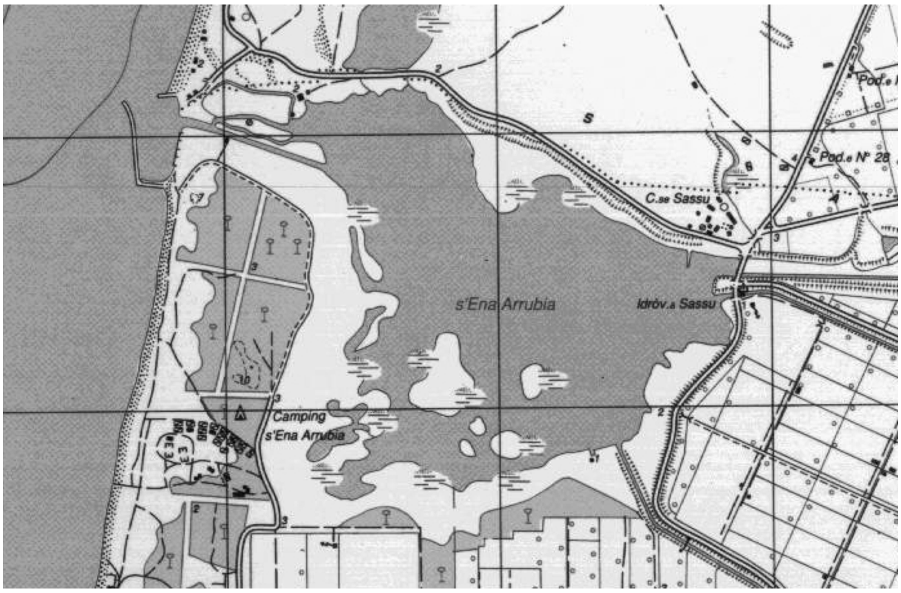

Figure 4.30. Map of S'Ena Arrubia Lagoon.

Budgets were calculated seasonally except for October, which was considered separately, as its hydrology is very different from that of November and December (see Figure 4.31 for rainfall data). Because the lagoon is characterized by small size and low depth, the one-box, one-layer model was used. The LOICZ model has been previously applied in S'Ena Arrubia Lagoon for the 1994-1995 period (Giordani *et al*. 2001).

Water and salt balance

Inputs showed salinity values between 3‰ and 5‰. Evaporation values were calculated according to Hargreaves' equation (Hargreaves 1975). Data relating to the groundwater supplies (S_G) are not available, but because most of the basin from which inputs flow is below sealevel, they are assumed to be zero, as are V_PS_P, V_OS_O and V_PS_E. Seasonal budgets are reported in Table 4.28 and the annual budget is shown in Figure 4.32. V_R values were always negative. The November-December period is distinctive because V_X was higher and water exchange faster, whereas the summer quarter exhibits longer residence time due to lower freshwater inputs.

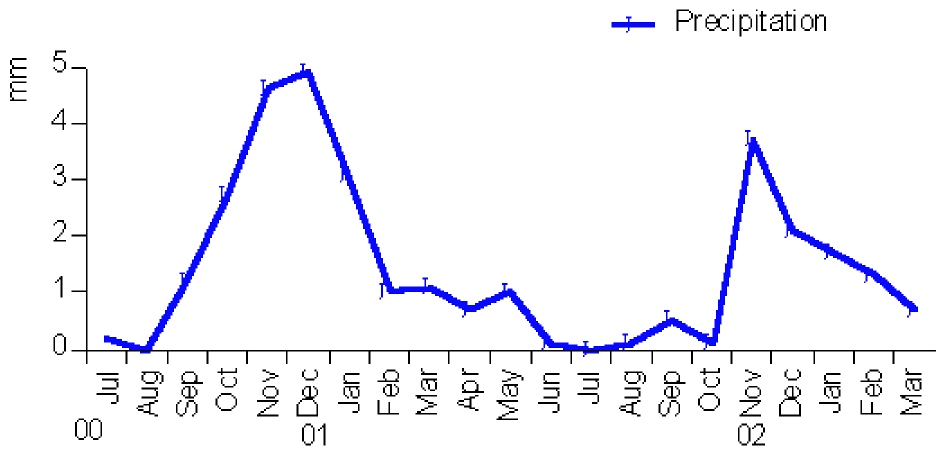

Figure 4.31. Precipitation dynamics in S'Ena Arrubia Lagoon.

Budgets of non-conservative materials

Concentrations of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) in inflow waters, the system and the adjacent sea are reported in Table 4.29.

DIP balance

DIP values present in precipitation waters are considered negligible and so equivalent to zero. DIP values measured in inflow waters were always rather high, particularly in spring and autumn months, with a maximum in October (17.7 mmol m^{-3}); in the lagoon, they ranged between 1.1 and 2.6 mmol m^{-3}. DIP seasonal budgets are reported in Table 4.30 and annual budget is reported in Figure 4.33. ΔDIP was negative in every period except November-December; in general, inputs were higher than outputs and this indicates that storing of inorganic phosphorus prevailed over mobilisation.

Table 4.28. Seasonal budgets of water, salinity and residence time in S'Ena Arrubia Lagoon. Water flux was expressed in $10^3 m^3 d^{-1}$, salinity in psu and residence time in days.

Season	V_Q	V_P	V_E	V_R	S_Q	S_{syst}	S_{ocn}	V_X	τ
Apr-May-Jun 01	25.4	0.6	3.0	-23.0	2.6	29.3	35.6	108.2	4
July-Ago-Sep 01	10.9	0.2	3.2	-7.9	3.2	32.8	37.2	54.9	8
Oct 01	10.8	0.1	1.9	-9.0	2.8	34.6	37.0	121.7	4
Nov-Dec 01	32.9	2.9	1.0	-34.8	1.9	33.6	37.0	342.9	1
Jan-Feb-Mar 02	33.4	1.2	1.4	-33.2	3.8	22.4	37.0	58.8	5
Annual (time-weighted)	23.7	1.0	2.2	-22.5	2.9	29.6	36.7	123.0	3

Table 4.29. Seasonal concentration of nutrients (mmol m^{-3}) in S'Ena Arrubia Lagoon.

Season	DIP_Q	DIP_{syst}	DIP_{ocn}	DIN_{atm}	DIN_Q	DIN_{syst}	DIN_{ocn}
Apr-May-Jun 01	15.2	2.6	0.11	46	80.1	3.6	1.30
July-Ago-Sep 01	12.3	1.5	0.08	46	43.6	14.4	0.85
Oct 01	17.7	1.1	0.03	46	49.6	2.9	1.13
Nov-Dec 01	7.7	1.1	0.12	46	75.8	15.4	2.36
Jan-Feb-Mar 02	14.0	1.4	0.08	46	145.0	9.6	2.54

Table 4.30. Seasonal DIP budgets in S'Ena Arrubia Lagoon.

Season	V_Q DIP_Q mol d^{-1}	V_R DIP_R mol d^{-1}	V_X DIP_X mol d^{-1}	*ΔDIP* mol d^{-1}	*ΔDIP* µmol m^{-2} d^{-1}
Apr-May-Jun 01	386	-31	-269	-86	-72
July-Ago-Sep 01	134	-6	-78	-50	-42
Oct 01	191	-5	-130	-57	-47
Nov-Dec 01	253	-21	-336	+101	87
Jan-Feb-Mar 02	468	-25	-78	-365	-304
Annual (time-weighted)	304	-19	-173	-111	-93

DIN balance

In calculating the DIN budget, significant supplies of DIN present in precipitation were considered; as data of the studied period were not available, data of 1992-1996 relative to the previous study carried out on the same site are used.

DIN seasonal budgets are reported in Table 4.31 and the annual budget is shown in Figure 4.34.

Table 4.31. Seasonal DIN budgets in S'Ena Arrubia Lagoon.

Season	V_{atm} DIN_{atm} mol d^{-1}	V_Q DIN_Q mol d^{-1}	V_R DIN_R mol d^{-1}	V_X DIN_X mol d^{-1}	Δ*DIN* mol d^{-1}	Δ*DIN* mmol m^{-2} d^{-1}
Apr-May-Jun 01	28	2035	-56	-249	-1758	-1.47
July-Ago-Sep 01	9	475	-60	-744	320	0.27
Oct 01	5	536	-18	-215	-308	-0.26
Nov-Dec 01	133	2494	-309	-4471	2153	1.79
Jan-Feb-Mar 02	55	4843	-202	-415	-4281	-3.57
Annual (time-weighted)	45	2284	-132	-1117	-1080	-0.90

Δ*DIN* is negative in April-June, October and January-March showing a dominance of uptake processes over releases, which conversely dominate (positive values) in November-December and July-September (1.79 mmol m^{-2} d^{-1} and 0.27 mmol m^{-2} d^{-1} respectively).

Stoichiometric calculations relative to the net metabolism of the system

Studies of biotic data from 2001 to 2002 (Trebini 2003) showed that primary production is mainly performed by phytoplankton in late autumn and winter and by macroalgae in the remaining period (Figure 4.35); considering these results two different ratios C:N:P were assumed: the Redfield ratio (106:16:1) was used in autumn-winter (October, November-December and January-February-March) whereas the Atkinson and Smith ratio for *Ulva* sp. (336:35:1) (1983) was preferred for the period from April to September because *Ulva* sp. was more abundant then *Enteromorpha flexuosa*.

Calculations (Table 4.32-A) show that nitrogen fixation generally prevailed over denitrification: the highest value, 1.74 mmol m^{-2} d^{-1}, occurred in the July-September quarter. With the exception of November-December, very high values of net ecosystem metabolism (NEM or (*p-r*)) were detected throughout the investigation period, so that there is a prevalence of productive processes. The highest value is that for the January-March quarter, equivalent to 32.2 mmol m^{-2} d^{-1}. The negative NEM in November-December (-9.2 mmol m^{-2} d^{-1}) could be due not only to the low production rates but also to high decomposition rates of organic substances produced during the summer months.

Because the 1994 to 1995 study used the Redfield ratio (106:16:1) for all the seasons (Giordani *et al.* 2001), the same was applied to the data from April to September 2001. Results did not show great differences in the general patterns (Table 4.32-B): lower NEM and (*nfix-denit*) values were estimated in the warm months and a slightly negative value for (*nfix-denit*) was observed during April-June (-0.32 mmol m^{-2} d^{-1}).

Table 4.32-A. Seasonal variation of (*nfix-denit*) and net ecosystem metabolism (*p-r*) (Atkinson and Smith ratio and Redfield ratio).

Season	**C:N:P** ratio	**ΔDIN_{exp}** (mmol m^{-2} d^{-1})	**(*nfix-denit*)** (mmol m^{-2} d^{-1})	**(*p-r*)** (mmol m^{-2} d^{-1})
Apr-May-Jun 01	336:35:1	-2.52	1.05	24.2
July-Ago-Sep 01	336:35:1	-1.47	1.74	14.1
Oct 01	106:16:1	-0.75	0.49	5.0
Nov-Dec 01	106:16:1	1.39	0.40	-9.2
Jan-Feb-Mar 02	106:16:1	-4.86	1.29	32.2
***Annual* (time-weighted)**		**-2.03**	**1.13**	**16.41**

Table 4.32-B. Seasonal variation of (*nfix-denit*) and net ecosystem metabolism (*p-r*) (Redfield ratio for all seasons).

Season	**C:N:P** ratio	**ΔDIN_{exp}** (mmol m^{-2} d^{-1})	**(*nfix-denit*)** (mmol m^{-2} d^{-1})	**(*p-r*)** (mmol m^{-2} d^{-1})
Apr-May-Jun 01	106:16:1	-1.15	-0.32	7.6
July-Ago-Sep 01	106:16:1	-0.67	0.94	4.5
Oct 01	106:16:1	-0.75	0.49	5.0
Nov-Dec 01	106:16:1	1.39	0.40	-9.2
Jan-Feb-Mar 02	106:16:1	-4.86	1.29	32.2
***Annual* (time-weighted)**		**-1.49**	**0.58**	**9.86**

Conclusions

A prevalence of nutrient uptake over release was observed in the lagoon *(ΔDIP* and ΔDIN were negative in most of the period); the positive values calculated for November-December for ΔDIP and also for July -September for ΔDIN indicate that mobilization processes prevailed occasionally.

It can be deduced from the (*nfix-denit*) values that nitrogen fixation prevailed consistently over denitrification; these results confirm findings of previous studies relative to the application of the LOICZ model to the 1994-1995 period (Giordani *et al.* 2001). Further, (*nfix-denit*) values were lower than 2 mmol m^{-2} d^{-1} while, in the 1994-95 application, (*nfix-denit*) values were higher than 2 mmol m^{-2} d^{-1} in the autumn months.

NEM was generally positive: the productive processes in the lagoon seem to prevail over respiration throughout most of the year. These results, as already pointed out by Giordani *et al.* (2001) confirm that S'Ena Arrubia Lagoon should be considered an autotrophic system. However, a negative value between November and December appeared in NEM values, which, while not reported in 1994-1995, suggests that respiration can prevail over production in some periods.

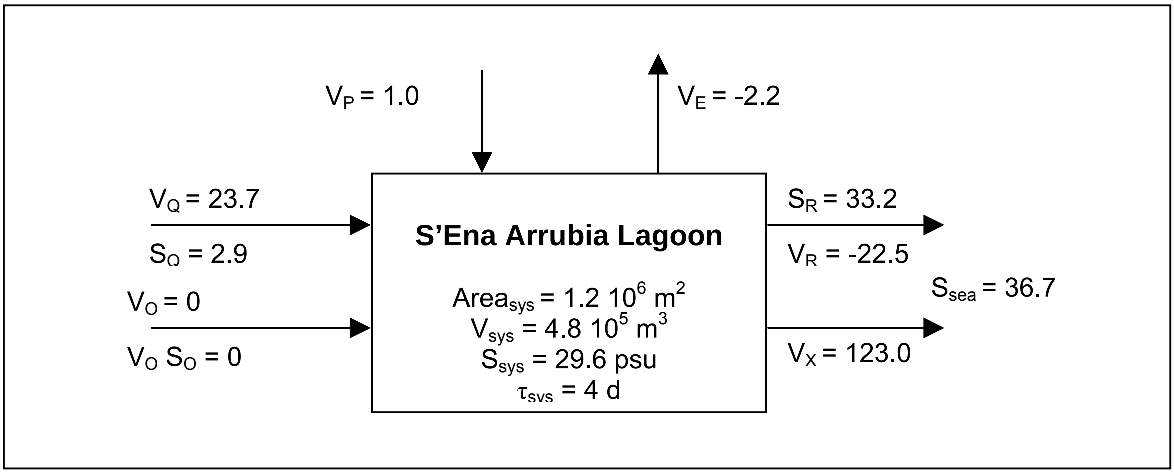

Figure 4.32. Water and salt budgets for S'Ena Arrubia Lagoon. Water fluxes are expressed in 10^3 $m^3\ d^{-1}$ and salinity in psu. Values were calculated as annual weighted averages of seasonal results.

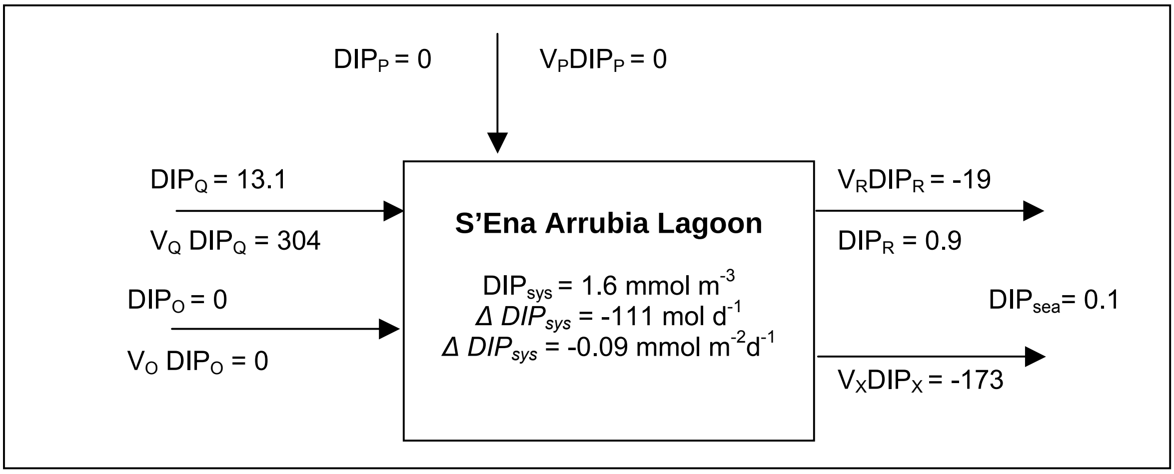

Figure 4.33. **DIP budget for S'Ena Arrubia Lagoon.** Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Values were calculated as annual weighted averages of seasonal results.

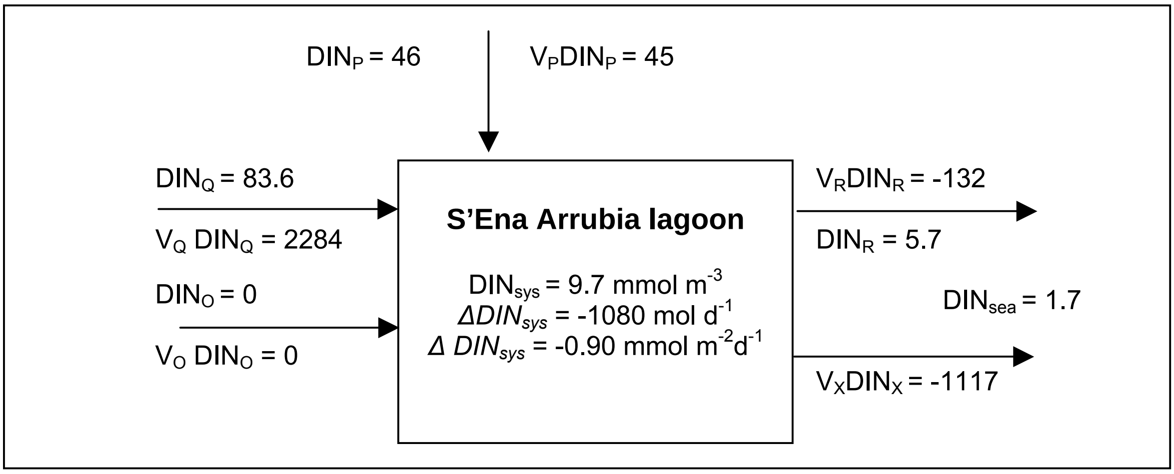

Figure 4.34. DIN budget for S'Ena Arrubia Lagoon. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Values were calculated as annual weighted averages of seasonal results.

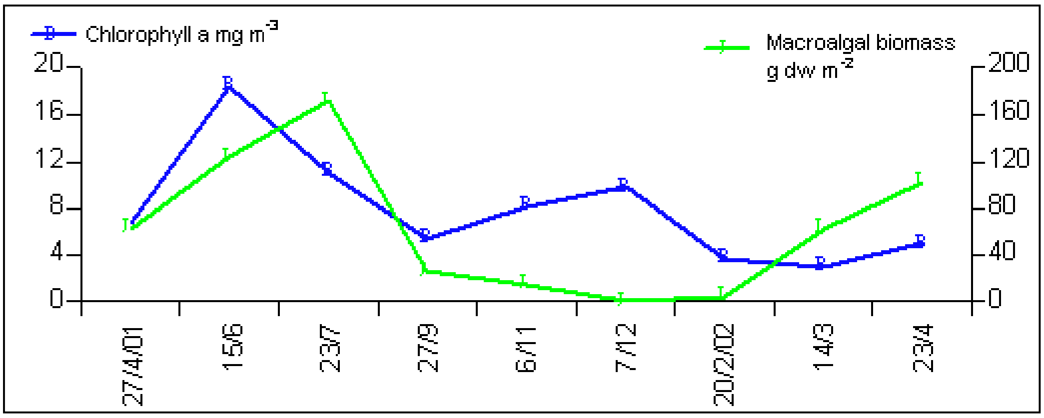

Figure 4.35. Chlorophyll *a* and macroalgae biomass dynamics.

Figure 4.36. Aerial view of S'Ena Arrubia Lagoon.

Figure 4.37. Canale delle acque basse and pumping station.

Figure 4.38. View of S'Ena Arrubia Lagoon.

5 COASTAL SYSTEMS OF THE TYRRHENIAN SEA (WEST COAST)

5.1 Lagoon of Orbetello, Tuscany

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Study area description

The Lagoon of Orbetello is located in southern Tuscany, on the west coast of Italy (Figure 5.1), between 42.41° N, 11.17° E and 42.48° N 11.28° E, and covers a total area of 25.25 km^2. This lagoon consists of two communicating basins known as Ponente (West) and Levante (East) measuring in area respectively 15.25 and 10.0 km^2 (values according to Travaglia and Lorenzini, 1985, modified as a result of recent filling operations), with an average depth of about 1 m.

Over the past thirty years, the Lagoon of Orbetello, as with many other coastal environments in the world (Morand and Briand 1996) has developed considerable seaweed (macroalgae) proliferation (see Lenzi 1992 and Bombelli and Lenzi 1996, for detailed reviews).

This phenomenon depends mostly on intensive aquaculture and agricultural activities, as well as the discharge of treated/untreated urban wastewater, which increased strongly as a consequence of the development of the tourist trade (Lenzi 1992). The increase in eutrophication has gradually led to qualitative and quantitative changes in the vegetation from seagrasses (phanerogams) to macroalgae (Figure 5.2). Various species of opportunistic macroalgae have thus alternated in the dominance of the submerged vegetation (Lenzi and Mattei 1998). Macroalgal blooms began to appear in the mid-1960s and have been periodically accompanied by microalgal blooms (Tolomio and Lenzi 1996). The algal masses produced almost uninterruptedly throughout the year are moved by the winds and accumulate at high densities, sometimes exceeding 20 kg m^{-2} (Lenzi, unpublished data). Decomposition of the seaweed biomass in summer, and the subsequent sulphate reduction processes, cause a drastic decrease of dissolved oxygen and development of toxic reducing gases, and are the main causes of aquatic fauna mortality (Izzo and Hull 1991). These harsh environmental conditions led to a reduction in the quantity and quality of the fish output from the lagoon beginning in the 1980s (Lenzi 1992) and the outflow of discolored water to the adjacent beach areas caused a problem for tourism.

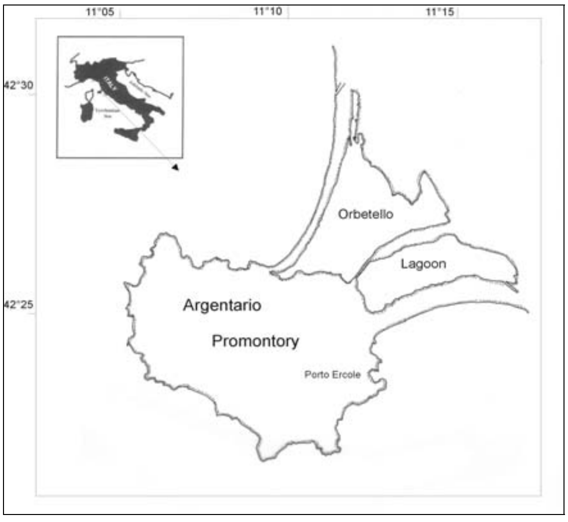

Figure 5.1. Location and map of the Lagoon of Orbetello.

A basin authority (Lagoon of Orbetello Environmental Reclamation Authority, OLERA) was set up to implement action strategies that could solve the environmental crisis. The OLERA acted in three main ways: removal of the macroalgal masses from the lagoon; increasing the inputs of clean seawater in the lagoon; reduction of nutrients originating from human activities (Lenzi and Mattei 1998).

Action was also taken to increase water renewal, through the three sea-lagoon canals. The hydraulic model proposed by Bucci *et al.* (1989) was adopted as a basis for the environmental management activity in the lagoon. This consisted essentially of pumping water from two sea-lagoon canals into the lagoon, and allowing it to exit through the third canal. After the establishment of the OLERA, the pumping was boosted from 8000 l s^{-1} to 20,000 l s^{-1}. The pumping rate is intensified in the warmer months. All domestic wastewaters, previously discharged directly in the lagoon, are collected and pumped to a treatment plant. The treatment plant effluent is discharged into a bounded shallow phytotreatment pond (marginal lagoon area) of about 12 hectares (Figure 5.3). The phytotreatment effluent water is then discharged into the main lagoon. Using this system it was possible to decrease the nutrient concentrations of these discharges with benefits to the whole lagoon (Lenzi *et al.* 1998a). Four large aquaculture plants discharge their waste water into the lagoon. The two largest plants discharged their effluent into a semi-closed 9 hectare area that was delimited by an embankment in 1996. The water from the two phytotreatment ponds and the wastewater from the two smallest fishfarms constitute persistent anthropogenic sources of N and P.

OLERA activities have thus resulted in a significant reduction in algal biomass production in the lagoon (Lenzi and Mattei 1998; Lenzi *et al.* 1998a). Since 1996, seagrasses have returned to the lagoon, and, as of 2000, they cover 60% of the bottom surface.

In this paper, the one-box, one-layer LOICZ biogeochemical model was applied to the Lagoon of Orbetello considering a period of one year using data collected between August 1999 and July 2000.

Results

The main data for the application of the LOICZ model are reported in Tables 5.1 and 5.2.

Table 5.1. Characteristics of the Lagoon of Orbetello (Lenzi *et al.* 2003) and the adjacent Tyrrhenian Sea (unpublished data, collected in 1999). S = salinity; DIN = dissolved inorganic nitrogen, average; DIP = dissolved inorganic phosphorus, average.

System		**Sea**	
Area (km^2)	25.25		
average depth (m)	1		
S_{sys} (psu)	35	S_{sea}(psu)	37
DIP_{sys} (mmol m^{-3})	0.39	DIP_{sea}(mmol m^{-3})	0.16
DIN_{sys} (mmol m^{-3})	44	DIN_{sea} (mmol m^{-3})	0.82

Water and salt balance

$V_O = V_{O1} + V_{O2} + V_{O3} + V_{O4} + V_{O5} = 146.84\ m^3\ d^{-1}$

$V_R = - V_Q - V_P - V_G - V_O - V_{sea} + |V_E| = - 491\times10^3\ m^3\ d^{-1}$

$V_X = (V_R S_R + V_{O1} S_{O1} + V_{O2} S_{O2} + V_{O3} S_{O3} + V_{O4} S_{O4} + V_{O5} S_{O5} + V_{sea} S_{sea}) / (S_{sys} - S_{sea}) = 2725\times10^3\ m^3\ d^{-1}$

$\tau = V_{sys} / (V_x + |V_R|) = 8$ d

where $\mathbf{V_R}$ is the residual flow, $\mathbf{V_X}$ the exchange flow, and τ is the average residence time. The annual water budget is shown in Figure 5.4.

Table 5.2. Mean water inputs estimated for the Lagoon of Orbetello for 1999-2000 (Lenzi *et al.* 2003, and unpublished data for 1999).

Source	**Water flow (10^3 m^3 d^{-1})**	**Salinity (psu)**	**DIP (mmol m^{-3})**	**DIN (mmol m^{-3})**
Precipitation (P)	67.1	0	0.0	46
Evaporation (E)	-28.5	0	0	0
Albegna river (Q)	86.4	0	0.5	147
Subterranean springs (G)	0			
Wastewater treatment plant (O1)	5.18	0	77	1052
Nassa fish farm (O2)	12.05	37	4.16	129
La Rosa fish farm (O3)	17.28	35	3.8	147
Ittima fish farm (O4)	51.8	30	2.5	119
Il Vigneto fish farm (O5)	60.5	25	2.26	186
Pumping from the Sea (Vsea)	219.2	37	0.16	0.82

Budgets of non-conservative materials

DIP balance
$DIP_R = (DIP_{sea} + DIP_{sys}) / 2 = 0.28$ mmol m^{-3}

$\Delta DIP = - [V_Q DIP_Q + V_P\ DIP_P + V_{O1}\ DIP_{O1} + V_{O2}\ DIP_{O2} + V_{O3}\ DIP_{O3} + V_{O4}\ DIP_{O4} + V_{O5}\ DIP_{O5} + V_E\ DIP_E + V_{sea} DIP_{sea} + V_R\ DIP_R + V_X\ (DIP_{sea} – DIP_{sys})] = -96$ mol d^{-1}

$\Delta DIP = - 96$ mol d^{-1} /(25.25 km^2) = -0.004 mmol m^{-2} d^{-1}

The DIP budget is shown in Figure 5.5.

DIN balance
$DIN_R = (DIN_{sea} + DIN_{sys}) / 2 = 22.41$ mmol m^{-3}

$\Delta DIN = - [V_Q DIN_Q + V_P DIN_P + V_{O1}\ DIN_{O1} + V_{O2}\ DIN_{O2} + V_{O3}\ DIN_{O3} + V_{O4}\ DIN_{O4} + V_{O5}\ DIN_{O5} + V_E DIN_E + V_{sea} DIN_{sea} + V_R DIN_R + V_X (DIN_{sea} - DIN_{sys})] = 85723$ mol d^{-1}

$\Delta DIN = 85723$ mol d^{-1} / (25.25 km^2) = 3.39 mmol m^{-2} d^{-1}

The DIN budget is shown in Figure 5.6.

Stoichiometric calculation of aspects of net system metabolism
The estimated average CNP ratio in lagoonal macroalgae is 712:76:1 (Lenzi *et al.* 1998a; Lenzi *et al.* 2003) resulting in the following estimates of metabolism:

NEM = $(p\text{-}r) = - \Delta DIP$ (C:P) = - (- 0.004 mmol m^{-2} d^{-1}× 712) = 2.8 mmol m^{-2} d^{-1}

$(nfix\text{-}denit) = \Delta DIN - \Delta DIN_{exp} = \Delta DIN - \Delta DIP$ (N:P) = 3.4 mmol m^{-2} d^{-1} - (-0.004 mmol m^{-2} d^{-1} × 76) = 3.69 mmol m^{-2} d^{-1}
where NEM is the net metabolism of the ecosystem, *nfix* is nitrogen fixation and *denit* is DIN lost through denitrification.

For comparative purposes, applying the Redfield ratio (106:16:1), NEM and (*nfix-denit*) result in values of 0.24 mmol m^{-2} d^{-1} and 3.45 mmol m^{-2} d^{-1}, respectively (Table 5.3). They are both smaller than the previous data, NEM by one order of magnitude.

[NEM $_{\mathrm{Redfield}}$ = $(p\text{-}r) = -\Delta DIP$ (C:P) = - (- 0.004 mmol m^{-2} d^{-1}× 106) = 0.24 mmol m^{-2} d^{-1}

$(nfix\text{-}denit)_{\mathrm{Redfield}} = \Delta DIN - \Delta DIN_{exp} = \Delta DIN - \Delta DIP$ (N:P) = 3.39 mmol m^{-2} d^{-1} - (-0.004 mmol m^{-2} d^{-1} × 16) = 3.45 mmol m^{-2} d^{-1}]

Table 5.3. Results of the stoichiometric calculations considering 2 different CNP ratio values (experimental and Redfield). Values are in mmol m^{-2} d^{-1}.

C:N:P	***ΔDIN exp***	**NEM *(p-r)***	**(*nfix-denit*)**
712:76:1	-0.30	2.8	3.69
106:16:1	-0.06	0.24	3.45

Conclusions

The positive value of *ΔDIN* means that the Lagoon of Orbetello can act a source of inorganic nitrogen, while *ΔDIP*, which is slightly negative, suggest that for this nutrient, the system can be considered well-balanced between DIP sources and sinks, although with a slight dominance of processes which remove inorganic phosphorus from the water column.

These processes could be the precipitation of insoluble orthophosphate compounds in the sediments. Therefore, this ecosystem acts as a weak DIP sink accumulating phosphorus, which is, according to Lenzi *et al*. (1998a, 1999) unavailable for algal blooms.

The positive NEM value means that production prevails over respiration. This result confirms the environmental improvement of the Lagoon of Orbetello after the OLERA restoration, as reported in recent papers (Lenzi and Mattei 1998; Lenzi *et al*. 1998a, 1999, 2003). Finally, the positive value of (*nfix-denit*) means dominance of the processes that increase DIN availability.

Figure 5.2. View of the Lagoon of Orbetello (photo by M. Lenzi).

Figure 5.3. Phytotreatment ponds (photo by M. Lenzi).

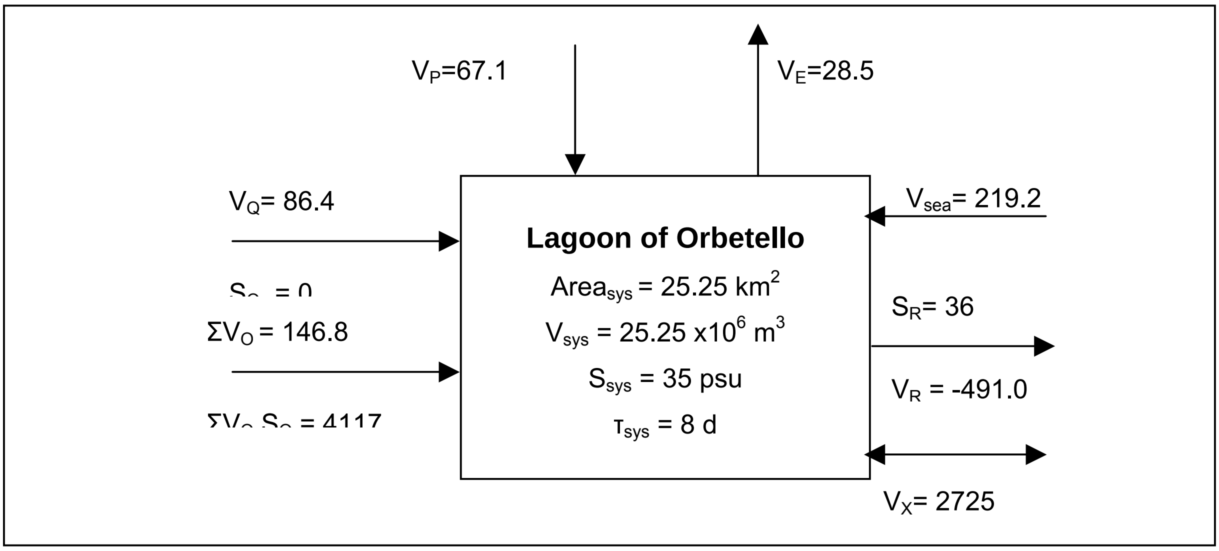

Figure 5.4. Water and salt budget for the Lagoon of Orbetello. Water fluxes are expressed in 10^3 $m^3\ d^{-1}$ and salinity in psu.

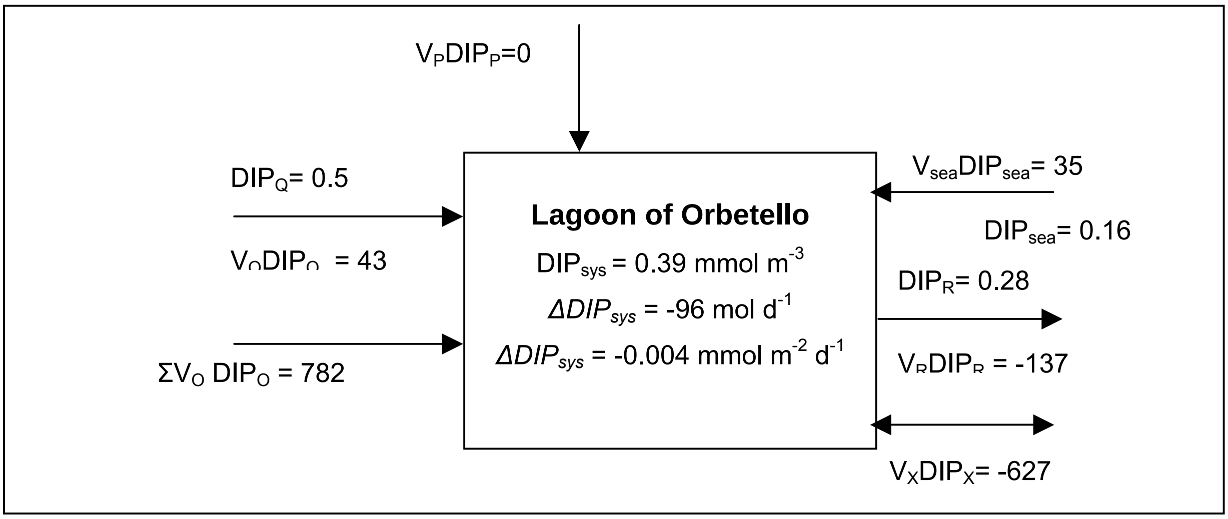

Figure 5.5. **DIP budget for the Lagoon of Orbetello.** Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

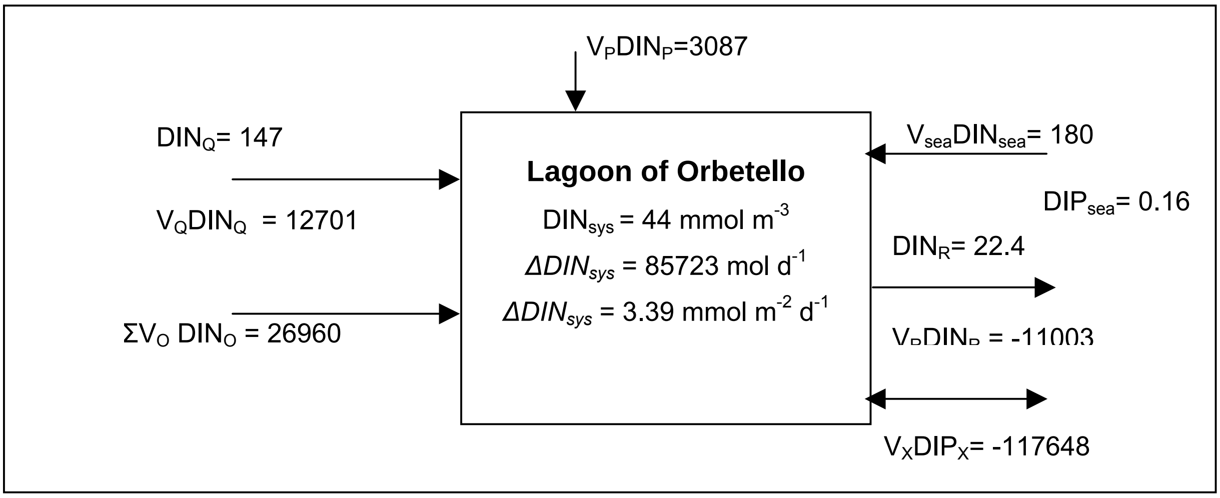

Figure 5.6. DIN budget for the Lagoon of Orbetello. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}.

6 COASTAL SYSTEMS OF GENOA AND THE LIGURIAN COAST

6.1 Ligurian Coast (Gulf of Genoa)

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Introduction

The Ligurian–Provencal Basin, together with the Gulf of Lions and the Catalan Sea, forms the north-western Mediterranean Basin. This region is characterized by a general cyclonic circulation fed by two distinct fluxes, one from the Tyrrhenian Sea through the Corsica Channel and the other from the north-western side of Corsica. The two fluxes merge north of the island generating a very stable current that closely follows the sea bottom bathymetry along the Italian coast. A marked front, recognizable both in temperature and salinity, separates the coastal waters from the colder and saltier waters of the basin interior (Gasparini *et al.* 1999). Less is known about the coastal circulation of the Ligurian Sea, but it appears to be associated with the general Mediterranean cyclonic vortex. Clearly, the morphology, meteorology and hydrodynamics of the area can modify the sub-basin scale circulation features (Manzella and Stocchino 1982).

The waters of the Ligurian Sea are characterized by a relative lack of nutrient salts and this is an impediment to greater productivity of the basin. The highest concentrations of nutrients were found near the coastline or in particular geographical areas such as river estuaries, ports and inlets; nevertheless high concentrations were also found in the open sea related to the upwelling of the deep, nutrient rich waters (Dagnino *et al.* 1990).

This study aims to quantify the fluxes of nitrogen and phosphorus in the coastal area of the Gulf of Genoa (Ligurian Sea), in order to understand the biogeochemical processes occurring in the system. The budgetary analysis was performed following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), using a two-layer model (designed for stratified systems) to describe the summer waters and nutrient dynamics in 1996. To complete the annual cycle, it will be necessary to consider the remaining seasons. Moreover, in this preliminary study we have not taken into account the coastal circulation in the area, which can influence nutrient distributions. The data obtained here, however, can supply preliminary information in order to compare this area with the other coastal systems in which the LOICZ Model was applied.

Study area description, sample collection and analysis

The study area (44.35-44.45 °N, 8.70-9.16 °E) (Figure 6.1), located in the Gulf of Genoa, is delimited on the north by the coastline between Genoa and the Promontory of Portofino, and on the south by the 50-m isobath. The area was defined according to the sampling strategies for environmental monitoring of coastal areas (Italian law, D.L.vo 152/99). It has a surface area of 52 km^2 and a mean water depth of 28 m.

The shoreline has a surface of about 200 km^2 and is largely urbanized (*ca.* 800,000 inhabitants), with intense industrial and harbor activity in the central-western part. Therefore, terrestrial sources of nutrients from sewage treatment waters and torrent-like rivers bring a significant supply of nitrogen and phosphorus to the study area.

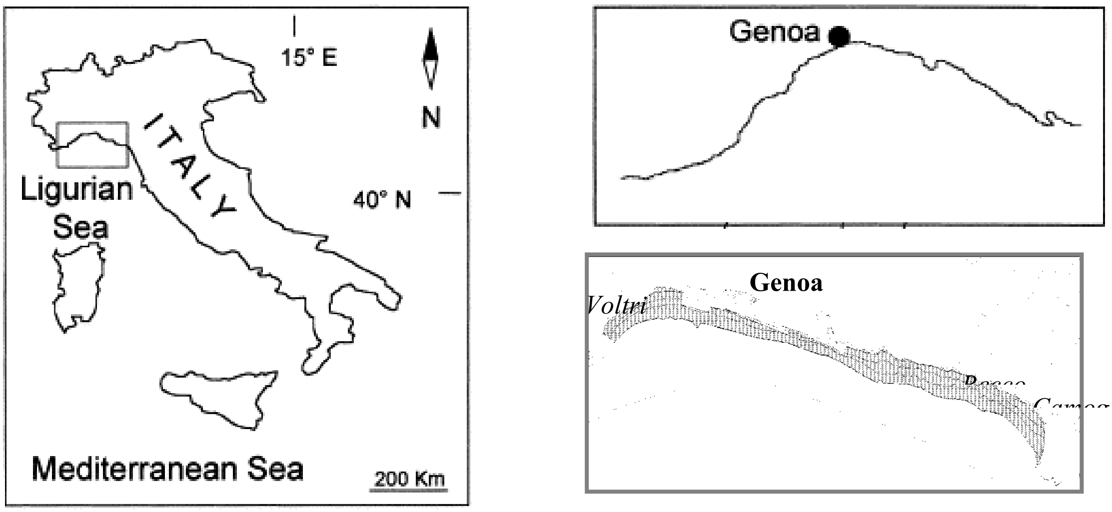

Figure 6.1. Location and map of the Gulf of Genoa, Ligurian Sea.

Sampling was carried out in the framework of the SAReF Ge-2 Project - University of Genoa, during summer 1996. Sampling stations were placed on transects with coast-offshore direction. Salinity and temperature were detected using a Sea-Bird SBE-9/11 plus. The water samples for nitrate, nitrite, ammonium and phosphate analysis were collected with a carousel sampler, equipped with Niskin bottles. Chemical analyses were carried out using a Technicon II AutoAnalyzer according to Hansen and Grasshoff (1983). All the data are reported in Castellano (1997) and Rivaro *et al.* (2000).

Air temperature and wet deposition data were obtained from Dipartimento di Ingegneria Ambientale-Università di Genova (DIAM 2002) Evaporation losses were calculated according to Hargreaves' equation (Hargreaves 1975). Riverine flows and nutrient concentrations used for these budgets and sewage nutrient loads were obtained from Amga S.p.A. (AAVV 1998). Atmospheric nitrogen input was obtained from Rete Italiana per lo studio delle deposizioni atmosferiche (RIDEP) (Mosello 1993), while phosphorus input was assumed to be zero since no data was available.

Water and salt balance

The water and salt budget for the study area was calculated using the two-layer model (Figure 6.2) to estimate the volume transfer between the system and the sea and between the surface and the deep layer of the system. In the figure, the upper solid box and the lower dashed box represent the upper and lower layers. The depth used for the upper mixed layer, determined following the temperature and salinity profiles, was 15 m. Surface area , mean depth and volume are indicated in Table 6.2.

Because of the specific characteristics of the input of treated sewage effluent to the system, we have modified the standard 2-layer LOICZ biogeochemical model, which assumes that all freshwater inputs occur in the surface layer. Here, the sewage piping systems are placed about at 50 m depth, so they occur in the lower layer. Following a diffusion model for sea outfalls in the Gulf of Genoa (Granelli *et al.* in press), we have estimated that about 30% of sewage treatment water occurs in the surface layer (V_{Gs}), while 70 % remains on the bottom (V_{Gf}).

Moreover, we have considered another input (V_Q'), coming from a dock in the port of Genoa (Old Port), where a sewage treatment water discharge flows and mixes with the resident sea water. This input of salt water (36.4 psu) occurs in the surface layer because it flows through a mouth with a depth lower than 15 m (above thermocline).

Results of the freshwater balance indicate that there is a net freshwater input into the study area of $543x10^3$ m^3 d^{-1}. V_R considers both marine and freshwater inputs from the land and is the sum of river runoff (V_Q = $343x10^3$ m^3 d^{-1}), discharges of treated sewage effluent (V_{Gs} = $30x10^3$ m^3 d^{-1} and V_{Gf}= $70x10^3$ m^3 d^{-1}), the water coming from Old Port (V_Q'= $68x10^3$ m^3 d^{-1}), precipitation (V_P = $43x10^3$ m^3 d^{-1}) and evaporation (V_E = $-11x10^3$ m^3 d^{-1}).

In the upper layer, a residual surface flow of $44290x10^3$ m^3d^{-1}(V_{surf}) compensates the net freshwater and saltwater inputs (V_Q, V_P, V_E, V_{Gs} *and* V_Q') and water entrained between the lower layer of the water column (V_D'). In the bottom layer, sea inflow (V_D) is balanced by vertical flow to surface layer (V_D'). V_z is the mixing volume between the layers, and its magnitude is the same in both vertical directions.

The water exchange time (τ) is 11 days for the upper mixed layer and 18 days for the lower layer. The water exchange time for the whole area is 16 days.

Budgets of non-conservative materials

Non-conservative dissolved inorganic phosphorus (DIP) and nitrogen (DIN) fluxes were calculated using the estimated volume transports. Nutrients content of the system, of its inputs and of the output environment are reported in Table 6.1. Results of the budget are summarized in Table 6.2.

Table 6.1. Nutrients content of the system, its inputs and the adjacent sea. (* = assumed)

P	**DIP_Q Rivers**	**DIP_Q' Dock**	**DIP_{Gs} Discharge**	**DIP_{Gf} Discharge**	**DIP_P**	**DIP_{syst} Upper**	**DIP_{syst} Lower**	**DIP_{sea} Sea**
mmol m^{-3}	2.61	0.61	50	50	0*	0.140	0.138	0.140
N	**DIN_Q Rivers**	**DIN_Q' Dock**	**DIN_{Gs} Discharge**	**DIN_{Gf} Discharge**	**DIN_P**	**DIN_{syst} Upper**	**DIN_{sea} Lower**	**DIN_{sea} Sea**
mmol m^{-3}	25.9	12	750	750	60	0.770	0.640	1.00

DIP balance

Figure 6.3 and Table 6.2 summarize the two-layer DIP budget. Non-conservative processes yielded a net sink for DIP (ΔDIP_{system} = -0.134 mmol P m^{-2} day^{-1}). This value is simply the sum of the *ΔDIP's* of upper and lower boxes. In fact, both in surface and bottom layers *ΔDIP* is negative, suggesting that net DIP uptake prevails in the system during summer.

DIN balance

Figure 6.4 and Table 6.2 present the two-layer DIN budget for the study area. As is the case for DIP, the area is a net sink for DIN (*ΔDIN* = -2.26 mmol N m^{-2} day^{-1}), in both surface and bottom layers.

Stoichiometric calculations of aspects of net system metabolism

The parameter (*nfix-denit*) is estimated using inorganic imbalances (*ΔDIP, ΔDIN,*). With the assumption that the system is dominated by phytoplankton and using the Redfield ratio of N:P (16:1) (Redfield *et al.* 1963), the (*nfix-denit*) obtained is positive for the upper layer, where the N_2 fixation process dominates, and negative for the lower, where the denitrification process prevails. Considering the whole system, the denitrification process slightly dominates and the study area appears to be a sink of fixed nitrogen.

The net ecosystem metabolism NEM (*p-r*), based on the C:P (106:1), is positive for the whole area: the system is interpreted to be autotrophic by about 14.2 mmol C m^{-2} d^{-1} and appears to be a net producer of organic matter.

Table 6.2. Summary of water exchange time, non-conservative nutrient fluxes, apparent net metabolism (*p-r*) and nitrogen fixation minus denitrification (*nfix-denit*) in the Gulf of Genoa.
(* weighted mean between mean depth of surface and bottom layers)

Parameters	**Surface**	**Bottom**	**System**
Area (km$_2$)	52	40	52
Mean depth (m)	11	22	28*
Volume (10^9 m^3)	5.72	8.80	14.52
τ (days)	11	18	16
ΔDIP (mol d^{-1})	-2272	-3589	-5861
ΔDIP (mmol m^{-2} d^{-1})	-0.044	-0.090	-0.134
ΔDIN (mol d^{-1})	-27998	-68926	-96924
ΔDIN (mmol m^{-2} d^{-1})	-0.54	-1.72	-2.26
(*p-r*)$_{\text{plankton}}$ (mmol m^{-2} d^{-1})	4.7	9.5	14.2
(*nfix-denit*)$_{\text{plankton}}$ (mmol m^{-2} d^{-1})	0.16	-0.28	-0.12

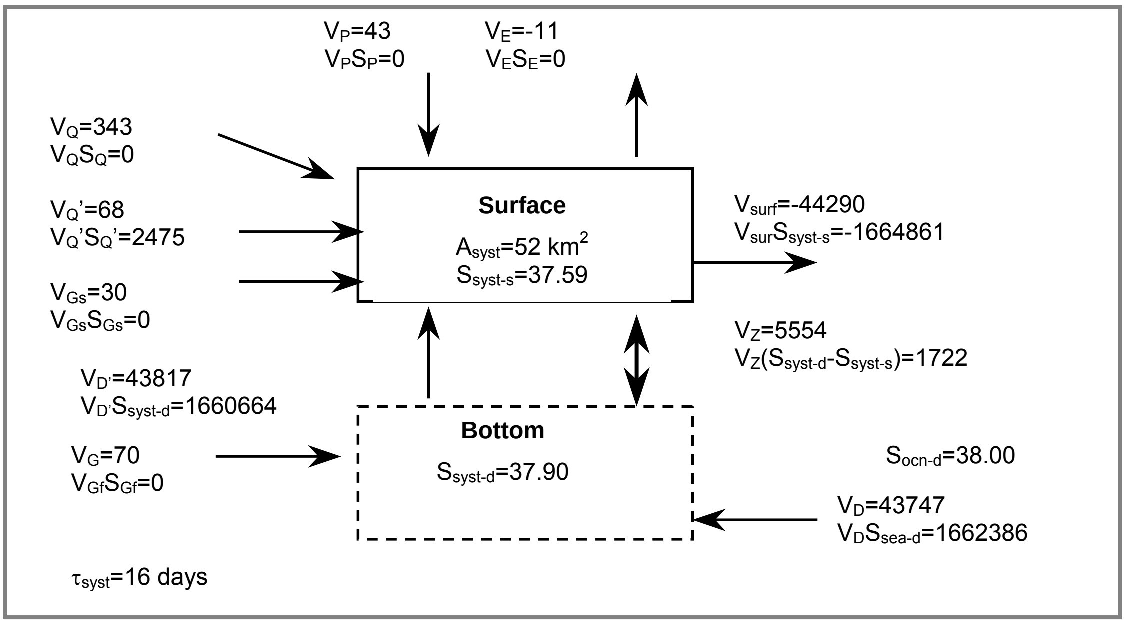

Figure 6.2. Two-layer water and salt budgets for the Gulf of Genoa. Water fluxes in 10^3 m^3 d^{-1}, salinity in psu

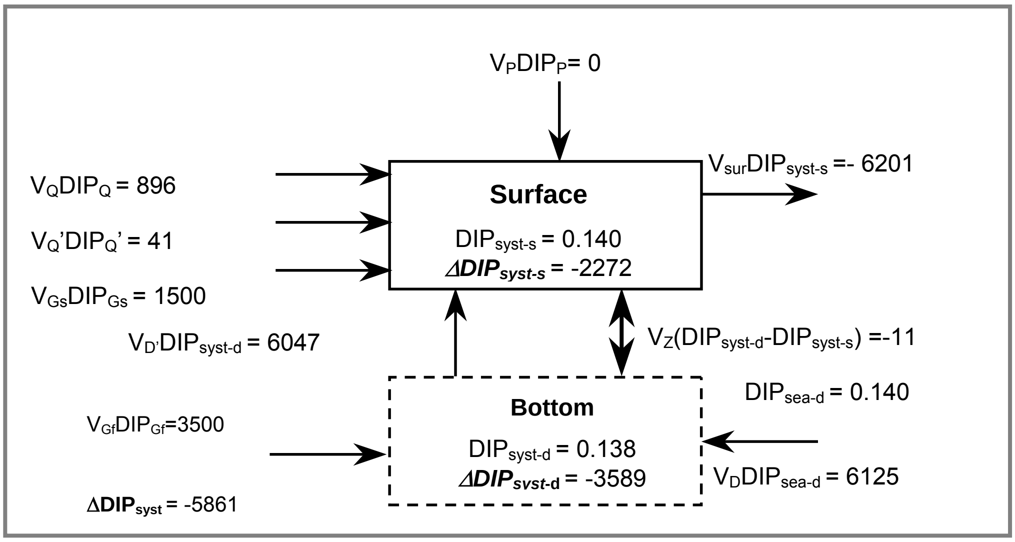

Figure 6.3. Two-layer dissolved inorganic phosphorus budget for the Gulf of Genoa. Fluxes in mol d^{-1} and concentrations in mmol m^{-3} .

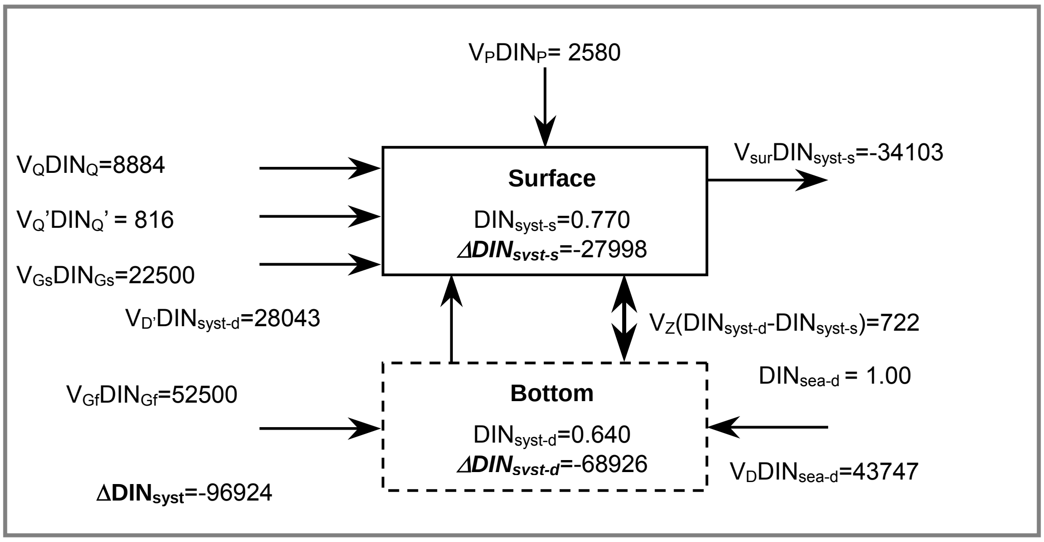

Figure 6.4. Two-layer dissolved inorganic nitrogen budget for the Gulf of Genoa. Fluxes in mol d^{-1} and concentrations in mmol m^{-3}.

6.2 Port of Genoa: Old Port, Multedo Oil Terminal and Voltri Container Terminal

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Study area description

The Port of Genoa (44.40-44.43°N, 8.75-8.94°E) (Figure 1), located in the Gulf of Genoa, extends over a surface of 7 km^2 along about 20 km of coastline; it is composed of independent systems with a mean water depth between 9 and 15 m and with a maximum of 50 m in the Multedo Oil Terminal for supertankers. The harbour receives domestic and industrial effluents from watercourses and through sewage treatment discharges. Therefore, significant amounts of nutrients are released in a semi-enclosed basin, resulting in phosphorus and nitrogen enrichment.

On the basis of its morphology, the Port of Genoa can be subdivided into three different areas, each with specific characteristics, separated from the sea: the Old Port Area, the Multedo Oil Terminal and the Voltri Container Terminal (Figure 6.5). Each area can be considered as an independent system. The budgetary analysis used to quantify fluxes of nitrogen and phosphorus, following the LOICZ Biogeochemical Modelling Guidelines (Gordon *et al.* 1996), has been performed on each system individually in order to understand the biogeochemical processes occurring in each one. Due to available data, models are representative of the summer conditions encountered in September 2002. To complete the annual cycle, it will be necessary to consider the remaining seasons. Moreover, in this preliminary study we have not taken into account the close coupling between the water column and the sediment, which can strongly influence the biogeochemical nutrient cycles. The data obtained, however, can supply preliminary information in order to estimate and to compare these areas with the other coastal systems where the LOICZ Model was applied.

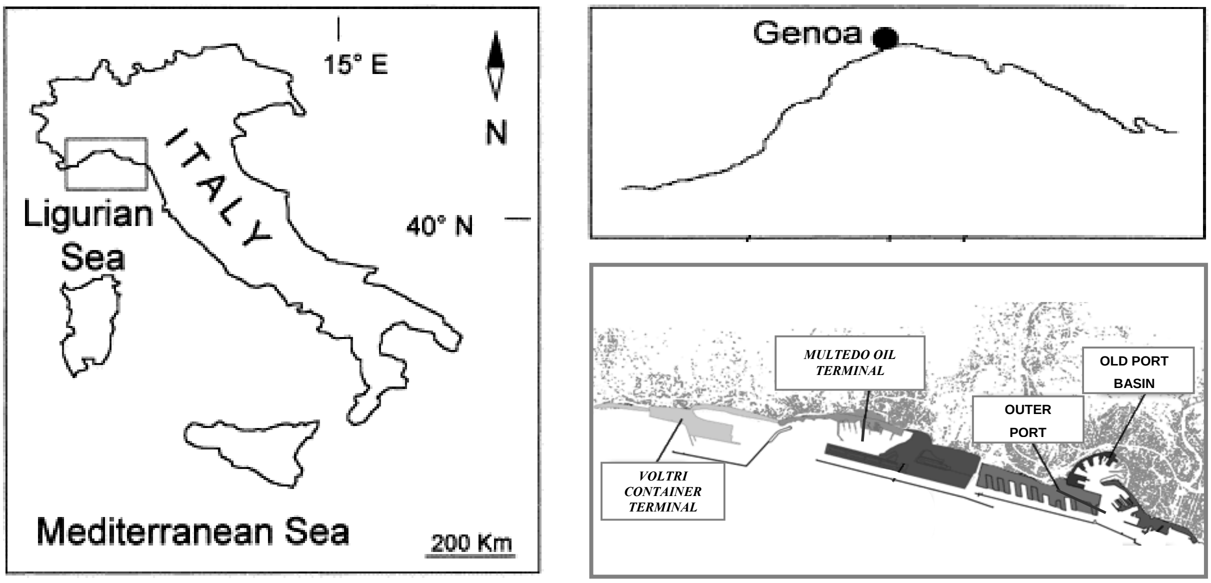

Figure 6.5. Location and map of the Port of Genoa, Gulf of Genoa.

Old Port area
This is the old area of the port of Genoa. It includes the ferry terminal, a small tourist port and a restructured zone, converted into exhibition area (aquarium, congress centre, cinema). In the outer port some shipyards are present. It has a surface area of 2.7 km^2 and a mean water depth of 13 m. Sewage treatment discharge (for about 220,000 inhabitants) flows into this dock, remaining in the surface layer (about 0.5 m) of the inner part because of its low salinity. It carries a large quantity of phosphorus and nitrogen, primarily as ammonium.

Multedo Oil Terminal
The Multedo Oil Terminal is one of the biggest in Italy and the Mediterranean; it is well sheltered from the sea by a long breakwater, a quiet water channel and the esplanade of a large airport. It has a surface area of 1.4 km^2 and a mean water depth of 15 m. A highly polluted watercourse (Chiaravagna) flows into the Oil Terminal, bringing a large amount of nutrients to the basin.

Voltri Container Terminal
The Voltri is one of the most important container terminals of the Mediterranean sea. It has a surface area of 2.1 km^2 and a mean water depth of 15 m. This basin receives no freshwater input, but on the outside of its entrances flow two sewage treatment water discharges (for about 94,000 inhabitants), which can enrich the nutrient content of its waters.

Water samples were collected in September 2002, inside the harbor and in the adjacent sea. Chemical analysis of nutrients were carried out using a Technicon II AutoAnalyzer according to Hansen and Grasshoff (1983). Salinity and temperature were detected using a multiparametric CTD (Idronaut Ocean Seven 316). Air temperature and wet deposition data were obtained from Dipartimento di Ingegneria Ambientale-Università di Genova (DIAM 2002). Evaporation losses were calculated according to Hargreaves' equation (Hargreaves 1975).

Riverine flows and nutrient concentrations used for these budgets and sewage nutrient loads were obtained from Amga S.p.A (AAVV 1998). Atmospheric nitrogen input was estimated from "Rete Italiana per lo studio delle deposizioni atmosferiche (RIDEP)" (Mosello 1993), while phosphorus input was assumed to be zero, as no data were available.

Water and salt balance

The water and salt budget for Genoa Harbour was calculated using the single-layer model for Voltri Container Terminal and Multedo Oil Terminal. A two-box model was used for the Old Port area, which presents a more complex morphology. In fact, it can be subdivided into two systems, the Old Port Basin and the outer port, which is directly connected to the sea through a large entrance. The Old Port Basin is more isolated and receives a freshwater discharge, which remains partly in the surface layer because of its low salinity; we have estimated that this layer is about 0.5 m deep (area-weighted mean value). Therefore the inner box of the two-box model has been considered as a two-layer system. This approach allows a simplification of the description of a complex site, where various processes and conditions are present, which must be taken into account when the results are evaluated.

Surface area, mean depth and volume of the systems are indicated in Table 6.3, while Figure 6.6 summarizes the salt and water budget for the three areas.

Old Port area
In the inner system, the freshwater input comes mainly from a discharge of treated sewage waters ($V_0 = 63x10^3\ m^3d^{-1}$). This input, together with the water entrained between the lower layer ($V_D' = 250x10^3\ m^3d^{-1}$) and precipitation ($V_P = 7.5x10^3\ m^3d^{-1}$), causes a residual surface flow (V_{surf}) of $318x10^3\ m^3d^{-1}$ toward the outer system.

The water exchange time (τ) of the inner system is 2 days for the upper layer and 42 days for the lower one. The water exchange time for the whole area is 20 days. The low exchange time of the upper layer is due to the continuous flux of freshwater in the surface water. These water residence times are not representative of the whole area, because they do not consider its irregular shape; probably, for some inner docks τ is higher than we have found.

The outer system receives a surface flow coming from the inner one (V_{surf}). This input is partially balanced from the flow entraining in the lower layer of the inner system ($V_D = 250x10^3$ m^3d^{-1}). Together with precipitation ($V_P = 11x10^3$ m^3d^{-1}), it causes a residual surface flow ($V_{R\ outer}$) of 75x 10^3 m^3d^{-1} toward the sea. The salinity gradient between the outer system and the sea can be maintained by a water exchange flow of 3297x 10^3 m^3d^{-1}. The water exchange time (τ) of the outer system is 7 days.

Multedo Oil Terminal

This basin receives a freshwater input from Chiaravagna torrent (V_Q = 5 x10^3 m^3 d^{-1}) and from precipitation (V_P = 9.5x10^3 m^3 d^{-1}); it has a residual flow toward the sea of 11.4x10^3 m^3d^{-1}(V_R). Vx was estimated as 339x10^3 m^3d^{-1}. The water exchange time for the whole area is close to 2 months.

Voltri Container Terminal

The only freshwater input in this area comes from precipitation (V_P = 14.3x10^3 m^3 d^{-1}) and the residual flow is low (V_R = 9.6x10^3 m^3d^{-1}) and Vx is 310x 10^3 m^3d^{-1}. The water exchange time (τ) is about 100 days.

Budgets of non-conservative materials

Non-conservative dissolved inorganic phosphorus (DIP) and nitrogen (DIN) fluxes were calculated using the estimated volume transports. Nutrient content of the three systems, of their inputs and of the outer sea are reported in Table 6.3. Figures 6.7 and 6.8 summarize the DIP and DIN budgets for the three areas.

Table 6.3. Nutrient concentrations (mmol m^{-3}) in the systems, in their inputs and in the outer sea. (* assumed)

P	**DIP_Q Rivers**	**DIP_P Precipitation**	**DIP_O Discharges**	**DIP_{sys} System**	**DIP_{sys} Upper**	**DIP_{sys} Lower**	**DIP_{sys} Outer**	**DIP_{sea} Sea**
Old Port area	-	0*	12.6	-	1.8	2.0	0.65	0.61
Multedo Oil Terminal	6.1	0*	-	1.59	-	-	-	0.55
Voltri Container Terminal	-	0*	-	0.52	-	-	-	0.56
N	**DIN_Q Rivers**	**DIN_P Precipitation**	**DIN_O Discharges**	**DIN_{sys} System**	**DIN_{sys} Upper**	**DIN_{sys} Lower**	**DIN_{sys} Outer**	**DIN_{sea} Sea**
Old Port area	-	60	770	-	26.0	27.0	12.6	11.8
Multedo Oil Terminal	100	60	-	22.9	-	-	-	18.8
Voltri Container Terminal	-	60	-	8.8	-	-	-	11.0

DIP and DIN balance

Old Port area
Non-conservative processes yielded a net sink for DIP (-0.66 mmol m^{-2} d^{-1}) and DIN (-43 mmol m^{-2}d^{-1}) in the upper layer of the inner system, while the lower is a source for the two elements (0.31 and 3.3 mmol m^{-2} d^{-1} respectively). The very high DIN value in the upper layer is due to the great amount of nitrogen from discharges that remains in the surface. In the outer system, *ΔDIP* (-0.14 mmol m^{-2}d^{-1}) and *ΔDIN* (-1.4 mmol m^{-2}d^{-1}) are negative, and the system appears a sink for both the elements.

Multedo Oil Terminal
This basin is a source for *ΔDIP* and *ΔDIN* (0.24 and 0.4 mmol m^{-2}d^{-1} respectively).

Voltri Container Terminal
This basin is a weak sink for DIP (-0.003 mmol m^{-2}d^{-1}) and DIN (-0.7 mmol m^{-2}d^{-1}).

Stoichiometric calculations of aspects of net system metabolism
Using to the LOICZ method (Gordon *et al.* 1996), the net ecosystem metabolism NEM (*p-r*) has been estimated on the basis of the Redfield ratio of C:P (106:1), while the parameter (*nfix-denit*) is estimated using inorganic imbalances (*ΔDIP*, *ΔDIN*) and the Redfield ratio of N:P (16:1) (Redfield *et al.* 1963). Results of the budget are summarized in Table 6.4.

Old Port area
The net ecosystem metabolism is highly positive for the entire inner compartment of the Old Port area (37.1 mmol m^{-2}d^{-1}) indicating a net production of organic matter. The inner box shows a negative value of NEM in the lower layer (-32.9 mmol m^{-2}d^{-1}) and a very high positive value in the surface layer (70.0 mmol m^{-2}d^{-1}), due to the great amount of nutrients carried from discharges. The calculation may not in fact correspond to the real productivity of the system, because the waters of the basin are highly polluted, which can limit production.

The outer system has a NEM of 14.8 mmol m^{-2} d^{-1}, but also this value seems to be too high for this area for the same reason of the inner one.

The (*nfix-denit*) obtained is negative for both upper and lower layers of the inner box (-32.5 and -1.7 mmol m^{-2} d^{-1} respectively), so it appears to be denitrifying more nitrogen than it is fixing. The highly negative (*nfix-denit*) value in the upper layer is due to the great amount of nitrogen carried by discharges. The outer box has a positive value of (*nfix-denit*), meaning that N_2 fixation dominates here.

Multedo Oil Terminal
This basin shows a negative value of NEM (-25.4 mmol m^{-2}d^{-1}) and can be considered as a heterotrophic system. The (*nfix-denit*) obtained is negative and denitrification prevails.

Voltri Container Terminal
The net ecosystem metabolism is slightly positive (0.3 mmol m^{-2}d^{-1}) and indicates good balance between production and respiration. The (*nfix-denit*) obtained is negative and the system is denitrifying.

Table 6.4. Summary of water turnover time, non-conservative nutrient fluxes, net ecosystem metabolism (*p-r*) and nitrogen fixation minus denitrification (*nfix-denit*).

	Old Port area				**Multedo Oil Terminal**	**Voltri Container Terminal**
	Inner box			***Outer box***		
Parameters	**Surface**	**Bottom**	**System**	**System**	**System**	**System**
Area (km^2)	1.1	1.1	1.1	1.6	1.4	2.1
Mean depth (m)	0.5	10.0	10.5	15.0	15.0	15.0
Volume (10^6 m^3)	0.55	11.0	11.5	24.0	21.0	31.5
τ days	2	42	20	7	60	99
ΔDIP (mol d^{-1})	-725	340	-385	-230	334	-7
ΔDIP (mmol m^{-2} d^{-1})	-0.66	0.31	-0.35	-0.14	0.24	-0.003
ΔDIN (mol d^{-1})	-47454	3613	-43841	-2225	557	-1445
ΔDIN (mmol m^{-2} d^{-1})	-43.1	3.3	-39.8	-1.4	0.4	-0.7
$(p\text{-}r)_{\mathrm{plankton}}$ (mmol m^{-2} d^{-1})	70.0	-32.9	37.1	14.8	-25.4	0.3
$(nfix\text{-}denit)_{\mathrm{plankton}}$ (mmol m^{-2} d^{-1})	-32.5	-1.7	-34.2	0.8	-3.4	-0.6

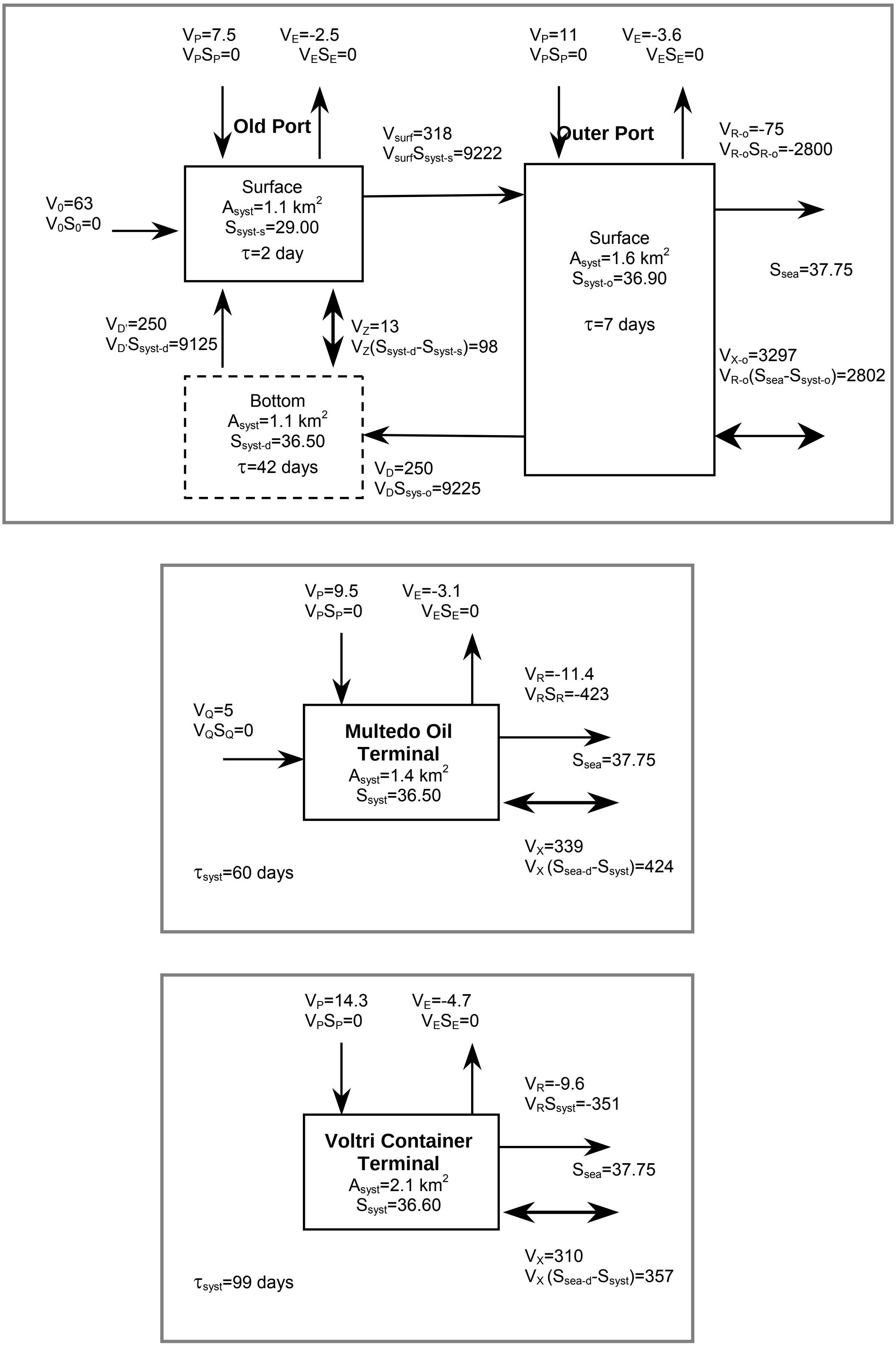

Figure 6.6. Water and salt budgets for the Port of Genoa. Fluxes in 10^3 m^3 d^{-1}, salinity in psu

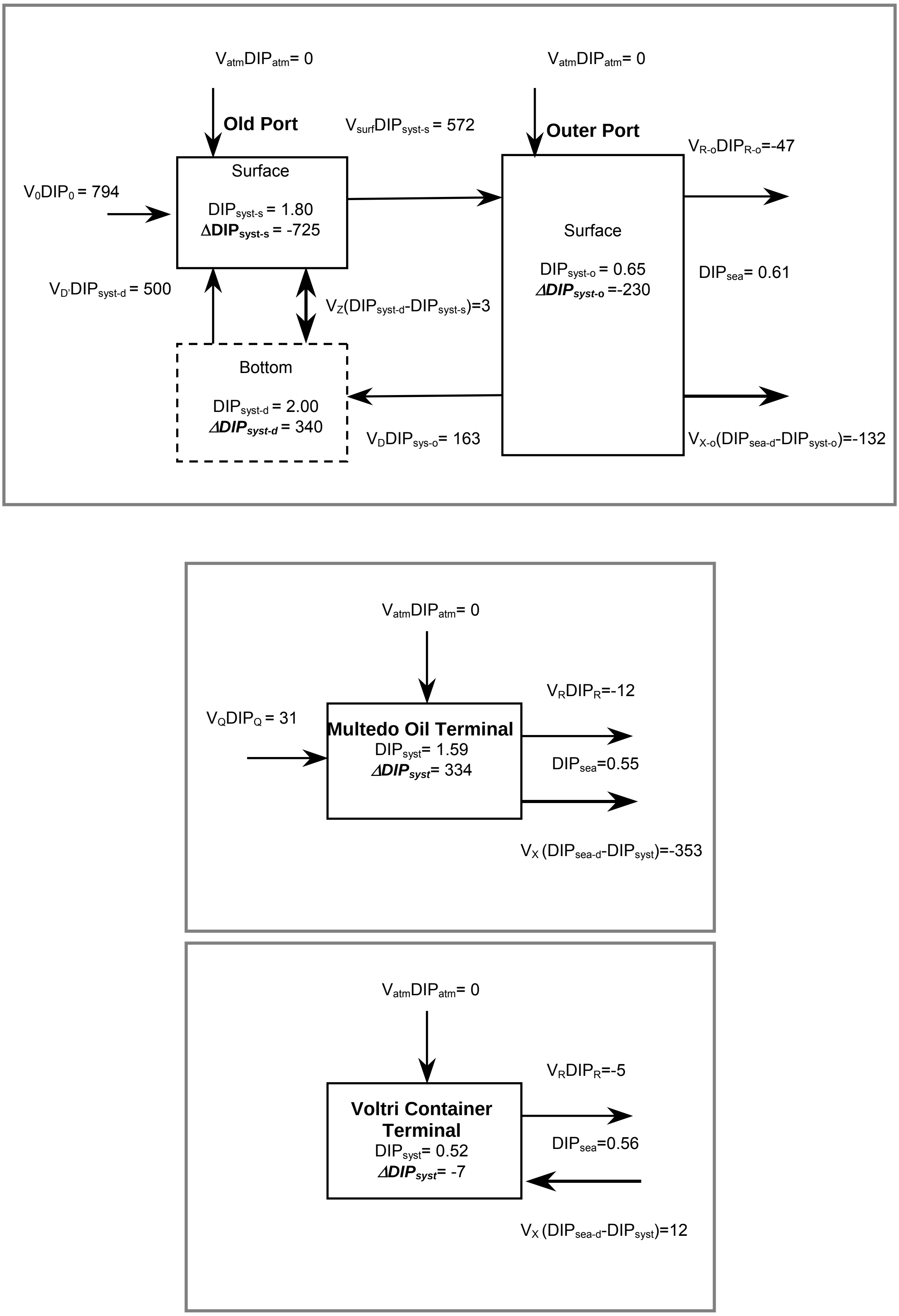

Figure 6.7. Dissolved inorganic phosphorus budget for the Port of Genoa. Fluxes in mol d^{-1} and concentrations in mmol m^{-3}

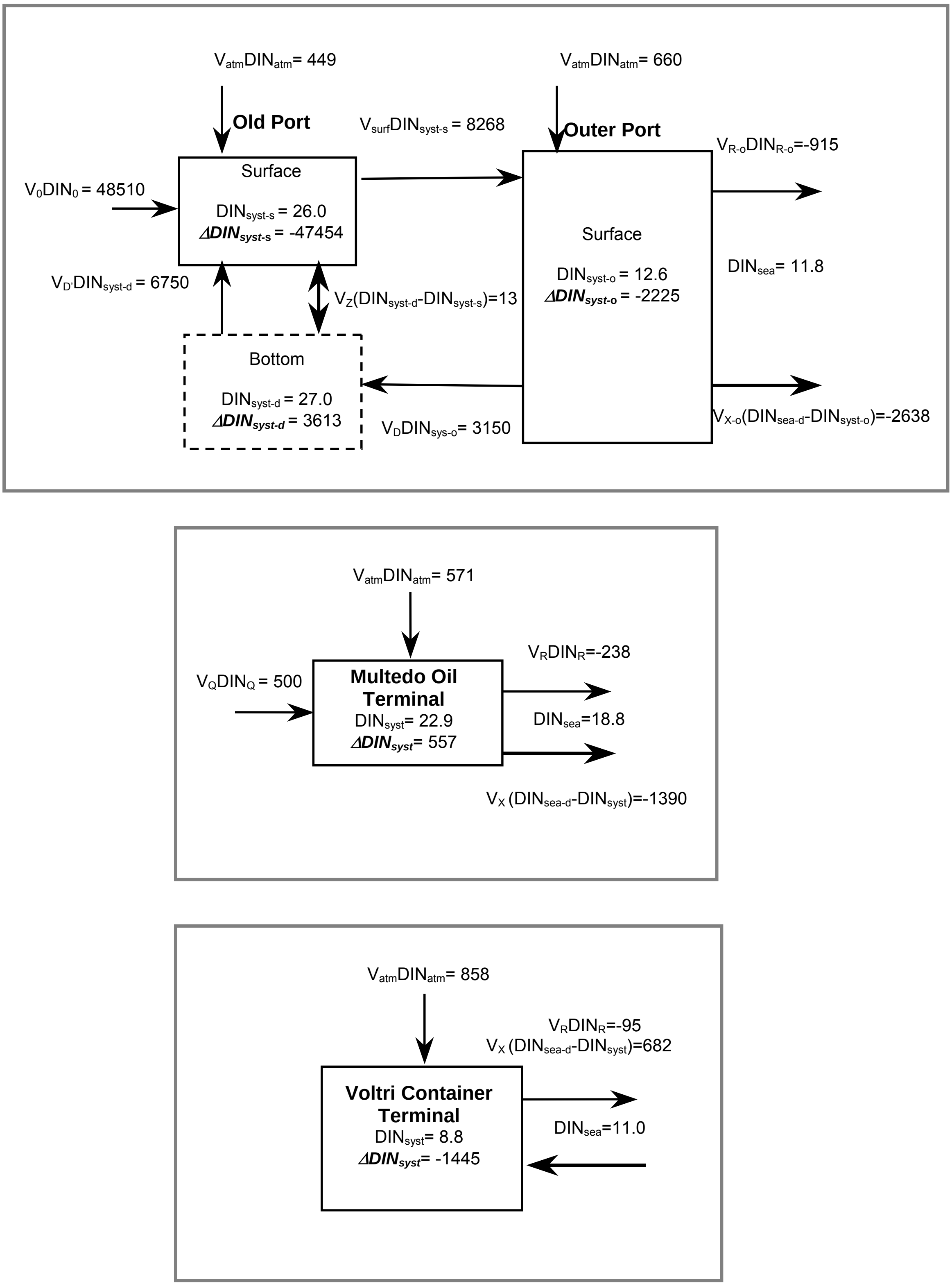

Figure 6.8. Dissolved inorganic nitrogen budget for the Port of Genoa. Fluxes in mol d^{-1} and concentrations in mmol m^{-3}.

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Appendix II Workshop Report

Transport of nutrients in transitional waters of the Italian coast: evaluation of fluxes and functions of ecosystems

Conference room, Thetis S.p.A.
Venice 14-15 April 2002

The Workshop considered the research aims and objectives of the LOICZ international programme in the context of national investigations on Italian lagoon and transitional aquatic systems.

In the opening session of the main objectives of the Workshop were presented (*P. Viaroli*). Two main points were made:

1. Notwithstanding the important activities of numerous research groups, LOICZ biogeochemical budgets have not been determined for much of the Mediterranean coast.
2. The LOICZ biogeochemical modelling approach uses data obtained during ecological investigations of lagoonal ecosystems. A wealth of data exists that is not being optimally exploited.

From these considerations the objectives of the meeting were defined:

i. To provide a forum for discussion and cooperation between researchers who are studying biogeochemical processes in lagoons, wetlands and salt- marshes at sites along the Italian coast. Initiatives of this type had already been initiated between 1976 (Ecologie Mediterranée) and 1988 (Carrada *et al*. 1988).
ii. Evaluate the amount of available information and present understanding of the biogeochemistry of carbon, nitrogen and phosphorus in transitional and coastal waters under the influence of catchment basins.
iii. Discuss the feasibility of the application of the LOICZ Biogeochemical Model to such areas.
iv. Promote an agreed common approach to studies of biogeochemical processes in these transitional ecosystems that can provide support to management or policy applications.
v. Consider the feasibility of developing one or more projects either in Italy or elsewhere in Europe (with Mediterranean EU partners and eventually partners from Eastern Europe and North Africa).

The presentation of *S. Guerzoni*, who is the focal point for LOICZ for Italy, underlined that the programme of IGBP and the project LOICZ had not, unfortunately, had strong support in the country. However, it is now clearly important to develop a more active participation in view of other initiatives, such as those concerning various observations for global change (GOOS, GTOS and IGBP itself).

The future orientation of the European Union research in the 6th Framework Programme was outlined by *C.N. Murray*, in particular the Water Framework Directive. It was emphasised that attention would be given to Networks of Excellence which considered themes that were outlined in the documents presented (e.g., hydrographic basins, transitional waters, integrated analysis of areas at risk – the Mediterranean could be one such area).

The scientific and technical aspects of the LOICZ biogeochemical model were presented by *G. Giordani* and *J.M. Zaldivar*.

The introductory session also included the participation of *F.X. Niell* of the University of Malaga who gave presentations of the application of the LOICZ model to Spanish estuaries and on the LOICZ typology for the classification of transitional waters.

A description of the challenges and difficulties related to the identification of good ecological indicators was presented by *P. Magni*.

In the discussions that followed these presentations *A. Basset* was asked to outline the guidelines for the Italian participation to the implementation strategy for monitoring transitional and coastal waters in the framework of the European Directive on Water. This action, which is developed through an *ad hoc* group coordinated by *G. Casazza* and *A. Basset*, is particularly relevant because future monitoring programmes in transitional areas must comply to the guidelines cited earlier.

In successive sections of the Workshop presentations of a series of sites were named where the LOICZ model had been applied. These included: Laguna di Orbetello (*M. Lenzi*), Laguna di S'Ena Arrubia (*F. Trebini*), la Piallassa Baiona (*M. Abbiati*), la zona umida di Torre Guaceto (*I. Cappello*), la Laguna di Lesina (*E. Manini*), la Laguna di Venezia (*L. Zaggia*), complesso lagunare di Capo Peloro (*M. Azzaro*), zone umide del ferrarese (*G. Castaldelli*).

On the basis of further discussions a programme of activities was proposed (with deadlines):

- A meeting at the end of May (place to be decided). Discussions of the constitution of Network of Excellence – project with European partners – Niell (Spain), PNEC (France), Greece? Bulgaria? Countries from Northern Europe?
- 7 June 2002, proposal of Network of Excellence to the European Commission?
- 15 June 2002, confirmation of titles and abstracts for the Report of the Workshop. The full articles to be prepared by 30 September 2002.
- 30 June 2002, send an abstract to the 3rd Congress of the Science of the Seas (Bari, November 2002).
- 30 September 2002, Italian LOICZ Report: Publication of an overview report to be presented in the framework of institutions that are working in the area of coastal systems. Important to have a reference publication.
- 30 September 2002, Italian LOICZ Report: to be published as LOICZ Report in English (a positive reply to this idea has already been received from C. Crossland Executive Officer, LOICZ IPO).
- Early October 2002, presentation of detailed project to the European Union.
- October 2002, informal international meeting on transitional environments in the European Mediterranean (LOICZ model, indicators, monitoring): Spain, France, Portugal, Greece, Bulgaria. Develop programme for international meeting in 2003.
- November 2002, Presentation 3rd Congress of Science of the Seas (Bari, November 2002). Presentation of the initiative in the name of all participants.
- Mid-2003, Final Workshop. Formal setting-up of national network of lagoon and transitional waters.
- Mid-2003, International Symposium on southern European lagoon and transitional water environments.

Appendix III Creation of a Southern European Lagoon Observational Network

1. Observational Networks

Southern European Lagoons are increasingly recognised as representing a highly diversified series of ecosystems ranging over the whole arc of the Mediterranean. They also are often systems of important economic value to local and regional communities, and as such are often strongly impacted by anthropogenic pressures. There is considerable scientific interest in understanding the ecological functioning of lagoons and the external pressures such as agriculture, industrial, tourism and aquaculture. he Workshop (Venice 14-15 April 2002) **"**Transport of Nutrients in Transitional Waters of the Italian Coast: Valuation of Fluxes and Functions of Ecosystems", and the recent international conference on "Southern European Coastal Lagoons: The Influence of River-Basin Coastal Zone Interactions", Ferrara, Italy, 10-12 Nov 2003, highlighted some of the information gaps that still need addressing.

2. Objectives

At present there are three EU national networks/programmes in the southern European arc studying biogeochemical and ecology processes in lagoons, wetlands and salt marshes. These are **PNEC** (France), **LaguNet** (Italy) and the recently formed network in Greece. International activities such as LOICZ and the EU thematic network ELOISE also collaborate directly or indirectly with these networks, as does the coastal initiative of the Global Terrestrial Observing System (**GTOS**) where these national initiatives could actively contribute in the future.

Given these developments and through discussions with the various networks, the proposal has been made to consider the setting up of a series of regional/national networks to support and encourage co-operation between research groups in the Southern European arc.

The objective of these regional/national networks would be the following:

i. To provide a forum for discussion and co-operation between research groups who are studying biogeochemical and ecology processes in lagoons, wetlands and salt marshes in southern Europe.
ii. To evaluate available information and current understanding of the biogeochemistry of carbon, nitrogen and phosphorus flows in transitional and coastal waters influenced by catchment basins.
iii. To promote a common approach to studies of biogeochemical and ecological processes that can provide support to management and policy applications (e.g., EU Water Framework Directive).
iv. To discuss the feasibility of providing scientific products to IGBP programmes and other regional and global monitoring/observation systems.
v. To consider the feasibility of one or more projects in collaboration with similar networks in southern Europe such as LaguNet (Italy), PNEC (France), the new Greek network and DITTY (EU project).

3. Rationale

The development of regional/national (informal) networks would allow a more focussed response to major policy and science needs such as the implementation of the EU Framework Water Directive or the assessment of the impact of coastal lagoon ecosystems to local, regional and global anthropogenic pressures (e.g., LOICZ programme). Such networks could also form a southern European contribution to the coastal initiative of the Global Terrestrial Observing system (GTOS).

The concept of a number of regional/national networks in the Mediterranean arc is a pragmatic way of focussing regional scientific and management interests at an effective scale, and allows collaboration between regional/national networks to develop as mutual interests and concerns are identified.

That such networks (over 20 lagoon sites) can effectively be developed is seen through the examples of the French (PNEC) and Italian (LaguNet, www.dsa.unipr.it/lagunet) networks, which are making a significant scientific contribution to the understanding of many aspects of river-basin coastal lagoon functioning. A wider geographical coverage is needed for the southern European arc.

4. Actions

A set of informal meetings could be held with groups already working on coastal lagoons, to discuss the interest and feasibility of setting up such networks in the Iberian Peninsula (Portugal-Spain) parallelling those in Italy and France.

Discussions with LOICZ should be held to discuss the possible further role of national networks in the development of coastal inventories and typology, and with GTOS regarding a southern European arc contribution to this future global observation system.

A further point for discussion would be the form of the links to be developed with the other regional/national networks, and the objectives to be identified. As a longer term step the feasibility of joint collaboration with the EU Network of Excellence (NE) should be considered and potential NE contributors identified.

Appendix IV A proposal of a Typology for Mediterranean transitional waters

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Typology can be defined as the discrimination of surface waters into units “ecosystem types”, to ensure that type-specific biological reference conditions can be reliably derived. It follows that typology has to focus on the identification of the major sources of variation in the biological quality element descriptors (mainly abundance, richness and diversity), in order to minimize their intra-type variation and to be functional for classification of ecological status.

According to this definition and meaning of Typology, an electronic discussion was carried out within the scientific community in the Mediterranean region, in order to achieve a preliminary evaluation of the Typology of Mediterranean transitional waters with an expert view approach.

During a week of on-line discussion, some documents were produced, many expert views on factor relevance were introduced and more than 140 contacts were received by the documents produced, which led to a hierarchical definition of a simple and reliable *a priori* Typology.

The major relevance of some factors was recognised: tidal range, salinity (and range), depth (mean), surface, residence time and substratum conditions (organic fraction and granulometry); agreement was reached on the first steps of the Typology definition:

1. a subdivision into running (deltas or river mouths) and lentic (still or slow-moving) transitional waters; and then,
2. a first subdivision of the lentic transitional waters according to tidal range into lagoons [tidal range ≥ 50 cm (micro tidal *sensu* coastal waters of the EU Water Framework Directive - WFD)] and non-tidal [tidal range ≤ 50 cm (not tidal);
3. a second subdivision of the lentic transitional waters into large (surface $\geq 3\ \mathrm{km}^2$) and small (surface $\leq 3\ \mathrm{km}^2$) lentic transitional waters.

The final document from the on-line discussion was submitted to the Coast Working Group, which accepted only the first subdivision, in agreement with the decision of some Member States (see Table IV.1).

Table IV.1. Typology of transitional waters by the Mediterranean Member States.

		France	Greece	Italy
River mouth/delta		X	X	X
Coastal lagoons	Microtidal lagoons	X	X	X
	Non-tidal lagoons			X

Italy agreed with the first level subdivision into river delta, micro- and non-tidal lagoons, while France and Greece considered coastal lagoons as a single group. This differentiation is attributable to a higher variation of tidal range among Italian lagoons than among both Greek and French lagoons. North Adriatic lagoons have a tidal range close to 1 m, which is greater than the range occurring in other parts of the Mediterranean pertaining to UE Member States.

To evaluate the *a priori* Typology scheme, a preliminary analysis of bibliographic data containing structural descriptors of biotic quality element (i.e., benthic macro-invertebrates) was performed on a sample of Italian lagoons. Thirty six Italian lentic transitional waters were selected, according to biological data availability, and a presence/absence matrix including 1084 benthic macro-invertebrate taxa was obtained in order to analyze relationship between biotic descriptors and structural features of transitional waters. Some major generalizations, with implications on Mediterranean transitional ecosystems Typology, arose from the data-set analysis, despite variability in the data-set due to different sampling effort and methodology, to taxonomic and functional spectra considered, to taxonomic resolution in published papers and to different number of contributions published on different lagoons:

1. Taxonomic composition and species richness, which are two quality element descriptors proposed by WFD, are extremely heterogeneous among lagoons. An analysis of similarity (Sorensen index) considering two WFD descriptors of quality elements (i.e., taxonomical composition and richness), emphasized the extreme heterogeneity of taxonomic composition among the considered coastal Italian lagoons. Average similarity among biotopes was less than 15% and it was always low even if lagoons very close to each other were compared. Moreover, less than 5% of the 1084 taxa were found in more than 15 out of the 36 biotopes while more than 50% of taxa were found in only one biotope.

2. Physiographical and hydrological characteristics of lagoons explain a highly significant proportion of the quality element descriptor variability. Multivariate analysis (e.g., multivariate regression) relating the biological data set to an abiotic data set, including physiographic and hydrological parameters, showed that a four level classification (outlet width/surface, minimum axis, maximum salinity, range of salinity) explained up to 75% of variation in the biotic data set (Table IV.2).

Table IV.2. Multivariate regression of taxonomic richness with physiographic and hydrological characteristics of the lagoons.

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.651[a]	.424	.406	62.684	.424	23.547	1	32	.000
2	.795[b]	.633	.609	50.855	.209	17.619	1	31	.000
3	.832[c]	.692	.661	47.371	.059	5.728	1	30	.023
4	.857[d]	.735	.698	44.693	.043	4.702	1	29	.038

a. Predictors: (Constant), Surface

b. Predictors: (Constant), Surface, max salinity

c. Predictors: (Constant),Surface, max salinity, salinity range

d. Predictors: (Constant),Surface, max salinity, salinity range, min axis

					Change Statistics				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
1	.670[a]	.449	.431	61.323	.449	26.040	1	32	.000
2	.780[b]	.608	.583	52.547	.159	12.581	1	31	.001
3	.830[c]	.689	.658	47.555	.081	7.851	1	30	.009
4	.870[d]	.757	.723	42.769	.068	8.090	1	29	.008

a. Predictors: (Constant), outlet width

b. Predictors: (Constant), outlet width, max salinity

c. Predictors: (Constant), outlet width, max salinity, min axis

d. Predictors: (Constant), outlet width, max salinity, min axis, salinity range

Outlet width of coastal lagoons and surface area, the latter as a measure of transitional biotope shape, were found to be the two major factors explaining biological data variation. Minimum axis, probably accounting for habitat heterogeneity inside transitional biotopes, and both maximum salinity and salinity range were the other factors contributing to biological data variation.

Canonical Correspondence analysis, performed after a reorganization of all the abiotic parameters into three groups describing sensitivity, heterogeneity and functional size of the transitional ecosystems, gave a result similar to that shown by multivariate regression, explaining up to 43.3% of the variation of the macro-invertebrate taxa matrix.

Note that for the analysis we considered only abiotic characteristics of lentic transitional waters, which are relatively independent of anthropogenic pressures. These latter can affect taxonomic composition and richness, as well, and are likely to be responsible for the unexplained variation in the data set.

Therefore, a four level factorial classification of transitional waters into types would greatly reduce the variability of the considered descriptor of biological quality, reaching the goal of improving Typology for *Reference conditions* analysis and ecological status *Classification*. In order to minimize the number of ecosystem types and to optimize the accuracy of ecological status classification, we think that a two level factorial definition of Mediterranean lagoon Typology is required and that more detailed definition, with three or more levels, could provide more accurate definition of monitoring programs at local and regional scales.

3. The inclusion of lagoon surface area in the proposed *a priori* Typology of Mediterranean lagoons is validated by the *a posteriori* analysis. On the basis of these preliminary results we found that surface area of lentic transitional waters, as a measure of transitional water shape, which is one of System B descriptors (WFD, 2000), represented the physiographic feature with the strongest functional, rather than phenomenological, influence on benthic macro-invertebrates quality element descriptors. Surface area explained a similar proportion of variation as outlet width but the former has a stronger theoretical foundation; a significant species area power relationship was observed in the data set (Figure IV.1). Interestingly, a similar result was found for phytoplankton quality element descriptors on different data set obtained from a sub-sample of sites (Figure IV.2).

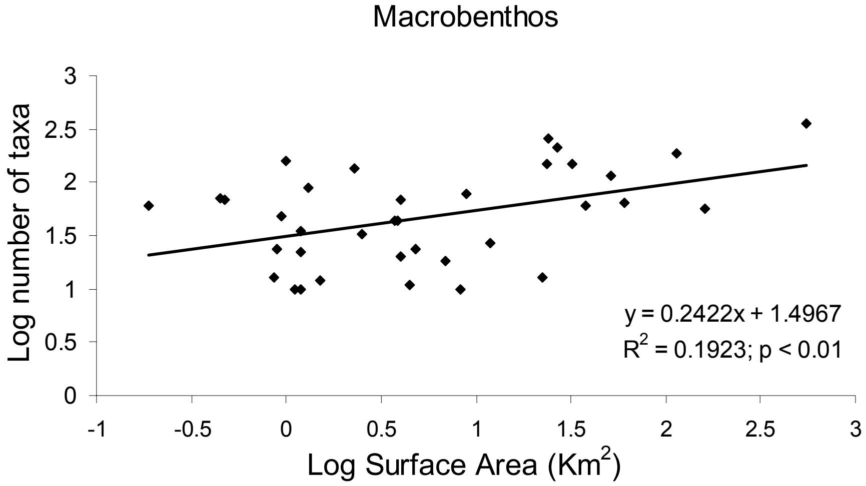

Figure IV.1. Relationship between surface area (km^2) and benthic macroinvertebrate taxa number recognized in each of the transitional ecosystem selected.

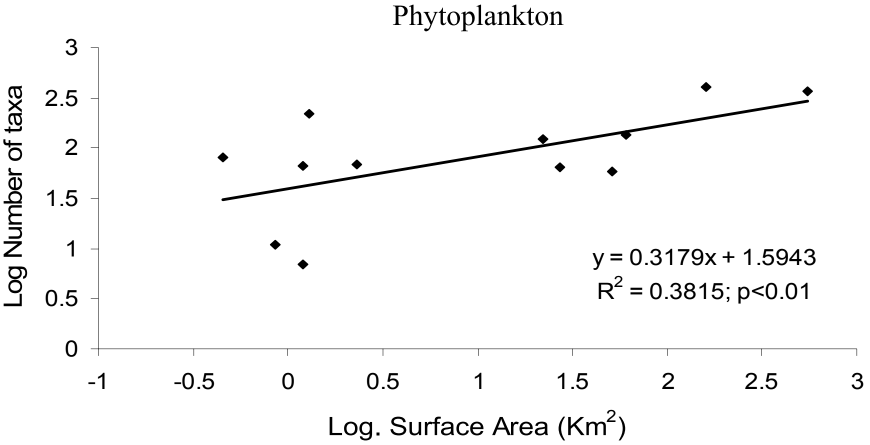

Figure IV.2. Relationship between surface area (km^2) and phytoplankton taxa number recognized in each of the transitional ecosystem of the sub-sample of sites selected.

Accounting for the species/area relationship would greatly reduce the intra-Type variability of a quality element descriptors such as species composition/richness. Thus, an *a posteriori* definition of Typology supported the second subdivision into small and large lagoons i.e., the relevance of surface area has to be taken into account to reach a consistent definition of transitional water Typology.

An *a posteriori* evaluation of the threshold between small and large lagoons was performed on an inventory of the Italian lagoons, including 175 biotopes; 139 having a surface area < 10 m^2 (Table IV.3). Maximum differentiation among groups of small and large lagoons was observed with a threshold of 2.5 km^2 (ANCOVA test, P≤0.001). Large and small lagoons, divided according to the above defined threshold, had significantly different number of taxa (t-Student test, P ≤ 0,02).

Table IV.3. Distribution of Italian lagoons smaller than 10 km^2 into classes of surface area

Surface Class	*N° of Lagoons*
0.5	57
1.0	28
1.5	11
2.0	8
2.5	4
3.0	3
3.5	4
4.0	4
4.5	4
5.0	1
5.5	2
6.0	1
6.5	0
7.0	5
7.5	0
8.0	0
8.5	4
9.0	1
9.5	1
10.0	1

Therefore, the final proposal, reached by *a priori* evaluation and validated by an *a posteriori* definition of Mediterranean lagoons Typology, can be summarized as:

1. **running transitional waters**
    - 1.1. deltas
    - 1.2. river mouths
2. **lentic transitional waters**
    - 2.1. micro tidal lagoons [tidal range ≥ 50 cm (micro-tidal *sensu* WFD coastal waters)]
        - 2.1.1. large (surface ≥ 2.5 km^2)
        - 2.1.2. small (surface ≤ 2.5 km^2)
    - 2.2. non tidal lagoons [tidal range ≤ 50 cm]
        - 2.2.1. large (surface ≥ 2.5 km^2)
        - 2.2.2. small (surface ≤ 2.5 km^2)

Since the questionnaire produced by the Coast Working Group for inter-calibration purposes takes into account only the first level of lentic transitional waters discrimination (between micro- and non-tidal lagoons), we suggest that as minimum requirement the selection of sites for inter-calibration also could include the surface area of lagoons, thereby providing both small and large examples of reference and polluted sites within each Member State.

Other factors are relevant to the biological quality element descriptors, as the preliminary analysis on the Italian lagoon data-base showed i.e., hydrodynamics (e.g., retention time (τ) and water flushing), sediment features (e.g., granulometry, organic matter content, geological origin), climatic/ meteorological constraints and water salinity. However, their relative importance and independence/ autocorrelation relationships would have to be directly tested within a research project aimed at defining typology of Mediterranean transitional waters.

We emphasize a key issue regarding the intercalibration. Most of the attention in this first stage of the WFD implementation was on Typology and Reference Conditions but Intercalibration will be performed utilizing descriptors. The selection of proper descriptors of ecological status of transitional waters is by far the most important and difficult challenge of the WFD. There is clearly a need to make things simple, but also to collect useful information. Some criteria for comparison and evaluation of descriptors - in terms of scientific concepts, standardization, variability, cost and simplicity - have already been proposed; we attached to this document two tabular models, which are suggested for the comparative evaluation.

Acknowledgement

This paper results from the contributions of the participants to the Naples *LaguNet* Forum on *Major challenges to bridge basic ecology to applications* (Naples, June 17-19, 2004) (see Appendix I for list of participants). The organisers thank all of them for their enthusiasm and effort in discussion of these topics. Thanks also to Anna Fauci and the staff of the Ecology group of Naples Federico II University for their invaluable contribution to the organisation of the Forum and the Presidency of the Campania Region for the grant, which made the Forum possible.

Appendix V List of acronyms and abbreviations

a) Scientific terms

DIN	Dissolved inorganic nitrogen
DON	Dissolved organic nitrogen
DIP	Dissolved inorganic phosphorus
DOP	Dissolved organic phosphorus
nfix	Nitrogen fixation
denit	Denitrification
p	Primary production
r	Respiration
NEM	Net Ecosystem Metabolism

Other terms used are explained within the document.

b) Institutions, agencies and organizations

APAT	Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici
ARPA	Agenzia Regionale Prevenzione e Ambiente
ARPAV	Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto
ASPIV	Azienda Servizi Pubblici Idraulici e Vari
CIRSA	Centro Interdipartimentale di Ricerca per le Scienze Ambientali in Ravenna, Università di Bologna
CNR-IAMC	Istituto Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche
CNR-ISMAR	Istituto di Scienze Marine, Consiglio Nazionale delle Ricerche
COHERENS	COupled Hydrodynamical Ecological model for REgioNal Shelf seas
DIAM	Dipartimento di Ingenieria Ambientale, Università di Genova
DIPTERIS	Dipartimento per lo Studio del Territorio e le sue Risorse
DRAIN	DeteRmination of pollutAnt INputs from the drainage basin
EEA	European Environment Agency
ELTCON	Environmental Characterization of the Lagoon of Varano
IBM-CNR	Istituto di Biologia Marina – Consiglio Nazionale delle Ricerche
ICRAM	Istituto Centrale per la Ricerca scientifica e tecnologica Applicata al Mare
IRMA-CNR	Istituto di ricerche sulle Risorse Marine e l'Ambiente - Consiglio Nazionale delle Ricerche
MAV-CVN	Magistrato alle Acque di Venezia - Consorzio Venezia Nuova
MAV-SAMA	Magistrato alle Acque di Venezia - Sezione Antinquinamento del Magistrato alle Acque
MELa1	Monitoraggio Ecosistema Lagunare 1
RIDEP	Rete Italiana per lo studio delle deposizioni atmosferiche
SIBM	Società Italiana di Biologia Marina
S.It.E.	Società Italiana di Ecologia
S.p.A.	Società per Azioni
S.r.l.	Società a responsabilità limitata
VESTA	Venezia Servizi Territoriali Ambientali