LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)
Core Project of the
International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
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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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4.6 S'Ena Arrubia Lagoon, western Sardinia

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<u>Study area</u>

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.

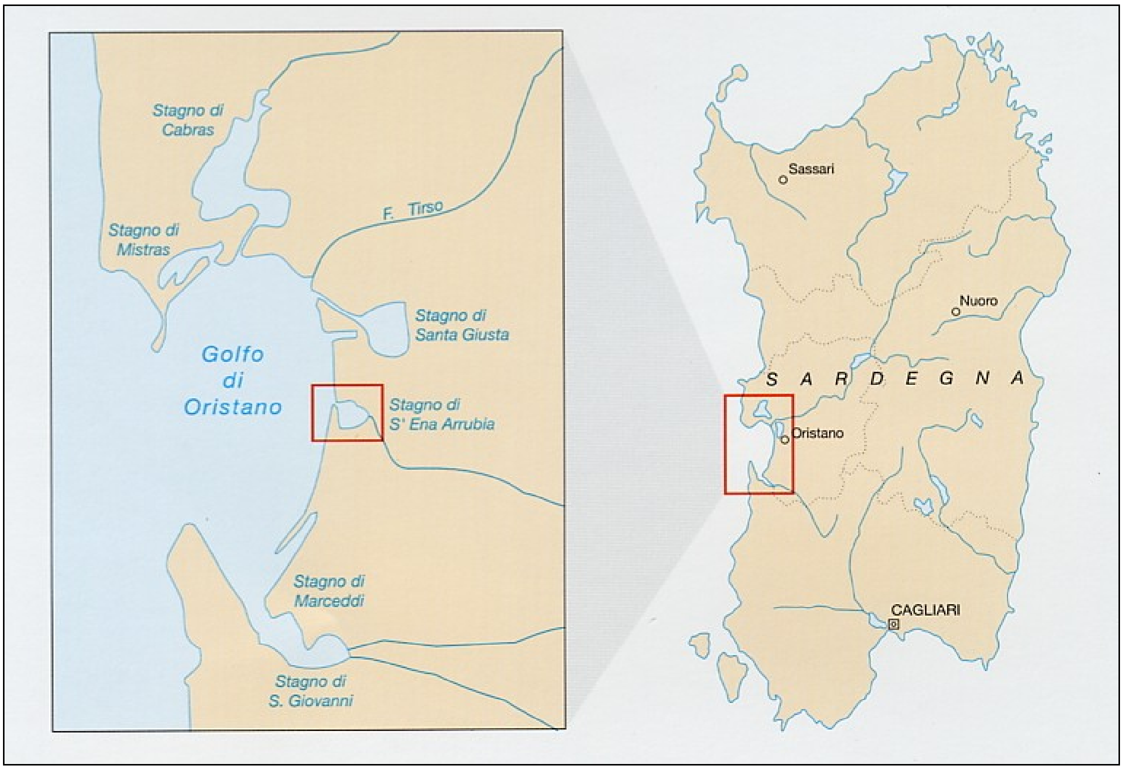

Figure 4.29. Location of S'Ena Arrubia Lagoon.

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.

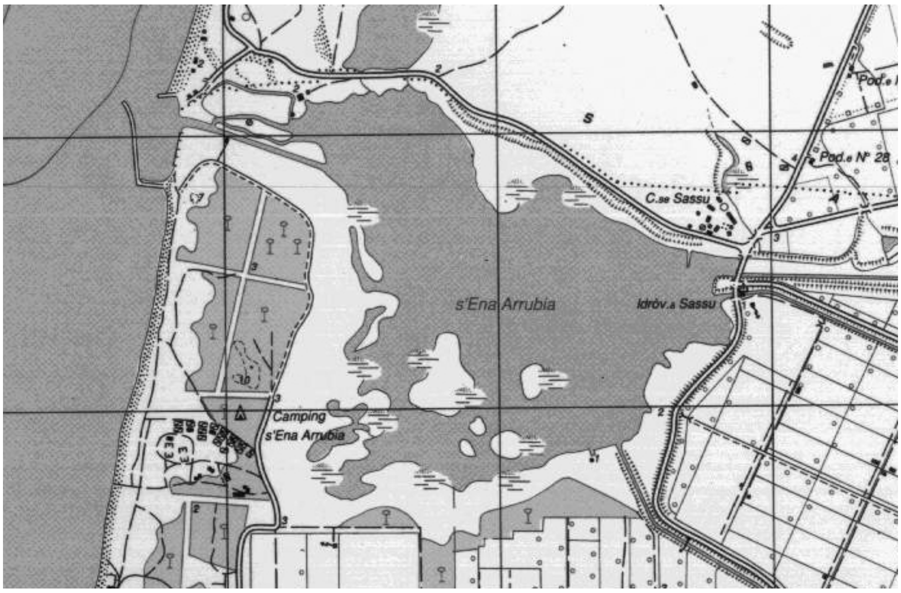

Figure 4.30. Map of S'Ena Arrubia Lagoon.

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).

<u>Water and salt balance</u>

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.

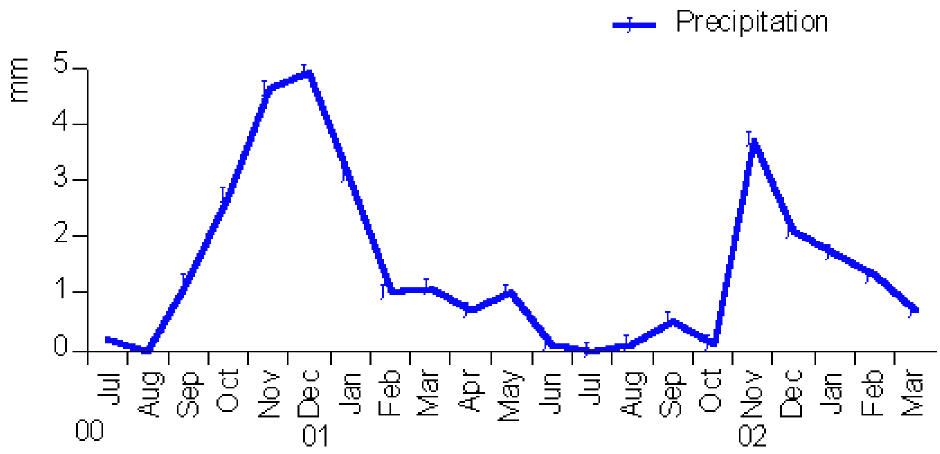

Figure 4.31. Precipitation dynamics in S'Ena Arrubia Lagoon.

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}	*ΔDIN* mol d^{-1}	*ΔDIN* 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.

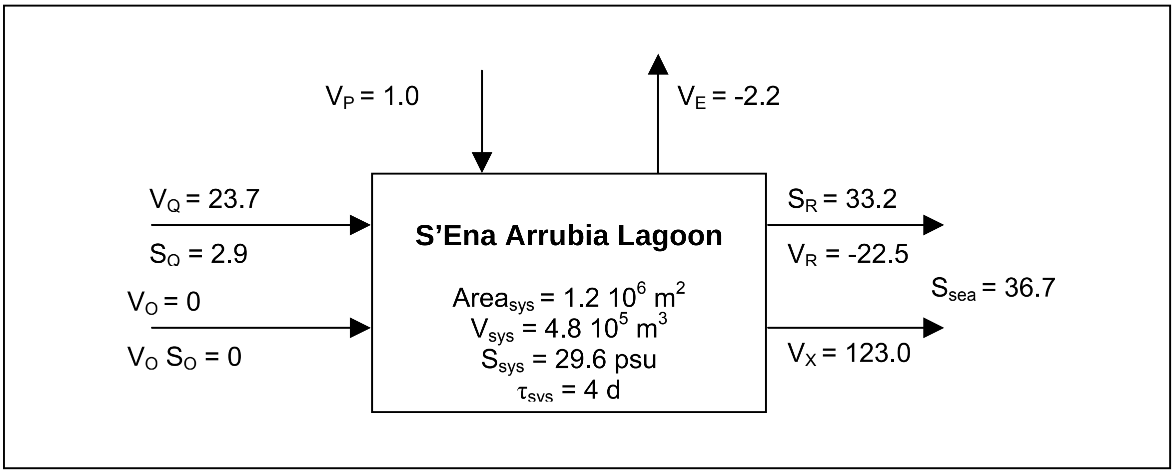

Figure 4.32. Water and salt budgets for S'Ena Arrubia Lagoon. Water fluxes are expressed in 10^3 $m^3\ d^{-1}$ and salinity in psu. Values were calculated as annual weighted averages of seasonal results.

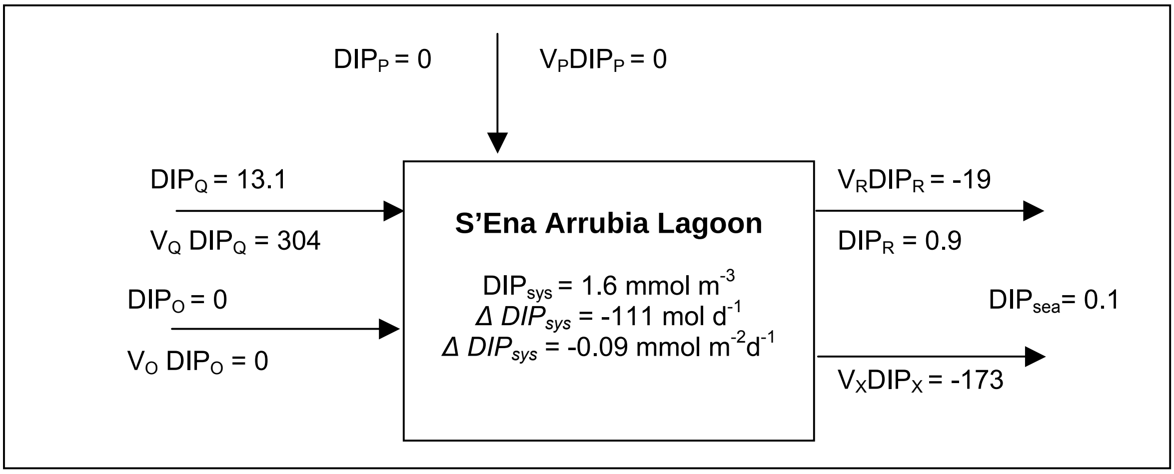

Figure 4.33. **DIP budget for S'Ena Arrubia Lagoon.** Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Values were calculated as annual weighted averages of seasonal results.

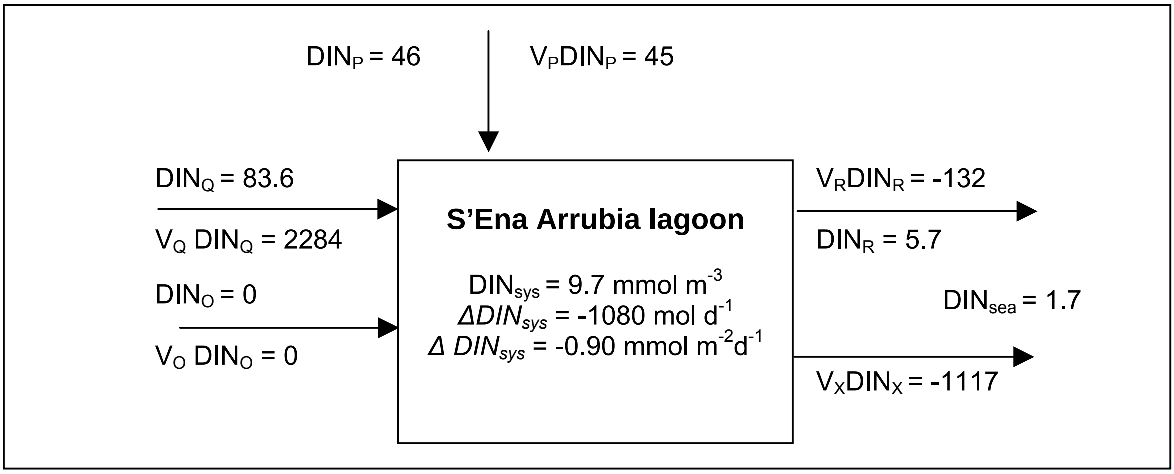

Figure 4.34. DIN budget for S'Ena Arrubia Lagoon. Concentrations are in mmol m^{-3} and fluxes in mol d^{-1}. Values were calculated as annual weighted averages of seasonal results.

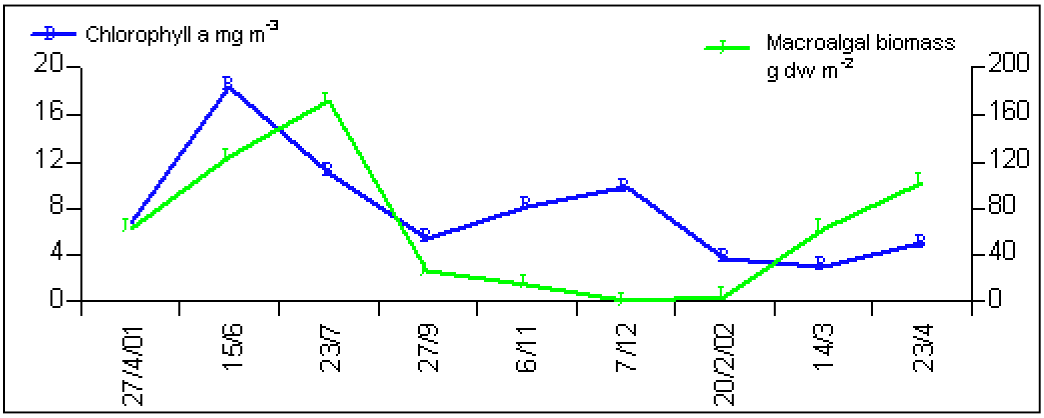

Figure 4.35. Chlorophyll *a* and macroalgae biomass dynamics.

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.