Land-ocean exchanges and budgeting in a river-estuary-ria-shelf system (NW Iberian Peninsula)

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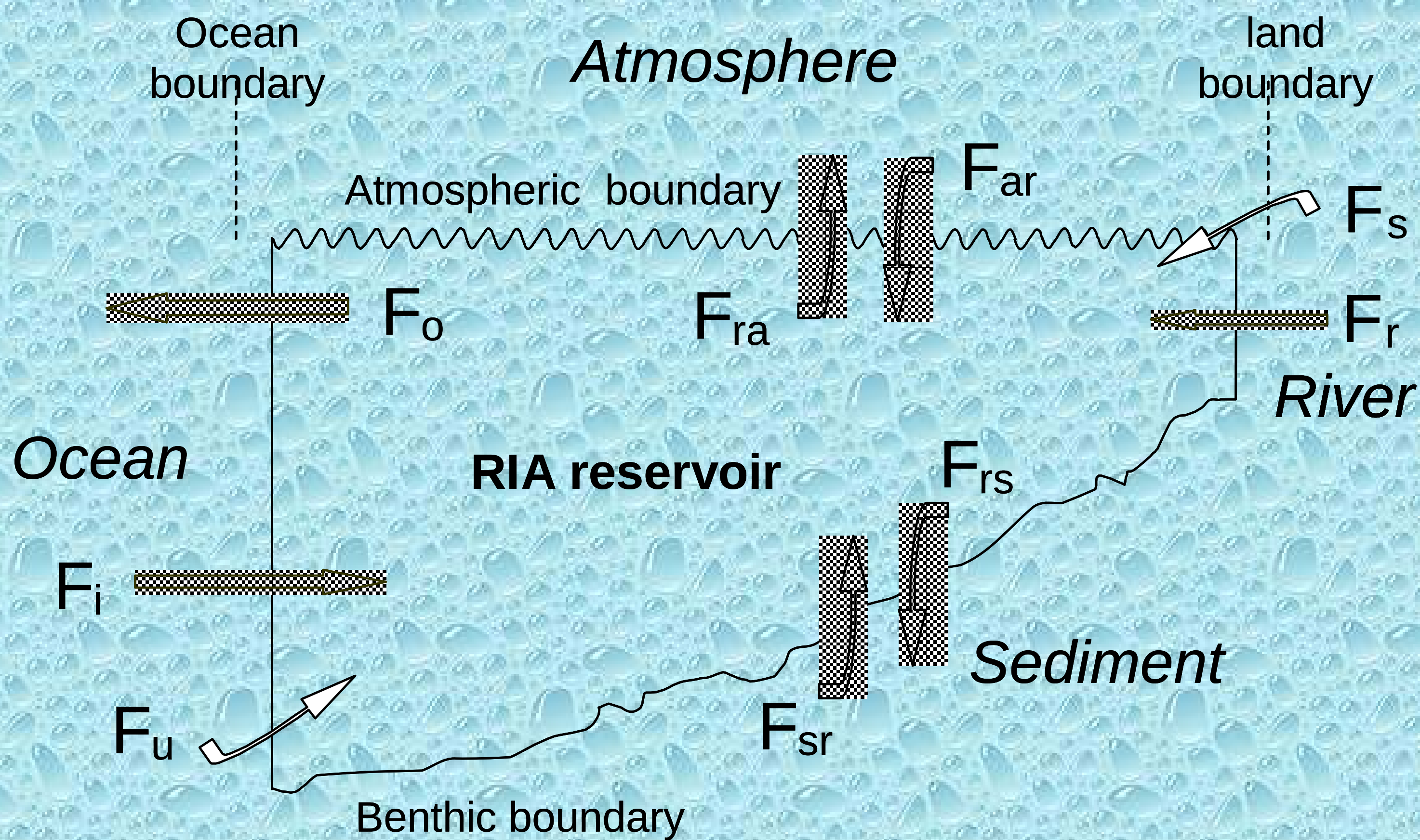
Rias are incised valleys where the estuarine zone can shift according to climatic changes

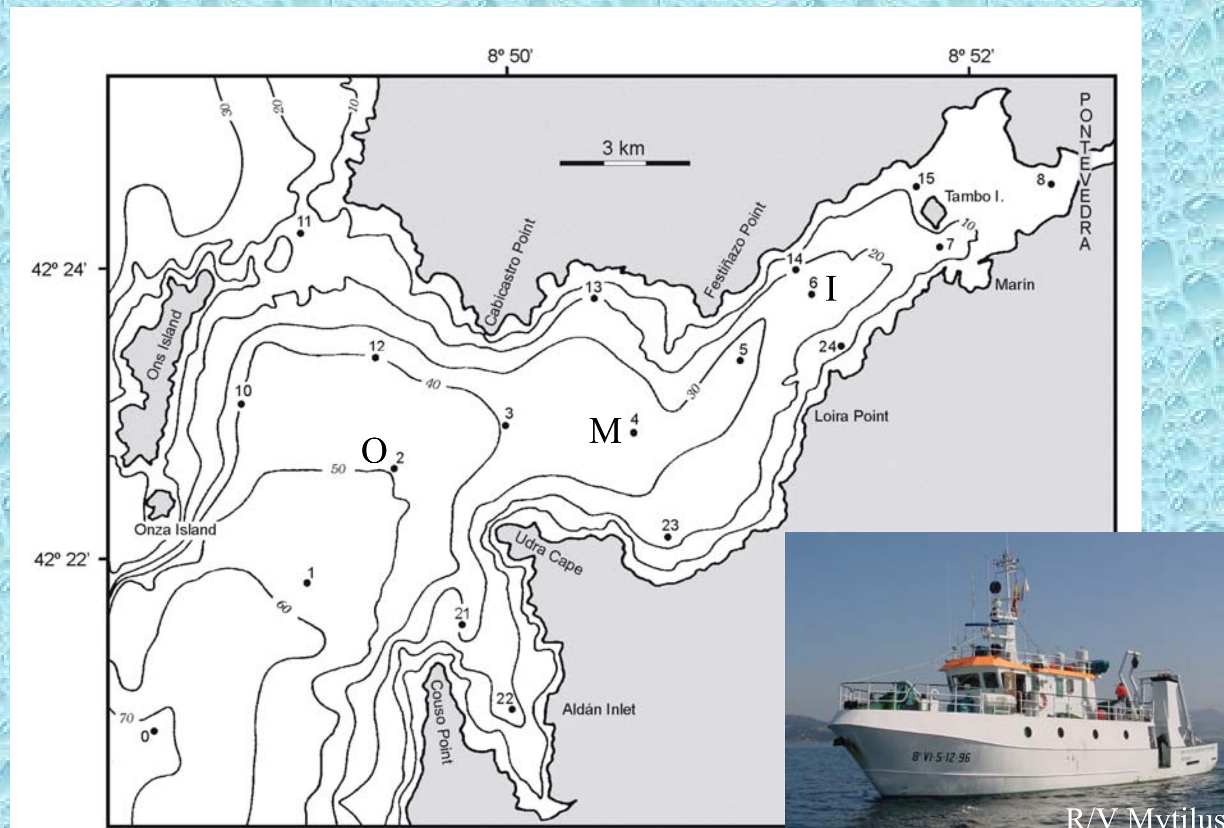


Biogeochemical fluxes in a ria reservoir

Ria of Pontevedra: systematic hydrodynamical, biogeochemical and biological research was carried out biweekly between October 1997-98.

The Ria with 141 km^2 and a volume of 3.47 km^3 extends 23 km from its head at the River Lérez in the east to the islands of Ons and Onza in the west. It has a ‘V’ formation and gradually widens seawards whereupon it divides into two channels, the southern with a depth of 60 m provides the main zone for marine and freshwater exchange. There are distinguishable zones in the Ria defined by the water column stratification, (1) the internal part from the River Lérez to Tambo Island (2) an intermediate section from Tambo Island to Udra Cape, and (3) an oceanic zone from Udra Cape to Ons island. Stratification is a function of river runoff in the winter and ENACW upwelling in the summer. Acting independently, freshwater runoff and wind forcing favour either water retention or ria flushing, with the result that zone 1 is the most estuarine-like and zone 3 the most oceanic.

Nortwestern of Iberian Peninsula:
Galician Rias

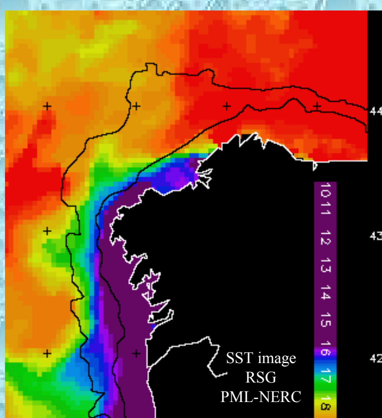


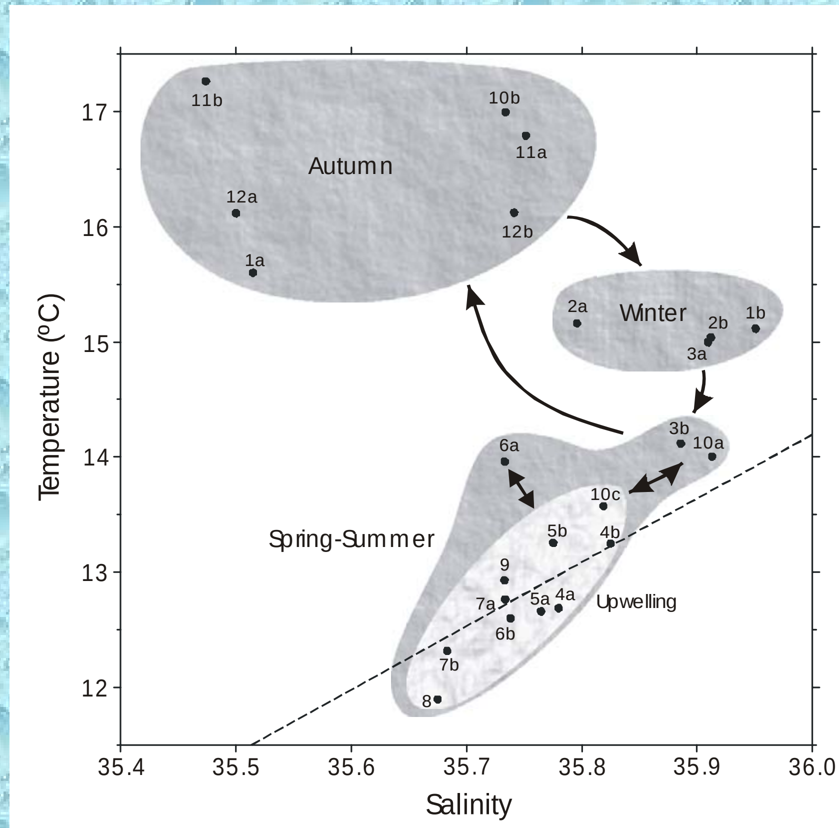
Map and bathymetry of the Ria Pontevedra. Numbers represent the hydrodynamic and biogeochemistry sampling stations and letters the biological stations.

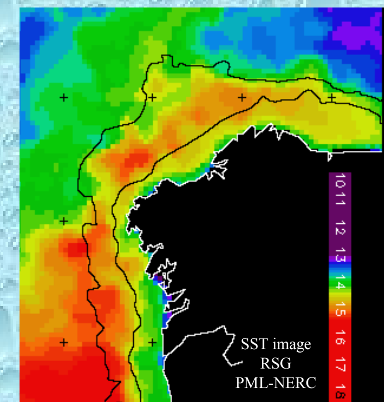
From the ocean boundary, favorable atmospheric conditions in spring induced coastal upwelling up the continental shelf, which intensified in summer and was detected in the inner ria. Thereafter, upwelling ceased and from November to March seawater transported by the poleward current was detected on the shelf and occasionally inside the ria.

ENACW upwelling

12-18 july 1998





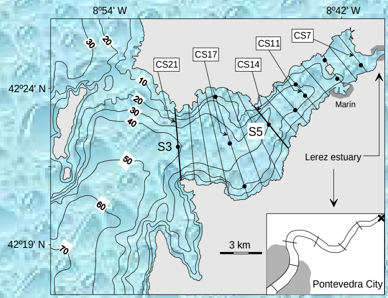


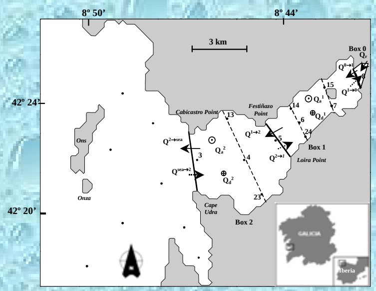
Poleward current

18-24 january 1998

Temperature-Salinity diagram of incoming seawater (50 m depth) in the Ria Pontevedra over an annual cycle. Numbers refer to calendar month and letters to the first (a) or the second (b) fortnightly cruises. The dashed line represents the T-S line for ENACW watermass. *Prego et al. (2001)*

From the continental boundary, the annual average contribution was 27 $m^3 s^{-1}$ of freshwater, mainly by the Lerez River. Winds speed higher than 4 $m s^{-1}$ are able to dominate the current at surface layers of inner ria zone, even against tidal effects. *deCastro et al. (2000)*





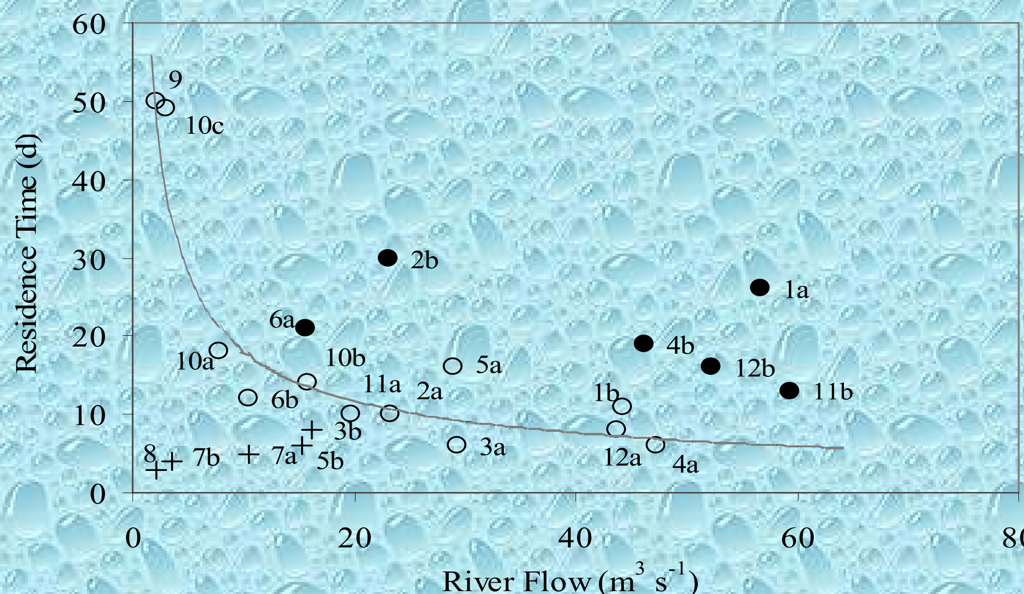
An analysis of the intra-annual variability of hydrographic residence times, τ, quantified with an iterative approach to the fraction of freshwater method using 23 quasi-steady state water-salt budgets. Mean τ was 6±2 d in the central ria and 2±1 d in the internal ria. The tidal contribution, equal to 10-25 % of total water renewal, was quantified for the first time for a Galician ria with the hydrodynamic model ECoS. *Dale et al. (2004)*

By means of a steady state box model and a first-order implicit finite difference model, the residence time of water (tr, days) in the inner-middle ria zones was shown to depend simultaneously on the river discharge (Qr, $m^3 s^{-1}$) and the seawater inflow (Qs, $m^3 s^{-1}$) via the relationship:

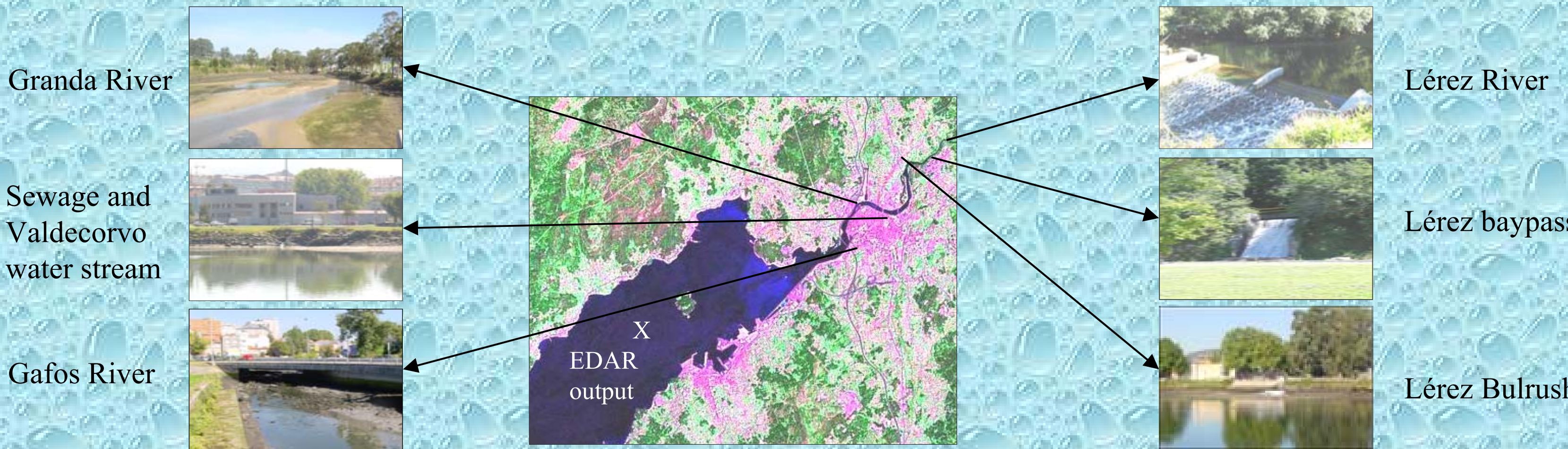
$$tr = 1 / (0.000696 \cdot Qs + 0.0125 \cdot Qr + 0.43)$$ *Gómez-Gesteira et al. (2003)*

It varies from around 3 days at the inner box to around 8 days at the middle one.

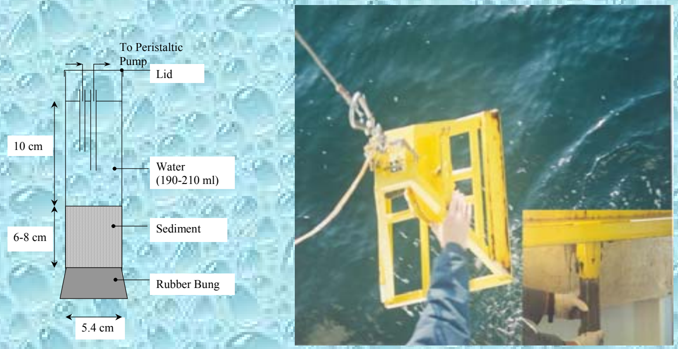
Cruise-by cruise variation of residence time in the Pontevedra Ria with residual freshwater inflow, Q_z.
The residence was calculated using a date specific fraction of freshwater method. Where applicable, each cruise is denoted by "a" or "b" referring to the first and second fortnight of the month respectively. October 1998 is indicated by "10c".



In the Western Galician Rias only the inner part can be considered as an estuary from both hydrographical and their resulting sedimentological considerations. One source of nutrients salts to the Rias are the continental discharges which only has been considered the main river. The Lerez estuary, placed in the inner zone of the Pontevedra Ria receive six freshwater and sewage contributions with less caudal than the main river. To attend this importance of the inputs, there were realized samplings each two weeks during 1998 from the *Zoea* boat and there were determined water flows and quantitative contents of nitrate nitrite ammonium, dissolved oxygen and silicate for each tributary.

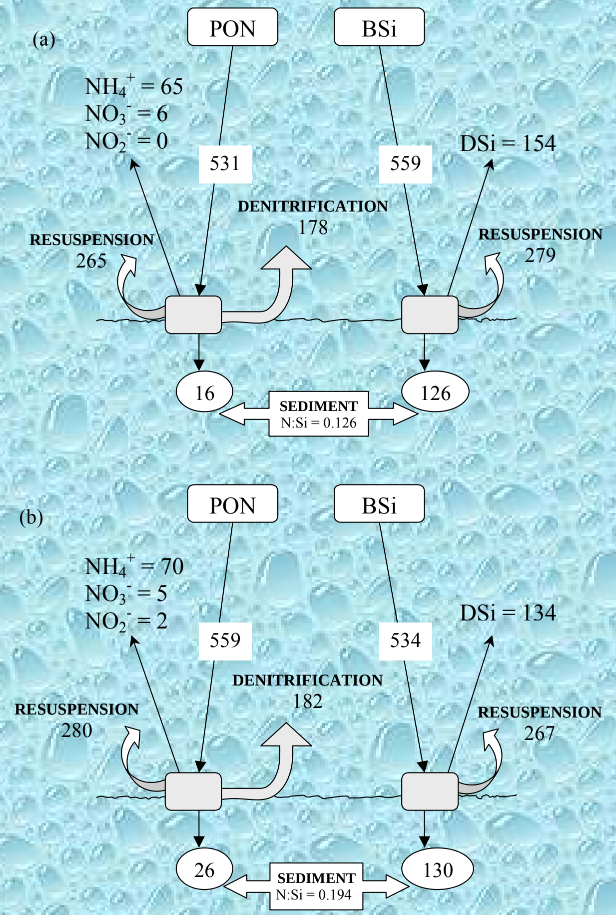


From the continental boundary, annually, to the inner zone of Pontevedra Ria are flowing 30.1 $m^3 s^{-1}$ of water; 750, 15 and 550 mol s^{-1} of nitrate, nitrite and ammonium; 2810 mol s^{-1} of silicate and 9400 mol s^{-1} of dissolved oxygen from land contributions. The Lerez River is the main freshwater source (86%), nitrate (79%), nitrite (47%) silicon (87%) and dissolved oxygen (88%). However, the discharges from the Placeres plant of sewage treatment (EDAR), the water stream of Valdecorvo and the Gafos and Granda small rivers, increase significant to the DIN (53%) with respect to the Leréz river and should be considered in the estuary ria zone.



Experimental incubation design. Triplicate sediment cores and a control of water only were used for nutrient flux assessment. All cores were maintained in a water bath at *in situ* temperature in darkness.

Sediment incubation microcosms, multitrap apparatus and water column variables have been employed to describe the dynamic changes in benthic-pelagic coupling between nutrient pools in the Pontevedra Ria, during spring and summer 1998. From the benthic boundary, sediment incubation cores showed that large quantities of ammonium are effluxed to the water column (250 µmolNH_4^+ m^{-2} h^{-1}) with upwelling conditions. Net denitrification, determined by mass balance was estimated at two stations as 178 µmolN m^{-2} h^{-1} and 182 µmolN m^{-2} h^{-1}. Denitrification was highest when upwelling relaxes and the flux of organic matter to the sediment increases. Regular inputs of offshore seawater ensured water renewal and re-oxygenation of bottom waters, thus preventing anoxia, particularly in the summer. *Dale and Prego (2002)*



Conceptual diagram for particulate organic N and Si benthic-pelagic coupling in the Pontevedra Ria during spring 1998 at (a) St.O and (b) St.M. Units µmol m^{-2} h^{-1}. Denitrification and storage do not add up exactly since the values in the figure are the mean of individually calculated rates from particulate deposition and nutrient efflux data on each sampling date, rather than from the mean values of particulate deposition and nutrient efflux.

Benthic boundary. Fluxes of particulate pelagic material were measured in the Ria using sediment traps moored at the base of the photic zone, deployed for 24 h from February to June 1998. Measurements were taken of water column hydrography, chlorophyll, primary production and phytoplankton. Samples were divided into low, moderate and high productivity periods, according to phytoplankton biomass.


Multitrap System

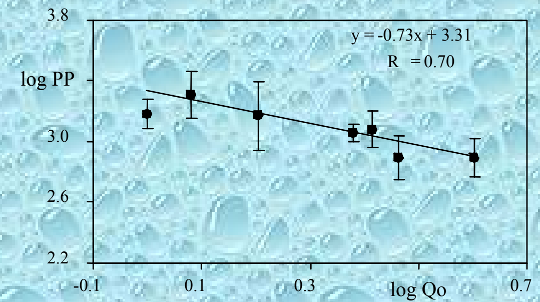
The trap system consisted of four bound Plexiglass tubes (6 cm diameter) filled with preservative-free filtered seawater. NaCl (35g) was added to each tube to raise the salinity and prevent particle loss. Water column particulate material was collected with a multitrap system anchored to the seafloor at two sites in the ria (Sts.O and M) for periods of 1 d. Trap deployment was intended to span the whole survey period although logistical problems limited the collection period to 6 months (February-July 1998).

The vertical flux of carbon ranged from 530 to 1780 mgC m^{-2} d^{-1}. Minimum values were recorded during high productivity periods, and were related to offshore advection of surface water. The daily export of carbon accounted for 75% of primary production. The contribution of phytoplankton to the sedimented carbon ranged from 18 to 66 %, and the fraction corresponding to living phytoplankton from 5 to 25 %. Diatoms were predominant, however, microflagellates accounted for about 20% and dinoflagellates for 13% of the total biomass, suggesting the rapid formation of aggregates, increasing the sinking speed of individual cells. A decrease in sedimentation was observed from the inner to the outer ria, and from low to higher productivity periods. However, no differences were found among stations and periods. Sedimentation is influenced by hydrography, showing a negative relationship with the water flux.

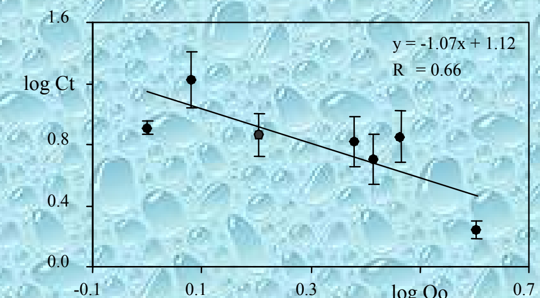
Ratio of biomass percentages sediment trap/water column for different phytoplankton groups.

	O			M			I		
	H	M	L	H	M	L	H	M	L
Dinoflagellates	1.26	0.87	3.95	3.56	1.82	5.42	6.01	3.65	4.30
Diatoms	0.93	1.10	1.35	0.94	0.91	0.63	0.82	0.92	1.12
Microflagellates	0.53	0.57	0.55	0.58	0.64	0.73	1.12	0.56	0.31

O: Outer station, M: Middle station, I: Inner station. H: High , M: Moderate, L: Low Productivity Periods.

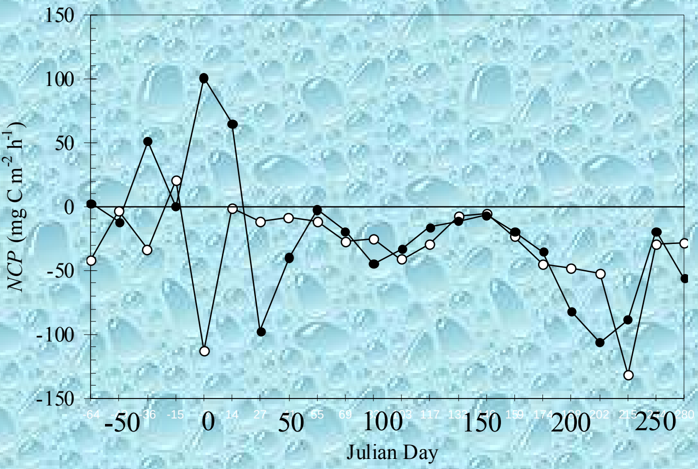


Log-log plot ($p < 0.01$) of seawater outgoing ria (Qo in 10^3 m^3 s^{-1}) flux *vs.* primary production (PP in mgC m^{-2} d^{-1}).



Log-log plot ($p< 0.01$) of seawater outgoing ria flux (Qo in 10^3 m^3 s^{-1}) *vs.* trap chlorophyll (Ct in mg m^{-2} d^{-1}).

Varela et al. (2004)



Time series of net community production (*NCP*, mgC m^{-2} h^{-1}) in the Pontevedra Ria over October 1997-1998 scaled from NO_3^- (●) and PO_4^{3-} (○) nutrient balances (B_p, Eq.5). A positive value implies net heterotrophy and negative value net autotrophy.

Seasonal and annual nutrient balance in the Pontevedra Ria, B_p, over the period November 1997-September 1998. A negative sign denotes a net loss of inorganic nutrients from the ria and a positive sign denotes a net input. Units are in mol s^{-1} and in equivalent carbon units.

Season	NO_3^-		PO_4^{3-}	
	mol s^{-1}	mg C m^{-2} h^{-1}	mol s^{-1}	mg C m^{-2} h^{-1}
Wet	1.74	8.3	-0.25	-20.2
Spring	-4.58	-21.9	-0.28	-22.7
Dry	-11.98	-57.2	-0.76	-61.4
Mean	-5.03	-24.0	-0.44	-35.8

The sum of the net non-conservative biogeochemical processes, which cause deviations in simple constituent mixing, can be represented by B_p and a non-steady state term dN_u / dT:

$$B_p = V\,(dN_u / dT) + \Sigma F$$

If no biogeochemical removal or addition of nutrient salts takes place ΣF will be purely dependent on physical mixing and transport processes, and therefore be zero.

A non-stationary state mass balance of the type advocated by IGBP-LOICZ has been used to asses net ecosystem metabolism in the ria. Nutrient fluxes into the reservoir were strongly driven by the incoming oceanic flow throughout the year, which supplied 88 and 98 % of the total NO_3^- and PO_4^{3-} load, respectively. The mean annual net community production (*NCP*) predicted by the NO_3^- balance was 24.0 mgC m^{-2} h^{-1}, and 35.8 mgC m^{-2} h^{-1} from the PO_4^{3-} budget. The Pontevedra Ria may be considered as net autotrophic, although the NO_3^- budget suggests alternation between autotrophy and heterotrophy over an annual cycle. *Dale and Prego (2005)*

Some considerations to the land-ocean studies:

The water-salts budget in estuaries and rias must be careful applied because water exchange is highly dependent of the quasi-stationary and boundary conditions. Thus, some the budget or 3-D model applied to the Pontevedra Ria had these problems.
The water residence time is a key to understand the physical and biogeochemical processes and human impacts to improve the integrated management of the ria environment.

When the carbon and nutrient budget is solved in estuaries and rias, the main river input could be insufficient to quantify the continental contributions and other minor freshwater flows must be take into account. Thus, in the Ria Pontevedra the DIN from the Lerez Rivez is only the 47% of total flux.

In the estuary and ria budgets, the nutrients contribution from the sediment boundary and the hydrodynamic-biogeochemical coupling cannot be obviated. Thus, in the Pontevedra Ria hydrodynamical processes play an important role in determining the quantity of nutrients remineralised and, in the case of nitrogen, the rate of denitrification at the benthic boundary layer.

It is necessary, in estuaries and rias, to study the biogeochemical cycle of other elements than C, N or P. Thus, in Ria Pontevedra metals as Cu (Cobelo-García & Prego, 2003) must be considered due to its micronutrient and contaminant effect.

In a ria, its estuary is the most vulnerable area under the influence of global change and human activities.

Ria future is uncertain towards sustainability or resource management issues.

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