UNIVERSITY OF ALGARVE

FACULTY OF SCIENCES AND TECHNOLOGY

"The LOICZ Biogeochemical budget approach applied to Ria Formosa lagoon, Algarve, South Portugal"

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JURI:

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RESUMO

Palavra-chaves:

ABSTRACT

The Ria Formosa lagoon is a mesotidal lagoon located in the south coast of Portugal. A single-box, single-layer LOICZ model was applied to data in 1987 and 1999 to estimate the biogeochemical budget of the Ria Formosa lagoon. Water exchange time in the lagoon was estimated to be about 2 days. Both the fluxes of DIP and DIN were negative, indicating that the system acts as sink of both DIP and DIN. Stoichiometric calculations assumed nutrient ratios in both Redfield proportions (C:N:P=106:16:1) and in proportions appropriate for macroalgae (C:N:P=335:35:1). Overall, the lagoon can be consider as "autotrophic", with a net ecosystem metabolism *(p-r)* 8.4 mmol C m^{-2} d^{-1} considering Redfield ratio. Nitrification dominated over nitrogen fixation since it was positive in both cases.

The Ria Formosa lagoon is sensitive to the tide. The water and nutrient budget in the lagoon has strong seasonal variation, especially the dry and rainy seasons. According to the standards of EEA, the Ria Formosa lagoon is between oligotrophic and mesotrophic.

Keywords: LOICZ budget; Nutrient budget; Ria Formosa; Portugal

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1. Background

1.1. Value of study of eutrophication in coastal lagoons

Lagoons are coastal stretches of water which are generally shallow and separated from the sea by a coastal sand bar. From a hydrological point of view, communication with the sea takes place via connecting channels. Such exchanges give the lagoon water a brackish quality. The lagoons have a close relationship with the surrounding wetland areas (coastal marshes) and receive numerous water inputs from their catchment areas. The lagoons are generally about a meter in depth but may be deeper depending on their geomorphologic origin. (Richard et al., 2005)

The EEA (1999; 2001) suggests that there is potential for eutrophication within the estuaries and lagoons of the Iberian coastal areas, including the Ria Formosa along the eastern part of the south coast of Portugal. A good understanding of the respective cycles of water, nitrogen and phosphorus will allow sensible management of this fragile system.

Land-Ocean Interactions in the Coastal Zone (LOICZ) is an international research project involving scientists from across the globe who have been investigating changes in the biology, chemistry and physics of the coastal zone. The research results are used to explore the role humans play in the coastal zone, their vulnerability to changing environments, and the options to protect coasts for future generations. Understanding material fluxes through the coastal zone is fundamental to LOICZ. The development of budget models for C, N, P across a spread of global sites is a major initiative and can be accessed through the Biogeochemical Budget Model.

The LOICZ model (Gordon et al., 1996) provides a tool to characterize the lagoon and allows observations made on one system to be applied to all the lagoons. Thus, by analyzing the causes of an ecological disequilibrium or highly productive aquacultural activity, the same conditions can be avoided or reproduced in other similar systems. A variety of lagoon site examples and different data types which show approaches that can be taken under the LOICZ modeling protocol for the first-order evaluation of the system physics and estimation of net metabolism of coastal systems, and modeling to meet LOICZ global change goals.

1.2. Description of study area

The Ria Formosa is a shallow mesotidal lagoon located on the coast of the Algarve region in South Portugal. It extends for about 55 km along the coast (37°03'N 007°47'W), (Figure 1). The average volume of the lagoon at mean tide is $92.10^6 m^3$ ($210. 10^6 m^3$ and $45. 10^6 m^3$ at high and extreme low tide). It is separated from the Atlantic Ocean by several barrier islands and sand spits. (Newton & Mudge, 2003)

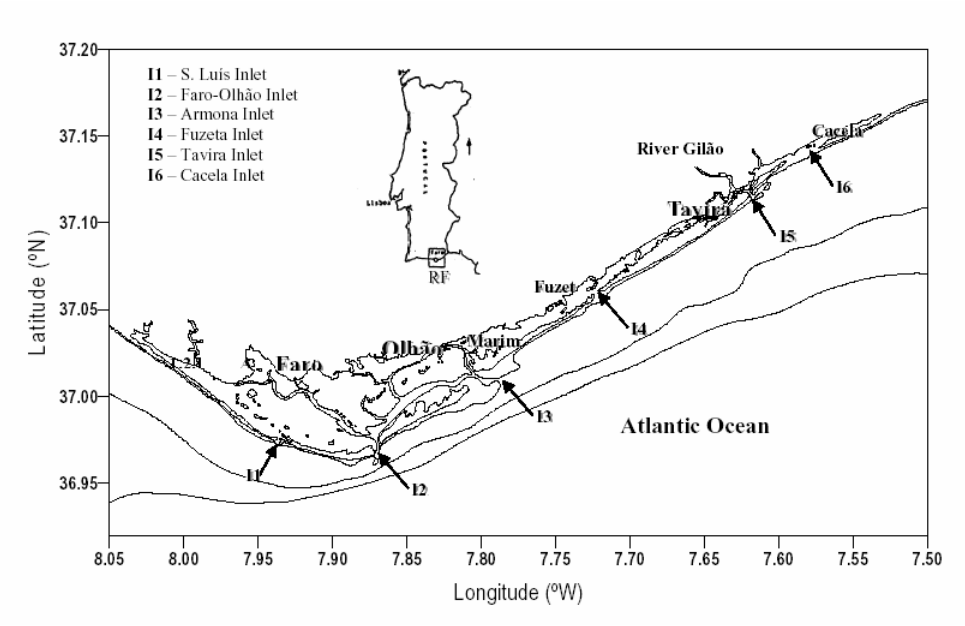

Figure 1 Ria Formosa, Algarve, Southern Portugal (Duarte et al., 2005)

Water is exchanged with the ocean through the six natural inlets (barras) and one is artificial - opened in 1997(INDIA project). These inlets lead to a tidal range of between 3.5 and 0.7 m at springs and neaps, respectively(Newton, 1995). The Ria Formosa water surface area at mean tide is about 58 km^2 and varies between 91 and 18 km^2 at extreme high and extreme low tide. The mean depth is 1.5m. The site has a semidiurnal tidal regime and the tidal range varies from 0.9 m (mean low tide) to 3 m (mean high tide). (Tett et al., 2003)

Although it is a region of restricted exchange, water residence times are very short, except maybe for water in the inner areas. About 50 – 75 % of the lagoon water is being exchanged daily with the tide (Falcão et al., 2003). The Ria Formosa receives freshwater inputs from small rivers (Gilão, Almargen, Seco) and seasonal streams and the river discharge is relatively small, but it is an important nutrient source for the lagoon because of the agricultural activity in the drainage region. (Newton et al., 2003)

In the lagoon there are several channels that are regularly being dredged in order to remain navigable. The climate in the region is Mediterranean with mild winters (average daytime temperatures 15-20^{0}C), hot summers (average daytime temperature 25-30^{0}C). The annual precipitation is about 650 mm and that is mainly in the winter. Mean salinity in the Ria Formosa is about 35.9 psu with mean values of 35.25 for the winter season and about 36.5 for the summer season with much higher values observed at the saltpans. (Newton & Mudge, 2003)

The site encompasses a complex of channels, barrier islands, with extensive mudflats, sandbanks, sand dune systems, salt marshes, marshland and sea grasses and also includes nurseries for the rearing of fish and bivalve mollusks. Ria Formosa is one of the most ecologically important and major wetlands in south Portugal, holding important habitats and vegetative communities for birds and other fauna. The area is a key over-wintering migration stopover site and a key breeding area for birds, an important area botanically, with several endemic plants present. The site is a Natural Park, including 10 000 ha costal lagoon, 5 000 ha salt marsh and mudflats, 2000 ha sandbanks and dunes and 1 000 ha saltpans and aquaculture ponds. The site is also designated an EU Special Protection Area and belongs to Natura 2000 and the Ramsar convention and contains a special protection areas for birds and biotope identified in CORINE. (Newton et al., 2003)

The Ria Formosa is also a valuable economic resource for the region with the tourism, fisheries, aquaculture and salt extraction industries. The population in the surrounding areas (the Ria Formosa watershed) includes about 124 000 resident inhabitants and 211000 in high season and 167000 in low season due to tourism. About 26 – 28% (respectively high season – low season) of the population is not connected to the centralized sewage treatment plants. (Ferreira et al., 2003)

1.3. Introduction of LOICZ Budget model

Under LOICZ I, the goal was to compile regional carbon/nitrogen/phosphorus data and budget models for numerous coastal areas of the world that can be used to produce global syntheses models of their flux in the coastal zone. LOICZ II continues to support the approach, to refine the methodology, and to begin to apply it to other coastal management questions. (http://www.loicz.org/science/budget/index.html.en)

In science, models are tools that help us conceptualize, integrate, and generalize knowledge. Natural systems such as ecosystems are usually very complex, and models vary greatly in the degree of simplification away from that complexity. Usually budget models are built to aggregate the many small individual pieces of a system into smaller sets of pieces which are similar to one another. Thus, all plant species in an ecosystem might be aggregated into "primary producers." Some grouping will occur for almost any model. As one applies a single model across a range of systems, the value of such groupings becomes readily apparent. For some purposes it may be adequate to group all organisms within an ecosystem into the "net biogeochemical reactions" which occur within the system. (http://www.loicz.org/science/budget/index.html.en)

One can proceed from these simple, highly aggregated, models to more complicated models which describe specific processes (e.g., primary production as a function of light; sediment transport as a function of river flow, etc.). Many such process models may be further combined into an integrated system model. However, in general, the more complex the model structure, the less statistically robust is the statistical output.

1.4. Budgets of Coastal Ecosystems

LOICZ Budget model had been implemented in many coastal ecosystems in the world (**Figure 2**). This model can be carried out at quite different spatial and temporal scales. Three spatial scales, defined in terms of linear coastline length, have been identified in the Implementation Plan as being of primary interest to LOICZ. They are:

- Local/Site (~1-100 km): These would address specific habitats such as saltmarshes, mangrove, forests, deltas, coral reefs, estuaries, bays and fishing banks. Modelling on this scale would be generic in nature, for example, mangrove forests can be modelled in a way that allows application of the models to other sites with similar conditions.
- Regional (~100-10,000 km): These would incorporate a variety of near-shore and off-shore habitats, in some cases out to the 200 m isobath. Modelling on this scale would be geographic in nature and would be carried out for a particular region of the world such as the North Sea, South China Sea, etc.

- Global: These would incorporate several regional models representing either the entire world's coastal zone or a substantial proportion, based on representative regions, the results from which are up-scaled to the global scale.

Details of budgets in the different regions can be found in the websites (**Table 1**). It is already used in many estuaries and bays in Africa, Asia, Australia, Europe and America.

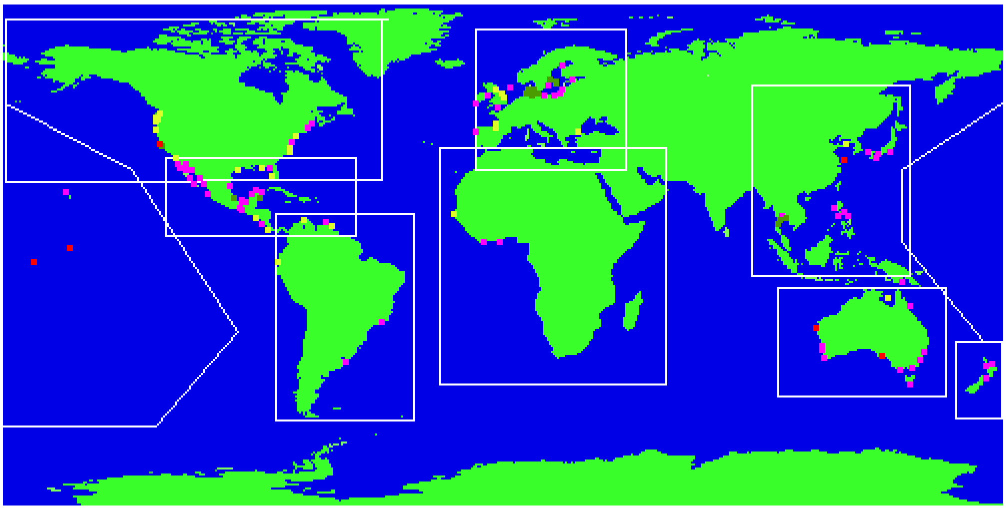

Figure 2 a global map of where LOICZ nutrient budgets have been applied

Table 1 Table of Current Budget Sites (http://nest.su.se/mnode/Budgetlist.htm)

Longitude (+E)	Latitude (+N)	System Name	Continent/Country	web reference
Africa				
9.7	3.9	Cameroon estuarine system	Africa/Cameroon	http://data.ecology.su.se/mnode/Africa/Cameroon/Cameroon/cameroonbu
8.28	4.8	Rio-del-Rey system	Africa/Cameroon	http://data.ecology.su.se/mnode/Africa/Cameroon/RiodelRay/riodelraybu
12.3	-6.05	Congo (Zaire) River estuary	Africa/Congo(Zaire)	://data.ecology.su.se/mnode/Africa/Congo/Congobud.htm
40.15	-3.2	Malindi Bay	Africa/Kenya	http://data.ecology.su.se/mnode/Africa/Kenya/Malindi%20Bay/Malindiba
3.5	6.5	Lagos Lagoon	Africa/Nigeria	http://data.ecology.su.se/mnode/Africa/Lagos/lagosbud.htm
23	-34.1	Knysna River system	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Knysna/knysnabud.htm
24.85	-34.15	Kromme estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Kromme/kromme_river_
25.07	-33.97	Gamtoos estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Gamtoos/gamtoos_river_
25.63	-32.87	Swartkops estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Swartkops/swartkopsbu
25.42	-33.72	Sundays estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Sundays/sundays_river_
32.05	-28.8	Mhlathuze estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Mhlathuze/mhlathuze__
30.5	-29.22	Thukela estuary	Africa/South Africa	http://data.ecology.su.se/mnode/Africa/S_Africa/Thukela/thukela_river_e
39.47	-6.19	Chwaka Bay	Africa/Tanzania (Zanzibar)	http://data.ecology.su.se/mnode/Africa/Tanzania/ChwakaBay/ChwakaBu
39.22	-5.92	Makoba Bay	Africa/Tanzania (Zanzibar)	http://data.ecology.su.se/mnode/Africa/Tanzania/MakobaBay/MakobaBu
6.27	34.83	Moulay Bousselham Lagoon	Africa/Morocco	http://data.ecology.su.se/MNODE/Africa/Morocco/bousselham/blbud.htm
Asia				

128.90	35.10	Nakdong Estuary	Asia/ South Korea	http://data.ecology.su.se/mnode/Asia/Korea/NakdongRiver/nakdongbud.h
127.80	34.90	Sumjin Estuary	Asia/ South Korea	http://data.ecology.su.se/mnode/Asia/Korea/SumjinRiver/sumjinbud.htm
113.59	22.57	Pearl River Estuary	Asia/China	http://data.ecology.su.se/mnode/Asia/China/pearlmirs/PMbudsrev2.htm
114.70	22.50	Mirs Bay	Asia/China	http://data.ecology.su.se/mnode/Asia/China/pearlmirs/PMbudsrev2.htm
113.08	22.01	Aimen Estuary	Asia/China	http://data.ecology.su.se/mnode/Asia/China/amp/3pearlbud.htm
113.39	22.13	Modaomen Estuary	Asia/China	http://data.ecology.su.se/mnode/Asia/China/amp/3pearlbud.htm
118.00	24.45	Jiulong Bay	Asia/China	http://data.ecology.su.se/mnode/Asia/China/JiulongRiver/jiulong.htm
125	31	East China Sea	Asia/China Japan	http://data.ecology.su.se/mnode/Asia/ECSt.htm
73.84	16.17	Mandovi Bay	Asia/India	http://data.ecology.su.se/mnode/asia/india/mandovi/mandovibud.htm
138.00	-2.00	Mamberamo Estuary	Asia/Indonesia	http://data.ecology.su.se/mnode/Asia/Indonesia/mamberamo/mamberamo
106.20	-6.00	Teluk Banten Bay	Asia/Indonesia	http://data.ecology.su.se/mnode/Asia/Indonesia/telukbanten/tbbud.htm
130.80	33.90	Dokai Bay	Asia/Japan	http://data.ecology.su.se/mnode/Asia/Japan/dokai/dokaibay.htm
130.3	33.6	Hakata Bay	Asia/Japan	http://data.ecology.su.se/mnode/Asia/Japan/Hakata/Hakatabay.htm
136.8	34.8	Ise Bay	Asia/Japan	http://data.ecology.su.se/mnode/Asia/Japan/threebays/isebay.htm
135.2	34.5	Osaka Bay	Asia/Japan	http://data.ecology.su.se/mnode/Asia/Japan/threebays/osakabay.htm
138.9	34.5	Tokyo Bay	Asia/Japan	http://data.ecology.su.se/mnode/Asia/Japan/threebays/tokyobay.htm
103.10	5.45	Kuala Terengganu Estuary	Asia/Malaysia	http://data.ecology.su.se/mnode/Asia/Malaysia/kt/kt.htm
124.30	39.80	Yalujiang estuary	Asia/N. Korea China	http://data.ecology.su.se/mnode/Asia/YalujiangRiver/yalujiang_river_estu
122.17	14.15	Calauag Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/calauag/Calauagbay.ht
123.88	13.52	Lagonoy Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/lagonoy/lagonoy.htm
119.90	16.35	Lingayen Gulf	Asia/Phillipines	http://data.ecology.su.se/MNODE/Asia/Philippines/lingayen/Lingayenbu
120.78	14.55	Manila Bay	Asia/Phillipines	http://data.ecology.su.se/MNODE/Asia/Philippines/manilabay/Manilabay

123.08	13.50	Ragay Gulf	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/ragay/ragay.htm
123.16	13.93	San Miguel Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/sanmiguel/SanMiguelba
123.89	12.90	Sorsogon Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/sorsogon/sorsogon.htm
120.21	14.79	Subic Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/subic/subic.htm
124.68	11.36	Carigara Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/carigara/Carigarabay.htm
125.78	6.74	Davao Gulf	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/davao/davao.htm
125.12	10.70	Sogod Bay	Asia/Phillipines	http://data.ecology.su.se/mnode/Asia/Philippines/sogod/sogod.htm
131.80	43.20	Amursky Bay	Asia/Russia	http://data.ecology.su.se/mnode/Asia/Russia/amurskybay/amurskybud.htm
141.33	53.00	Amur estuary	Asia/Russia	http://data.ecology.su.se/mnode/Asia/Russia/amurskybay/amurskybud.htm
131.82	43.27	Ussuriyskiy Bay	Asia/Russia	
124.00	36.00	Yellow Sea system	Asia/S. Korea N. Korea China	http://data.ecology.su.se/mnode/Asia/YellowSea/yellowseabud.htm
120.10	23.10	Chiku Lagoon	Asia/Taiwan	http://data.ecology.su.se/mnode/Asia/Taiwan/Chikulagoon/clbud.htm
120.20	22.70	Tapong Bay	Asia/Taiwan	http://data.ecology.su.se/mnode/Asia/Taiwan/TapongBay/tapongbaybud.h
120.10	23.00	Tsengwen Estuary	Asia/Taiwan	http://data.ecology.su.se/mnode/Asia/Taiwan/TsengwenRiver/tsengwenbu
121.40	25.20	Tanshui Estuary	Asia/Taiwan	http://data.ecology.su.se/mnode/Asia/Taiwan/TanshuiRiver/tangshuibud.h
99.67	9.20	Bandon Bay	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/bandonbay/bandonbay.htm
101.50	13.75	Bangpakong Estuary	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/Bangpakong/bp.htm
100.55	14.05	Chao Phraya Estuary	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/ChaoPhraya/cp.htm
99.80	13.66	Mae Klong River	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/maeklongriver/maeklong.h
100.18	8.37	Pakphanang River	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/pakphanang/Pakphanang.h
101.62	12.87	Prasae River	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/prasaeriver/prasaer.htm
99.75	14.50	Tachin River	Asia/Thailand	http://data.ecology.su.se/mnode/Asia/Thailand/tachinriver/tachin.htm
106.06	9.72	Hau River	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/hau/haubud.htm

107.73	16.36	Cau Hai Lagoon	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/cauhai/cau_hai_bud.htm
109.27	12.22	Nha Trang Bay	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/NhaTrang/nhatrangbud.ht
108.10	10.80	PhanTheit Bay	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/PhanThiet/phanthiet.htm
109.50	12.60	VanPhong Bay	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/VanPhongBay/budgets_fo
106.50	9.80	Tien Estuary	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/Tien/tienbud.htm
108.80	15.80	Thubon Bay	Asia/Vietnam	http://data.ecology.su.se/mnode/Asia/Vietnam/ThuBon/thubon.htm
Australia				
143.50	-8.50	Fly River Estuary	Australasia/Papua New Guinea	http://data.ecology.su.se/mnode/Pacific/NewGuinea/FlyRiver/flyriver.ht
145.27	-15.53	Annan	Australia	http://data.ecology.su.se/mnode/Australia/tropical/tropical_systemsbud.ht
153.03	-30.65	Bellinger	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
153.17	-27.37	Brisbane	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
153.55	-28.53	Brunswick	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
153.03	-27.15	Caboolture	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
147.00	-18.00	Central Great Barrier Reef	Australia	http://data.ecology.su.se/mnode/Australia/GBRbud.htm
153.35	-29.43	Clarence	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
115.80	-32.20	Cockburn Sound	Australia	http://data.ecology.su.se/mnode/Australia/cockburnsound/cockburnbud.ht
145.43	-16.28	Daintree	Australia	http://data.ecology.su.se/mnode/Australia/tropical/tropical_systemsbud.ht
147.30	-42.90	Derwent Estuary	Australia	http://data.ecology.su.se/mnode/Australia/Derwent/derwentbud.htm
152.87	-31.42	Hastings	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
151.80	-32.90	Hawkesbury-Nepean	Australia	http://data.ecology.su.se/mnode/Australia/HawkNep/hawknepbud.htm
142.20	-11.15	Jardine	Australia	http://data.ecology.su.se/mnode/Australia/tropical/tropical_systemsbud.ht
150.80	-34.00	Lake Illawara	Australia	http://data.ecology.su.se/mnode/Australia/Illawarra/Illawarrabud.htm
147.00	-38.00	Lake Victoria	Australia	http://data.ecology.su.se/mnode/Australia/GippslandLakes/gippsland.htm
153.33	-27.68	Logan	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht
153.05	-30.90	Macleay	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.ht

152.50	-31.87	Manning	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.htm
146.12	-17.60	Moresby	Australia	http://data.ecology.su.se/mnode/Australia/tropical/tropical_systemsbud.ht
153.02	-30.65	Nambucca	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.htm
145.00	-38.00	Port Phillip Bay	Australia	http://data.ecology.su.se/mnode/Australia/PortPhillipBay/ppbbud.htm
153.58	-28.88	Richmond	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.htm
114.00	-26.00	Shark Bay	Australia	http://data.ecology.su.se/mnode/Australia/SB.HTM
137.00	-34.30	Spencer Gulf	Australia	http://data.ecology.su.se/mnode/Australia/spgbud.htm
115.90	-32.00	Swan-Canning Estuary	Australia	http://data.ecology.su.se/mnode/Australia/swancanning/swanbud.htm
153.55	-28.17	Tweed	Australia	http://data.ecology.su.se/mnode/Australia/subtropical/subtropicalbuds.htm
117.30	-35.00	Wilson Inlet	Australia	http://data.ecology.su.se/mnode/Australia/wilsonin/wilsonbud.htm
Central America/Mexico				
-85	10	Gulf of Nicoya	Central America/Costa Rica	http://data.ecology.su.se/mnode/CentralAmerica/GulfofNicoya/nicoyabud
-111.5	26.65	Bahia Concepcion	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/bcbud.htm
-107.63	24.42	Bahia de Altata-Ensenada del Pabellon	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/epbud.htm
-88.1	18.61	Bahia de Chetumal	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/chetumal/chetumalbud.h
-115.97	30.45	Bahia San Quintin	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/SanQuintin/SanQuintinb
-93.83	18.35	Carmen-Machona Lagoons	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/carmenmachona/carmen
-93.17	15.45	Carretas-Pereyra	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/cpbbbud.htm
-92.83	15.22	Chantuto-Panzacola	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/cpbud.htm
-88.67	21.43	Dzilam Lagoon	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/dzilam/dzilambud.htm

-110.37	24.13	Ensenada de la Paz	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/elpbud.htm
-112.31	29.33	Estero El Sargento	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/el sargento/elsargentobu
-111.53	28.75	Estero La Cruz	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/elcbud.htm
-116.63	31.75	Estero Punta Banda	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/epbbud.htm
-90.41	20.83	Laguna de Celestun	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/celestun/celestunbud.htm
-89.7	21.27	Laguna de Chelem	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/chelem/chelembud.htm
-91.69	18.67	Laguna de Terminos	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/terminos/terminosbud.ht
-97.5	24	Laguna Madre	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/lmbud.htm
-42.7	-22.93	Marica-Guarapina	Central America/Mexico	http://data.ecology.su.se/mnode/South America/MG/mgbud.htm
-93.15	18.38	Mecoacan Lagoon	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/mecoacan/mecoacan.htm
-86.76	21.1	Nichupte Lagoonal system	Central America/Mexico	http://data.ecology.su.se/MNODE/mexicanlagoons/Nichupte/nichuptebud
-87.03	21.58	Ria Lagartos	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/RioLagartos/rlbud.htm
-114.7	31.75	Rio Colorado delta	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/colorado/coloradodelta.h
-114.38	29.82	San Luis Gonzaga	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/slgbud.htm
-105.53	22.13	Teacapan-Agua Brava-Marismas Nacionales	Central America/Mexico	http://data.ecology.su.se/mnode/mexicanlagoons/tabbud.htm
Europe				
12	55	Belt Sea	Europe/Denmark	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic Sea/baltic_se

3	57	Southern North Sea	Europe/Denmark Germany Netherlands Belgium UK	http://data.ecology.su.se/mnode/Europe/NorthSea/NORTHSEA.HTM
21	55	Curonian Lagoon	Europe/Estonia Russia	http://data.ecology.su.se/mnode/Europe/curonianlagoon/curonbud.htm
-9	51.5	Lough Hyne	Europe/Ireland	http://data.ecology.su.se/mnode/Europe/LoughHyne/LH.HTM
23	58	Gulf of Riga	Europe/Latvia	http://data.ecology.su.se/mnode/Europe/Gulf of Riga/rigabud.htm
14.35	53.75	Szczecin Lagoon	Europe/Poland Germany	http://data.ecology.su.se/mnode/Europe/BalticRegion/WestBaltic/Szczeci
19.1	54.3	Gulf of Gdansk	Europe/Poland Russia	http://data.ecology.su.se/mnode/Europe/GulfofGdansk/gdanskgulf.htm
-8.8	42.2	Ria of Vigo	Europe/Spain	http://data.ecology.su.se/mnode/Europe/RiaVigo/RV.HTM
17.7	59	Himmerfjard	Europe/Sweden	http://data.ecology.su.se/mnode/Europe/Himmerfjard/LONGBUDS.HTM
12	57	Kattegat	Europe/Sweden Denmark	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic Sea/baltic_se
23	64	Bothnian Bay	Europe/Sweden Finland	http://data.ecology.su.se/mnode/Europe/BothniaGulf/GBbud.HTM
19	62	Bothnian Sea	Europe/Sweden Finland	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic Sea/baltic_se
18	57	Baltic Proper	Europe/Sweden Finland Denmark Germany Poland Baltic states	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic Sea/baltic_se
23	64	Bothnian Bay	Europe/Sweden, Finland	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic2001/baltic_s
19	62	Bothnian Sea	Europe/Sweden, Finland	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic2001/baltic_s
18	57	Baltic Proper	Europe/Sweden Finland Denmark Germany Poland Baltic states	http://data.ecology.su.se/mnode/Europe/BalticRegion/Baltic2001/baltic_s
-1.3	50.8	Solent Estuary	Europe/UK	http://data.ecology.su.se/mnode/Europe/Solent/SOLENT.HTM
-5.5	52.7	Irish Sea	Europe/UK Ireland	http://data.ecology.su.se/mnode/Europe/Irish Sea/Irishbud.htm

3 - 6	42-44	Gulf of Lions	Europe/France	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/France
33	45.33	Donuzlav Estuary	Europe/Ukraine Black Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Ukrai
31.5	46.6	Dnieper-Bug Estuary	Europe/Ukraine Black Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Ukrai
30.48	46.08	Dniester Estuary	Europe/Ukraine Black Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Ukrai
32.02	46.59	Malii Adzalik Estuary	Europe/Ukraine Black Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Ukrai
24-26	39.83-41	Northern Aegean	Europe/Greece Aegean Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Greec
22.5-23	40.33-40.66	Inner Thermaikos Gulf	Europe/Greece Aegean Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Greec
18.44-18.46	40.19-40.22	Lake Alimini Grande	Europe/Italy Adriatic Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Italy/A
8.67	39.83	S'Ena Arrubia Lagoon	Europe/ItalySardinia Mediterranean Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Italy/a
12.28	44.63	Comacchio Lagoon	Europe/Italy Adriatic Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Italy/c
2.25-12.33	44.78-44.83	Sacca di Goro Lagoon	Europe/Italy Adriatic Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Italy/S
12.23	44.58	Smarlacca Lagoon	Europe/Italy Adriatic Sea	http://data.ecology.su.se/MNODE/Europe/Med_Aegean_BlackSea/Italy/s
North America				
-71	42.5	Boston Harbor	North America/USA	http://data.ecology.su.se/mnode/North America/bhbud.htm
-76.2	38.2	Chesapeake Bay	North America/USA	http://data.ecology.su.se/mnode/North America/chesapeake/ches2/ches2.ht
-71.3	41.6	Narragansett Bay	North America/USA	http://data.ecology.su.se/mnode/North America/NRB.HTM
-84.4	30	Ochlockonee Bay	North America/USA	http://data.ecology.su.se/mnode/North America/ochbaybud.htm

-123	38	Tomales Bay	North America/USA	http://data.ecology.su.se/mnode/North America/TOMALES.HTM
-88	30.5	Mobile Bay	North America/USA	http://data.ecology.su.se/mnode/North America/MobileBay/Mobilebud.htm
-84.97	29.67	Apalachicola Bay	North America/USA	http://data.ecology.su.se/mnode/North America/Apalachicola/apabud.htm
-122	37.75	North San Francisco Bay	North America/USA	http://data.ecology.su.se/mnode/North%20America/SFBay/sfbaybud.htm
-122	37.75	South San Francisco Bay	North America/USA	http://data.ecology.su.se/mnode/North%20America/SFBay/sfbaybud.htm
Oceania/New Zealand				
-157.4	2	Christmas Island lagoon	Oceania (Pacific)	http://data.ecology.su.se/mnode/Pacific/CHI.HTM
-171.7	-1.9	Canton Atoll lagoon	Oceania (Pacific)/Kiribati	http://data.ecology.su.se/mnode/Pacific/canbud.htm
-157.5	21.5	Kaneohe Bay	Oceania (Pacific)/USA	http://data.ecology.su.se/mnode/Pacific/KB.HTM
175.00	-36.50	Hauraki Gulf	Oceania/New Zealand	http://data.ecology.su.se/mnode/New_Zealand/HaurakiGulf/Haurakibud.h
174.30	-37.00	Manukau Harbour	Oceania/New Zealand	http://data.ecology.su.se/mnode/New_Zealand/ManukauHarbor/Manukau
174.00	-41.10	Pelorus Sound	Oceania/New Zealand	http://data.ecology.su.se/mnode/New_Zealand/PelorusSound/ps.htm
South America				
-65	-42.74	Bahia Nueva	South America/Argentina	http://data.ecology.su.se/mnode/South America/bn/bnbud.htm
-56.7	-34.9	Rio de la Plata estuary	South America/Argentina	http://data.ecology.su.se/mnode/South America/RiodelaPlata/RLP.HTM
-42.2	-22.81	Araruama lagoon	South America/Brazil	http://data.ecology.su.se/mnode/South America/araruama/arrev2/ar2budre
-48.6	-27	Camboriu Estuary	South America/Brazil	http://data.ecology.su.se/mnode/South America/camboriu/camboriubud.ht
-48.5	-25.5	Paranagua	South America/Brazil	http://data.ecology.su.se/mnode/South America/Paranagua/paranaguabayb

-43.07	-22.95	Piratininga-Itaipu	South America/Brazil	http://data.ecology.su.se/mnode/South America/PI/pibud.htm
-37.33	-11	Rio Piaui	South America/Brazil	http://data.ecology.su.se/mnode/South America/Piaui/Piauibud.htm
-37.03	-10.87	Rio Sergipe	South America/Brazil	http://data.ecology.su.se/mnode/South America/Sergipe/rio_sergipebud.ht
-73.58	-45.5	Aysen	South America/Chile	http://data.ecology.su.se/mnode/South America/Aysen/Aysenbud.htm
-80	-2.67	Guayaquil Estuary	South America/Ecuador	http://data.ecology.su.se/mnode/South America/guayaquil/Guayaquilbud.
-64.13	10.52	Laguna Restinga	South America/Venezuela	http://data.ecology.su.se/mnode/CentralAmerica/laRestinga/llr.htm

2. Data and Materials

2.1. Water data

The Ria Formosa watershed extends over 864 km^2 with a perimeter of 166 km (PH&P, 2000). There are five main streams and reduced or practically nonexistent runoff during summer.

Precipitation data were from DEKLIM VASClimO PrcpClim(Surface Climate Observations project) Resolution-0.5x0.5.$^{\circ}$ The precipitation data are monthly data from 1999. Evaporation data were calculated using the Hargreaves equation (Hargreaves, 1975). The data related to the wastewater treatment plant are calculated based on population density and land use (Ferreira et al., 2003).

Table 2 Annual discharge of river and streams of the Ria Formosa watershed (PH&P, 2000)

	Length(km)	Mean annual discharge (m^3/year)
Gilão	32.7	7.7×10^7
Almargem	49.5	3.6×10^6
S. Lourenço	24.7	2.2×10^6
Seco	21.3	4.1×10^6
Cacela	6.4	2.4×10^5

2.2. Salt data

Salinity data were the average of different stations from June to May (1988/89) (Newton et al, 2003) (Fig. 2). To give good spatial coverage, as well as to represent the variety of conditions experienced within the Ria Formosa, a subset of 16 sampling stations were chosen from a larger survey of 22 stations. Stations 7 and 14 at the seawater inlets were chosen to represent the seaward boundary conditions. Some stations located close to towns were selected to represent areas subject to domestic sewage inputs (stations 1, 9, 10 and 18). Station 20 was chosen close to the mouth of the river Gilão flowing into the system to represent areas subject to freshwater inputs. Some stations located along the channels were chosen, from the inner lagoon to the seaward boundary, to represent intermediate situations (stations 2–6, 12 and 16).

The salinity gradient is calculated from sites near the inlets. The mean salinity of the lagoon system is 35.8 (site 3, 4, 5, 6, 9 and 12), and that of ocean is 36. In the summer, the salinity in the lagoon is higher than the ocean, but the salinity we used was the annual mean.

The salinity data in 1999 are from the BarcaWin 2000 database[*], which were used for the study of seasonal cycle of water budget.

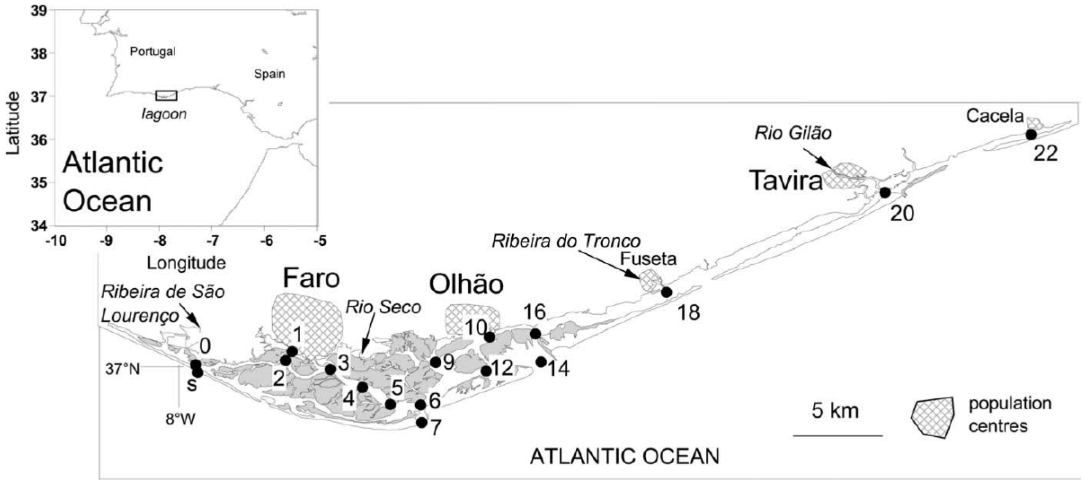

Figure 3 Location of the Ria Formosa lagoon with sampling sites.(Newton & Mudge, 2005)

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[*] Support by Sónia Cristina

2.3. Nutrient data

The dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) data for the lagoon and the inshore ocean are from the observation (1987/88) (Newton & Mudge, 2005). DIN represents NO_3^- + NO_2^- + NH_4^+. All these nutrients data are got from several cruises. The details of the data variability and observation error are not discussed here. One who interested in data analysis can look at the the BarcaWin 2000 database.

The fluxes of water, salt, DIP and DIN were calculated using simple box models following Gordon et al. (1996). The nutrient concentration calculated for the nutrient concentration of ocean is the inlets sites (Site 7 and 14), and that of lagoon system is the average of concentration of other sites. In 1987, there is special site set for the concentration of River Gilão.

The other nutrient concentrations data are from the BarcaWin database. In 1999, there were four cruises which collected nutrient concentration data , and which represent the seasonal cycle of the nutrients (**Table 4**).

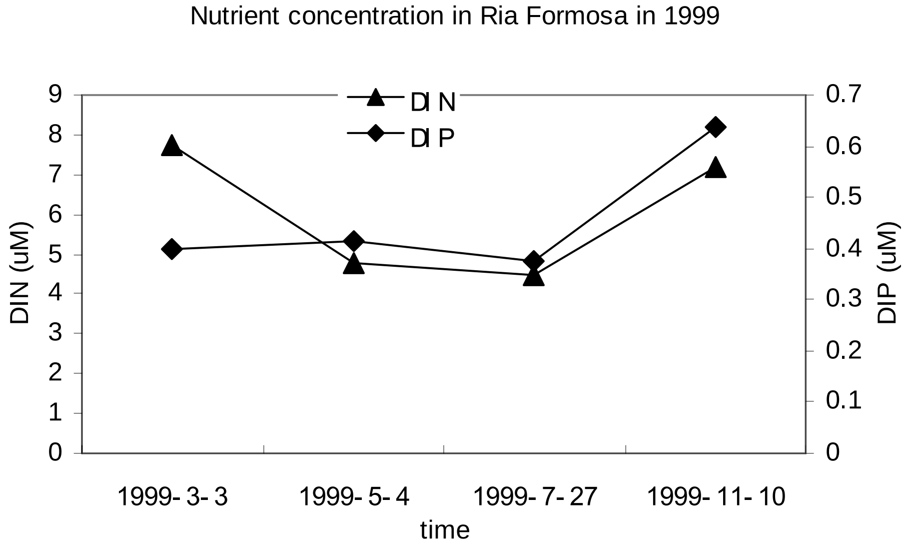

Figure 4 The seasonal nutrient variation in Ria Formosa in 1999

2.4. Benthic nutrient fluxes

Exchange of nutrients across the sediment-water interfaces of Ria Formosa was studied from water samples collected at low and high tide over one year (1987-1988) (Falcao & Vale, 1990). Because tidal flushing appears to be an important removal mechanism in this lagoon, nutrient concentrations in sediment samples varied within a broad range of values: nitrates from 0.2 to 8.8 µM; phosphates from 0.05 to 5.6 µM and silicates from 9.2 to 14 µM.

In the budget calculation, the benthic nutrient fluxes are important to the ecosystem. But the values of the fluxes varied within a broad range, we choose the value from a eight-day experiment in autumn/winter. Based on concentration variations over the first eight days, fluxes of nutrients were determined by multiplying the slope of their concentrations versus day (m) by the water-volume/sediment-area ratio (v/s) of the chamber. Summary 4 sites include muddy, sand, clams and vegetation sediment types, the fluxes of PO4 is 40.5 umol $m^{-2}d^{-1}$, NO3 is -110.25 umol $m^{-2}d^{-1}$ and NH4 is 704 umol $m^{-2}d^{-1}$. The benthic fluxes in this experiment are used for all the budget calculations.

2.5. LOICZ budget model

Budget models " are simple mass balance calculations of specific variables (such as water, salt, sediment, CNP, etc.) within defined geographic areas and over defined periods”. Usually budget models are built to aggregate the many small individual pieces of a system into fewer sets of pieces which are similar to one another. Thus, all plant species in an ecosystem might be aggregated into "primary producers." Details on the data and methodologies can be found in LOICZ Biogeochemical Modelling Guidelines (Gordon et al., 1996).

Budgeting the fluxes of materials to and from a system may be undertaken by many different procedures, but there are inherent similarities among these procedures. Basically, a budget describes the rate of material delivery to the system ("inputs"), the rate of material removal from the system ("outputs"), and the rate of change of material mass within the system ("storage"). Some materials may undergo internal transformations of state which lead to appearance or disappearance of these materials. Such changes are sometimes referred to as "internal sources or sinks" (**Figure 5**).

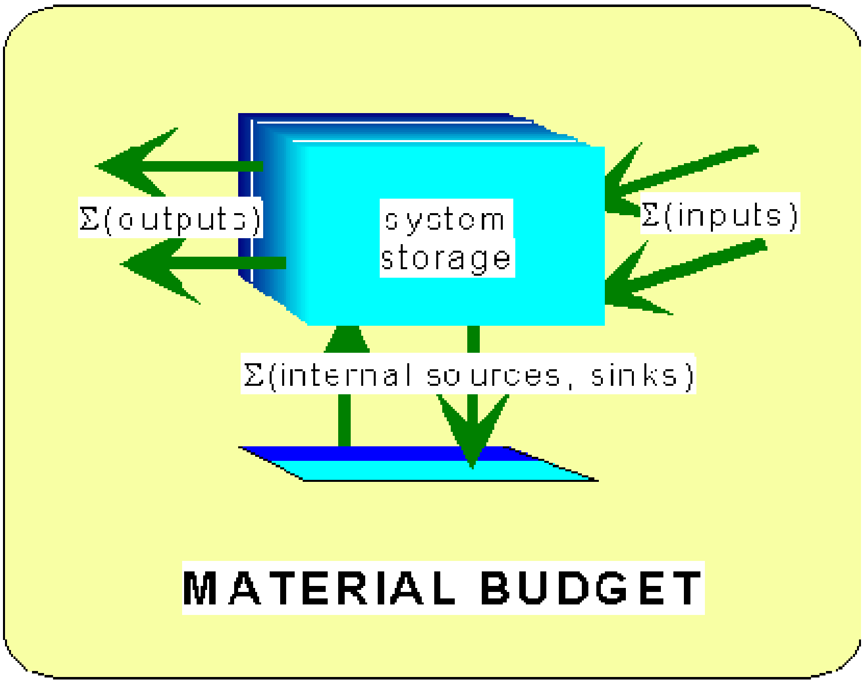

Figure 5 Generalized diagram characterizing material budgets.(Gordon et al., 1996)

3. Results

3.1. Water and Salt Budgets

3.1.1. Water budget

In the Ria Formosa the major freshwater inputs are from the small rivers Gilão, Almargen, Seco (V_Q), as well as from direct precipitation (V_P) and the input from the 28 WWTP serving the population of the region as other sources (V_O). The main water output is the evaporation (V_E) which exceeds the annual precipitation especially in the summer months. Groundwater supply (V_G) is assumed 0.

The water budget of the Ria Formosa lagoon was calculated using the single box-single layer model considering its shallowness and the good vertical mixing in the system. The water budget can be written as:

$$dV_{Sys}/dt = V_Q + V_P + V_O + V_E + V_R$$

,where V_{Sys} refers to the Ria Formosa volume, V_Q include the inflows from surface runoff and river input, V_P - direct precipitation, V_O - other inflows such as sewage outflow, V_E - to evaporation and V_R - to residual flow. It is the difference between V_{in} and V_{out} which driven by the water budget ($V_R = V_{in} - V_{out}$).

For annual fluxes we assumed the system is steady ($dV_{Sys}/dt = 0$), and the residual flow could be obtained as follows:

$$V_R = V_{in} - V_{out} = - V_Q - V_P - V_O - V_E$$

All of the fluxes are positive except for evaporation (V_E) and residual flow (V_R) because of the direction of the flow (negative value for outflow from the system and positive for inflow to the system). The residence flow is negative (-242.1×10^3 m^3/D), indicating the water is from water to the ocean in the inlets area (**Table 3**). The biggest part for the water balance is surface runoff.

Table 3 Calculation of water balance of Ria Formosa lagoon

V_Q	V_P	V_E	V_O	V_R
10^3 m^3/D	10^3 m^3/D	10^3 m^3/D	10^3 m^3/D	10^3 m^3/D
239.0	84.8	-126.9	44.2	-241.1

3.1.2. Salt budget

The Salt budget according to the LOICZ budgeting procedure (Gordon et al., 1996) has to be written as:

$$V_x = \frac{V_R S_R}{(S_{sys} - S_{ocn})}$$

, where S_{sys}/S_{ocn} represent the salinity of the system/ocean, S_R is the residual flow salinity and V_X represents mixing between the system and coastal ocean.

There are different ways to calculate the salinity in lagoon system and ocean systems. The gradient of salinity between the system and open ocean determines the “mixing water flux”. This lagoon system is a mesotidal system; the mixing water flux is the biggest component in the water budgets. Therefore, a reliable salinity gradient in the lagoon boundary is the key to the water and nutrient budget calculations. The average of salinities in outer lagoon (Sites 4, 5, 6, 9 and 12) was taken as the salinity in lagoon system. The average of the salinities in Sites 7 and 14 was taken as the salinity of ocean.

The mixing flux is positive (43277×10^3 m^3/D) (**Table 4**), and is much higher than the other water fluxes. In this lagoon system, tidal mixing is the main physical mechanism driving the ecosystem.

Table 4 Calculation of Salt balance for the Ria Formosa lagoon

V_R	S_{Syst}	S_{Ocean}	S_R	V_X	τ
10^3 m^3/D	psu	psu	psu	10^3 m^3/D	day
-241.1	35.8	36	35.9	43, 277	2.0

3.2. Budgets of non-conservative materials

The following equation represents the nonconservative material balance for the system:

$$V_{Sys}\, dY_{Sys}/dt = V_Q Y_Q + V_R Y_R + V_X (Y_{Ocn} - Y_{Sys}) + FLUX_{Ben} + \Delta Y_{Sys}$$

, where Y is the concentrations of the non-conservative materials and ΔY_{Sys} represents the changes that the non-conservative material undergoes in the system. The material inputs taken into consideration are from the river and waste water inflow and the surface runoff. All the other fluxes as well as the atmospheric input are considered to be 0 and have no influence on the concentration of the investigated materials. The concentrations are presented in **Table 5**.

Table 5 DIP and DIN concentrations in the field observation (1987/88)

DIP_Q	DIP_O	DIP_{sys}	DIP_{sea}
mmol m^{-3}	mmol m^{-3}	mmol m^{-3}	mmol m^{-3}
0.85	0.08	0.70	0.65
DIN_Q	DIN_O	DIN_{sys}	DIN_{sea}
mmol m^{-3}	mmol m^{-3}	mmol m^{-3}	mmol m^{-3}

26.10	0.71	11.40	11.00

3.2.1. DIP budget

The annual DIP budget for 1987-1988 is shown in **Table 6**. The sum of the estimated annual DIP imports from all sources (river and waste water inflow) is 207 mol d^{-1}, the benthic flux is 2349 mol d^{-1} and the sum of the exports from the lagoon is about 2000 mol d^{-1}. ΔDIP is negative and thus the lagoon acts as a sink of DIP.

Table 6 DIP budget for Ria Formosa lagoon

V_QDIP_Q	V_ODIP_O	V_RDIP_R	S $Flux_B$	V_XDIP_X	ΔDIP	
mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mol d^{-1}	mmol m^{-2} d^{-1}
203	4	-164	2349	2164	-4556	-0.079

3.2.2. DIN budget

The annual DIN budget for 1987-1988 is shown in **Table 7**. The estimated sum of the annual DIN inputs is 6269 mol d^{-1} and the outputs is - 20011 mol d^{-1}. The estimated ΔDIN is negative (about 20696 mol d^{-1}). Therefore, the lagoon was expected to act as a sink of DIN.

Table 7 Annual DIN budget for 1987-1988, Ria Formosa

V_QDIN_Q	V_ODIN_O	V_RDIN_R	S $Flux_B$	V_XDIN_X	ΔDIN	
mol d^{-1}	mol d^{-1}	mol d^{-1}	Mol d^{-1}	mol d^{-1}	mol d^{-1}	mmol m^{-2} d^{-1}
6238	31	-2700	34438	-17311	-20696	-0.36

3.3. Stoichiometric calculations of aspects of net system metabolism

According to the LOICZ biogeochemical model the rates of DIP and DIN fluxes (ΔDIP, ΔDIN) in the Ria Formosa are used to estimate net ecosystem metabolism (NEM) and nitrogen fixation minus denitrification (*nfix-denit)*. *DIP* scaled by the Redfield N:P ratio (16:1for phytoplankton and 35:1 for macroalgae) is an estimate of expected **Δ***DIN* associated with the oxidation of organic matter and the difference between observed *DIN* and the expected value is an estimate of (*nfix-denit*), which is 8.4 mmol m^{-2} d^{-1} for phytoplankton and 26.5 mmol m^{-2} d^{-1} for macroalgae.

Table 8 Net Ecosystem Metabolism (*p-r*) $\Delta DIN_{exp,\ \mathrm{and}}$ *(nfix-denit)* for Ria Formosa lagoon

Phytoplancton (C:N:P=106:16:1)			**Macroalgae (C:N:P=335:35:1)**		
NEM	**ΔDIN$_{exp.}$**	**(*Nfix-denit*)**	**NEM**	**ΔDIN$_{exp.}$**	**(*Nfix-denit*)**
mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}	mmol m^{-2} d^{-1}
8.4	-1.26	0.9	26.5	-2.77	2.41

The Net Ecosystem Metabolism or production - respiration is calculated as ΔDIP multiplied by the negative of the Redfield C:P. For phytoplankton (C:N:P=101:16:1) the calculated (*p-r*) is about 8.4 mmol m^{-2} d^{-1}; and for macroalgae (C:N:P=335:35:1) about 26.5 mmol m^{-2} D^{-1} (Atkinson & Smith, 1983). Again, the rate associated with low flow conditions is considered to be the typical rate. The system appears to be autotrophic.

3.4. The seasonal variation in the lagoon system

The climate of Ria Formosa is typical Mediterranean, hot dry summer and warm wet winter. Four cruises data on March 3rd, May 4th, Jul 27th and Nov 11st represent winter, spring, summer and autumn in 1999, respectively (**Figure 4**). The rainfall and runoff have a strong seasonal pattern with minima in summer. Net export of water from lagoon to the sea in spring and autumn, indicated by the negative residual flow (V_R), was due to large runoff and precipitation in rainy season (**Table** 9). The precipitation and runoff in winter in 1999 is not typical, and is much smaller than the annual mean, so the exchange time is very long. However, it indicates the lagoon system is also sensitive to the seasonal water runoff difference. In autumn, the water runoff and precipitation is much higher than the other seasons, the gradient of the salinity near the inlets area is very small because of the large fresh water input. Therefore, the model is not suitable in autumn season because the small salinity gradient leads to large uncertainties in the exchange term of the water and salt budget. If we want to get better results for the budget calculation in the rainy season, the boundary of the water body should set in the boundary between water plume and open ocean water. (your meaning is unclear here) This value should be considered in the future observations.

A net export of water from lagoon to the sea in the rainy seasons and in reverse in dry season, which indicated by residual flow (V_R). The mixing volume (Vx) is always the biggest the part of the water budget, indicating the system is sensitive to the tide. The residence time (τ) seems to be less than one week, which is similar to results given by a previous application of a hydrodynamic model (Duarte, Azevedo & Pereira, 2005).

Results of seasonal non-conservative materials are summarized in **Table 10**. Except the autumn rainy season, the annual net ecosystem metabolism (NEM), taken as the difference between ecosystem production and respiration (p-r), was 11.1 mmol C m^{-2} d^{-1}, indicating the system can be considered as net "autotrophic". The calculation of (nfix-denit) was negative in spring and summer indicating a dominance of denitrification processes over nitrogen fixation, in reverse a dominance of nitrogen fixation in autumn and winter.

Table 9 Water fluxes (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 (Ssyst, Ssea), mixing water between lagoon and sea (V_X) and water exchange time (τ) in the Ria Formosa lagoon in 1999

Season	**V_P**	**V_E**	**V_Q**	**Vo**	**V_R**	**Ssyst**	**Ssea**	**Vx**	**τ**
	10^3 m^3/D					psu		10^3 m^3/d	Day
Winter	38.2	-117.2	8.4	44.2	26.4	36.2	35.8	2406.1	35.8
Spring	124.5	-136.6	576	44.2	-608.1	35.26	36.28	21415.2	4
Summer	6.9	-136.6	1.0	44.2	84.5	36.48	36.2	11023.1	7.8
Autumn	226.8	-117.2	1510	44.2	-1663.7	35.88	35.85	-2386411	0.04
Annual[*]	56.5	-130.1	195.1	44.2	-165.7	35.98	36.09	11614.8	15.9

Table 10 Seasonal variation of∆DIP, ∆DIN , ∆DIP, *(nfix-denit)* and net ecosystem metabolism *(p-r)* in the Ria Formosa lagoon in 1999 Unit: mmol m^{-2} d^{-1}

Season	**∆DIP**	**∆DIN**	**ΔDIN_{exp}**	***(nfix-denit)***	**NEM*(p-r)***
Winter	-0.053	-0.74	-0.85	0.11	5.6
Spring	-0.148	-3.07	-2.37	-0.7	15.7
Summer	-0.113	-2.05	-1.81	-0.24	12.0
Autumn	2.837	156.71	45.39	111.32	-300.7
Annual*	-0.105	-1.95	-1.68	-0.27	11.1

In general, the Ria Formosa lagoon system is a net producer of organic matter in dry seasons (∆DIP<0 and NEM>0), and a sink of organic matter in the rainy season. Nitrogen removal happened in the dry season while nitrogen fixation dominated in the rainy season in the processes of *nfix-denit*.

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[*] The annual mean here excludes the autumn rainy season.

4. Discussion

4.1. The main mechanisms in the lagoon ecosystem

In Ria Formosa lagoon, tidal flushing is the main physical factor affecting the ecosystem, as has been shown by many studies, including both observations and hydrodynamic models (Newton, 1995; Newton et al., 2003; Newton & Mudge, 2003; Tett et al., 2003). In this budget model study, the lagoon ecosystem is sensitive to the tidal flushing, as indicated by the fact that the mixing flux is the biggest term in the water budget.

Runoff can be considered the main driving force of eutrophication, in the Ria Formosa lagoon system. The main source of nitrogen is run-off from agricultural land brought to the sea via rivers. Therefore, the ecosystem is also sensitive to the seasonal cycle. In dry seasons, the system is productive, and in rainy season it is heterotrophic. Nitrogen fixation and denitrification processes dominate in rainy season and dry season respectively. Although the results of the rainy season should be recalculated, the seasonal cycle proved to be the main force in the lagoon ecosystem. You do not include the rainy season results in the average annual estimates…can you say anything about how this might affect the average annual result? Also, it is possible (does it make sense) to compare the annual result for the 1999 year to the average result from the earlier period? If so, perhaps you could do so here….If not, why not?

4.2. Estimate of the eutrophication status

The Ria Formosa lagoon have the potential to the eutrophication based on the EEA report (EEA, 2001). The entire region is most productive (Mudge & Bebianno, 1997) with many fisheries based in the lagoon. The Ria Formosa has increased nutrient loading due to land runoff and sewage discharges (Mudge & Bebianno, 1997; Newton, 1995) which are exacerbated by reduced tidal exchange in the inner regions although the water quality has deteriorated in recent years due to intense economic activity and tourism (Bebianno, 1995).

Eutrophication refers to an increase in the rate of supply of organic matter to an ecosystem, which most commonly is related to nutrient enrichment enhancing the primary production in the system (Nixon, 1995). Nixon proposes the following definitions for the different eutrophication levels based on phytoplankton primary production:

- oligotrophic < 100 g C m^{-2} y^{-1}
- mesotrophic 100 - 300 g C m^{-2} y^{-1}
- eutrophic 301 – 500 g C m^{-2} y^{-1}
- hypertrophic >500 g C m^{-2} y^{-1}

In this study, the phytoplankton primary production is from 37 to 116 g C m^{-2} y^{-1}, considered Redfield ratio and CNP ratio in macroalgae in 1987, and the value is 49 g C m^{-2} y^{-1} considered Redfield ratio in 1999. Therefore, the lagoon ecosystem is between the oligotrophic and mesotrophic. There is no large increase in the last 10 years, but there is still potential for eutrophication in the lagoon.

4.3. Comparison with other model results

There are other studies of using hydrodynamic models to study the water exchange in Ria Formosa lagoon. The EcoDynamo model is a two dimensional coupled hydrodynamic-biogeochemical model that includes pelagic and benthic processes and variables. The residence time in this model varies with location: the areas located near inlets have relatively small residence times, of less than five days, for the removal of 90% of their water, whereas inner areas, may have a half residence time of over two weeks (Duarte, Azevedo & Pereira, 2005). The model result is quite similar to the results in 1999. (**Table 11**) The MOHID system had a similar result of water exchange time to the result in 1987.

Table 11 Comparison of residence time estimates with those of hydrodynamic models

	Residence time
LOICZ budget model	2 days (1987), 16 days(1999)
MOHID system (Martins et al., 2003)	2.1 days
Hydrodynamic model (Duarte et. al, 2005)	Less than five days (inlet area, removal of 90%); Two weeks (inner area, half residence time)

Comparing the results of water exchange time to other models is to validate assessment of exchange time calculated in the budget model. This assessment should be considered with great care as if there is accumulated error in water budget results, it seems difficult to interpret the results in the following nutrients budget calculation. Though the results seem to be reasonable, the water and salt budgets still need to be carefully validated, especially the calculation of the salinity gradient in the boundary area.

4.4. Comparison with other lagoons in South Europe

Some of the sites in South Europe and Morocco are compared here with the results in Ria Formosa lagoon (Dupra et al., 2001). The mixing fluxes (V_X) in Ria Formosa lagoon is the biggest one among the results in the other lagoons. The Ria Formosa is characterized by its strong tidal mixing. Although this strong mixing can not cause the metabolism difference comparing with other lagoons, it changes the environment variables which cause the change of ecosystem, e. g. sediment structure.

The Ria Formosa is nitrogen fixation dominated system, which is not typical among the lagoons around Mediterranean sea. This result may relate to river input and coastal land use which need to investigate in the future.

Table 12 Comparison with other lagoons in South Europe

	Area km^2	Depth m	V_R 10^3 m^3 d^{-1}	Vx 10^3 m^3 d^{-1}	Residence Time days	NEM mmol m^{-2} d^{-1}	*(nfix-denit)* mmol m^{-2} d^{-1}
Ria Formosa lagoon (Portugal)	58	1.5	-241.1	43,277	~2(1987)	8.4	0.9
Lagoon of Venice (Italy)	360	1.5	-1,216 -1,136	19,248 12,511	10 (1999) 14 (2001)	-2.7 1.2	-1.8 -1.72
Thau lagoon (France)	75	4.5	-170	5,894	~55(1995-2002)		
Moulay Bousselham Lagoon (Morocco)	35	1	-545	1,763	14	-0.04	-1.7

4.5. Budget modelling tool potential for managers

The results of LOICZ budget model must also be applicable to management questions. The linkages between biogeochemical modelling and socio-economic and management issues can be seen in a wide variety of existing applied studies including fisheries management, eutrophication, effects of habitat alteration, and fate and effects of contaminants. (Gordon et al., 1996) The LOICZ biogeochemical modelling results presented in this thesis will help scientists summarise existing and new data in consistent and rigorous formats that will be more useful to coastal zone managers. It is also hoped that they will assist in the development of more applied models that could be used by managers in the decision-making process.

There is now a consensus in the scientific community that cumulative changes, driven by direct human use of coastal space and resources, may result in changes to the Earth system which in turn will impact future human use of coastal space and resources. LOICZ is a project designed to improve our scientific understanding of this global feedback loop and hence provide a sound scientific basis for the management of the world's coastal areas. (Gordon et al., 1996)

4.6. Conclusions and further work

The work is studying the water and nutrient budget in Ria Formosa lagoon, the main conclusions of this work are:

- The system is relatively sensitive to tides;

- The residence time of the system is about 2 days to two weeks;
- The ecosystem is autotrophic and N-fixation dominated;
- The system is a sink of carbon and nitrogen;
- The system has strong seasonal variation;
- The ecosystem falls between oligotrophic and mesotrophic status in Nixon’s classification system of eutrophication.

The model should be validated in future studies with more data support, like the runoff data need to be validated with SWAT model results. The nutrient from groundwater and atmospheric deposit should be considered in the system.

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