Nitrogen and phosphorus removal from agricultural sewage by wetlands under contrasting hydrologic regimes

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SUMMARY

Two wetlands dominated by *Phragmites australis*, which were previously rice fields, were used under contrasting hydrological regimes, intermittently and permanently flooded. The aim was to study their role as filters of nitrogen and phosphorus contained in the water transported through the network of channels used to irrigate ricefields in the delta of the Ebro River (NE Spain). In both wetlands, most of the forms of nitrogen and phosphorus were retained, except dissolved organic nitrogen in the intermittently flooded wetland and particulate nitrogen and dissolved organic phosphorus in the continuously flooded wetland.

The intermittently flooded wetland retained 70.7 kg N ha^{-1} and 1 kg P ha^{-1}, while the permanently flooded wetland retained 62.1 kg N ha^{-1} and 0.55 kg P ha^{-1}. The wetland that was flooded intermittently showed a higher retention efficiency of nitrogen and phosphorus than the continuously flooded wetland.

KEYWORDS: nitrogen, phosphorus, hydrology, restored wetlands, filters.

RESUMEN

Eliminación de nitrógeno y fósforo de aguas servidas agrícolas por humedales sometidos a regímenes hidrológicos distintos. Dos marismas dominadas por *Phragmites australis*, que anteriormente habían sido campos de arroz, se estudiaron bajo dos regímenes hidrológicos distintos, una alternando períodos de inundación con períodos de desecación y la otra con inundación continua, para conocer su papel como filtros del nitrógeno y el fósforo contenidos en el agua de irrigación de los arrozales del Delta del Ebro (NE España). Ambas marismas actúan como retenedoras de la mayoría de las formas de nitrógeno y fósforo, excepto nitrógeno orgánico disuelto en la inundada intermitentemente y nitrógeno particulado y fósforo organico disuelto en la inundada continuamente.

La marisma inundada de forma intermitente retuvo 70.7 kg N ha^{-1} y 1 kg P ha^{-1}, mientras que la inundada de forma continua retuvo 62.1 kg N ha^{-1} y 0.55 kg P ha^{-1}. La marisma sometida a un régimen hidrológico de inundación y desecación intermitentes mostró una mayor eficiencia en la retención de nitrógeno y fósforo que la inundada permanentemente.

PALABRAS CLAVE: nitrógeno, fósforo, hidrología, humedales restaurados, filtros.

INTRODUCTION

Wetlands have largely been used as filters to remove nutrients from wastewater (Kadlec & Tilton, 1979). Reductions of more than 50 % of the total nitrogen and phosphorus inputs are common in wetlands dominated by emergent macrophytes (Finlaysson & Chick, 1983).

Agricultural control of the water flow imposes changes in hydrologically related wetlands. As a common consequence, many wetlands close to agricultural areas remain dry or are overflowed at intermittent intervals.

There are substantial differences in the nutrient cycling between permanent and periodically flooded wetlands. De Groot & Van Wijck (1993) demonstrated that the organic carbon, nitrogen and phosphorus contents of the sediment decrease considerably when waterloggged soils are subjected to periods of desiccation due to the effects of various biogeochemical processes.

In areas where nature conservation is in conflict with extensive agriculture the use of wetlands for wastewater purification can be a suitable land use to reconcile economic development and environmental protection. This is the case of the delta of the Ebro River (NE Spain), where a pilot study has been initiated to restore marshes which were used for rice production for many years and, at the same time, use the marshes as filters of nutrients associated with waste water from the rice fields. In this paper the retentions of nitrogen and phosphorus are compared in continuously and intermittently flooded wetlands restored from rice fields.

STUDY AREA

The study sites were two small wetlands which received water from the channels used to irrigate the rice fields. The water entered each study site through a channel and drained each area through another channel. Outstanding physical, hydrological and biological differences between the two areas are reported in Table I. The wetlands were located 5 km apart. No major differences in meteorological or other general environmental factors affected them during the period of study.

One of the wetlands, la Tancada (TA, 5,724 m^2), was permanently flooded (monthly average depth 7 cm, minimum depth 2 cm) while the other, l'Encanyissada (EN, 4,500 m^2), received water intermittently. In TA, water was inflowing at a constant monthly discharge, approximately 41.4 $m^3\ d^{-1}$. In EN, water flowed through the marsh intermittently, fifteen days every month, approximately at 24.5 $m^3\ d^{-1}$. The EN marsh was a temporary aquatic ecosystem which remained dry fifteen days every month during the study period. During the flooded periods the water depth in EN marsh was approximately the same as in TA marsh.

TABLE I. Amounts (g) of nitrogen and phosphorus which flowed into (CE) and out of (CS) the two wetlands during the study period, and efficiency (E), as percentages of the inputs, of the wetlands as filters of different forms of nitrogen and phosphorus. *Cantidades (g) de nitrógeno y fósforo que entraron (CE) y salieron (CS) de los dos humedales durante el período de estudio, y eficiencia (E), como porcentajes de las entradas, de los humedales como filtros de las diferentes formas de nitrógeno y fósforo.*

		EN			TA	
	CE	**CS**	**E**	**CE**	**CS**	**E**
NO_3	3689	1879	49	9561	1761	81
NO_2	149	95	36	226	134	41
NH_4	1626	1080	34	662	643	3
DIN	5464	3054	56	10449	2568	75
DON	14068	16648	-118	47387	8540	82
PN	39843	8751	78	43552	54829	-125
Ntot	60275	28453	53	101388	65937	35
SRP	736	.369	50	302	70	77
DOP	184	118	36	88	127	-144
PP	191	171	11	245	120	51
Ptot	1111	658	41	635	317	50

MATERIAL AND METHODS

Monthly data and water samples were collected from each wetland for a five month period during the plant growing season in 1991. Conductivity (Portable conductivity meter calibrated to refer measurements to 25°C) was measured *in situ*. Oxygen concentration (Winkler method) and total alkalinity (acid titration) were determined in water samples.

Total (after peroxodisulfate digestion) and soluble nitrogen and phosphorus in the water inflowing and outflowing the wetlands were analyzed from filtered (pre-ashed Whatman GF/C filters) and unfiltered water samples. Organic and particulate forms were calculated as differences between the analyzed fractions. All the analysis were performed following Grasshoff *et al.* (1983), and in triplicate samples.

Aboveground plant fresh weight was measured *in situ* from nine plots (50 x 50 cm) in each wetland. Aliquots of each species were desiccated at 60 °C until constant weight and conversion factors were used to calculate aboveground dry weights from the fresh weights measured *in situ*. The samples were taken each month from sites that were close to the previous month's sampling points to avoid the clearing effect. The plots were regularly distributed at equidistant distances in the marshes.

Carbon and nitrogen contents of the plants were determined from aliquots of the biomass samples in an elemental analyzer.

Water flow was estimated at the inflowing and outflowing channels (20 cm wide, 10 cm depth) as the water velocity (measured by eye with small straw floating particles) times the area of the channel section.

RESULTS

General characteristics of the water

Conductivity and alkalinity were higher in the outflow than in the inflow waters (Fig. 1). Inflowing conductivities and alkalinities were similar in both wetlands. Conductivity increase was similar in both wetlands. Alkalinity increase was higher in TA than in EN.

Conductivity, alkalinity and oxygen concentrations of the outflowing water showed higher changes with respect to the inflowing water in EN than in TA, due to the fact that the former was occasionally dry during the study, while the latter was permanently flooded.

Oxygen concentrations in the water inflowing to EN were lower than in the water inflowing to TA. This is because the water flow in the channel irrigating EN was low, and the water was frequently stagnant, while in the channel irrigating TA the water flow was rapid.

Nutrients

Nitrogen

The concentrations of dissolved inorganic nitrogen (nitrate, nitrite and ammonium) were quite similar to those of DON and PN for most of the study period. However, at some sampling times the concentrations of DON and PN reached peaks over 1 mM while the maximum DIN concentration was 250 μM.

Outstanding differences were observed for most of the period between the soluble forms of nitrogen in the inflowing and outflowing water of both wetlands (Fig. 2).

In TA there was a continuous decrease of nitrate concentration between 50% and 100%, while ammonium concentrations were quite similar in the inflowing and the outflowing water (Table I). In EN, the concentrations of all the forms of dissolved inorganic nitrogen decreased as water passed through the wetland, except just after the first flooding.

No clear effect of any of the two wetlands on the dissolved organic nitrogen was observed. Clear retention was observed only at the end of the study period in EN (Fig. 3).

Particulate nitrogen was retained during the first

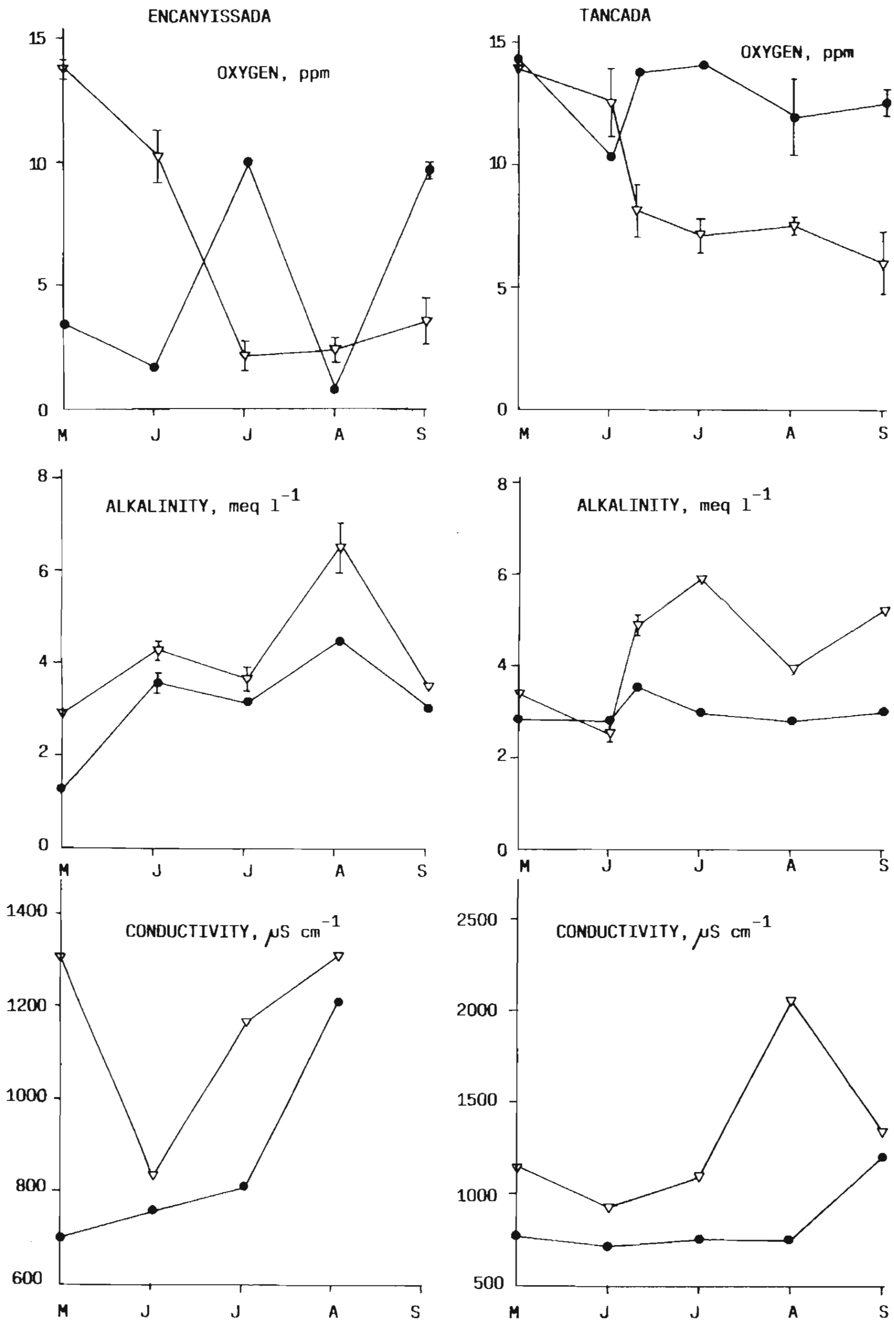


FIGURE 1. Conductivity, alkalinity and oxygen concentrations in the inflowing (full circles) and outflowing (open triangles) waters of l'Encayissada -EN-, the intermittently flooded wetland- and la Tancada -TA-, the permanently flooded wetland during 1991. *Conductividad, alcalinidad y concentraciones de oxígeno en las aguas que entran (círculos llenos) y que salen (triángulos vacíos) en l'Encanyissada (EN), el humedal inundado de forma intermitente, y la Tancada (TA), el humedal inundado de forma permanente, durante 1991.*

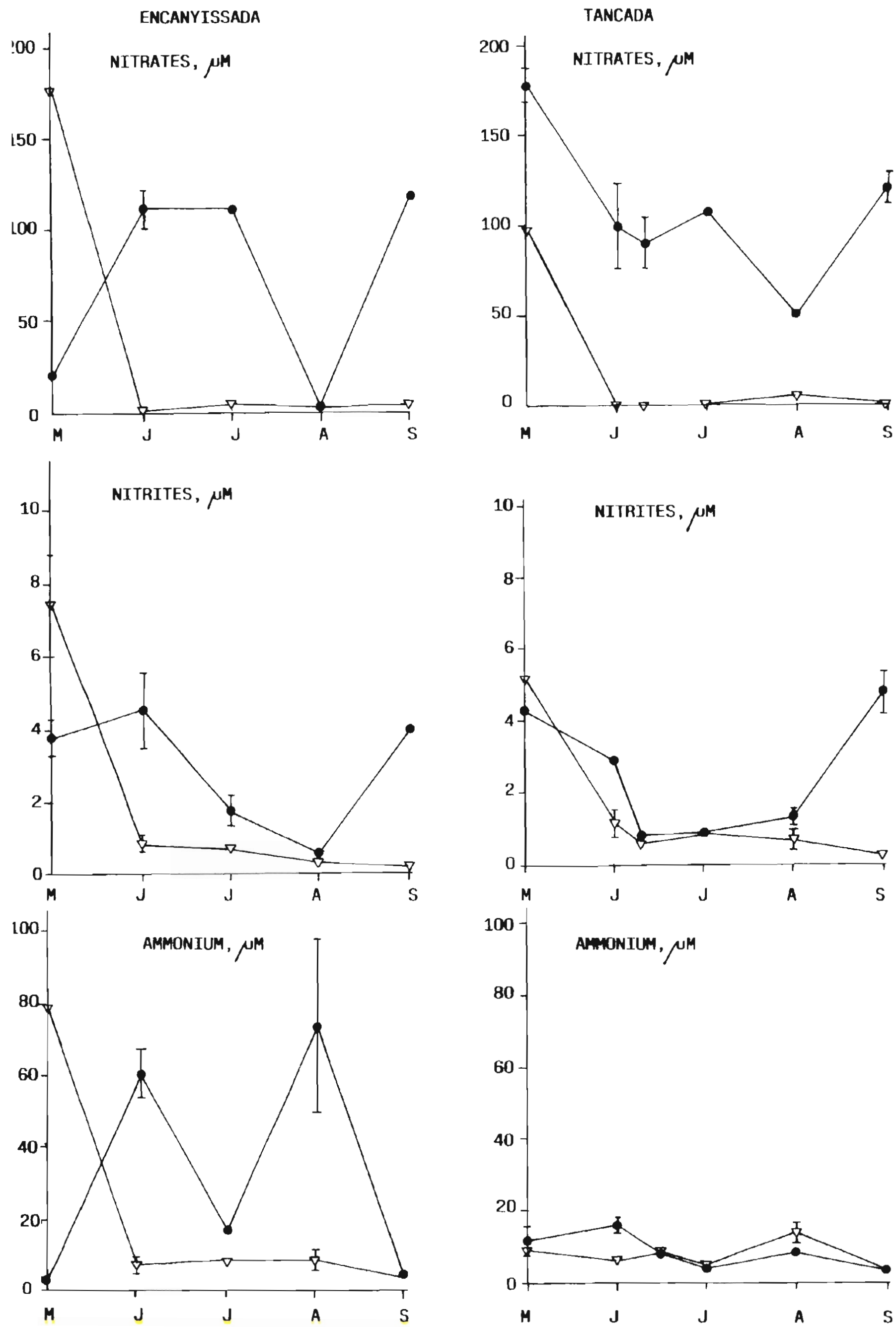


FIGURE 2. Concentrations of dissolved inorganic forms of nitrogen in the water inflowing (full circles) and outflowing (open triangles) the studied wetlands. *Concentraciones de formas inorgánicas de nitrógeno disuelto en el agua que entra (círculos llenos) y que sale (triángulos vacíos) en los humedales estudiados.*

half of the study period in EN. However, during the second half, the concentrations in the outflowing water were higher than in the inflowing water. In TA, no clear pattern was observed.

Phosphorus

Significant differences were found for most of the study period between the concentrations of the different forms of phosphorus in the inflowing and outflowing water of both wetlands (Fig. 4). The concentrations of the different forms of phosphorus -soluble reactive, dissolved organic and particulate- were of the same order of magnitude, most of them between 0.5 and 3 μM.

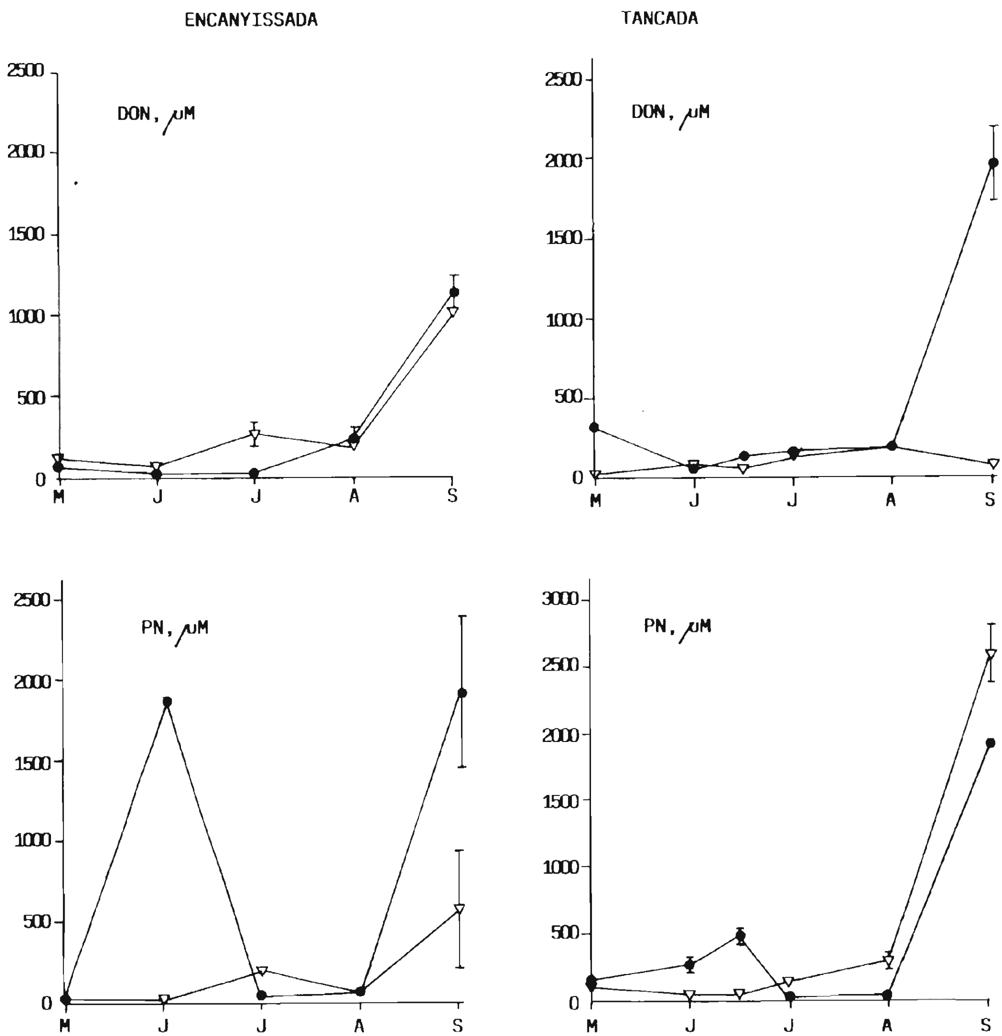


FIGURE 3. Concentrations of dissolved organic (DON) and particulate nitrogen (PN) in the waters inflowing (full circles) and outflowing (open triangles) the studied wetlands. *Concentraciones de nitrógeno orgánico disuelto (DON) y particulado (PN) en las aguas que entran (círculos llenos) y que salen (triángulos vacíos) en los humedales estudiados.*

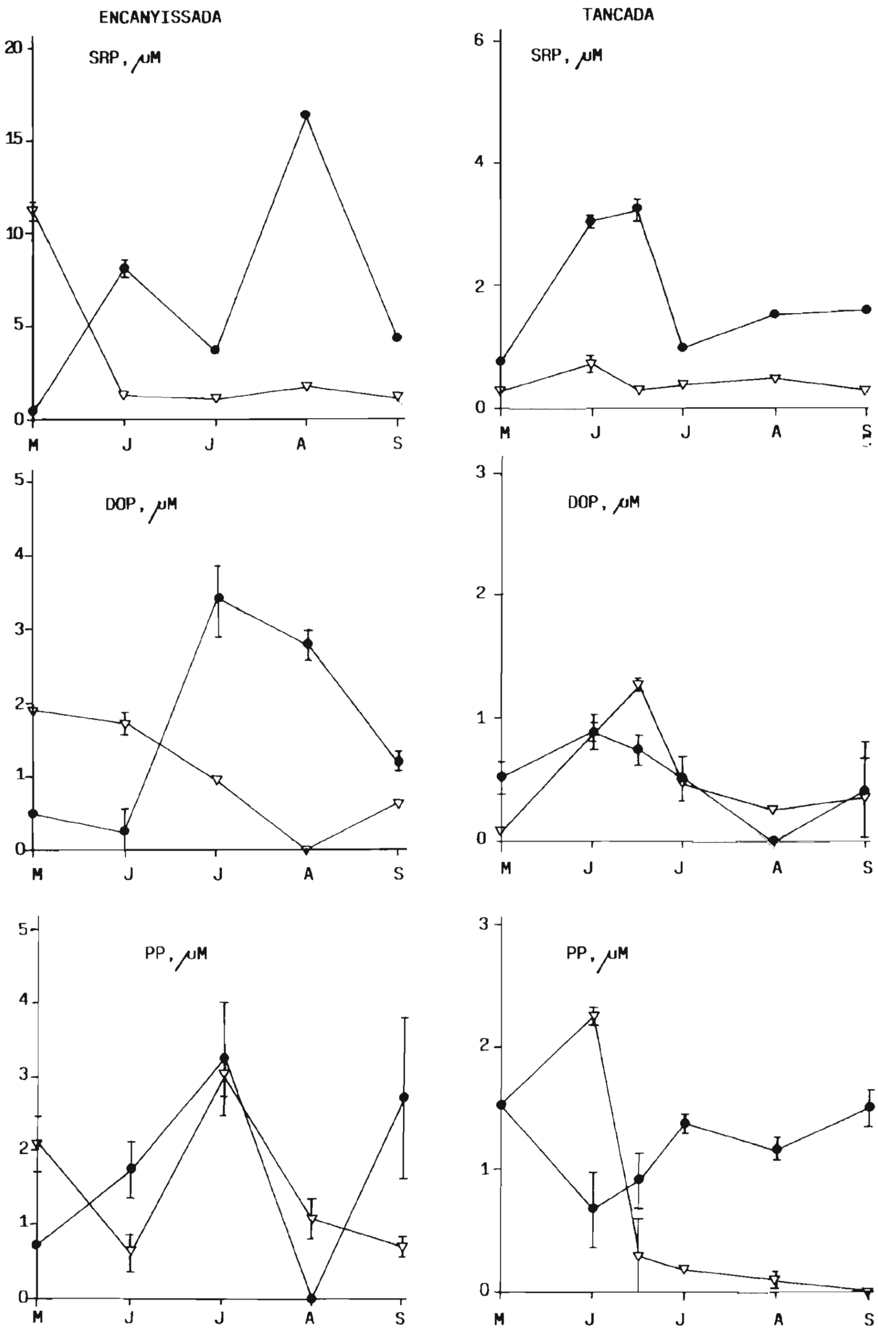


FIGURE 4. Concentrations of soluble reactive (SRP), dissolved organic (DOP) and particulate phosphorus (PP) in the waters inflowing (full circles) and outflowing (open triangles) the studied wetlands. *Concentraciones de fósforo reactivo soluble (SRP), orgánico disuelto (DOP) y particulado (PP) en las aguas que entran (círculos llenos) y que salen (triángulos vacíos) en los humedales estudiados.*

In both wetlands the concentration of SRP (soluble reactive phosphorus) decreased from the inflowing to the outflowing water continuosly, except in EN for just the first flooding.

EN released DOP (dissolved organic phosphorus) at the beginning and retained it at the end of the growing season. No clear pattern was observed in TA.

Continuous changes in the relative concentration of PP (particulate phosphorus) in the inflowing and outflowing water were found in EN. In TA the concentration of PP was lower in the outflowing than in the inflowing water for all the study period except at the beginning.

Plants

Phragmites australis (Cav.) Trin. ex Steud and *Typha angustifolia* L. dominated the biomass of both wetlands. Total plant biomass was higher in EN, which was three years old, than in TA, which was two years old (Fig. 5). In EN *Phragmites* and *Typha* biomasses fluctuated between 234-646 g dw m^{-2} and 13-229 g dw m^{-2}, respectively, during the growing season. In TA, both biomasses increased during the growing season. In this case, the maximum *Typha* biomass -462 g dw m^{-2}- was higher than the maximum *Phragmites* biomass -398 g dw m^{-2}-.

Other species contributing to the total plant biomass were *Juncus subulatus*, *Cynodon dactylon* and *Aster squamatus* in EN and *Scirpus maritimus* and *C. dactylon* in TA. However their contribution to total plant biomass was less than 30 % during most of the study period in both wetlands and usually less than 10 %.

A continuous increase in total plant biomass was observed in TA, while the same total plant biomass in EN was found until July and a rapid increase occurred in August.

In TA the biomass/necromass ratio was close to 1 at the beginning of the study period, increased during the growing season, and decreased at the end of the study period. In EN this pattern was not so clear, although high values of the ratio were common during the growing season and a ratio of 1 was observed in the last month of the study, after a sharp decrease plant biomass.

Total plant nitrogen was higher in EN than in TA, in accordance with the higher plant biomass (Fig. 6). In TA total plant nitrogen per unit area increased continuously during the study period, to a maximum of 9.3 g N m^{-2}, while in EN it decreased during the first half of the growing season and increased during the second half.

In TA plant nitrogen per unit area increased continuously to a maximum of 8 g N m^{-2} during the study. In EN plant nitrogen decreased during the first half of the growing season and increased during the second half.

DISCUSSION

The potential use of freshwater wetlands restored from rice fields as filters of nutrients contained in the irrigation waters of paddy fields is clear from the results presented here. This role as filters of nutrients is common to other types of shallow aquatic ecosystems, rice fields (Forès, 1989) and natural wetlands (Schubel & Carter, 1983).

Taking into account the volumes of water flowing through the wetlands during the study period and the concentrations of total nitrogen, both wetlands retained approximately the same amount of total nitrogen per unit area, 70.7 and 62.1 kg N ha^{-1}, respectively in EN, the intermittent, and TA, the permanently flooded wetland. However, these amounts constitute quite different percentages, 53% and 35% respectively, of the total nitrogen inflowing per unit area to EN (134 kg ha^{-1}) and TA (178 kg ha^{-1}). Percentages of nitrogen retained in marshes are usually over 50% of the incoming nitrogen (Mitsch & Gosselink,

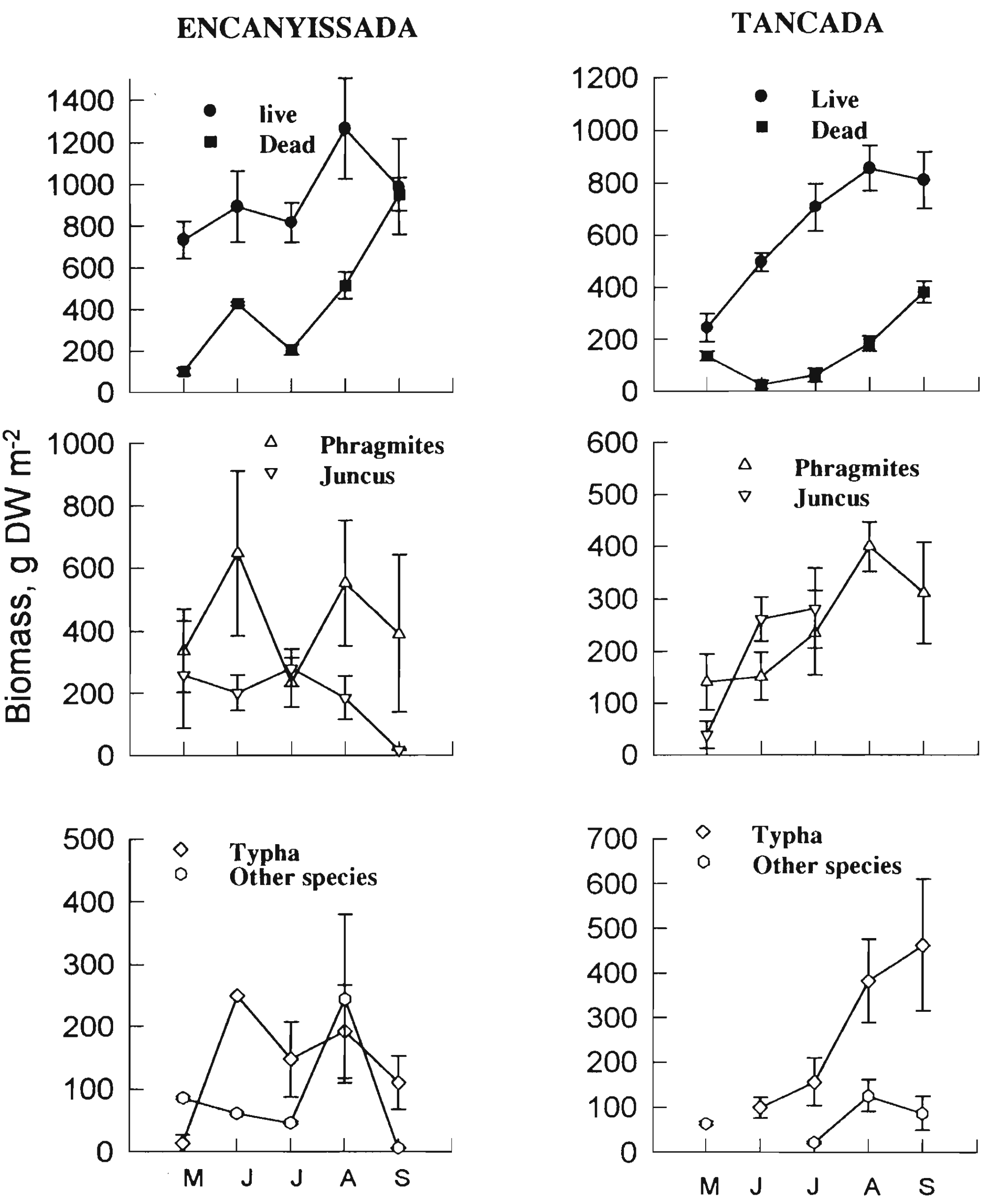
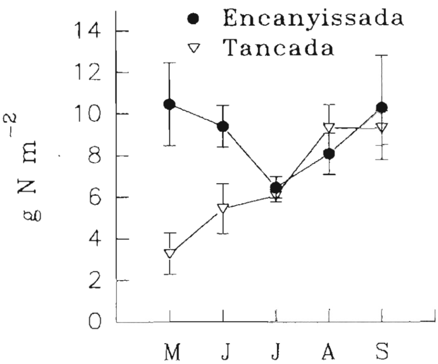


FIGURE 5. Total live and dead biomass and biomasses of different species in the wetlands during the study period (g dry weight m^{-2}). *Biomasa viva y muerta total y biomasas de las diferentes especies en los humedales durante el período de estudio (g peso seco m^{-2}).*



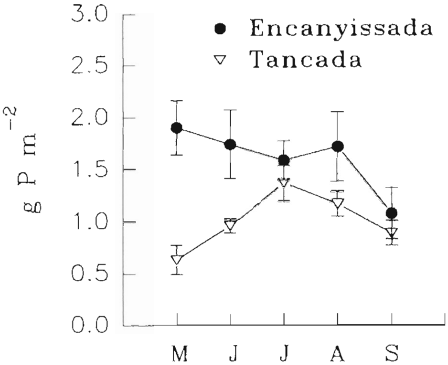


FIGURE 6. Total nitrogen and phosphorus contained in the vegetation in the two wetlands during the study period (g m^{-2}). *Nitrógeno y fósforo totales contenidos en la vegetación de los dos humedales durante el período de estudio (g m^{-2}).*

1993). The relatively low efficiency of TA, the continuously flooded marsh, is mostly due to low ammonium retention. Although the amount of ammonium flowing into TA wetland was lower than that flowing into EN wetland, the percentage of ammonium retained by Tancada was 3% of the inflowing ammonium, while it was 34% in the case of l'Encanyissada.

The percentages of total phosphorus retained by marshes dominated by emergent macrophytes are quite diverse. Verhoeven & Van der Toorn (1990) reported values between 3-87% of the total incoming phosphorus. In our case, quite similar percentages of the total incoming phosphorus were retained in both wetlands, 41% and 50% in the intermittently and continuously flooded wetland, respectively. However, per unit area the intermittently flooded wetland retained twice more, 1 g ha^{-1}, than the permanently flooded wetland, 0.55 g ha^{-1}, in spite of the fact that the former received much more phosphorus per unit area, 2.46 kg ha^{-1}, than the latter, 1.11 kg ha^{-1}.

The hydrologic regime -permanent versus intermittent flooding- imposed some differences between the two wetlands with respect to the detailed budgets of nitrogen and phosphorus. Differences observed at the beginning of the study occurred because EN wetland remained dry for several months before the first flooding, while the soil in TA wetland remained wet during the months before the initial flooding. This justifies the higher concentrations of DIN (nitrate plus nitrite and ammonium) and SRP in the outflowing water of EN compared to the inflowing water, because drying sediment for a long period of time (e.g., several months) causes mineralization of organic fractions of nitrogen and phosphorus, which can be drained through the marsh after flooding. In contrast, alternation of short periods of sediment desiccation and inundation (e.g., shorter than 1 month), increases the retention rates of nitrogen and phosphorus by a marsh by increasing the denitrification rates and the P-adsorption capacity of the sediment (De Groot & Van Wijck, 1993).

Permanent flooding favors the development of anaerobic conditions in the sediment (Patrick & Delaune, 1972) and, consequently, the transformation of oxidized into reduced forms of nitrogen (Valiela, 1984), and phosphorus release from the sediment to the water column (Mortimer, 1971). This can be the reason for the somewhat higher concentration of ammonium in the outflowing water than in the inflowing water of the permanently flooded wetland (TA) some time at the end of the study period and for a lower retention efficiency of phosphorus by this marsh compared to EN, the intermittently flooded wetland. Permanently flooded conditions also favor the establishment of an anaerobic environment in the sediment and, consequently, the inhibition of the nitrification process, which may be an additional explanation for the relatively low retention efficiency of nitrogen in the permanently flooded wetland compared to the intermittently flooded one.

The effect of emergent macrophytes as a nutrient sink seems not to be important in the wetlands studied. According to Richardson & Marshall (1986) the amounts of nutrients accumulated in emergent macrophytes during the growing season are between 10-50% of the amounts taken up by other compartments. Moreover, plant growth is seasonal and the nutrients retained in spring and early summer are released when the plants die and decompose, which happens during late summer, the final period of our study. Nutrients can be removed from a wetland by plant harvesting. This practice was not followed in the two wetlands studied because it would have been inconsistent with another objective of our research program consisting of restoring wetlands as an habitat for wildlife.

From the results presented here it is difficult to conclude which kind of hydrological regime is more suitable for use with these wetlands as natural filters of nitrogen and phosphorus. From the general budget calculated for each wetland, it can be concluded that the intermittently flooded wetland retained more nitrogen and phosphorus per unit area of wetland than the continuously flooded wetland. Then, successive periods of flooding and desiccation would be more efficient than continuously flooded wetlands, because the amounts of nitrogen and phosphorus exported to other ecosystems would be lower. However, more research is needed on the relationships between nutrient retention efficiency and the duration of the periods of flooding and desiccation to define precisely the most efficient type of hydrological regime to use wetlands as natural filters of nutrients.

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