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FLAMINGO FOOTSTEPS ENHANCE NUTRIENT RELEASE FROM THE SEDIMENT TO THE WATER COLUMN

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ABSTRACT

A two phases experiment was carried out in a shallow coastal lagoon in the Ebro Delta (NE Spain) in order to know the potential effect of flamingo footsteps on nutrient release from the sediment to the water column. The experiments consisted of artificial simulation of repeated footsteps in microcosms located in the lagoon.

The amounts of particulate matter and nutrients (nitrate, ammonium, total nitrogen, soluble reactive phosphorus, total phosphorus and soluble reactive silica) in the water column of the disturbed microcosms were much higher than in the water column of the undisturbed (no footsteps) microcoms and than in the water column of the lagoon (neither enclosure nor footsteps).

The amounts of particulate matter and nutrients are significantly higher in sediment with a higher proportion of fine particles than in sediment with a lower proportion of fine particles. The amounts of particulate matter and nutrients in the water column of disturbed sediments were directly related to the number of footsteps and inversely related to the time passed after the footsteps.

INTRODUCTION

Flamingos and other long-legged birds in aquatic ecosystems include continuous disturbance of the sediment by the birds' feet, which could enhance nutrient exchange between the sediment and the water column. Indirect evidence for this and other effects (increasing water turbidity and decreasing dissolved oxygen concentration, abundance of macrophyte and macroinvertebrate populations and community diversity) of flamingos walking in shallow aquatic ecosystems have been presented by various authors (Hutchinson, 1951; Vareschi, 1978; Hurlbert, 1983; Johnson, 1992; Montes and Bernués, 1991). Direct demonstrations of the effects of flamingo populations on the limnological characteristics of shallow ecosystems are not easy because of the mobility of the birds. The aim of the experiments described in this paper was to determine whether nutrient concentrations in the water column increase as a consequence of the disturbance of the sediment by flamingo footsteps.

When the flamingo walks on the sediment, it sometimes paddles and stirs up the sediment with its feet (Cramp and Simmons, 1977; Johnson, 1992). However, the most frequent movement is just sinking the foot a few cm into the sediment. The very high density of flamingos observed during many hours of the day suggests that footsteps may affect the limnology of the shallow water masses of the world where they live.

In order to demonstrate the potential effect of flamingo footsteps on the nutrient exchange between the sediment and the water column in shallow ecosystems, an experiment simulating footsteps with a flamingo's leg was carried out in a coastal lagoon.

MATERIAL AND METHODS

Two experiments were performed in Tancada, a typical 1.8 km^2 coastal lagoon located in the Delta of the Ebro River (NE Spain). The experiments were carried out in the south zone of the lagoon, 50 m far away from the shore. The bottom of the lagoon was very flat and the average depth was 37 cm (Comín, 1984). A flamingo (*Phoenicopterus ruber roseus*) population of 40-1,000 birds was present in this lagoon throughout all the year.

In both experiments, a leg from a male adult flamingo, provided by the Natural Park of the Ebro Delta, was used to simulate flamingo footsteps. The experiments were conducted during calm days, in order to avoid the effects of sediment and water disturbance by the wind. A plastic tube - 20 cm diameter - was softly sunk ten cm into the sediment of the lagoon, isolating a microcosms. The top of the tube was always above the water surface, in such a way that no water from the lagoon could enter the water column isolated inside the tubes. Sediment was disturbed following a delay of one minute after the tube had been sunk into the ground. The flamingo footsteps were simulated sinking the flamingo's leg softly through the water column isolated within the tubes and down there between 2 and 5 cm into the sediment and taking the leg out from the sediment and through the water column out of the tube softly in a continuous movement.

Water samples were collected from the mid depth of the water column with a long, thin plastic tube connected to a syringe. The samples were preserved at 4 °C, and analyzed in the laboratory the next day after sampling.

The first experiment was carried out in spring 1992, to assess whether flamingo's footsteps resuspend sediment and increase nutrient concentrations in the water column in the short term. In some way, it was performed to have a qualitative confirmation of our hypothesis. After setting up the tubes, after a delay of one minute, the first sample of water was collected. Immediately after that, 15 footsteps were simulated with the flamingo's leg in one minute. Three water samples from the tubes were collected, immediately after the simulation, after 15 minutes and after 30 minutes. Control samples were also collected from a water column within a plastic tube with no disturbance, and from the lagoon water column in the vicinity of the experimental area. All the treatments were performed in triplicate.

The second experiment was carried out in spring 1993 to determine the effects of different intensity of flamingo footsteps in two areas of the lagoon with different sediment at a longer term. After setting up the tubes in the sediment and waiting 1 minute, the first water sample was collected from the tubes, before the disturbances. Then, in different tubes, 1, 3, 5, 10 and 15 footsteps were simulated in one minute. These are usual number of flamingo footsteps at the walking rate frequently observed while they eat in the study area. Water samples from the tubes were collected 5, 15, 30, 60 and 120 minutes after the disturbances. The experiment was conducted simultaneously in two close zones of the lagoon with a slight difference in texture. All the treatments were performed in triplicate.

Water analysis included suspended sediments (dry weight of suspended material retained in 0.45 mm glass fiber filter), dissolved inorganic nitrogen (ammonium, nitrate and nitrite), soluble reactive phosphorus, total nitrogen and phosphorus and soluble reactive silica.

Methods used for the analysis followed Grashoff *et al.* (1983). Sediment texture was determined as percentages of the total dry weight corresponding to different size particle fractions. Water content and organic matter content were determined from loss of weight at, respectively, 100 °C and 400 °C. The sediments of the two areas where the second experiment was performed had a slight difference in their textural composition (**Table 1**). The first experiment was carried out in the area with the coarser sediment (A in **Table 1**).

Table 1: Percentages of the particles sizes (sand, clay and silt), and water and organic matter contents of the sediments from the two experimental areas where the experiments were performed.

Site	Size % particles	% Water	Loss on ignition mg/g
A	69.18-30.80-0.01	31±1	17.5±6.9
L	59.60-40.35-0.03	31.5±4.6	18.5±5.6

RESULTS AND DISCUSSION

Short term effects

Particulate matter in the water column of the microcosms where the sediment was disturbed by footsteps is much higher than in non disturbed microcosms and in open water of the lagoon (**Figure 1**). The effect of disturbing the sediment was a resuspension of particulate matter 10 times higher than the concentration in the open water. It reached 0.2 g/l at its maximum, 15 minutes after disturbing the sediment. This was the net effect because in this figure it is included the decrease in particulate matter produced by enclosing a zone of the water column in the microcosm (difference between open water and non disturbed in **Figure 1**). These results are particularly reliable because no significant changes were observed in the particulate matter suspended in the open water column during the experiment. From this figure, it is also clear that the operation of locating the experimental tubes in the sediment did not produce a resuspension of particulate matter. On the contrary, a slight decrease in suspended particulate matter takes place within the tubes because of particles sinking in a more stable water column originated by isolating a portion of the lagoon within the tube.

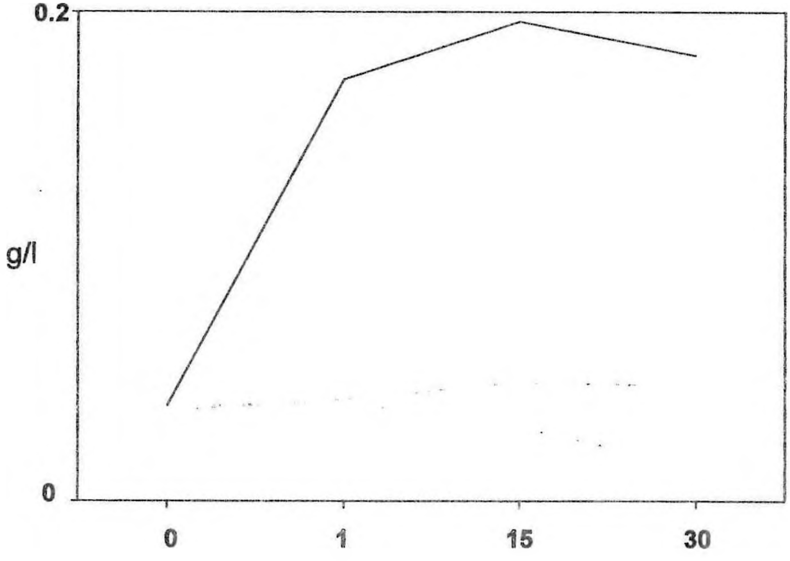

Figure 1: Suspended matter (g/l) in the water column in disturbed -with footsteps- (continuous line), non disturbed microcosms (discontinuous line), and in open water (points). The horizontal axis indicates the time of samplings: before footsteps simulation (time 0) and 1, 15 and 30 minutes after the disturbance.

Nutrient concentrations also increased in the short term **(Figure 2)** as a consequence of sediment disturbance by flamingo footsteps. In the non-disturbed microcosms a slight and short increase of most of the nutrients forms was observed after locating the tubes in the sediment. The concentrations rapidly returned to similar values as in open water. In the disturbed microcosms, the pattern of concentration changes observed was quite common for most of the nutrients: after a slight change (T_0) with respect to the concentrations in the open water (Control), a relatively rapid increase took place in 15 minutes, from T_1 to T_2. The concentrations reached in the disturbed microcosms are 2-3 times higher than those in the initial conditions for all the nutrients. A final phase of decreasing concentrations was observed for most of the nutrients during the second quarter of this 30 minutes experiment. This was not observed for nitrate and SRP.

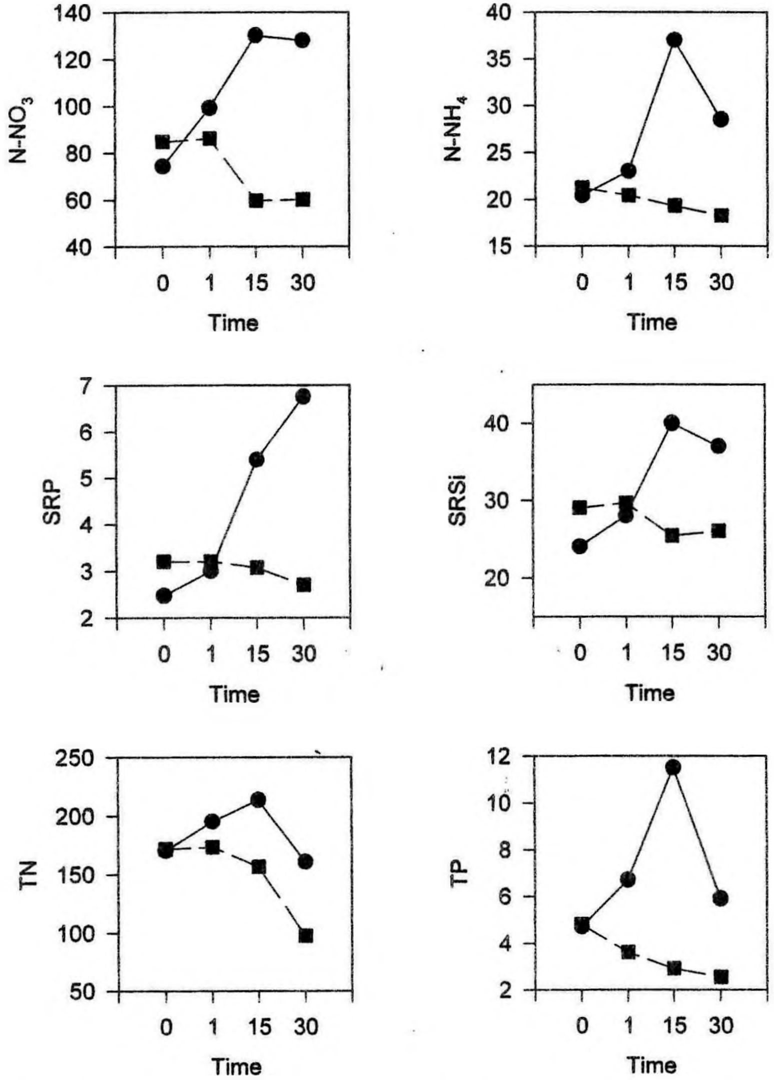

Figure 2: Nutrient concentrations (μM) in disturbed (circles) and non disturbed (quadrats) microcosms Horizontal axis as in **Figure 1**.

It can be concluded from this experiment that disturbance by flamingo footsteps produces nutrient release from the sediment to the water column in a short period of time, 15 minutes.

Long term effects

The amounts of particulate matter resuspended by the effects of footsteps disturbance were higher in the area where the sediment contained a higher proportion of finer grains (L in **Table 1**) than in the area where the sediment contained a higher proportion of coarser grains (A in **Table 1**) (**Figure 3**). This was also observed for most of the nutrient forms analyzed (TN, NO_3, NH_4, and SRP), their concentrations were double in the finer sediment respect the coarser sediment, but not for TP and SRSi (**Figures 4-9**).

The kinetics of particulate matter resuspension can be described as: a rapid increased in 5 minutes, in both types of sediments, and a slow decrease for between 2 hours, in the finer sediment and highest disturbance, and 15 minutes, in the case of coarser sediment and lowest disturbance. The same type of kinetics is observed for all the nutrient forms. However, in general, there is a delay in the nutrient concentration increase with respect to the particle resuspension.

If nutrient concentration increase is due to desorption from the resuspended particles and/or exchange between the sediment and the water column, it takes a time for these processes to be reflected in the water column. The time for most of the nutrients to reach the maximum concentration in the water column was about half an hour, while maximum particle resuspension was observed in the 5 minutes sampling.

In general, the maximum nutrient concentration is observed half an hour after the disturbances. At this time, the amount of particulate matter resuspended had began to sink in most of the treatments. For most of the cases in our experiment, adsorption of nutrients to sinking particles is not an important process sequestering nutrients from the water column to the sediment, at least in a short period of time, because nutrient concentrations were still high compared to the initial conditions after most of the particles resuspended had sunk again. So, in addition to desorption and adsorption linked to the particles some other mechanisms must play an important role controlling the nutrient concentrations.

Among others, solubilization from the disturbed sediment and from the resuspended or previously floating organic particles should be considered (Kennish, 1986). Further evidence for this consideration is the fact that all nutrient concentrations were increasing between 15 and 30 minutes, while resuspended particle matter was clearly sinking.

The concentration of most of the nutrients decreased after the maximum at a slower rate per time than they increase, except for SRP in the finer sediment and SRSi in the coarser sediment, which decreased rapidly (at the same rate as it increased, in half an hour).

In these two cases, it is likely that adsorption into particles is taking place because it is well known that this process is very effective for removing phosphorus and silica from the water column (Kennish, 1986). However, it is not clear from our results to what extent it is occurring because of the lack of correspondence between the decreases of nutrient and particulate matter concentrations in the water column. Other processes must also be involved in controlling the nutrient concentrations in the water column. A combination of a rapid nutrient release from the interstitial water to the water column, slower desorption from the resuspended particles to the water, and later adsorption onto the particles can take place for these two nutrients, because these processes occur at different scales of time (Anderson, 1976; Carrit and Goodgal, 1954).

There is a direct relationship between the number of footsteps and the amount of particulate matter resuspended in both types of sediment. However, this type of relationship is not found between the number of footsteps and the maximum nutrient concentration reached in the water for most of the nutrients. Particle resuspension is directly related to the physical disturbance created by the footsteps. The energy associated with the disturbance intensity produced in our experiments is probably at the limit of the energy required to resuspend the types of sediment in our study area because very similar results of particulate matter resuspended were obtained with 10 and 15 footsteps. However, the concentrations of the nutrients in the water column are the result of different biogeochemical processes after the mechanical disturbance. These processes may take place with different intensities and rates and may have opposite effects on the final nutrient concentrations .

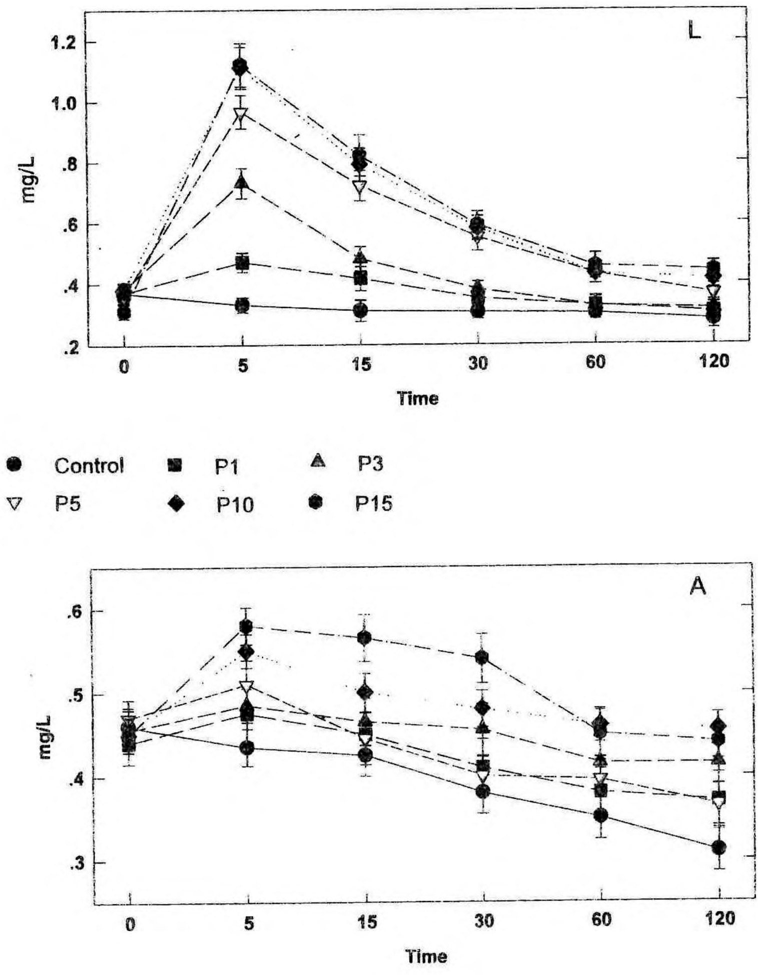

Figure 3: Suspended particulate matter in the water column of the microcosms during the second experiment. Above: microcosms in the finer sediment zone (L in **Table 1**); below: microcosms in the coarser sediment zone (A in **Table 1**). Horizontal axis indicates time of sampling (0 is sampling before footsteps were performed). The different number of footsteps performed in the different treatments are indicated by the number besides the symbols in the figure (Control corresponds to the treatments without footsteps). (See the text for further explanations).

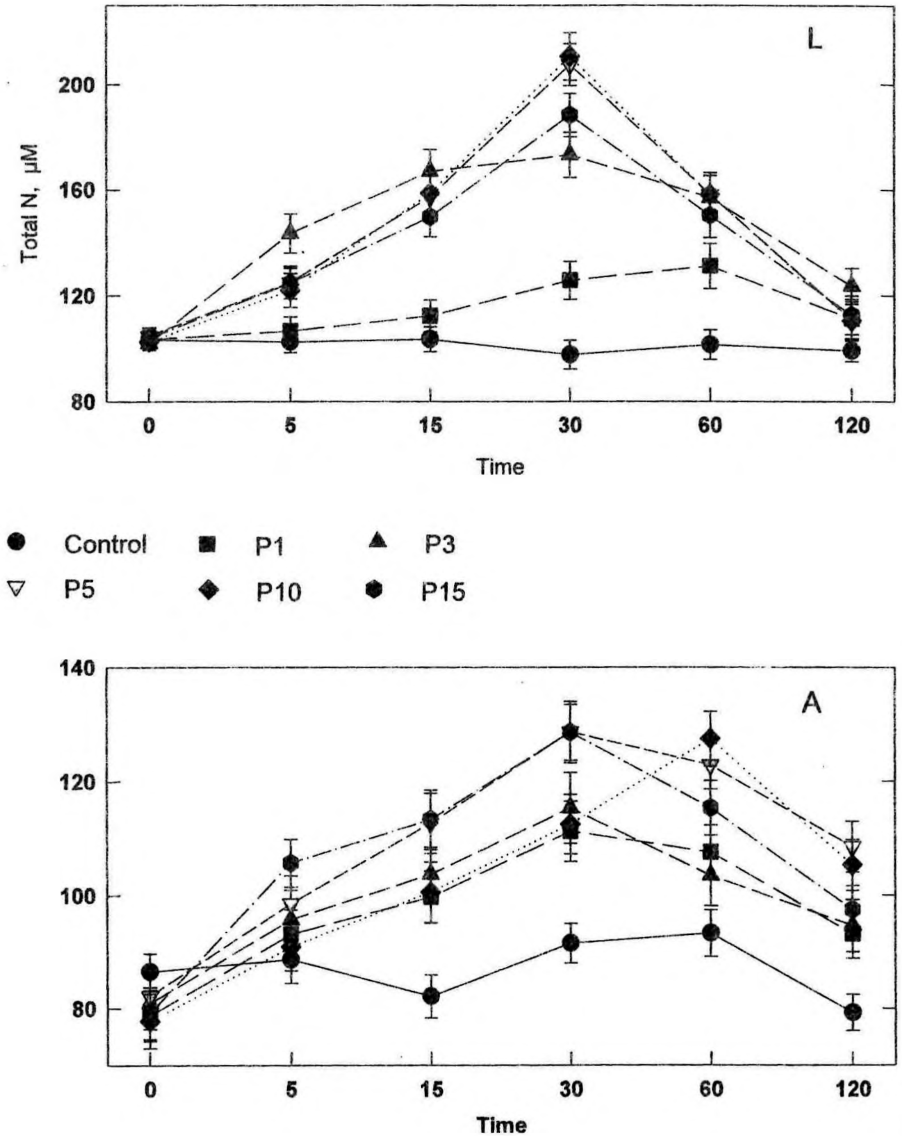

Figure 4: As Figure 3 but for total nitrogen.

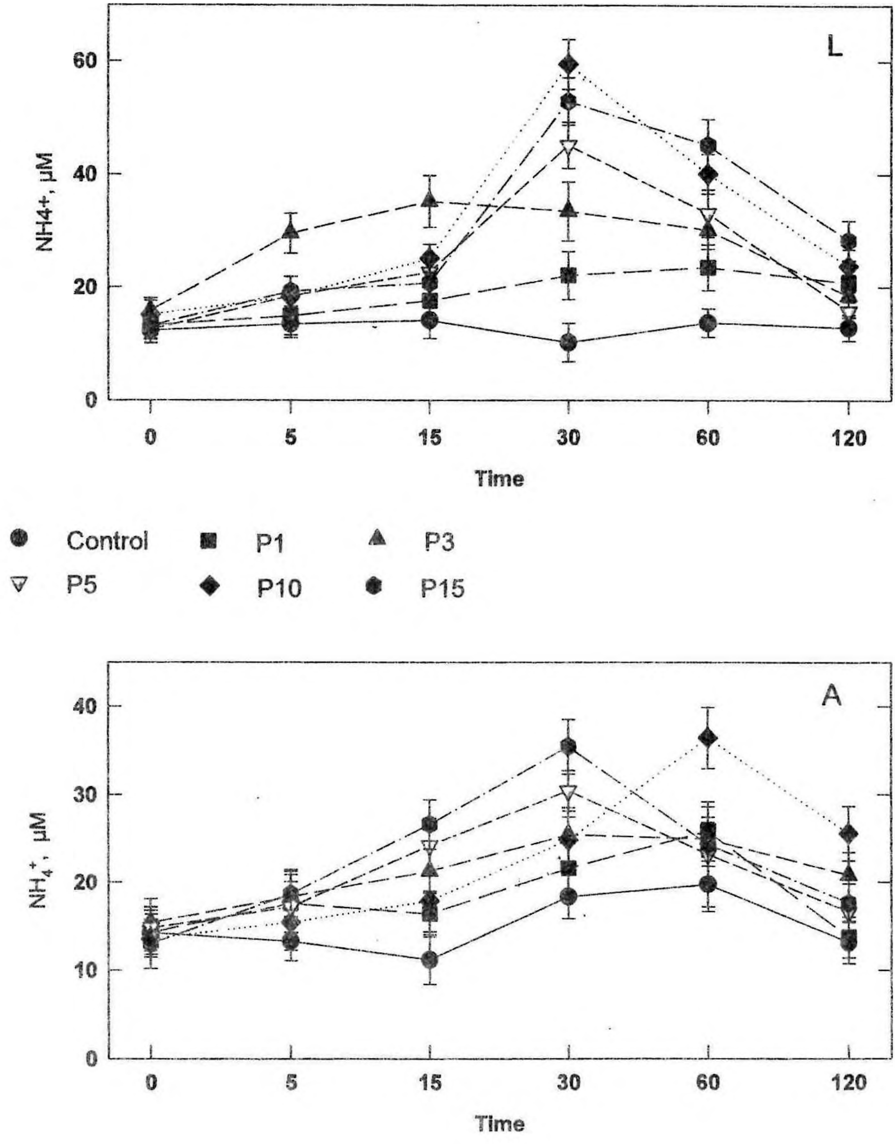

Figure 5: As Figure 3 but for dissolved inorganic nitrogen in the form of ammonium.

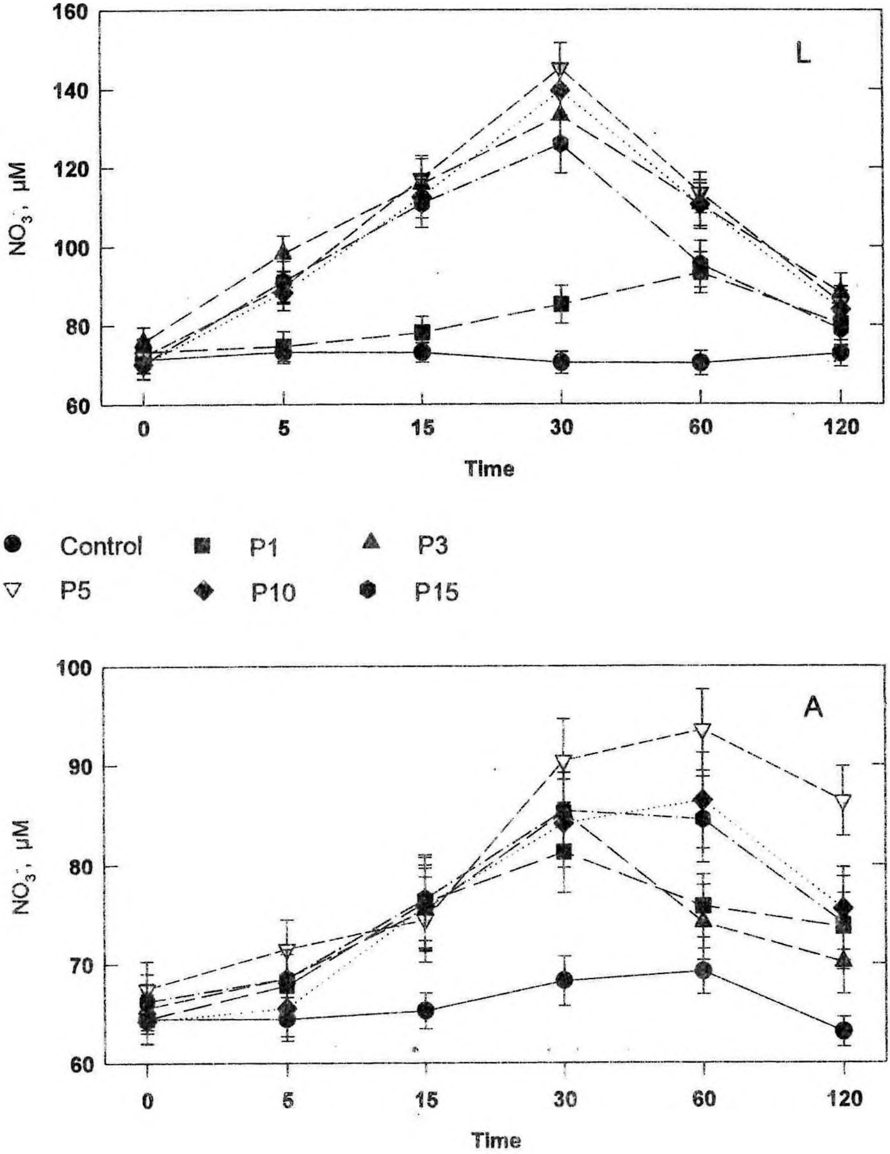

Figure 6: As Figure 3 but for dissolved inorganic nitrogen as nitrate.

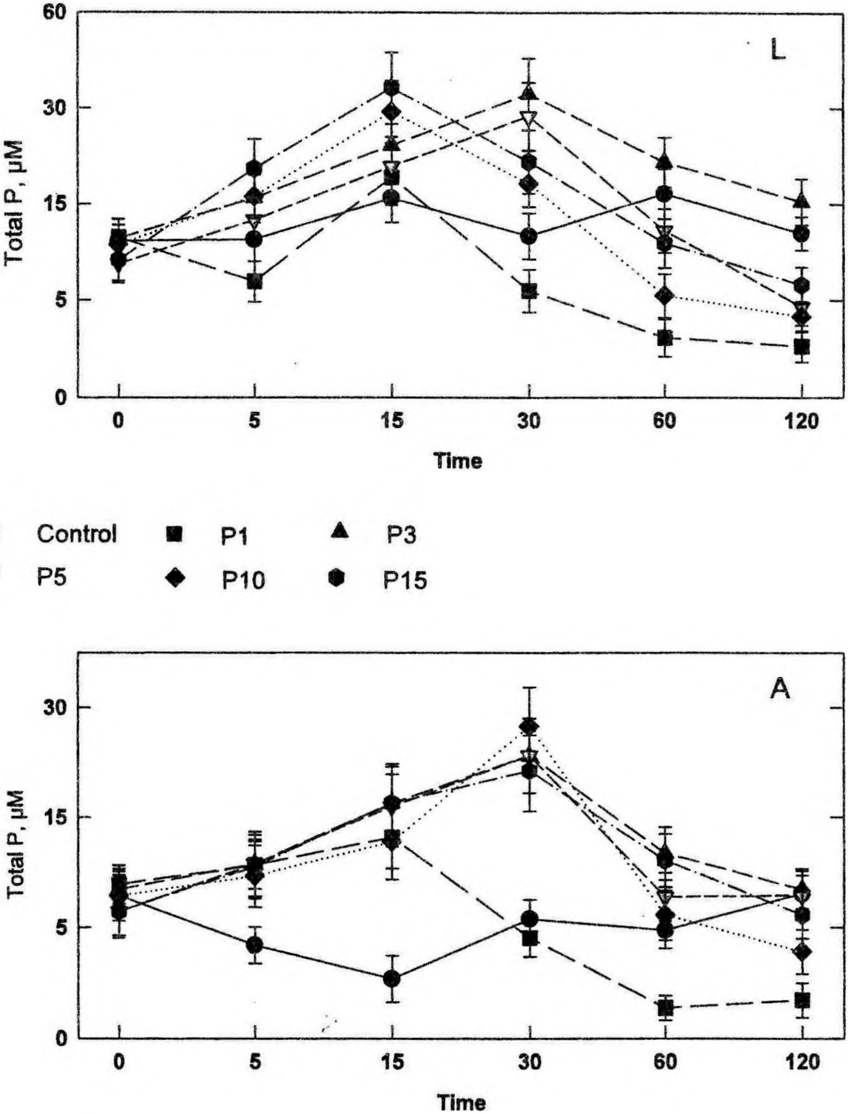

Figure 7: As Figure 3 but for total phosphorus.

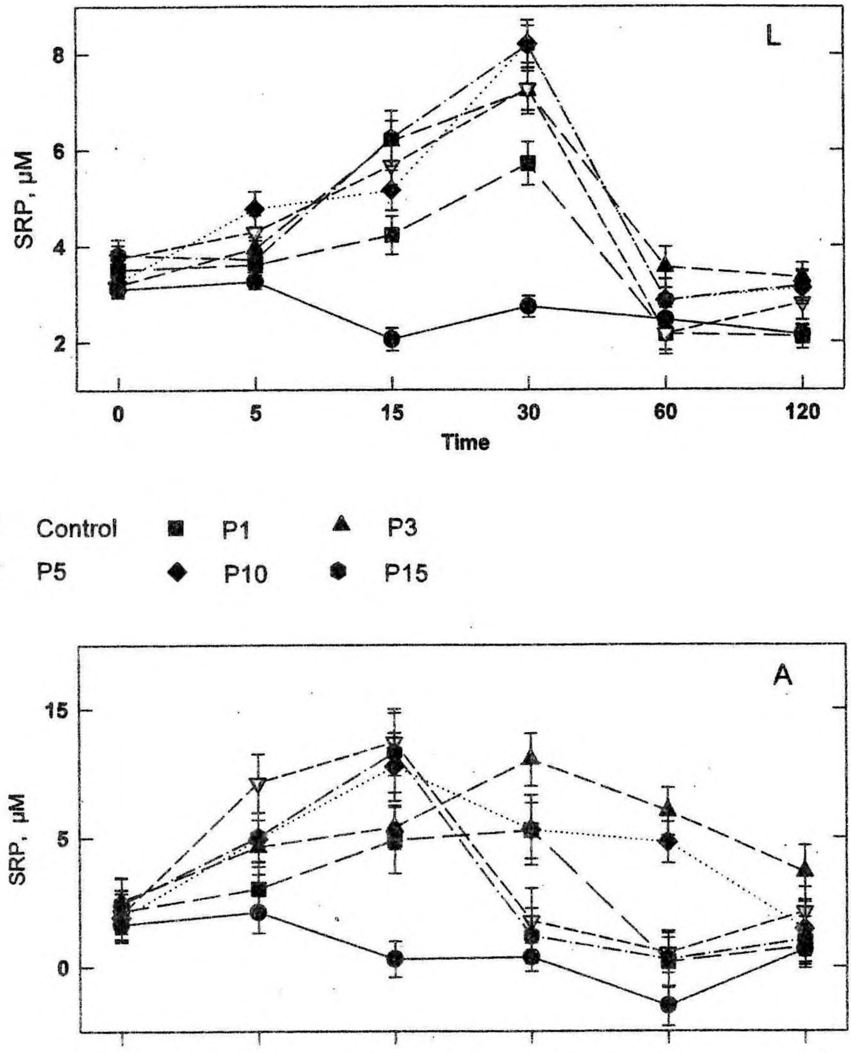

Figure 8: As Figure 3 but for soluble reactive phosphorus.

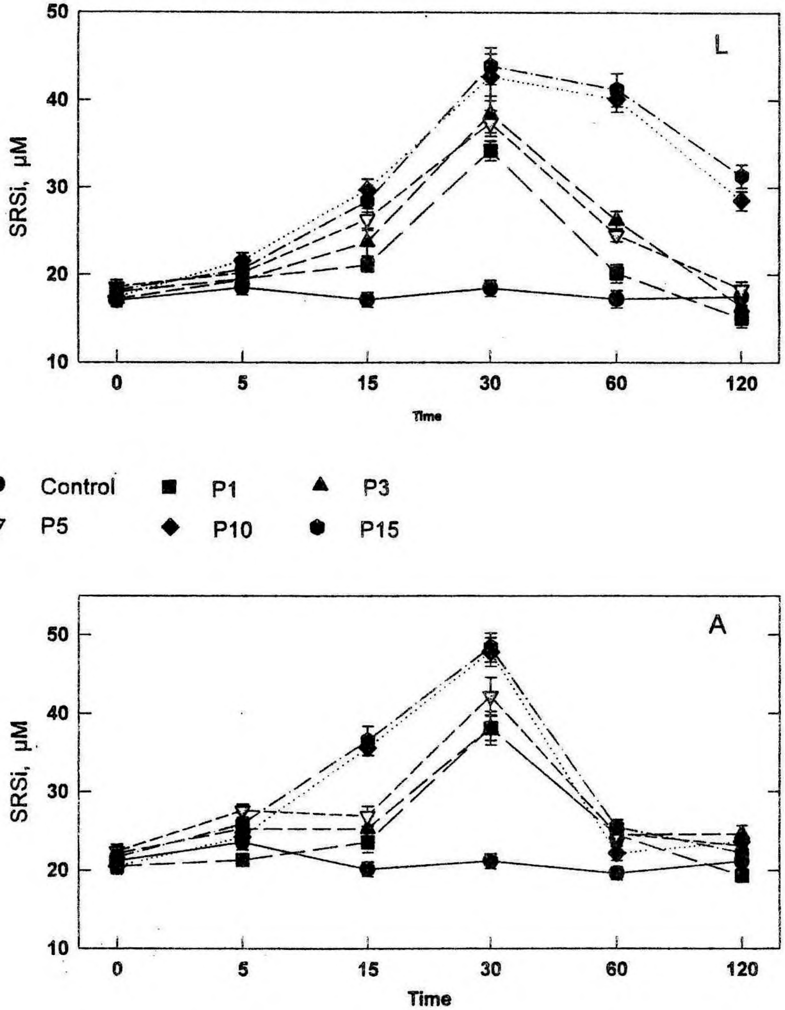

Figure 9: As Figure 3 but for soluble reactive silica.

CONCLUSIONS

Flamingo footsteps at the walking rate frequently observed while the birds eat in the study area -between 3 and 15 footsteps per minute- cause sediment resuspension and nutrient release from the sediment to the water column in the short term, the two-hour period of our longer experiment. In the experimental conditions, increased suspended particulate matter and nutrient concentrations in the water column lasted for 2 hours, which may not be enough to decrease water transparency or to stimulate phytoplankton growth. In natural conditions, a continuous effect of flamingo footsteps can take place in a defined area if different individuals walk on the same place or the same individuals remain active in the same area. Then the effects described here can last for longer. However, flamingos usually sleep and stay without movements during night hours. Further experimental evidences are required in order to check the role of flamingos in the nutrient cycles and other aspects of the limnology of shallow aquatic ecosystems.

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