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A new evaluation of some *Azolla* blooms: the Guadiana cases

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Summary

Azolla is a free floating aquatic heterosporic pteridophyte that in some conditions becomes a weed. In previous works we have studied the causes and consequences of the first major *Azolla* bloom in Portugal. This occurred in the Guadiana river in April 1993. A similar phenomenon, also with an extension of several kilometers, took place in 1995, in the same river and in the same month of the year. In this paper we compare the two cases, in order to achieve consistent explanations for the blooms and to have more information about its evolution and environmental impact.

Introduction

Azolla is a free-floating aquatic heterosporic pteridophyte which contains an endosymbiotic community (cyanobacteria and bacteria) living in the dorsal lobe cavity of the fern leaf. Although several studies have produced important results on the comprehension of the morphology, physiology, biochemistry and genetics of the *Azolla-Anabaena*-bacteria symbiosis, we still have difficulties in dealing with the real problems caused by the uncontrolled growth of *Azolla* over wide areas, namely when this plant becomes a weed (Carrapiço 1990, 1994).

Azolla normally exists in small channels or in sheltered areas of large rivers and there is no notice of such biotopes plenty occupation in Europe. This fern is considered to be represented in Portugal by two species (*Azolla filiculoides* and *Azolla caroliniana*) which grow in different hydrographic basins (Tagus, Sado, Mondego, Vouga, Coa and Guadiana) (Franco 1971), but recent studies suggest that only *Azolla filiculoides* is present in the country (Pereira *et al.* 1998).

In previous works we have studied the causes and consequences of the first large *Azolla* bloom in Portugal, which occurred in the Guadiana river in April 1993. A similar phenomenon was repeated in 1995. In this paper, we analyse the water quality evolution during recent years together with a semi-quantitative distribution of *Azolla* in a large section of the river. We compare the two bloom situations in order to achieve consistent explanations for the blooms and to have more information about its evolution and environmental impact.

Material and Methods

Data from National Water Quality Network (DRARN Alentejo, 1997) were used to study the evolution of the main physical and chemical parameters in the Guadiana river during the period 1989-1995. Two stations located in the Guadiana river course were selected: station 1 (38° 49' 55''N, 07° 04'59''W), near the Portuguese-Spanish border and station 2 (37° 40' 54''N, 07° 39'34''W), 180km south of the later, which was at the southern edge of these *Azolla* blooms. A third station, situated between the two, could have made an important contribution to this study, but the lack of consistent field data did not allow its inclusion in this work. Data on *Azolla* distribution comes from DRARN reports and our own *in situ* observations (Baioa 1997). Identification of *Azolla* species was made in collected material. Factor analysis was performed with STATISTICA/Mac v. 4.1.

Results and Discussion

The Guadiana river has a hydrographic basin area of 66960 km^2, 11700 km^2 being in Portuguese territory, which corresponds to 260 km long, the remainder being in Spain. In the years of 1990-93, the climatic conditions in Portugal, namely in the south, were characterised by lower rainfall with long dry seasons. A similar situation occurred again in 1995. These environmental conditions associated with the presence of several river dams, has led to the appearing of low flows during the years of 1993 and 1995. Agricultural activity in the upper area of the Guadiana hydrographic basin, associated with the presence of several industries and especially untreated domestic effluents coming from several towns and villages, contributed to the organic contamination present in the Guadiana river during this period. The lower flows observed (3.64 - 1.13 $m^3.s^{-1}$ in 1993 and 0 $m^3.s^{-1}$ from April to November 1995) also promoted higher nutrient concentrations. This fern depends on the phosphorus concentration for its development and growth, the desirable phosphorus level in floodwater for a good *Azolla* growth being over 0.4 $mg.l^{-1}$ (Costa *et al.*, 1994). The phosphate content has changed, during the first months of 1993 in different river sites with maximum concentrations in April (12.3 - 1.46 $mg.P_2O_5.l^{-1}$, stations 1 and 2 respectively), the month in which the *Azolla* bloom occurred (Carrapiço *et al.*, 1994). In 1995, station 1 showed high phosphate content from May to November (7.16 - 10.37 $mg.P_2O_5.l^{-1}$), while at station 2 the concentration of the same parameter did not exceed 0.30 $mg.l^{-1}$ during this period. In 1995 the *Azolla* bloom also occurred in April.

Azolla exists usually in small channels or in sheltered parts of the Guadiana river. The species observed was *Azolla filiculoides* and the number of sporulated plants in 1993 was high ($\geq$ 75%), this has also probably happened in the past, as a result of similarly stressed climatic conditions. This fact, associated with the nutrient concentration in the river, namely phosphorus, allowed the fern to progressively occupy new ecological spaces, ending with the bloom observed in 1993. A similar situation happened in 1995, especially in the upper area of the Portuguese river section.

In order to achieve consistent explanations for the blooms and to have more information about their evolution, we have analysed the changes in water quality over recent years at stations 1 and 2 together with semi-quantitative information on *Azolla* presence in the river section between the two stations. A principal components analysis was performed to each station, using data from October 1989 until November 1995 (Fig.1). Nine main variables were considered: water temperature (TEMP), dissolved oxygen saturation, % (DO), chlorides (CHLOR), total phosphorus (PTOT) and phosphates (P_2O_5), nitrates (NO_3) and ammonia (NH_4), river flow and presence relative abundance of *Azolla*. In both analyses, the first three factors explain more than 70% of the variance.

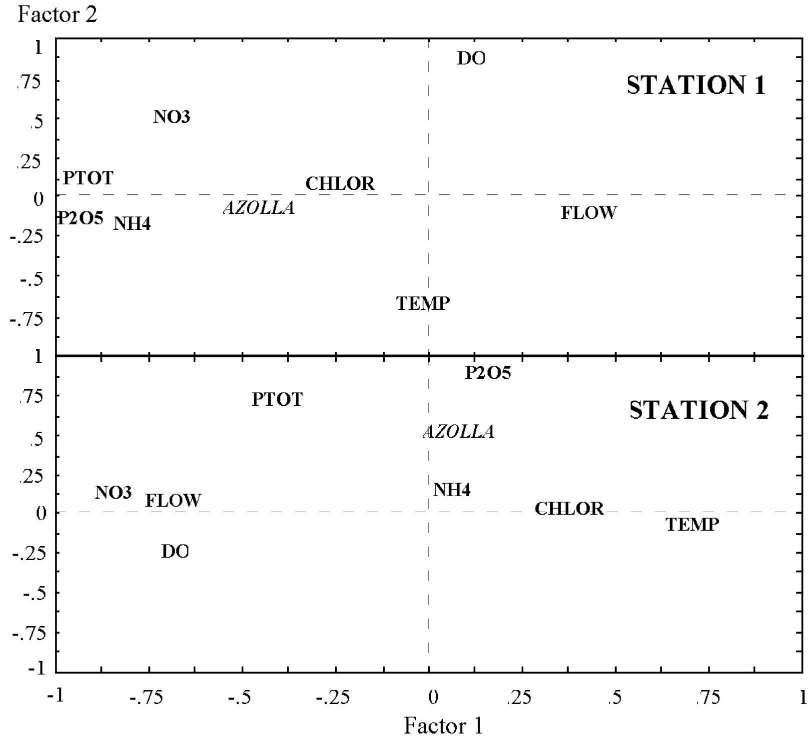

Fig.1 - Principal components analysis for nine environmental parameters (October 1989 to November 1995). In the upper section, variables projection in the space of factors 1x2 for the station 1, in the lower side the same projection for the station 2.

In the analysis of station 1 data, the first axis is highly positively correlated with river flow and negatively with the indicators of organic enrichment, that is PTOT, P_2O_5 and NH_4. The second axis is correlated mainly with those variables indicating oxidative conditions, that is DO and NO_3 and negatively correlated with water temperature. In the analysis of station 2 data, factor 1 is correlated negatively with variables related with oxidative conditions, NO_3, DO and river flow and positively with water temperature, while factor 2 is correlated positively with PTOT and P_2O_5 and correlation with *Azolla* presence is still significative.

After a global analysis of six years data, we may conclude that, at the northern station, the variability in the ecological situation is due mainly to river flow which is responsible for PTOT and P_2O_5 concentration in the water. The presence of *Azolla* in the river does not appear to be significantly correlated with those variables but the contrary occurred at southern station. Here, nutrient concentrations is the result of the river's input but also of several effluents, a paper mill being the most relevant, and also internal processes. In April 1993, the uncontrolled growth of *Azolla*, covered an area of the Guadiana river in an extension of several kilometers lengthwise, between the two stations. Station 2 is at the upper limit of the tidal influence and until 1995 chloride analysis were at low levels. In the period April - November 1995 chlorides concentration rose to 1240 mg.l^{-1} Cl (127.6 mg.l^{-1} Cl was the highest concentration previously registered in April 1993). The 1995 *Azolla* bloom was much less significant, corresponding to the phosphorus concentrations and, apart from its presence at station 2, the greater fern density was located several kilometers to the north. As mentioned before, river flow was 0 $m^3.s^{-1}$ at that time and phosphorus concentration at station 2 was below the desirable phosphorus level in floodwater for good *Azolla* growth. Salinity may also have played a role in *Azolla* growth and distribution.

Both events ended with the closing of the life cycle of *Azolla* and the disappearance of the fern in its vegetative form. Fortunately, the climatic and ecological conditions that accelerated the development of the fern, also contributed to its disappearance. The high temperatures and the low flows observed associated with the fern biomass removal, were the main factors contributing to the acceleration of the *Azolla* sporophyte decease.

In the river, the fern was always located in lentic environments or where some type of obstacles exist. Associated with this situation small streams were full of *Azolla* and they must be one of the main sources for this type of river's bloom. High nutrients concentration and temperature and low flows are the ideal conditions for the development of the fern. Nevertheless, in 1995, *Azolla* developed in the upper river, where the phosphate level was high, but it was also observed in a much larger area downstream with poor nutrients concentration. Apparently, the *Azolla* plasticity allows the plant to develop even if some of those factors are not present, which makes adequate control difficult.

In conclusion, we must say that a management program must include monitoring and prevention control actions and an adequate environmental education, which can solve future *Azolla* bloom problems. It seems to occur between March and May in low river flows and high local or in an upper areas where phosphorus content are promoting conditions for this type of environmental hazard. Finally, a monitoring program must be considered as a priority including: 1. main sources of nutrient input, 2. special attention to PTOT and P_2O_5 concentrations and 3. since February until May, *Azolla* population, biomass and sporulation rates, should be monitorised.

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