Research Article

The Water Hyacinth, *Eichhornia crassipes*: an invasive plant in the Guadiana River Basin (Spain)

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Abstract

The recent invasion of water hyacinth *Eichhornia crassipes* (C. Mart.) Solms (1883) in the Guadiana River Basin (Spain) is described and the distribution of this Amazonian floating plant is analyzed from a geobotanical and chorological perspective. Georeferenced locations of invasion in Spain and Portugal are presented and the relative growth rate (RGR) and doubling time (DT) indexes defined by Gopal (1987) were calculated. The sexual reproductive cycles were determined in order to evaluate the invasive capacity at these latitudes. Predictive models of the plant's potential distribution in the Guadiana River were constructed based on expert knowledge and using a Geographic Information System, on the basis of the water's physico-chemical parameters. Given the size of the potential area of distribution, it seems necessary to make provision for an important increase and subsequent maintenance in the level of the means and logistics targeted at the prevention and control of this weed.

Key words: *Eichhornia crassipes*, GIS model, growth index, Portugal, Spain, Water hyacinth, aquatic weed

Introduction

The water hyacinth, *Eichhornia crassipes* (C. Mart.) Solms (1883), (Liliales: Pontederiaceae, Figure 1) is an invasive plant that is native of the Amazon basin (Barret and Forno 1982) and whose capacity for growth and propagation causes major conservation problems with considerable socioeconomic repercussions. It is a species of great ornamental value used in gardening because of the beauty of its foliage and flowers but is on the IUCN's list of the 100 most dangerous invasive species and the TOP20 of Spain's GEIB (Biological Invasion Specialist Group). Most of the problems associated with *E. crassipes* are due to its rapid growth rate, its ability to sucessfully compete with other aquatic plants, and its ease of propagation. These

characteristics give rise to enormous amounts of biomass that cover the water surface of a great variety of habitats often interfering with the use and management of water resources. Some of the principal problems are its interference with navigation, water flow, and the recreational use of aquatic systems, as well as the risk it poses of mechanical damage to hydroelectric systems. It is also responsible for drastic changes in the plant and animal communities of freshwater environments and acts as an agent for the spread of serious diseases in tropical countries. The impact of *E. crassipes* on the physico-chemical characteristics of the water in general are declines in temperature, pH, biological oxygen demand (organic load), and nutrient levels (Rai and Datta Mushi 1979). Sometimes there is a complete decline of dissolved oxygen, leading to the deaths of a great number of fish.

Figure 1. *Eichhornia crassipes* from Badajoz (Spain). Photo by E.Albano.

Distribution

The species was discovered in 1823 by the German naturalist C. von Martius who was studying the flora of Brazil. He named it *Pontederia crassipes*. Sixty years later, Solms included it in the *Eichhornia* genus as described by Kuntz in 1829. At the present time *E. crassipes* is distributed across the tropics and subtropics between 39°N and 39°S (Figure 2). Man has clearly been the main agent of the species' spread around the world, since its entry into Africa, Asia, Australia, and North America coincided with the arrival of the vessels of the first explorers or with historically documented human activities.

The first reference to *E. crassipes* in the United States was at the beginning of the XX century on the occasion of the Louisiana Purchase (Sculthorpe 1967). The spread continued to Florida where there are many references to control the spread and infestations that occurred (Schardt 1984). It was also introduced into North and South Carolina. In the countries of South America, there are reports of its presence in 1902 in Brazil, 1942 in Argentina, 1959 in Paraguay, Uruguay, Bolivia, Ecuador,

and Colombia, 1976 in Venezuela, and 1979 in Chile. In Central America, it is cited in Mexico, Nicaragua, Costa Rica, and El Salvador in 1965, Panama in 1966, and Puerto Rico and the Dominican Republic from 1971.

E. crassipes has spread over a great part of tropical and subtropical Africa. The plants are thought to have been introduced in Sudan into the River Congo, and that tributaries of the Congo may have extended the plant during floods. Since the 1940s, the plant has infested many African countries and has become a major problem for this continent in terms of the conservation of its aquatic ecosystems (Mendonca 1958; GISD 2005).

It was introduced into Asia at the end of the XIX century through Japan and Indonesia (Ueki et al. 1975) and became naturalized in rice fields in the south and gradually extending northwards. In Indonesia, there are references to its appearance in Bogor where it was grown as an ornamental in the Botanical Gardens (Backer 1951). Today it extends from the plains up to an altitude of 1600 m. In India, it first appeared in Bengal at the beginning of 1890, and is now present throughout the country except in the more arid western part of Rajasthan, in the rugged regions of the north, and in Kashmir. It has recently been cited in Taiwan (GISD 2005) and mainland China (Jianquing et al. 2001).

According to Parsons (1963), its introduction into Australia and Oceania occurred in 1890 near Darwin (Northern Territories). Today, it exists in the coastal areas of all the federated states of Australia and has also appeared in many islands of the Pacific Ocean (Burton 2005).

In Europe it was possibly introduced as an ornamental in the first third of the XX century in Portugal, because the first reference to its presence there dates from 1939. Since then, it has spread over the central-west of the country through irrigation canals and currently exists in the middle and lower Sado and Tagus Basins (Guerreiro 1976; Figueiredo et al. 1984; Amaral and Rocha 1994; Figure 3 and Annex 1). In Spain, the first documented cases date from 1989, appearing only sparsely and more or less sporadically between parallels 36° and 43°N, forming small localized populations that disappeared when the ponds or wetlands in which they had been detected dried out, or because of the salinity of the habitat (GIC 2006).

The greatest damage due to its fast expansion has been in the middle reaches of the River Guadiana in the SW Iberian Peninsula. Detected
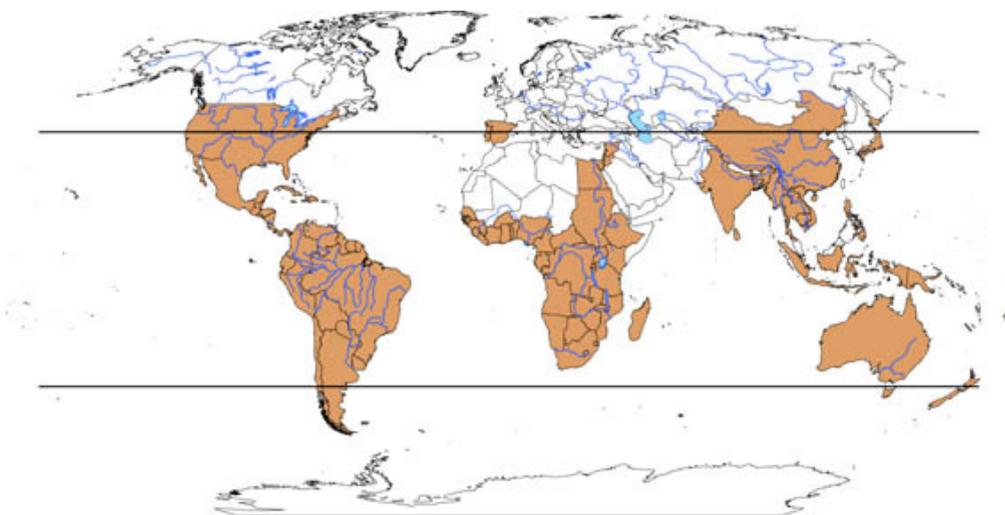
Figure 2. World-wide distribution of *Eichhornia crassipes* based on GIC (2006) data.
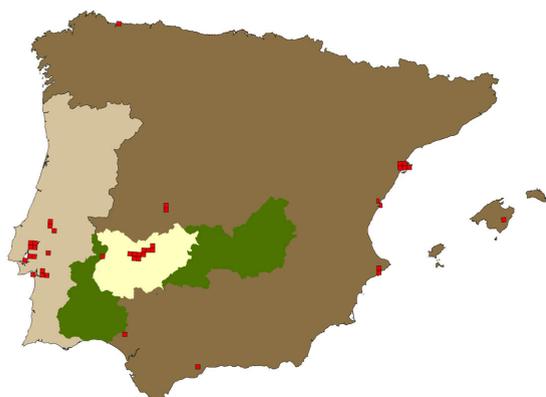

Figure 3. Location of *Eichhornia crassipes* in the Iberian Peninsula and the Balearic Islands. Guadiana River Basin, green line. (see Annex 1).

in the Autumn of 2004, it underwent a marked recession during the winter but in April 2005 there occurred a strong regeneration of the fragments that had been left on the banks. By October and November it occupied an area of approximately 200 ha, covering 75 km of river, and producing in that period a biomass of 175 000 Tm. Due to it rapid expansion, mechanical extraction was carried out by the Confederación Hidrográfica del Guadiana (CHG) of Spain's Ministry of the Environment since the affected zone is an important area of irrigation farming and hydraulic works and this alien plant weed provoked acute social alarm.

We conducted studies during the infestation and species removal period (2004-2006) and the objective of the present work is to discuss the factors that are involved in this invader's success in the Guadiana, to analyze the risk of further infestation, and to propose precautionary measures to prevent its spread in the area.

Factors involved in the success of *E. crassipes* in the Guadiana Basin

Abiotic factors

The plant's present area of distribution covers a broad range of regimes in terms of physico-chemical parameters. The northernmost limit of the area of distribution of *E. crassipes* is where the mean January temperature is 1°C, the mean annual temperature is 13°C, and the average lowest temperature in the year is -3°C (Ueki et al. 1976). The optimal mean temperature for plant growth is between 25°C and 27°C (François 1970). Experimental studies under controlled laboratory conditions have shown that the number of daughter plants is greatest at certain levels of temperature and relative humidity (day/night temperatures of 25/20°C to 40/25°C, and relative humidity of 15/40% to 75/95%) (Freidel et al. 1978). Also, growth stops if the water temperature falls below 10°C or rises above 40°C (François 1970). In 2005, the mean temperature in the zones of infestation in the

River Guadiana ranged between 17.7°C and 19°C (datum taken by averaging the mean temperatures at several stations of the ICA Network – Spain's nationwide water quality monitoring network – selected to cover the affected section). Rather than a limiting growth, temperature is a factor favouring the plant's growth in this part of the River Guadiana.

Another determining factor for the growth of *E. crassipes* is pH. This has to be between 6 and 8. When the values move outside this interval, the plant can regulate pH of the medium within this range with its growth frequently resulting in the alkalinization of the water. Maximum growth (number of plants and dry weight) is at pH 7, with pH 3.2–4.2 being very toxic for the plant, 4.2–4.3 inhibitory, and 4.3–4.5 possibly inhibitory (Berg 1961). The waters of the River Guadiana have a pH between 7.25 and 8.1 (as measured with the multiparameter Seth Multiline P4 meter), so that, as was the case with temperature, the conditions are near optimal for the growth and vegetative reproduction of *E. crassipes*.

With respect to nutrient concentrations, plants growing where these are low are reported to take on a paler hue of green and a purple colouration in the roots (Lugo et al. 1979). Maximum growth of *E. crassipes* has been observed at N:21 mg/L, P:62 mg/L, and Fe:0.6 mg/L. Deficiency of N or P has less adverse effect than that of Ca. A lack of Ca prevents the plant's vegetative reproduction (Desougi 1984), the minimum concentration necessary being Ca:5 mg/L (Oki et al. 1978), with this element being essential for seed formation (Talatala 1974). Nitrates are the main nutrient responsible for the growth of this invading plant. Their concentration in the River Guadiana in 2005 varied between 19.63 to 23.52 mg/L in the zones of greatest infestation. Phosphate concentrations were between 0.02 to 3.31 mg/L. Therefore, although the phosphate levels were not excessively high, nitrate levels were optimal for growth of the water hyacinth in this section of the infested basin. The mean calcium concentration was 48.58 mg/L (datum taken by averaging the mean calcium concentrations at the aforementioned stations of the ICA Network) – 10 times greater than the minimum required for the plant's vegetative reproduction.

The presence of these nutrients in the river is linked to the intense agricultural activity in its adjacent floodplain. These are fertile soils which in the 1960s were transformed from the tradi-tional dryland farming and livestock raising into large areas of irrigation with the construction of very large hydraulic works. This led to agricultural practices of fertilizer use in which the input of nutrients is often non-sustainable and which have notably affected the water quality of the Guadiana in its chemical composition.

With respect to luminance, *E. crassipes* is classified as heliophilous. Its fastest growth is at 240 000 lux, and its minimum requirement is 24 000 lux, i.e., it can grow under a broad range of light intensities (François 1980). In the River Guadiana, a good part of the riparian fringe that would naturally exist along the banks (gallery forest of black poplar, willows, alder, and ash) has been lost. With the lack of shading these habitat are in direct sunlight thus the present-day conditions also favour the plant's propagation.

The speed of the current must also be taken into account. The floating form of the plant does not take root so that it is exposed to the kinetic action of the water current. To be able to constitute a stable population it requires the support of macrophytes or helophytes (rush or reed beds) on which to anchor. Since the current facilitates the dispersal of propagules and stolons, and hence the colonization of new areas, it is an abiotic factor of considerable importance for the potential propagation of the infestation in a given territory. Indeed, in the present case this factor was determinant in the plant's dispersal. Our censuses of propagules in the Guadiana (July-September 2005) found the greatest rate of propagule dispersal to be during September, with an average of 4.5 propagules in 15 minutes. The reason for the differences in dispersal rate in different months could be the highly variable flow regime of the Guadiana.

There have been interesting studies showing that both the depth of the water and changes in water level are important for the growth of this species. The plants have more roots when they are floating in deep water than in shallow water, while the leaf area, and the summer growth of the plant, are greater in the latter case (Oki and Ueki 1984). In rivers infested with *E. crassipes* and that are characterized by major fluctuations in water level, such as the Nile, there have been some studies on the connection between variations in the populations and these ecological factors (Freidel et al. 1978). Major oscillations in its water levels are also a characteristic of the Guadiana, not only because it is a Mediterranean river affected by strong summer droughts, but also because of the great dams that have been

constructed on its upper reaches (La Serena, Cíjara, García Sola, etc.) with the consequent greater frequency of changes in flow. These anthropogenically induced oscillations in flow regime affect various environmental factors that contribute to its spread. First, they can reduce the average water temperature. Second, they increase water movement. Third, they lead to the possibility of seed-bearing plants being left stranded on dry banks, with the consequent drying and wetting cycles subsequently favouring the seeds' germinative capacity.

Flora and fauna associated with E. crassipes

The successful invasion of invasive plants is also due to the lack of predators and competitors. The water hyacinth in its native habitat is food for manatees (*Trichechus manatus*) which maintain the populations in equilibrium. The lack of any equivalent aquatic fauna in the Guadiana notably determines the success of the plant's populations in this river.

With respect to other types of relationships, the stems and roots of the water hyacinth often harbour microorganisms such as the nitrogen-fixing *Azotobacter chroococcum* (Purchase 1977), and vertebrates and invertebrates with which it may not infrequently form symbiotic relationships – amphibians, bony fish, snakes, rodents, annelids, and arachnids and other arthropods (Ultsch 1976; Achaval et al. 1979; Leentvaar 1974; Auffenberg 1980; Godley 1982; Costa and de Silva 1978; O'Hara 1967; Moghraby 1975). On several occasions, moorhen (*Gallinula chloropus*) were observed pecking at the aerenchyma of water hyacinths in periods of food shortage, as well as several representatives of the insects taking nectar during flowering.

Our pollinator censuses (September 2005) showed the agent responsible for cross-pollination at these latitudes to be the common honey-bee (*Apis mellifera*) unlike in the plant's natural habitat where the pollinators are the long-tongued bee *Ancyloscelis gigas* and the stingless bee *Trigona* sp. (Barret 1977). The existence of this vector plays an essential role in the sexual reproduction of the water hyacinth and in the sexual contribution to its propagation. Seed set in open and bagged flowers was estimated (GIS, 2005b, unpublished data), and seed germination ablility was proved so the species can reproduce sexually in the Guadiana River.

As the geographical distribution is so widespread, and the species involved vary from country to country the list of plants accompanying *E. crassipes* is enormous. For this reason, some authors (Gopal 1987) are unwilling to affirm that this plant forms phytocoenoses sensu strictu. It often occupies the same niche as rootless floating plants such as the cosmopolitan genera *Lemna* (duckweeds), *Spirodella*, or *Wolffia* (watermeals), or aquatic ferns such as the *Azolla* (mosquito ferns) or the *Salvinia* (water spangles) (Gopal 1987). Also, the floating carpets of water hyacinth constitute a habitat that is well-suited to the germination and initial growth of the seedlings of many species.

In the case of the Guadiana infestation, the accompanying vegetation consisted of beds of reeds and rushes dominated by *Phragmites communis*, *Typha latifolia*, *T. angustifolia*, *T. dominguensis*, and other smaller species such as *Polygonum persicaria*, *Echinochloa crus-galli*, *Veronica anagallis-aquatica*, *Roripa nasturtium-aquaticum*, and *Rumex conglomeratus* which found mechanical support in this invasive plant. There were also small free-floating aquatic plants such as *Lemna minor* and *Azolla filiculoides* and macrophytes such as *Ceratophyllum demersum*, *Potamogeton crispus*, and *P. natans* and *Myriophyllum spicatum* which was less abundant.

Nevertheless, these associated species were affected by the fast growth of the alien invader. At the beginning of the infestation when the patch was small in size, they co-existed with the invader, but as *E. crassipes* expanded it completely eliminated these associated aquatic species from the habitat. Indeed, in other countries too, various studies on the interaction between *E. crassipes* and competing species (mainly of the genera Pistacia and Sesbania) have found that the competitor ends up being excluded (Gay 1960; Chadwick and Obeid 1966; Little 1975).

The water hyacinth's competitive success seems also to be related to the levels of eutro-phication and the area occupied by the rest of the vegetation present in the habitat (Morris 1974). Thus, the devastating capacity of *E. crassipes* in the waters of the Guadiana is a result of the nutrient levels that are near complete eutro-phication and of the small proportion of the water surface that is naturally occupied by native aquatic vegetation.
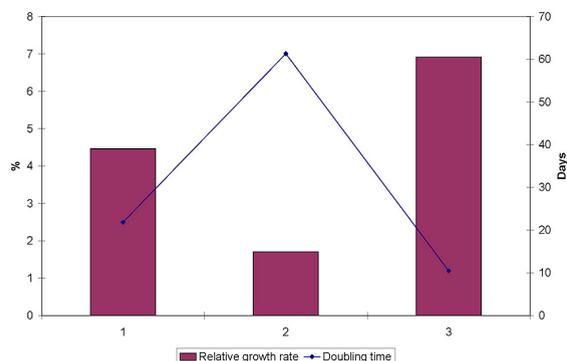
Figure 4. Plots of the relative growth rate and the doubling time in 3 experiments: (1) culture ex situ; (2) culture in natural conditions; and (3) culture in experimental rafts.

Reproductive capacity of E. crassipes

Together with the undeniable importance of the aforementioned external factors, the species' genetic make-up which is responsible for its reproductive strategy and capacity for growth is also of great importance in contributing to the invasion. It is known that variations in the invasive potential of an alien aquatic plant reflect its preference for the new habitat and the availability of propagules (Mandryk and Wein 2006). In the present case, *E. crassipes* is a plant that reproduces both vegetatively and sexually, the former being the more important for the plant's rapid expansion and colonization through the formation of stolons.

E. crassipes has an extraordinary growth rate. This has been calculated in other countries to be an increase in biomass of 400–700 tons per ha per day, or an increase in water area coverage by a factor of 1.012–1.077 per day. We conducted experiments to evaluate the growth rate of *E. crassipes* in the River Guadiana: Experiment 1 (37 individuals), 2 (50 individuals), and 3 (80 individuals) (for detailed methods see GIC 2006). Experiment 1 was made in experimental baths in August 2005, Experiment 2 in the river, September-October 2005, and Experiment 3 July 2006, in artificial lakes. Temperature of growth and physicochemical parameters were measured. The results gave a daily relative growth rate (RGR) (Gopal, 1987) that varied between 4 and 6%, and doubling times (DT) (Gopal, 1987) of between 10 and 60 days, depending on the experimental conditions (see Figure 4). These results are similar to those previously published by the bibliography on this topic.

Modeling the potential evolution of *E. crassipes* in the River Guadiana

The measures put into effect by Spain's Ministry of the Environment in 2005/6 have so far managed to contain the infestation to a 75 km section of the river. But in light of the risk represented by the plant's capacity for reproduction and growth and the abiotic and biotic factors that favour its success, we determined its future distribution to plan and implement the appropriate control of the weed in this area.

We used a GIS (Geographic Information System) to construct predictive models of the plant's potential distribution on the basis of the water's physico-chemical parameters – temperature, pH, conductivity, and nutrient concentrations (calcium, phosphates, and nitrates). Statistical models were not developed, for the potential spread was validated by the expert knowledge way.

The physico-chemical data used in the GIS came from 200 stations of the ICA network (Red Integral de la Calidad de las Aguas) of the CHG (Ministry of the Environment). After the selection and processing of the raw data, they were subjected to a preliminary analysis (Exploratory Spatial Data Analysis, ESDA). This preliminary step is an indispensable requirement for interpolation, since one must examine the distribution of the data, identify local and global outliers, look for overall trends, examine the spatial autocorrelation and directional variation of the data, understand the covariation between the multiple variables, and transform the data if necessary (Moreno 2005).

First, the study area was digitized (Arcview, Esri©) using as base cartography 1:25.000 maps (National Geographic Institute) and orthophotographs (Ministry of Agriculture, Fisheries, and Food). With this material, we created a vector polygon layer of the River Guadiana and some of its tributaries, from the Orellana Dam (Spain) to Cheles-Alqueva (Portugal).

To construct the map inputs, values were needed for the entire area of study. It was thus necessary to interpolate between the zones where the sampling stations were located. The interpolation technique used as being the best suited to the spatial characteristics and the data was the inverse distance weighted (IDW) mean (Felicísimo 1994). The calculations were performed using the Geostatistical Analyst Tool of the ArcGIS program. A cross validation was
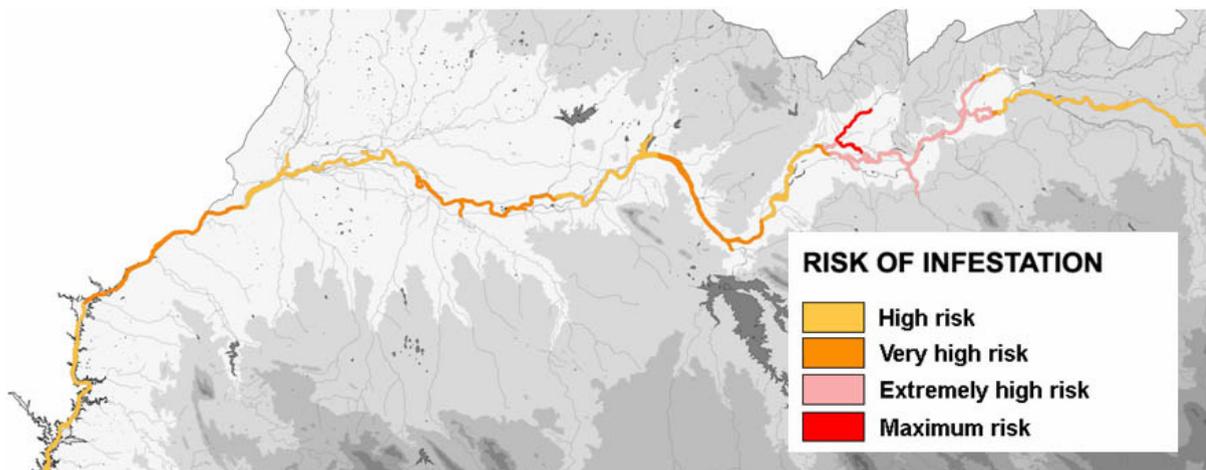
Figure 5. Map of areas on risk of being recovered by *Eichhornia crassipes* in the Guadiana River Basin.
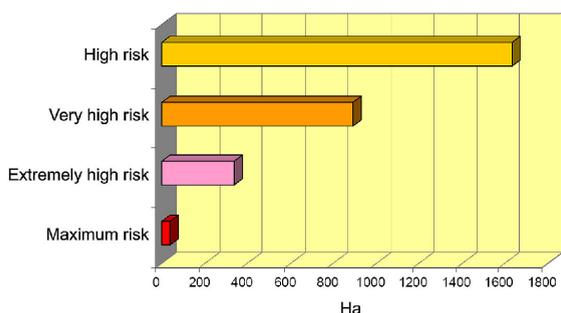

Figure 6. Main Areas (Ha) and risks of the infestation by *Eichhornia crassipes* in the Guadiana River Basin.

then performed obtaining different graphs and summaries of the measured and predicted values (Moreno 2005).

With the interpolated surfaces corresponding to the different physico-chemical variables, the final maps were generated using the ArcGIS and ArcView programs. The interpolated surfaces were rasterized to layers with a resolution of 25 m. Using map algebra, we created an appropriate legend for each selected physico-chemical variable. From the values of the different variables favouring growth and the analysis of their cartography in the study area, we used overlay techniques to construct a map of the risk of water hyacinth infestation. Levels of risk were defined based on expert published knowledge on the physicochemical parameters related to the higest growing levels.

In Figure 5, we show the map that results from dividing the level of risk of the sections of the river basin studied into four categories: sections where the risk of infestation is high, very high, extremely high, and maximal. Figure 6 shows the main Areas (Ha) and risks. In the study area, therefore, there are no physico-chemical conditions that would limit the distribution and persistence of the plant – indeed, this section of the Guadiana Basin is extraordinarily vulnerable to infestation. The area also showed favourable conditions for the plant's continued growth and expansion year after year, with the different levels of risk never being less than highly vulnerable. The highest level of risk (red) is situated in the municipality of Guareña (38°N) and in the zone of the mouth of the Búrdalo tributary (38°N). Zones of extremely high risk (pink) correspond to Don Benito and the Ruecas river. The other zones of the Guadiana are either at very high (orange) or high (yellow) levels of risk.

Consequently, it is foreseeable to expect major infestations in the area that is presently colonized, both in population size and in spatial extent. Its expansion to areas that are presently free of infestation is also to be expected. These include the Vegas Bajas (Lower Floodplains, between Mérida and Badajoz) area and the Alqueva Reservoir in Portugal, of recent construction and the largest reservoir in Western Europe. Given the size of the potential area of

distribution, it would seem necessary to make provision for an important increase and subsequent maintenance in the level of the means and logistics targeted at the prevention and control of this weed.

Management and control of the *E. crassipes* infestation

Today there is a global agreement among scientists and managers that there is no totally effective method to eradicate *E. crassipes* indicating the best option is integrated management and control of the weed. Each of the methods that have been studied and used have their particular characteristics of time, effort, cost, environmental consequences, and efficacy so that the combination of various agents has been proposed to best control the plant (Gopal 1987). In the case of the infestation of the Guadiana, physical means have been used to control the weed (i.e. mechanical removal). The results have been positive although in no sense has the possibility of the evolution of the populations been discarded.

At the end of World War II, chemical control was the main approach for controlling *E. crassipes*. In the 1960s, various research articles reported on use of herbicides for the control of infestations of *E. crassipes*. Since then various types of herbicides have come on the market showing different degrees of effectiveness and environmental consequences. Those most used have been amitrol, 2,4-D amine, diquat, glyphosate, and paraquat (Gopal 1987). No chemical control agents have been used in the recent infestation of the Guadiana since Spanish legislation does not presently permit the use of any herbicide in natural water courses.

The strategy that is presently the centre of interest for dealing with alien plant weeds is biological control. Indeed, *Neochetina eichhorniae* and *Orthogalumna terebrantis* have a sympatric distribution and a synergic relationship (DelFosse 1977) in weakening *E. crassipes*. They are therefore the most widely used and the two species have similar temperature requirements.

Insects and other arthropods contribute to increased incidence of diseases by damaging the leaf tissues or by transmitting pathogenic agents. In the case of *E. crassipes*, a strong correlation has been observed between the presence of *Acremonium zonatum* and the attack of mites (Charudattan et al. 1978; DelFosse 1976) and weevils (Sanders et al. 1985), although it is unclear whether these arthropods are vectors of the pathogens or the fungal spores are deposited in the tunnels they create.

There are two pre-requisites for the integration of chemical control and the use of insects and phytopathogens: that the concentration of the chemical is sufficiently low to leave the plant alive but with reduced vigour and that the substance does not affect the insects, the pathogenic agents, or their pathogenicity. Although there has been little attention paid to the integration of chemical and biological control, Center et al. (1982) reported that in an experimental study weevils were more effective in combination with a growth retardant. Great caution is needed in selecting which herbicides to use together with biological control. Roorda et al. (1980) found that while 2,4-D amine, glyphosate, and paraquat have very few effects on adult mites (mortality < 20% at concentrations of 500–1000 mg/l) diquat, diazinon, endosulfan, and azinphos-methyl are toxic for both larvae and adults.

The present trend is the study of a broad spectrum of aspects concerning the biological control of *E. crassipes* – the effect of nutrients on this control (Coetzee et al. 2006), the photosynthetic and biomass productivity of plants affected by biocontrol (Ripley et al. 2006), and integrated control with insects and phytopathogens (Jiménez and Balandra 2007). At a general level, in countries where *E. crassipes* infestation affects hundreds of thousands of hectares, integrated control may include several different measures. For example, the pathogen *Cercospora rodmanii* can be integrated into control programs with arthropods such as *Neochetina* and sub-lethal doses of chemical herbicides (Charudattan 1985). In these treatments, the chemical herbicide is used solely to put the plant under slight stress, so that the mites or other insects would not be affected as they would be with conventional treatments (Wright and Center 1984). The arthropod population is most likely to survive the herbicide treatment, and will then cause even greater damage to the plant by affecting the new shoots. This would also make the plant more susceptible to diseases, which was the reason for the use of mycoherbicides such as *C. rodmanii* to maximize the stress on the plant (Charudattan 1985).

Notwithstanding the different measures put into practice in different countries around the world, the goal of controlling *E. crassipes* has not been attained with much less the eradication occuring at present. For that reason, there have been attempts in the last few years to approach the control of the plant by putting it to practical use, which would also contribute to reducing the cost of its elimination. In the United States of America, Australia, and South Africa, where the plant is the cause of great environmental problems, there are many centres that specialize in its use, and there have been frequent recommendations to integrate physical control with different forms of using the extracted biomass.

Different applications have been found for *E. crassipes*. It makes suitable feed for many animals, and can be a source of protein for man. Its use has been recommended in farming as fertilizer and compost for mushroom culture, and even to improve harvests of certain cereals. It has been tested as source of pulp for the production of paper, and there have been descriptions of its potential for phytoremediation in wastewater treatment (Zimmles et al. 2006; Evel et al. 2006), including its subsequent use after having been grown in wastewater to produce biogas (Verma et al. 2006).

For the case of the Guadiana the measures carried out to date by Spain's Ministry of the Environment have managed to retain the infestation within a seventy five km section of the river. An urgent procedure plan of action was set up. This plan is based fundamentally on physical methods with manual and mechanized extraction of the plant and the installation of physical barriers to prevent the spread of the plague downstream. Environmental awareness measures were also taken through various communications media to obtain the collaboration of citizens in preventing the plague. In synthesis, to the date more than two hundred of thousand metric tons of biomass have been extracted, with notable maxima in the campaign of 2005. This has meant an approximate total cost of more than eight million euros.

In order to prevent propagation, an important dam (Montijo) was drained dry through its bottom gates, and the plants that were left stranded were collected. Steel gratings of minimal aperture were installed to prevent propagation via the two large irrigation canals leaving this reservoir, and barriers were put in place. Two types of barrier are in use, the Huelva type and the Zaragoza type, both designed specifically for the Spanish situation. The Huelva-type barriers are placed diagonally across the channel. They are held to the banks, with 30-mm corrugated steel posts and welded rings secured by padlocks and steel cables. They consist of elliptical cross-section floats, attached to a 40-cm deep wire mesh, with a weighted tether to ensure its permanent submersion. The Zaragoza-type barriers are fixed. They are secured by two cast concrete blocks with anchor rings. Their cylindrical floater design, gives practically null slew and fast vertical oscillation, providing an excellent guarantee of containment at sites with a strong current. Altogether, two thousand meters of the first and five thousand and two hundred meters of the second have been used. The mechanized extraction techniques used were crane trucks equipped with a grapple, backhoes with bucket, and thirty five meters boom cranes. Sites of difficult access were cleaned by manual extraction from motor boats.

On the other hand (GIC 2006), to initiate pilot trials was recommended in order to investigate on its use as livestock feed, as fertilizer-compost, and as a source of energy. Given that the expectations of its use could indirectly encourage expansion of the plant, these pilot trials must be performed by enterprises under the coordinated direction of organisms of Public Administration and under controlled conditions.

The present situation can be described as under control with no spread of the plant to the Alqueva Reservoir in Portugal. The guidelines set out in the Convention on Biological Diversity have been put into effect. These guidelines require that once the establishment of an exotic invasive species has been detected, the States involved individually or conjointly apply the precautionary principle and adopt measures (i.e. eradication, containment, and control) to mitigate detrimental effects.

Acknowledgements

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Annex 1. Presence of the natural populations of *Eichhornia crassipes* plants in the Iberian Peninsula.

Location	Location coordinates		Habitat	Dates of records	Reference
	Latitude	Longitude			
SPAIN					
La Aljaima (River Guadalhorce)	36°44'N	04°40'W	River	Before 2004	GIC 2005
PN Doñana (Almonte, Huelva)	37°15'N	06°31'W	Wetland	Before 2004	García-Murillo et al. 2004
River Algar (Altea)	38°30'N	00°10'E	River	July 1998	Piera et al. 1999
Bolulla	38°40'N	00°10'E	Stream	July 1988	Carretero 1989
Valverde de Mérida	38°50'N	06° 10'W	River	October 2004	GIC 2005
San Pedro de Mérida	38°50'N	06°20'W	River	May 2005	GIC 2005
Valdetorres	38°50'N	06°30'W	River	May 2005	GIC 2005
Son Navata (Felanitx)	39°28'N	03°06'E	Pond	August 2005	Majol 2006
Mérida	38°50'N	06°00'W	River	May 2005	GIC 2005
Yelbes	39°00'N	05°50'W	River	May 2005	GIC 2005
Medellín	39°00'N	06°00'W	River	October 2004	GIC 2005
Villagonzalo	39°00'N	06°10'W	River	May 2005	GIC 2005
Partida de Patos	39°50'N	00°00'E	River	June 1992	Tirado et al. 1994
Navalmoral de la Mata	39°50'N	05°30'W	Pond	November 1997	Rico 2001
Talayuela (Arroyo Fresnedoso & Santa María)	39°60'N	05°27'W	Stream	October 2005	GIC 2006
Ulls de l'Arispe (Ebro Delta)	40°40'N	00°35'E	Wetland	Beginning of 1990	Dana et al. 2004
Sèquia de la Plana	40°00'N	00°00'E	River	November 1992	Tirado et al. 1994
Laguna de Arnao (Castropol)	43°30N	07°01'W	Pond	Beginning of 2004	González Costales 2006
PORTUGAL					
Leziria	38°20'N	08°30'W	Canals	Between 1939 and 1976	Moreira et al. 2005
River Sado	38°20'N	08°40'W	River	Between 1939 and 1976	Moreira et al. 2005
Comporta	38°20'N	08°50'W	Ricefield	Between 1939 and 1976	Moreira et al. 2005
Setúbal	38°30'N	09°10'W	Ricefield	Between 1939 and 1976	Moreira et al. 2005
Canha	38°40'N	08°50'W	River	Between 1939 and 1976	Moreira et al. 2005
Alcochete	38°40'N	09°00'W	Wetland	Between 1939 and 1976	Moreira et al. 2005
Elvas, Torre de la Bolsa	38°50'N	07°10'W	River	Before 1960	Anthos 2006
Ribeira Estaçao do Lauve	38°50'N	08°30'W	Canals	Between 1939 and 1976	Moreira et al. 2005
River Soraia	38°50'N	08°50'W	River	Between 1939 and 1976	Moreira et al. 2005
Benavente	38°50'N	09°00'W	Stream	Between 1939 and 1976	Moreira et al. 2005
River Sto. Estévâo	39°00'N	08°50'W	River	Between 1939 and 1976	Moreira et al. 2005
Vilafranca da Xira	39°00'N	09°00'W	Canals	Between 1939 and 1976	Moreira et al. 2005
Santarem	39°10'N	08°30'W	Canals	Between 1939 and 1976	Moreira et al. 2005
Chamusca, Vila Nova da Barquinha River Xarrama, Torrao	39°20'N	08°30'W	River	Between 1939 and 1976	Moreira et al. 2005