Short communication

A first report of water hyacinth (Eichhornia crassipes) soil seed banks in South Africa

E. Albano Pérez a,*, J.A. Coetzee b, T. Ruiz Téllez c, M.P. Hill b

a Grupo HABITAT, Departamento de Producción Forestal, Centro de Investigación Finca la Orden-Valdesequera, Consejería de Economía, Comercio e Innovación, Junta de Extremadura, Km. 372, 06187-Guadajira, Badajoz, Spain
b Department of Zoology and Entomology, Rhodes University, P.O. Box 94, Grahamstown 6140, South Africa
c Grupo de Investigación en Biología de la Conservación, Facultad de Ciencias, Universidad de Extremadura, Avda Elvas s/n, 06071- Badajoz, Spain

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Abstract

We investigated water hyacinth seed banks in several aquatic systems in South Africa. Fifteen sites, mainly in the Eastern and Western Cape provinces, were surveyed from August to October 2009. Soil seed density varied between 0 and 2534 seeds/m² but did not differ significantly between the type of waterbody (impoundment vs. river) or the history of control carried out at a site. Average germination was 54.17% with very fast velocities (Vigour Index = 36.66) and maximum germination around three days. Although we demonstrated the existence of an important reservoir of seeds, results from this study indicated that a combination of factors such as water fluctuation, eutrophication and seed decomposition might have had a great influence on dispersal and persistence of seeds.

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1. Introduction

Water hyacinth (Eichhornia crassipes (Mart.) Solms-Laubach) (Pontederiaceae) was first recorded in South Africa around the beginning of the twentieth century (Gopal, 1987) and has since become highly invasive in this country (Hill and Cilliers, 1999). Most of the research conducted in South Africa has focused on impact and control strategies (Hill and Coetzee, 2008; Hill and Ockers, 2001; Oberholzer and Hill, 2001). However, there have been no studies on the role of seed banks, which may be a potent source of re-infestation of cleared areas (Edwards and Musil, 1975).

Although water hyacinth populations spread predominantly via daughter plant propagation through the formation of stolons (Ruiz et al., 2008), a number of studies have quantified seed production by water hyacinth in its region of origin. A single inflorescence with 20 flowers produces up to 3000 seeds and the number of seeds per square meter of vegetation range from 400 to 3400, depending on the sampling site and time of year (Cronk and Fennessy, 2001; Pieterse and Murphy, 1993). The seeds are released in capsules of 40 to 300 seeds each that either sink or accumulate in the floating mat (Cronk and Fenessy, 2001) and are reported to show dormancy (Obeid and Tag el Seed, 1976) which can be broken by wetting, drying and re-wetting (Baskin et al., 2003).

E. crassipes seeds are long-lived (>5 years) (Edwards and Musil, 1975; Gunnarsson and Petersen, 2007; Thompson et al., 1998) and thus seed persistence is one factor that influences water hyacinth eradication (Cacho et al., 2006) and long-term control. However, a high proportion of the flowers and fruits of E. crassipes are destroyed or damaged by insects, snails, and other organisms in its region of origin, but not in its introduced range (Pieterse and Murphy, 1993). Thus an accurate quantification of the seed bank dynamics will aid in the long-term management of this weed throughout the world.

* Corresponding author. E-mail address: ealbper@unex.es (E. Albano Pérez).
Seed banks have been widely quantified in freshwater marshes and wetlands (Brock and Rogers, 1998; Riddin and Adams, 2009), but few of them have looked for seeds of a particular species throughout sediments of ponds or rivers (Wang et al., 2009). Studies of this nature on water hyacinth have not been done on aquatic systems in South Africa.

Germination rates also give an indication of how quickly habitats respond when optimum conditions occur (Riddin and Adams, 2009). Germination of water hyacinth seeds in sediments is prevented if the sediments are shaded or light levels and temperatures are low. In habitats where the water is shallow with a rooting medium suitable for initial seedling development, propagation by seeds may be crucial for the invasion of new areas (Edwards and Musil, 1975).

The objectives of this study were therefore to quantify the extent of *E. crassipes* seed banks at several sites in South Africa and to evaluate the potential germination of these seeds with a view to improving the long-term management of this weed over the country.

2. Material and methods

2.1. Study site

Seed banks from 15 waterbodies infested with water hyacinth in South Africa were sampled between August and September 2009 (Table 1; Fig. 1). All sites have a history of water hyacinth invasion and flowering had been recorded the previous year. Fourteen were located in the Eastern and Western Cape provinces and one in the Northern Cape, in two types of waterbodies (rivers and impoundments). This sample is representative of Mediterranean climate regions of South Africa. All control measures that had been implemented at each of the sites over the last decade were recorded to determine if control measure (biological control, herbicide application, integrated control, and no control (Table 1)) influenced the seed banks.

2.2. Seed bank sampling

At each location four soil cores were collected, 5 m apart where possible, obtaining 60 samples in total. For this, an auger of 20 cm depth and 7 cm diameter was used (i.e. about 38.32 cm³), collecting samples of 770 cm³. Each sample was placed in watertight plastic bags, labelled and kept on ice. They were taken back to the laboratory and washed over a column of sieves (5, 2, 1, 0.5, and 0.25 mm) in an Electromagnetic Sieve Shaker (EMS-8). The sediment from each was left at room temperature in order to dry. The seeds were then hand sorted and identified directly using a binocular microscope when necessary, and preserved in tap water at 4 °C until the commencement of the germination tests.

2.3. Germination test

We undertook growth chamber germination trials to assess seed germinability within these samples. Seeds of each sample (4 replicates per population with 50 seeds when possible) were sown in a 9-cm diameter Petri dish containing a solution of monosodium phosphate (NaH₂PO₄) in distilled water at a concentration of 375 mg/L, since this is the optimal medium to achieve the maximum germination percentage (Albano Pérez et al., 2011). Sowing was conducted as quickly as possible to avoid subsequent fungal contamination. The dishes were then placed in a precision temperature, light, and humidity controlled refrigerated chamber (Selecta HOTCOLD-GL 2101507) under humidity-free conditions of 13 h light at 35 °C, and 11 h darkness at 10 °C, for a period of 21 days. During this experimental period, daily counts of the germinated seeds were made, noting

### Table 1

| Population | Location                  | Coordinates | UTM          | Type of wetland | Date water hyacinth first recorded | Climate       | Type of control       |
|------------|---------------------------|-------------|--------------|-----------------|-----------------------------------|---------------|-----------------------|
| **Eastern Cape** |
| P1         | New Years Dam, Bend River | −33,29596   | 26,14725     | River           | 1985                              | Temperate     | Biological            |
| P2         | New Years Dam Boat Launch | −33,29696   | 26,11422     | Dam             | 1985                              | Temperate     | Biological            |
| P3         | Seaview Rd, Port Elizabeth| −33,99525   | 25,53375     | Dam             | 1990                              | Coastal       | No control            |
| P4         | Swarptkops                | −33,78397   | 25,39914     | River           | 1982                              | Coastal       | Biological/Chemical    |
| P5         | Kubusi                    | −32,55500   | 27,49378     | Dam             | 1985                              | Cool temperate| Biological/Chemical   |
| P6         | Laing Dam                 | −32,93247   | 27,47282     | River           | 1987                              | Cool temperate| Biological/Chemical   |
| **Western Cape** |
| P7         | Goudini                   | −33,64420   | 19,29980     | River           | --                               | Mediterranean | No control            |
| P8         | Khuitjaskraal, Berg River | −33,42480   | 19,18370     | River           | 1980                              | Mediterranean | Biological            |
| P9         | Khuitjaskraal Dam, Breede River | −33,43628 | 19,17581     | Dam             | 1980                              | Mediterranean | Biological            |
| P10        | Kersefontein, Berg River  | −32,91796   | 18,33034     | River           | 1980                              | Mediterranean | Biological/Chemical    |
| P11        | False Bay                 | −34,08992   | 18,50908     | Dam             | 1999                              | Mediterranean | No control            |
| P12        | Exit 34 off N1, near Belville | −33,83554  | 18,7399      | Dam             | 2007                              | Mediterranean | No control            |
| P13        | Princessvlei              | −34,04940   | 18,47949     | Dam             | 1980                              | Mediterranean | Biological/Physical    |
| P14        | Liesbeek                  | −33,93614   | 18,47514     | River           | 1982                              | Mediterranean | No control            |
| **Northern Cape** |
| P15        | Vaal River                | −27,70539   | 26,08142     | River           | 1970                              | Cool temperate| Biological/Chemical   |
those which presented a radicle of at least 0.1 mm in length under a stereo microscope.

2.4. Data analysis

Statistical analysis of the data was carried out using non-parametric tests and the software package SPSS. Differences between studied variables were compared using a Kruskal–Wallis non-parametric analysis of variance by ranks test.

The germination rate was calculated according to the Vigour Index (V) formula of Jain (1971): 
\[ V = \left( \frac{\text{a}}{1} + \frac{\text{b}}{2} + \frac{\text{c}}{3} + \ldots + \frac{\text{z}}{n} \right) \times 100 / \text{s}, \]
where \( a, b, c, \ldots, z \) represent the number of seeds that germinate each day, \( n \) is the number of days that the experiment lasted, and \( s \) the number of seeds sown. Its value can oscillate between 0 and 100, values lower than 5 involve slow velocities; between 5 and 11.11 medium; between 11.11 and 33.33 fast; and higher than 33.33 very fast velocities (Cabello et al., 1998). Germinability was expressed as the percentage of sown seeds that germinated during the whole experimental period, and pointed out by the following categories: null (0%), low (0%<30), moderate (30%<70), high (70%<100) and maximum (100%) (Ruiz and Devesa, 1998).

3. Results

Water hyacinth seeds were recovered at 9 of the 15 sites sampled (Table 2), but there was no pattern with regards to locality, duration infested, climate or method of control (Table 1).

3.1. Seed density

The highest seed density (4228 seeds/m²) was found in the dam on Seaview Road, Port Elizabeth (P3). Seed density at the 6 populations (P1-P6) from the Eastern Cape Province (1235 seeds/m², \( n=24 \)) was significantly higher (Kruskal–Wallis test, \( P<0.05 \chi^2=4.04, n=56 \)) than the 8 populations (P7-P14) from the Western Cape Province (324 seeds/m², \( n=32 \)) (Fig. 2).

There was no significant difference (Kruskal–Wallis test, \( P<0.18 \chi^2=1.79, n=60 \)) in the density of seeds between the 8 river populations (798 seeds/m², \( n=32 \)) and the 7 dam populations, (682 seeds/m², \( n=28 \)), or between the locations where biological or chemical control was carried out and the rest of the populations (Kruskal–Wallis test, \( P<0.31 \chi^2=1.09, n=60 \)).

3.2. Germination

Of the 9 sites from which seeds were recovered, three populations did not germinate (P1, P2 and P12) while the rest varied between 25% and 80%, with highly significant differences among them (Kruskal–Wallis test, \( P<0.001 \chi^2=39.07, n=24 \)) (Fig. 3). Germinability was high in two populations, medium in three and low in one (Ruiz and Devesa, 1998) (Table 2).
The values of the Vigour Index varied between 27 and 50, which are very fast germination speeds (Cabello et al., 1998): 4 populations classified as maximum and 2 populations as quick (Table 2).

### Table 2
Mean seed density (±SE, n=4), germination percentage (±SE, n=4), germinability (Cabello et al., 1998), Vigour Index (±SE, n=4) and germination speed (Cabello et al., 2001) from each population.

| Population | Mean seed density (seeds/m²) | % germination | Germinability | Vigour Index | Germination speed |
|------------|-------------------------------|---------------|---------------|--------------|------------------|
| P1         | 2534±2575.91                  | 0             | Null          | 0            | –                |
| P2         | 195±129.93                    | 0             | Null          | 0            | –                |
| P3         | 4228±2348.48                  | 80.05±17.78   | High          | 34.60±27.16  | Maximum          |
| P4         | 0                             | 0             | –             | –            | –                |
| P5         | 390±450.11                    | 41.65±49.98   | Medium        | 27.77±33.33  | Quick            |
| P6         | 0                             | 0             | –             | –            | –                |
| P7         | 0                             | 0             | –             | –            | –                |
| P8         | 260±519.75                    | 25±50         | Low           | 50±100       | Maximum          |
| P9         | 1494±1960.58                  | 80.12±24.42   | High          | 35.14±44.62  | Maximum          |
| P10        | 715±884.47                    | 46.42±53.92   | Medium        | 45.45±54.54  | Maximum          |
| P11        | 0                             | 0             | Null          | 0            | –                |
| P12        | 130±259.88                    | 0             | –             | –            | –                |
| P13        | 0                             | –             | –             | –            | –                |
| P14        | 0                             | –             | –             | –            | –                |
| P15        | 650±807.99                    | 51.78±40.98   | Medium        | 27±36.27     | Quick            |

4. Discussion

The relative importance of sexual reproduction in the spread of *E. crassipes* in different areas is very difficult to assess and has rarely been quantified in areas of invasion (Pieterse and Murphy, 1993; Sculthorpe, 1967). Even though some studies show that a high proportion of fruits are destroyed or damaged by insects, snails and other organisms (Lallana, 1987), the persistence of some seeds must not be underestimated and is important for the formation of new genotypes. Observations in infested reaches strongly suggest that seeds may be far more significant than has been acknowledged up until now. This study has shown the existence of water hyacinth seed banks in some South African waterbodies. Even though prior seed density data do not exist for this species, mean seed density (1177 seeds/m²) was in the same order of magnitude as the densities for other aquatic species, such as the native *Sarcocornia perennis* in South Africa (7929 seeds/m²) (Riddin and Adams, 2009) or the invasive *Spartina* in China (around 2000 seeds/m²) (Wang et al., 2009). Mean seed density was moderately high in New Years Dam sites (2534 seeds/m²) and in Kluitjeskraal Dam (1494 seeds/m²) and high in Seaview Road (4228 seeds/m²). This variability among locations could be due to different patterns of wetting or flooding each year (Brock and Rogers, 1998), which is very common in unpredictable climates (Table 1). Another factor which can have an influence on seed density is the historical period of invasion (the longer the weed has been there, the higher the number of seeds in the sediment). However, this pattern did not emerge from this study as the weed had been present at all sites tested for a considerable time.

The movement of seeds is very difficult to quantify by direct measurements, in particular due to the irregularity of flood events (Vécrin et al., 2007). Seed dispersal by water, called hydrochory, is of particular interest in wetlands. Water hyacinth seeds are considered hydrochorus and are dispersed by rain wash, downstream flow and floods. Hydrochory is important in riparian wetlands where its main effect is to redistribute seeds...
from the sites where gravity has deposited them (Cronk and Fenessy, 2001). Type of control carried out could be another factor which has an influence in the seed bank dynamics, since lower seed production is assumed where the plant is being removed. However, no significant differences were found between the different control measures.

The complexity of seed bank dynamics makes it difficult to predict germination responses (Vécrin et al., 2007). However, we can confirm the presence of significant numbers of viable water hyacinth seeds in a number of South African systems. The maximum germination percentage observed was 80, which is similar to *S. perennis* of estuaries in South Africa (Riddin and Adams, 2009). However, this rate is achieved in 90 days for *S. perennis* and 3–4 days for *E. crassipes*, which reveals a rapid colonization capacity. Rapid germination provides a competitive advantage for space in erratic and unstable habitats (Brock and Rogers, 1998). Germination percentages were variable, with the maximum around 80, so most of the locations had medium-high germinability (Ruiu and Devesa, 1998) (Fig. 3). This is corroborated by the values of the Vigour Index, which indicated very fast germination speed (3 days in all the cases). If these seeds are carried to favourable sites, they will germinate, especially after clearing programmes have permitted light penetration into the water column. In most of the genera in the Pontederiaceae the aerial fruit becomes submerged because the peduncle bends toward the water. The fate of the seeds is generally to drop into the adjacent sediment and germinate there if conditions are favourable (i.e., enough oxygen, light, and space for growth). The seed’s resting place ultimately determines whether it will germinate and if it does, whether it will be able to survive (Cronk and Fenessy, 2001). If water hyacinth seeds drop into water enriched with phosphates, they will germinate with very fast velocities (Albano Pérez et al., 2011). Many of the aquatic ecosystems in South Africa are highly eutrophic, ranking as some of the most extreme in the world in the industrialized areas of South Africa (Coetzee et al., 2007), so they potentially will be re-infested if seeds arrive. In ephemeral wet ecosystems, the ability to germinate in anaerobic conditions may also afford a selective advantage. The substrate type can strongly influence germination of wetland plants, and salinity also plays an important role (Cronk and Fenessy, 2001).

The preservation, management and restoration of ponds and rivers are the subject of intense research that requires the understanding of aquatic plant biology to support the development of new management techniques. Successful colonization depends on a single plant that is able to produce numerous seeds, and if only one propagule of a species arrives in a new area, a whole population of this species can develop at this place (Sculthorpe, 1967). Further studies are needed to investigate the water hyacinth seed bank dynamics in order to contribute to the knowledge of seed movements through the water corridors. In conclusion, the high *E. crassipes* seed numbers found in South African waterbodies indicates that despite the huge effort made to eradicate or control the weed, adequate seed reserves are available to allow the re-infestation of South African waterbodies, and this could occur where clearance has been undertaken previously.

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