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Ecological basis for the control of *Gunnera tinctoria* in São Miguel Island

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Summary

Gunnera tinctoria, an herbaceous plant from South America, is naturalised in São Miguel island (Azores). In this research an ecologically based strategy for *G. tinctoria* control is suggested. Infestation structure, altitudinal range, associated plants, phenology and natural enemies were studied. *G. tinctoria* was found from 100 to 900 m of altitude, in plane or highly sloped terrain, on rich soil or gravel, in roadsides, trails, and water streams. Infestation foci were found at 40 Km from introduction site. Populations consisted of isolated or small groups of plants, with reduced cover, associated with other weeds. According to three plant invaders classification systems this plant presents several negative characters in terms of conservation: high seed production, vegetative reproduction, high impact on the landscape, invasion of natural vegetation. Priority of control should be given to satellite populations in high conservation value sites. Control of heavier infestations will need a persistent and global approach.

Introduction

Natural populations of *Gunnera* sp. are restricted to super-humid areas with heavy rainfall; they prefer high altitudes and open or lightly shaded areas, and are often pioneers on bare land (Bergman *et al.*, 1992). The Gunneracea includes the genus *Gunnera* L., with terrestrial, rhizomatous, perennial herbs, sometimes gigantic, from tropical and warm temperate regions. The larger kinds are grown for the striking effect of their enormous leaves, the smaller forms, for their rosettes or cushions of decorative roundish leaves (Bailey & Bailey, 1976). The majority of the species are found in Southern Hemisphere and in the archipelagos of the Pacific Ocean. The genus *Gunnera* with about 50 species, extends through Malaysia, Solomon Islands, Tasmania, New Zealand, New Guinea, Abyssinia, Juan Fernandez Islands, Mexico, Central and South America, Tropical and South Africa, Madagascar, Indonesia, Hawaii (the highest boreal latitude 22° N) (Willis, 1980; Bergman *et al.*, 1992). Escapees from gardens are now naturalised in temperate regions such as Britain, Ireland, Oregon and Azores. The temperature tolerance of *Gunnera* spp. is quite wide, since several species survive to the large seasonal fluctuations of temperature in Europe (Bergman *et al.*, 1992).

The most common species, *Gunnera tinctoria* (Molina) Mirbel (Gunneraceae) is found in Chile from Coquimbo to Magalhães, in Argentina from Neuquem to Chubut and to the North of Chile, and through the Andean region to Colombia and Venezuela, Peru and Ecuador (Schick, 1980; Schick, 1981). This species is cultivated for ornament and is locally naturalised in western Europe (Molina, 1978). In Chile *G.tinctoria* is found from the coast to 2000 m of altitude, always in humid habitats, near water streams, rivers, lakes, in wetlands, wet sloped terrain, and in landslides (Molina, 1978; Schick, 1981). In the rhizomes bluish spots of *Nostoc punctiforme* are found, which fix the atmospheric nitrogen allowing the rapid establishment of the plant, one of the first in the vegetal succession (Schick, 1980). In culture, rich, moist soil is needed, and preferably a sunny location, but severe winds may damage the leaves. *G. tinctoria* propagates by division of the rhizome or by seeds (Bailey & Bailey, 1976).

Silva & Silva (1974) mentioned *G. tinctoria* as collected in 1964 by Dansereau in Furnas, São Miguel island (Azores). The species was mentioned for the first time as naturalised in the Azores in Flora Europaea (Cook, 1968). Furtado (1987) presented a synthesis on *G. tinctoria* distribution

n São Miguel and suggested some control measures. Chemical control of the plant in São Miguel was also tested (Anonymous, 1986).

In 1995 a project was initiated aiming to determine what are the biotopes invaded by the plant in São Miguel island (Azores), to update and map its distribution, to evaluate its impact on human activities and in natural ecosystems. In this context, a Geographic Information System was developed and the distribution of *G. tinctoria* in São Miguel was updated (Silva & Pena, in press). In this paper data is presented regarding phenology, and impact, of *G. tinctoria* in São Miguel. Three classification systems of plant invaders were followed, to evaluate the impact of the plant in the natural ecosystems, and to determine the need of taking actions to avoid the spread of the plant. A global strategy for *G. tinctoria* control is suggested.

Materials and Methods

Study site

Study sites were located at São Miguel island (Azores) with average annual temperature ranging from 12.2 to 17.3°C and annual rainfall between 2309 and 1020 mm/year, at 50 and 550 m of altitude, respectively. About 43% of the island is covered by pastures, 16 % by timber forest, but important areas of natural vegetation are also found (5%), with about 45 endemic species of vascular plants.

Distribution in São Miguel island

Local persons familiar with the distribution of *G. tinctoria* in a particular area were consulted to establish general areas that were invaded by this species. The areas were visited and roads and trails in the area were driven or walked thoroughly. Collected data included the limits of the distribution, using a 100x100 m gride on a 1:25000 (Serviço Cartográfico do Exército) map, and altimeter readings of elevation. At each plot the percentage of covering, the Braun Blanquet sociability coefficient, and the types of vegetation (endemic, indigenous, non indigenous) were recorded according to Palhinha (1949) and Hansen & Sunding (1993). Percentage of cover (c) was estimated using the following classes: 1 - $0\%<c\leq25\%$; 2 - $25\%<c\leq50\%$; 3 - $50\%<c\leq75\%$; and 4 - $75\%<c\leq100\%$. A data base, containing the information regarding each 100x100 invaded plot was organised, and data base searches were used to determine the proportion of invaded plots at different altitudes, locations, and with different cover and sociability classes. Total area invaded by *G. tinctoria* was estimated by multiplying the central values of cover classes (12.5%, 37.5%, 62.5%, and 87.5%) by their respective frequency.

Phenology, stand structure, and natural enemies

Phenology was followed along the year at the centre of the distribution (500 m of altitude), and development of panicles, flowers and fruits was analysed. Number of seeds per panicle was estimated by calculating the mean number of seeds in 30 branches and multiplying by the total number of panicle branches. Fruits were air dried for one week. One hundred fruits were placed in a 9 cm diameter Petri dish covered with humidified filter paper. Petri dishes were placed in a chamber regulated to 15°C and 8 hours photophase. Germination was studied since April, and for each month four replicates were prepared. The number of panicles per hectare was estimated by counting the number of panicles along transepts in 25 m^2 plots. Thirty petioles and leaf blades were measured at different sites. Phytophagous insects and pathogenic fungi were surveyed, by direct observation of leaves, petioles, rhizomes, roots, and panicles.

Plant invaders classification systems

The classification systems of plant invaders, namely those of Hiebert & Klick (1988) modified by Klick *et al.* (1989), Harris (1992), and Cronk & Fuller (1995) were used to evaluate the invasive potential of *G. tinctoria* in São Miguel island.

Results

Distribution in São Miguel island

The invaded areas were concentrated in the eastern part of the island, in the Furnas valley, where the plant was originally introduced. Scattered plants were found in the roads to Sete Cidades (Protected Landscape) to Lagoa do Fogo (Nature Reserve), and to Planalto dos Graminhais

(Nature Reserve). The heaviest infestations were found at Pico da Vara (Nature Reserve) trails and water streams. A total of 301 (100x100 m) plots were found to be invaded. The Furnas valley includes more than 60% of the invaded plots and the Pico da Vara region includes more than 20%, while the western part of the island only comprises about 6%. *G. tinctoria* spread from Furnas to Sete Cidades 40 km to the West, and to Pico da Vara region, 12 km to the East. The majority of the invaded areas consisted of isolated or small groups of plants and showed a small cover of *G. tinctoria* (Table 1). Invaded plots were located mainly along roadsides and trails (87%), water streams (8%) or in highly sloped wet terrain (5%), associated with exotic vegetation (72%), although 28% of the plots included endemic vegetation. The plant was found in pomitic soils (Salto do Cavalo), in gravel (road to Lagoa do Fogo), in organic rich soils (Pico do Ferro) and in the margins or rooted in water stream beds (Ribeira da Mulher, Ribeira Quente). *G. tinctoria* is present in plane areas (Furnas) and highly sloped terrain (Pico da Vara trails, road to Lagoa do Fogo), and was found from 100 to 900 meters of altitude, although 85% of the invaded plots were found above 300 m, and 60% above 500 m. The total area covered by *G. tinctoria* in São Miguel island is about 70 ha.

Table 1. Proportion of *Gunnera tinctoria* invaded plots in São Miguel island presenting different levels of Braun Blanquet sociability and cover percentages, in a total of 301 (100x100 m) plots.

Sociability	% plots	Cover	% plots
1	63.7	1	71.6
2	22.7	2	15.4
3	8.1	3	9.7
4	5.1	4	3.3
5	0.3		

G. tinctoria rarely survives under *Cryptomeria japonica* (L. fil) D. Don stands and was not found invading pastures. *Hedychium gardnerianum* Roscoe, one of the worst weeds in the Azores, controlled by cutting, could be gradually replaced, since associated *G. tinctoria* plants resprouted more rapidly (in about one month) than the former species. At Sete Cidades some scattered plants were found in the roadside, like in many other roads, associated with planted *Hydrangea macrophila* (Thumb.). *G. tinctoria* was found as a weed in a park at Pico do Ferro, and is planted in several gardens in Furnas. In São Miguel *G. tinctoria* is associated with other weeds, but also with native vegetation, including indigenous and endemic plants (Table 2).

Phenology and stand structure

Panicles begin to develop in February, but without differentiated flowers (Figure 1). In March bisexual flowers develop at the apex of panicle branches, and female flowers at the base. In April pollination occur, and in May anthers fall, styles desiccate, and endocarp is differentiated. In June only a few seeds are viable, flowers with anthers or styles become rare. The fruit, initially green, enlarges. From July to October fruits become orange/red, and germination rate increases. In São Miguel *G. tinctoria* flowers and fruits appear from April to October, while in South America those phenophases are found from October to February.

A considerable variation was found in the number of seeds per panicle, from different sites (Figure 2). In the road to Lagoa do Fogo, panicles present less than 40000 seeds while at Pico do Ferro, mean number of seeds is about 130000. Leaf diameter varied between 30 and 110 cm. Petiole length follows leaf diameter. Highest number of panicles per hectare was found at Pico do Ferro. Higher rhizome transverse section was found at Ribeira da Mulher (water stream).

Natural enemies and dispersers

Only birds were found to feed on *G. tinctoria* fruits in São Miguel. Since endocarps with seeds were found since July in faecal pellets, birds could function as dispersal agents. Frequent visitors are *Fringilla coelebs moreleti* and *Turdus merula azorensis*. No insects were found feeding in flowers or fruits, and no feeding damage was found in rhizomes and roots. Leaves are damaged by rabbits and goats. Insects were occasionally found on leaves. Thysanoptera and polyphagous Lepidoptera larvae may damage young plants. Various invertebrates (Mollusca, Annelida, Chilopoda, Blattodea) use the plant rhizome as shelter. A species of *Nectria* was found on the rhizome.

Table 2. List of vascular plant species associated with *Gunnera tinctoria* in São Miguel island (Azores). Classified according to Palhinha (1949) and Hansen & Sunding (1993).

Endemic

Ericascoparia ssp. *azorica* (Hochst.) Webb
Festuca jubata Lowe
Holcus rigidus Hochst. ex Seub.
Hypericum foliosum Aiton
Ilex perado ssp. *azorica* (Loes.)Tutin
Leontodon fili Paiva et Ormonde
Vaccinium cylindraceum J. E. Sm.
Viburnum tinus ssp. *subcordatum* P. Silva

Indigenous

Blechnum spicant (L.) Roth
Calluna vulgaris (L.) Hull
Centaurium scilloides (L. fil) Samp.
Culcitamacrocarpa C. Presl
Hydrocotyle vulgaris L.
Juncus effusus L.
Laurus azorica (Seub.) Franco
Lysimachia nemorum L.
Myrsine africana L.
Osmunda regalis L.
Potentilla erecta (L.) Räusch.
Pteridium aquilinum (L.) Kuhn
Rubus ulmifolius Schott
Woordwardia radicans (L.) Sm.

Non-indigenous

Clethraarborea Aiton
Cryptomeria japonica (L. fil) D.Don
Erigeron karvinskianus DC.
Fragariavesca L.
Hedychium gardnerianum Roscoe
Hydrangeamacrophila (Tumb.)
Leycesteria formosa Wall
Lolium perenne L.
Plantago lanceolata L.
Polygonum capitatum Buch. Ham. ex D. Don
Prunella vulgaris L.
Ranunculus repens L.
Schrophulariaauriculata L.
Selaginella kraussiana (G. Kunze) A. Br.

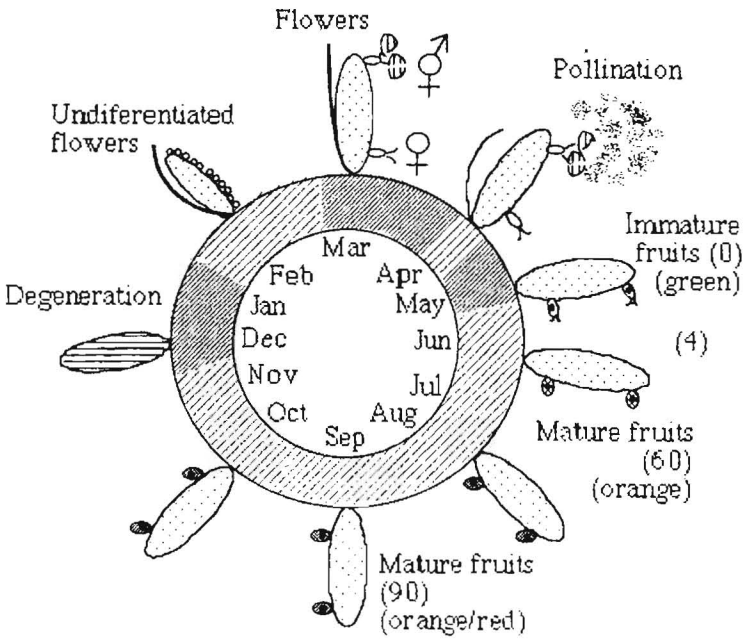

Figure 1. Phenological cycle of *Gunnera tinctoria* in São Miguel island (Azores). Development of flowers and fruits in a panicle branch. Only two flowers are shown for simplicity. Numbers in parenthesis refer to the germination rate.

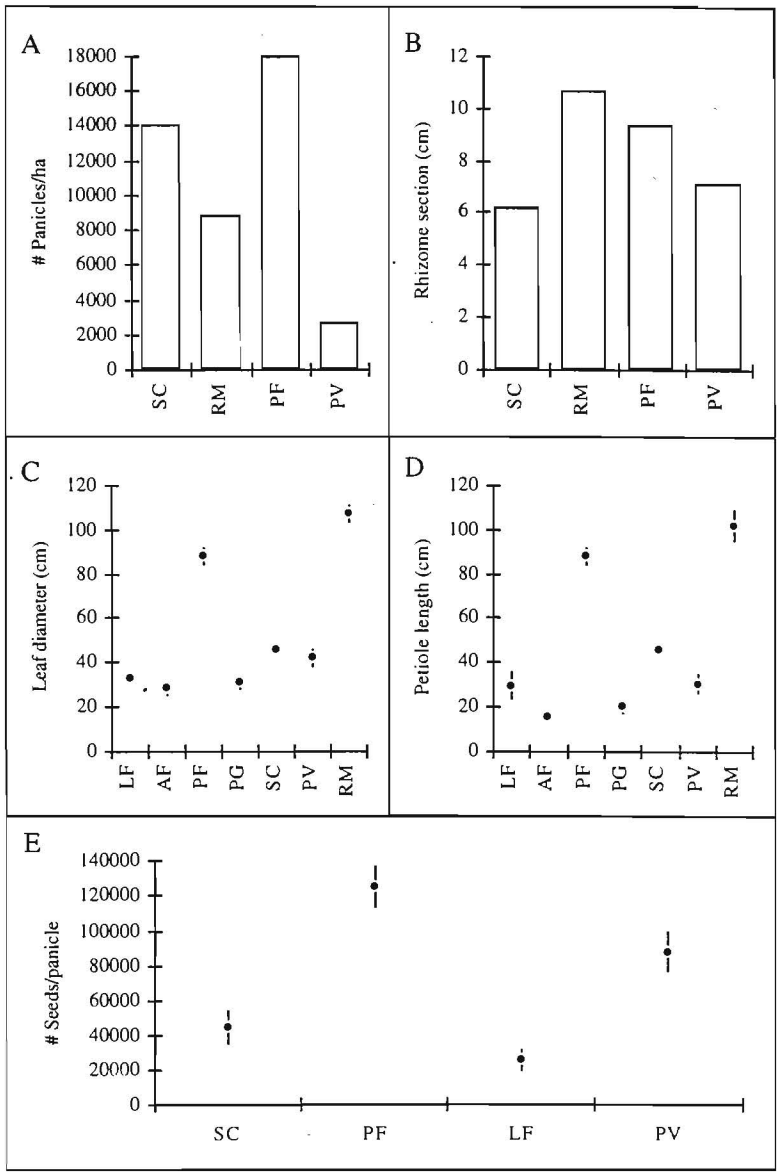

Figure 2. Performance or *Gunnera tinctoria* in São Miguel island. A, number of panicles/ha; B, rhizome section (mean); C, leaf diameter (mean and standard error); D, petiole length (mean and standard error); E, number of seeds/panicle (mean and standard error). LF Lagoa do Fogo, AF Achada das Furnas, PF Pico do Ferro, PG Planalto dos Graminhais, SC Salto do Cavalo, PV Pico da Vara, RM Ribeira da Mulher.

Plant invaders classification systems

According to the system of Cronk & Fuller (1995) the plant receives a rank of 4 (maximum 5), invading important natural or semi-natural habitats, rich in plant species, natural parks and areas with rare or endemic species.

According to the system of Harris (1992) the plant presents 12 negative characters (in a total of 26 examined), what is not far from the maximum, 14, obtained by Harris for several invasive plants in the Redwood National Park: invades habitats with ecological value, disturbed, and with difficult access, predominates in road sides, presents high seed production, seeds are adapted to dispersal by birds, perennial, regenerates from rhizome, causes high impact on the landscape, reaches one meter high and above, survives to several cuttings, and biological control is not available.

Hiebert system (Kick *et al.*, 1989) to quantify the significance of the impact (higher rank is given to characters that increase impact) is based in the following parameters (ranking range in parenthesis): A) Current level of impact - age of last disturbance in invaded sites (-10 - 15), number of populations (1 - 5), average population size (1 - 5), effect on natural processes (0 - 15), significance of threat (0 - 5), level of visual impact on natural landscape (0 - 5); B -Innate ability to be a pest - ability to complete life cycle in area of concern (-10 - 0), mode of reproduction (1 - 4), vegetative reproduction (0 - 4), frequency of sexual reproduction (0 - 4), number of seeds per plant (0 - 4), dispersal ability (0 - 3), germination requirements (0 - 4), competitive ability (0 - 4).

For each parameter, the options that fit *G. tinctoria* are the following (ranking in parenthesis): found in sites disturbed 11-50 years before present (2), number of populations >51 (5); average population size 11-100 (2); invades and modifies existing native communities (10); threat to areas primary resources (4); major visual impact on natural landscape (5); completes life cycle in the area (0); reproduces vegetatively and by seed (4); vegetative reproduction results in moderate increase in population size (2); sexual reproduction ≥1 times a year (4); >1001 seeds per plant (4); long distance dispersal (3); germination in a wide range of conditions (4); highly competitive for limiting factors (4). A total of 53 for the significance of impact includes *G. tinctoria* in the serious threat category implying that immediate research and control measures are necessary. In Indiana Dunes National Lakeshore only 5% of the exotic plants presented the same classification (Klick *et al.*, 1989).

Control strategy

In the Azores, specific natural enemies were not found, and *G. tinctoria* populations in São Miguel are, apparently, not regulated by natural enemies. A classical biological control program needs about 1 to 2 million dollars and 12-24 scientists' years for its accomplishment (Harley & Forno, 1992). Natural enemies would have to be surveyed and their specificity tested in South America since, to our knowledge, no studies were performed regarding this subject.

Its association with other plant invaders, like *Clethra arborea* and *Leycesteria formosa*, implies that a global approach should be followed in order to control these different plants simultaneously.

Satellite populations at the road to Lagoa do Fogo (Nature Reserve) and Sete Cidades (Protected Landscape) and Planalto dos Graminhais (Nature Reserve) should be controlled by cutting leaves and panicles (to avoid further dispersion), mechanical removal of rhizome, and local application of glyphosate. The effort needed is affordable and the conservation value of those sites is high culturally and ecologically. Destruction of rhizome fragments is imperative, and the rhizome is not difficult to remove since it is not deeply buried in the soil. At the Pico da Vara (Nature Reserve) streams and secondary trails, a persistent effort is needed due to association with other weeds and difficult access. The conservation value of these places justifies the costs. From our experience of opening transects in invaded areas, we estimate that to clear one hectare by manual removal, 640 men's hours are needed, not taking into account the difficulties to remove and destroy rhizome fragments.

On the basis of the phenological cycle of the plant in the Azores, panicles should be cut before June, when seeds are not viable, avoiding dispersion by birds. Furthermore, plants frequently cut present smaller panicles (Anonymous, 1986).

Chemical control was achieved with two foliar applications of glyphosate (10 l/ha) separated three months (Anonymous, 1986). This method can not be used in water streams or in areas were the plant is closely associated with endemic or indigenous species, that could be affected by foliar sprays, unless a more accurate cut stump application was developed. On the other hand it could be used locally to control populations in secondary roads and trails.

Control feasibility (Klick *et al.*, 1989) can be quantified by the following parameters (ranking range in parenthesis): number of populations (1 - 5), average population size (1 - 5), seed banks (1 - 5), vegetative regeneration (1 - 4), level of effort required (1 - 5), side effects of control measures (-5 - 0), effects of delay in action (0 - 4), and availability of biological control (0 - 2).

An higher rank is given to characters that facilitate control. For each parameter, the options that fit *G. tinctoria* are the following (ranking in parenthesis): > 51 populations (1); population size 11-100 (4); seed bank (unknown, possible ranking 3); sprouts from stumps (2); repeated chemical and mechanical control required (1); control measures will cause moderate impacts to community (-2); delay in action will result in moderate increase in effort (2); no biocontrol (0). A total of 11 (maximum of 30) shows that control of *G. tinctoria* in São Miguel will not be easy to implement.

Discussion

G. tinctoria invaded biotopes with high conservation value in São Miguel island. With this plant, a new type of atmospheric nitrogen fixing symbiosis was introduced in this island. A similar situation occurred when *Myrica faya* Aiton was introduced in Hawaii with its symbionte, a bacterium of the genus *Frankia*, increasing the amount of nitrogen in young volcanic soils (Vitousek, 1990). Three systems of classification of plant invaders showed that the plant has the potential to become a significant threat to natural ecosystems. Monitorization of this species is now facilitated, with the existence of a geographic information system, but since the plant is frequently associated with other weeds in difficult access sites, a persistent and global approach for the control of plant invaders in Azores is necessary.

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