Eradication of potentially invasive plants with limited distributions in the Galapagos Islands

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Abstract A cooperative project between the Charles Darwin Foundation and the Galapagos National Park Service has been initiated to attempt to eradicate several populations of potentially-invasive plant species from the Galapagos Islands. More than 600 introduced plant species have been recorded in Galapagos, of which many are already serious invaders. Among the cultivated and recently naturalised species, many are potentially invasive, but still have limited distributions and can be eradicated. This paper discusses attempts at plant eradication in the Galapagos using three examples with differing degrees of invasiveness. A priority list of species to be eradicated is being compiled by means of a risk assessment system based on a database, literature, local knowledge, ongoing surveys and information from elsewhere. The target plants are then mapped. If an effective control treatment is known for a particular species, the field team performs the eradication work. If not, trials are conducted to determine the best technique. Once removal has been carried out, locations are monitored at appropriate intervals until the plant has not been recorded for at least three years. *Pueraria phaseoloides*, a known invasive vine, was recently introduced at a single site (0.04 ha) and has not been seen again since it was last treated in 1997. *Rubus glaucus*, a potentially-invasive scrambler, was introduced more than 25 years ago and is sparsely distributed over about 5 ha. The timber tree *Citharexylum gentryi* was introduced in 1950 but was only recorded by scientists in 1999. It has many invasive characteristics, has mature reproductive stands and is distributed over about 171 ha. All known reproductive individuals of both *R. glaucus* and *C. gentryi* have now been removed and monitoring continues.

Resumen Un proyecto cooperativo entre la Fundación Charles Darwin y el Parque Nacional Galápagos se ha inicializado para intentar erradicar algunas poblaciones de especies invasivas de Galápagos. Más de 600 especies de plantas introducidas han sido registradas en Galápagos, de las cuales muchas son catalagodas como altamente invasivas. Entre las especies cultivadas y recientemente naturalizadas muchas son potencialmente invasivas, pero tienen distribuciones limitadas y aun pueden ser erradicadas. El propósito de este documento es discutir los esfuerzos de erradicación de plantas usando tres ejemplos con diferente grado de invasividad. Se selecciona una lista de especies prioritarias a ser erradicadas a través de un conjunto de criterios que juzgan el riesgo de invasividad de cada especie basado en; la información de la base de datos, bibliografía, conocimiento local, monitoreo e información de otros sitios. Las plantas seleccionadas son posteriormente mapeadas. Si el tratamiento de control efectivo es conocido para una especie particular, el personal de campo realiza el trabajo de erradicación. Si no, experimentos son conducidos para determinar la mejor técnica. Una vez que el trabajo inicial ha sido llevado a cabo, las poblaciones son monitoreadas cada tiempo apropriado hasta que ningun individuo sea observado por tres años consecutivos. *Pueraria phaseoloides* una trepadora conocida como invasiva fue recientemente introducida en un solo sitio y no ha sido observada otra vez desde que fue tratada en 1997. *Rubus glaucus*, una especie potencialmente invasiva, fue introducida hace más de 25 años y está distribuida de forma esparcida en algo menos de 5 ha. El árbol maderable *Citharexylum gentryi* fue introducido en 1950, pero fue registrado por primera vez por científicos en 1999. Tiene algunas características invasivas, forma grupos de individuos maduros y reproductivos y está dispersado sobre unas 171 ha. Todos los individuos reproductivos de *R. glaucus* y *C. gentryi* localizados fueron removidos y el monitoreo continúa.

Keywords Galapagos; eradication; invasive plant; *Citharexylum gentryi; Pueraria phaseoloides*; *Rubus glaucus.*

INTRODUCTION

One of the most serious threats to the unique flora and fauna of Galapagos is invasion by introduced plants. Over 600 introduced plant species have been recorded in Galapagos (Tye *et al.* 2002) of which 45% may be naturalised (cf. Mauchamp 1997). The areas with the biggest invasive plant problems are principally in the humid highland regions of the inhabited islands. Five of the islands have permanent human communities: Floreana, San Cristobal, Isabela, Santa Cruz and Baltra (which is an arid island with a military base and airport). Even though the populated areas (i.e. not National Park) take up less than 4% of the archipelago, they have disproportionately affected the restricted and vulnerable highland areas.

Most potentially-invasive plants have been introduced deliberately; therefore, the agricultural zones act as a source of spread to adjacent protected areas. Most invasions commence in the urban and agricultural zones with plants principally dispersing into the National Park along paths and roads (Schofield 1973; Jaramillo 1999). For example, species such as *Urochloa brizantha*, *Abrus precatorius*, *Dalechampia scandens*, and *Leucaena leucocephala* have dispersed from the agricultural zone and are starting to invade the arid and semi-arid areas of Santa Cruz. The

Pages 287-292 In Veitch, C. R. and Clout, M. N. (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

most graphic example of dispersal is *Cinchona pubescens*, of which a few trees were introduced in 1946 (Jäger 1999), and are responsible for the invasion of more than 11,000 ha of the humid highlands in Santa Cruz.

Quantitative studies on the impacts of widespread invasive species have shown that the distribution and abundance of native species have been seriously changed. Jäger (1999) showed that *Cinchona pubescens* severely affected the native vegetation in both the *Miconia robinsoniana* and the fern-sedge vegetation zones. The invasion of the tree *C. pubescens* also threatens populations of rare endemic herbaceous species with restricted distribution such as *Pernettya howellii* and *Acalypha wigginsii*. Other invasive species such as *Psidium guajava, Lantana camara, Syzygium jambos, Pennisetum purpureum* and *Rubus niveus* are widely dispersed in four of the populated islands (Lawesson and Ortiz 1994). These are altering native ecosystems and causing some economic losses to the agricultural sector. The principal invasives are trees, scramblers, climbers and grasses (Tye *et al.* 2002). Trees, in particular, are a threat as the native vegetation rarely exceeds 10 m in height and the humid highlands are covered with low scrub and herbaceous vegetation. Therefore, to protect the native ecosystem it is imperative to eradicate or contain potentially-invasive species with limited distribution before they become widespread. Attempting to eradicate populations that are restricted in distribution is much more cost-effective than long-term control and has a high probability of success.

In the year 2000 an inventory of the agricultural zone of the island of Santa Cruz was completed, taking the number of introduced species in Galapagos to over 600. One hundred previously-unrecorded species were found, of which some are already known to be invasive in other parts of the world. An example of differences in establishment time is *Psidium guajava*, one of the most invasive plants in Galapagos. This species was introduced to San Cristobal Island in about 1869 and was restricted to small plantations. It did not become invasive until the 1950s (80 years later). However, in Santa Cruz it was introduced in 1930 and became invasive within only 40 years. Another example is *Lantana camara,* which was introduced to Floreana in 1938 as an ornamental but did not become invasive until 1970 (Eckhardt 1972).

In order to select which species to include in the eradication programme, we are developing a system to prioritise our eradication activities (Tye 2001; Tye *et al.* 2002) based on distribution, plant biology, potential invasiveness (both in Galapagos and elsewhere), availability of treatment methods, and ease of treatment. If potential invasives are treated during the establishment or 'lag phase' there is a much higher probability of eradication. Also, species that are not utilised by the local community are selected for eradication. This guarantees the support of the community and reduces the risk of re-introduction.

A programme to eradicate several species has been initiated in Santa Cruz Island and is to be expanded to other islands. The programme commenced in Santa Cruz because most resources are there and it is the island with the most complete invasive database. Target species include the trees *Citharexylum gentryi* and *Leucaena leucocephala,* several scramblers in the genus *Rubus*, and climbers such as *Dalechampia scandens* and *Pueraria phaseoloides*. *Rubus* spp. in particular are known as invasives worldwide. In Galapagos the most invasive is *Rubus niveus*, which is present on three islands and is distributed over more than 10,000 ha, but has a limited distribution on Isabela Island. *Rubus adenotrichos*, *R. glaucus* and *R. megalococcus* all still have limited distributions and are currently being targeted by the eradication programme.

This paper outlines the methodology and success in eradication of three species with differing distributions but confined to Santa Cruz: the climber *Pueraria phaseoloides* (Fabaceae), the scrambler *Rubus glaucus* (Rosaceae) and the tree *Citharexylum gentryi* (Verbenaceae). These species were selected because they were considered potentially invasive or showing signs of becoming so, and the probability of eradication success is high.

Pueraria phaseoloides: This species (tropical kudzu) is native to Southeast Asia and is used as ground cover to fix nitrogen and as a forage plant. The USDA (2001) has listed it as a noxious weed because of its invasive potential. It is related to the highly-invasive *Pueraria lobata* ohwi (kudzu) which is one of the most serious pests in southeast U.S.A. *Pueraria phaseoloides* was introduced by one farmer in 1996 and was only found in one location (to our knowledge). It is located in the agricultural zone (450 m altitude) in a pasture dominated by the introduced pasture grass *Urochloa brizantha*.

Rubus glaucus: This species (mountain blackberry) is native to the Andes in northern South America and was introduced into the Galapagos sometime before 1974. It is the only species of this genus that is commonly cultivated in Ecuador and used commercially for its edible fruits (Romoleroux 1996). It is only naturalised within the National Park in the north-west highlands of Santa Cruz, in an area previously used for agriculture but which was incorporated into the National Park in 1974. This species is present in several Pacific islands and is considered by Sherley (2000) as having serious potential as an invasive. *Rubus glaucus* has the potential to spread in both native forests and fern/grasslands. It occurs in well-drained soil from 600-700 m altitude. In Santa Cruz, the representative native species are the tree *Scalesia pedunculata,* the shrub *Tournefortia rufo-sericea*, the herbs *Alternanthera halimifolia* and *Pilea baurii,* and ferns such as *Adiantum henslovianum* and *Blechnum occidentale.*

Citharexylum gentryi: This species (white wood) is a 20 m tall tree native to lowland coastal and Amazonian Ecuador and is common in humid and littoral forests (Jørgensen and León-Yanez 1999). The seeds of *C. gentryi* were introduced accidentally around 1950 in the leaves of a bromeliad that were used as a living fence (D. Uribe pers. comm.). It apparently has medicinal properties and can be

used as an anti-inflammatory (D. Uribe pers. comm.). *Citharexylum gentryi* is naturalised in the agricultural lands of Santa Cruz and has a huge potential to spread into the transition zone dry forests of the National Park. This species is considered highly invasive as it is reproductive from a young age, produces many fleshy fruits, has great dispersal ability, and can colonise relatively-undisturbed areas. Two other species of the same genus, *C. spinosum* and *C. caudatum*, are invasive in Pacific islands such as Fiji, French Polynesia, and Hawaii, with *Citharexylum spinosum* mainly invasive in arid habitats below 500 m (Smith 1985).

METHODS

The process of eradicating (localising, treating, and monitoring) the three selected species *Pueraria phaseoloides, Rubus glaucus* and *Citharexylum gentryi* is outlined below. Since little is known about these newly-discovered species in the Galapagos, some background information is presented in the results.

Locating and monitoring target species

A survey of the farms of all sectors of the agricultural zone of Santa Cruz was carried out in 2000 and special attention was paid to the target species. All landholders in this survey were questioned to find out if they had these species or any other unknown invasives.

Pueraria phaseoloides: The plant was identified in 1996 by a Charles Darwin Research Station (CDRS) botanist. Adjacent fields and farms were thoroughly searched and other farmers in the community were questioned as to whether they had sown these species. After the initial treatment in March 1996, the site was revisited initially at two-month intervals, later extended to every six months. The last known plants were sprayed in September 1997 and the site has been visited at yearly intervals since.

Rubus glaucus: This was first identified in 2000 by CDRS botanists. Most infestations consisted of thickets that were between 3 m and 10 m in diameter. An area of about 20 ha was extensively searched around the infestations and along adjacent watercourses. A series of GPS-directed 500 m transects with monitoring stations every 50 m (a total area of 100 ha) was laid out along the altitudinal contours. Monthly visits were made to the site from April 2000 (except September) to January 2001.

Citharexylum gentryi: This tree was first brought to the attention of CDRS in 1999. Two methods were employed to search for untreated trees during post-treatment monitoring. Firstly, a radius of about 100 m around known (treated) trees and areas between patches of trees were searched intensively. Secondly, an area of 1200 ha based around the known infestations and areas that could potentially have other plants was searched. Over a five-week period a series of GPS-directed transects 100 m apart was walked by trained observers looking for adults and seedlings. Monthly visits were made to the site from April 2000 (except September) to January 2001. After elimination of adult individuals (by January 2001), follow up to control seedlings is being done every three months.

Techniques for control of target species

There were two stages to control operations: firstly to remove all seed-producing adults and then seedlings and immature plants. Once no more individuals were found in a given area a system of monitoring was initiated in the local area to look for further individuals. Chemical control methods were used, including for seedling control, since this is faster and cheaper than manual control, and none of the species were growing in highly-sensitive natural vegetation. A limited number of herbicides are available in Ecuador, which prohibits importation of unregistered products, and stricter controls exist for Galapagos. Hence, for this programme we have only used products that are commercially available, effective, and cause the minimal possible environmental damage. Similarly, we try to use application methods that are logistically easy, and t have minimal impact on the surrounding native vegetation.

Pueraria phaseoloides: The 20 x 20 m plot and later regrowth was spot sprayed with a 5% solution of Roundup™ (Monsanto) (41% glyphosate salt) between March 1996 (initial treatment) and September 1997 (follow-ups).

Rubus glaucus: Thickets were sprayed with a 2% solution of Roundup (41% glyphosate salt) until leaves were wet. Germinating seedlings were sprayed with a 1.5% solution of Roundup. Treatment commenced in April 2000 and is continuing.

Citharexylum gentryi: All individuals were treated with the product Combo™ (Dow) a two-part mix (267 ml: 6 g) of picloram salt (24% v/v) and metsulphuron methyl (66% w/w). The product was dissolved in freshwater. Seedlings were sprayed with a 1% solution of Combo. Individuals between 1 cm and 30 cm in diameter were cut down using a machete or chainsaw as close to the ground as possible and the cut area (particularly the bark) was painted immediately with a 5% solution of Combo. Individuals greater than 30 cm in diameter were similarly treated with a 10 % solution of Combo. Regrowth from trunks was sprayed with a 10% solution of Combo. Treatment commenced in April 2000 and will continue until no seedlings have reappeared for at least three years.

RESULTS

In summary, *P. phaseoloides* has not been seen since 1997 (after three years it was declared eradicated) and all known seed-producing individuals have been removed of *R. glaucus* and *C. gentry*i (Table 1).

Table 1 Eradication effort (includes control and monitoring) for three species of potentially invasive species in Galapagos.

Species	Habit	Infestation area (ha)	Eradication status to date	Effort (person-hours to April 2001)
Pueraria phaseoloides	Climber	0.04	Eradicated	120
Rubus glaucus	Scrambler	5	No reproductive individuals	565
Citharexylum gentryi	Tree	171	No reproductive individuals	2870

Pueraria phaseoloides: All plants in the 0.04 ha patch have been destroyed and the last individual was seen in September 1997. Foliar application of 5% Roundup resulted in 100% mortality of adult plants. Plants were observed flowering but never produced any mature fruits. To date the only known dispersal mechanism of this species in Galapagos is humans. A total of 120 person-hours was spent in community consultation, treatment, and monitoring of this plant.

Rubus glaucus: Was reported for the first time in February 2000, although local people had known of its existence for some time (probably planted in the 1960s or 1970s for fruit production). An infestation of approximately 5 ha was found. About 100 ha of the surrounding area were searched using a grid of equidistant points, but no further plants were found. Plants are generally located along watercourses. It was observed to produce fruits during September and these were removed. Several treatments and monitoring visits were made between April and November of 2000. All adult plants were eliminated and no new adults have been found since. However, seedlings have been subsequently found and treated. The foliar application of 2% Roundup resulted in high mortality of adult plants but also resulted in the death of much surrounding vegetation. However, good regeneration of *Scalesia pedunculata* was recorded on the bare ground. A total of 490 person-hours has been spent so far on the treatment and monitoring of this plant.

Citharexylum gentryi: Is dispersed over an area of 171 ha in the agricultural zone of Santa Cruz, and a single tree has been found in the National Park. Over 1200 ha have been searched for this species. It is located between 100 and 400 m in altitude in two zones in the sector of Bellavista (the southern side of the agricultural zone) and in Camote (the south-eastern side of the agricultural zone). It occurs generally in mixed forests of introduced trees such as *Cedrela odorata* and *Psidium guajava* but is sometimes found in remnant native forest dominated by *Psidium galapageium.* Abundant black, berry-like drupes, with a single seed up to 6 mm in diameter, are produced for most of the year. In Galapagos, adult trees (i.e. >6 cm in diameter and >3 m tall, producing fruit) can reach a diameter of 1.2 m and a height of 22 m. The mean diameter and height of the treated trees was 19 cm and 7.5 m. Around where the trees were originally introduced the density of adult trees was about 14/100 m^2 whereas away from the founder patch the density was about 5/100 m^2 and the majority of trees were less than 15 cm in diameter.

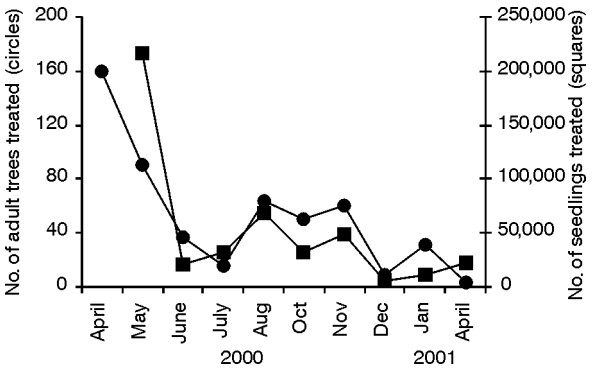

Fig. 1 Total numbers of adult trees (circles) and seedlings (squares) of *Citharexylum gentryi* treated.

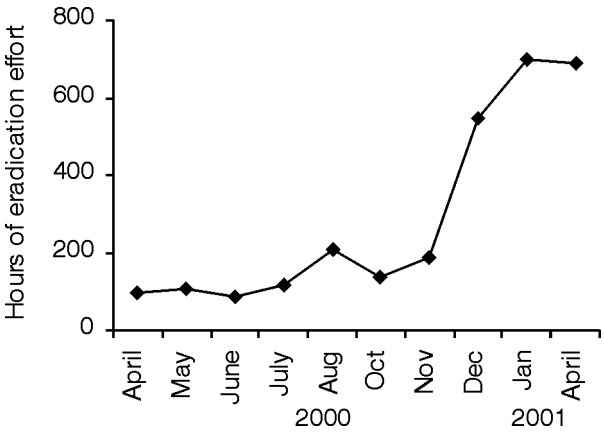

Fig. 2 Person-hours of eradication effort invested in control and monitoring of *Citharexylum gentryi*

Between April 2000 and April 2001 all known seed-producing trees were felled and treated. Figure 1 shows the progressive reduction of the adult individuals and seedlings. A total of 570 adult trees were treated. Once this canopy was removed there was a large flush of seedlings. The number of seedlings treated (approximately 450,000) decreased with time, although monthly effort on this task was kept the same until the last three surveys, when it was increased to ensure that further seedlings at low density would not escape detection (Fig. 2). In some areas of dense infestation, maize was sown to reduce seedling germination. The cut stump method using 5% Combo was effective for smaller trees but those greater than 30 cm diameter often resprouted and needed further treatment (using 10% Combo).

DISCUSSION

This programme demonstrates that eradication of potentially-invasive plants is possible in Galapagos. So far, with relatively few resources, we have managed to eradicate one species and remove all seed-producing adults of two other species. There are some obvious differences between the three examples discussed here, including the establishment time and size of infestation. *Pueraria phaseoloides* was introduced recently, only cultivated in a small area, and was found by botanists almost immediately. It had no chance to reproduce and become naturalised. Assuming that it has not been cultivated elsewhere in the islands, and given that it has not been seen for more than three years in a site that is very easy to monitor, it is safe to pronounce it eradicated. Conversely, *R. glaucus* and *C. gentryi* are both naturalised, have been present for 25 and 50 years, and have distributions of at least 5 ha and 171 ha respectively. *Rubus glaucus* is still in the establishment phase whereas *C. gentryi* is in the expansion phase. Both have produced reproductive offspring and the presence of seedlings suggests that a seedbank has formed. Although it is not known how long the seedbanks of these species persist, a study of *Rubus niveus* in Galapagos showed that after one year in the soil at least 25% of the seeds were still viable (O. Landázuri pers. comm.). *Citharexylum gentryi* has a sizeable hard seed that can remain dormant for at least six months (M. Soria pers. obs.). Hence, before these species can be eradicated the seedbank must be exhausted. This is a difficult task and preventing further seed input requires careful and repeated monitoring for many years. Fortunately, it takes C. *gentryi* from 3-6 years to reach reproductive age (it is far easier to prevent seed production in a slow-growing species that reproduces only after several years than it is for an annual), and few seeds are produced by *R. glaucus* (which can probably reproduce after 12 months), so the effect of missing a few small individuals during monthly monitoring is not great.

The other important factor when considering eradication, is capacity for dispersal. In Galapagos, wind-dispersed species are among the most difficult to control, since there are few bird species that are efficient seed dispersers. Both *R. glaucus* and *C. gentryi* to date have little dispersal potential and are mainly dispersed short distances by gravity. *Rubus glaucus* has a fleshy drupe which is evolved for animal dispersal, but few potential agents exist. The Galapagos flycatcher has been observed to disperse *R. niveus* (A. M. Guerrero pers. comm.) and may also disperse *R. glaucus*. *Citharexylum gentryi* has a berry-like drupe but no animal dispersal has been observed. Dispersal by water seems to have caused the occurrence of these species along streams, which makes them easier to locate.

Success of eradication also depends on accessibility. *C. gentryi* is found in farmland and is easier to locate compared to *R. glaucus* which is found in dense forest on rough terrain within the National Park, which increases the chance of escaping discovery. The *R. glaucus* site is nearly 10 km from the nearest road and all equipment must be carried to it. Both *R. glaucus* and *C. gentryi* will require at least three more years of monitoring and treatment. However, considering their potential invasiveness and the vulnerability of the community they are invading, their eradication must be considered top priority.

In the next six years we intend to expand this programme and attempt to eradicate 30 species of potentially-invasive plants archipelago-wide. Before this can be initiated, a complete introduced species database is required for the four main populated islands. Presently, good data exist for Santa Cruz and Floreana only. Without full information we cannot declare a species eradicated with any confidence. Also sufficient and systematic monitoring is required, to ensure that all individuals of the target species have been discovered. Effective control methods (principally chemical control) need to be developed for many of the lesser-known species as little information is available worldwide on their treatment. A protocol to evaluate eradication success needs to be refined. Another problem is getting community support to work with plants that are useful or are not obviously weeds today. One landholder could not understand how the beautiful little water plant *Eichhornia crassipes* (Martius) Solms could ever be a problem. If *Urochloa brizantha* were ever to be eradicated it would be very difficult to prevent its re-introduction because it is highly regarded for pasture. Therefore, one strong component of the eradication programme is a long-term education campaign explaining the threats of these plants, the production of a list of permitted species, and a quarantine system that prevents further introductions. Although difficult and requiring long-term commitment, this project may actually reduce the number of introduced plant species and will save millions of dollars in future management.

ACKNOWLEDGMENTS

We would like to thank our colleagues in the Galapagos National Park Service, especially René Valle, for their essential collaboration in this project. We are grateful to the Worthington Family Foundation and Monsanto for financial assistance. We also thank Marcel Rejmánek, Heinke Jäger, and Carol West for their comments on this paper.

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