The consequences of herbivore eradication on Santiago: are we in time to prevent ecosystem degradation again?

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Introduction

Santiago Island in the north of the archipelago is the second largest of the uninhabited islands. Its size (58 465 ha) and altitude (908 masl) have led to the formation of many vegetation types with a rich biodiversity including single island endemics.

The unique flora and fauna were devastated during 100 years of herbivory by goats, pigs, and donkeys. Following many attempts, a concerted effort finally eradicated pigs in 2001, donkeys in 2004, and goats in 2006 (Carrion *et al.*, 2007; Cruz *et al.*, 2005; Lavoie *et al.*, 2007). Free of the major threat to the biodiversity, natural ecological and evolutionary processes were expected to resume (Lavoie *et al.*, 2007). As predicted, the island's vegetation is recovering, and the populations of three highly threatened island endemic plant taxa, *Galvezia leucantha* subsp. *porphyrantha* Tye and H. Jäeger, *Scalesia atractyloides* Hook f., and *Scalesia stewartii* Riley are increasing (Tye, 2000; Tye and Jäger, 2000; Tye, 2007).

The Galapagos snap-dragon (*Galvezia leucantha* subsp. *porphyrantha)* was known from three populations in 2000, comprising about 130 plants (Tye and Jäger 2000). Two of these populations were fenced to protect them from herbivores. A total of six populations are now known and surveys of five of these in 2007 recorded 220 plants, 63 of which were located outside the fences (Simbaña, W. CDF, unpubl data).

Scalesia atractyloides was feared extinct until a few individuals were rediscovered in the 1990s (Tye and Jäger, 2000). The species has two distinct varieties. One variety, reduced to two adults, is now known from four locations, and monitoring at one location in 2007 recorded 21 plants. Five plants of the second variety were rediscovered in 1995 (Tye and Jäger, 2000). It has since been found in twelve sites and monitoring of eleven of these in 2007 recorded 1404 adults and over 2000 young plants. The fast recovery of these species and the predicted long term effect of herbivore eradication has led to the proposal to move each of these taxa into IUCN categories of lesser threat (Tye, 2007).

However, ecosystem degradation is a complex process and is rarely caused by a single introduced species. Eradication of what may seem to be the principal invasive changes the system dynamics and interactions between species. Rather than resulting in a reversal of the degradation process, this can lead to unwanted secondary consequences. Thus although eradications can have very successful outcomes, they can also have unexpected and undesirable effects, which, if not mitigated, can lead to problems as difficult and expensive to reverse as the initial eradication (Zavaleta *et al.*, 2001; Zavaleta, 2002).

During the final stages of goat eradication, one of the worst invasive plants in the archipelago was found in the highlands of the island. The species, *Rubus niveus* (blackberry), originates from the Himalayan region of India and was introduced to San Cristóbal in the 1970s for its fruit. It is now a serious problem in the highlands and agricultural zones of San Cristóbal and Santa Cruz and is becoming established in Isabela (Sierra Negra and Cerro Azul volcanoes), Santiago, and Floreana (Renteria *et al.*, 2007).

Blackberry is fast growing, forming dense impenetrable thickets that prevent native forest regeneration. It produces fruit at about six months of age and can reproduce vegetatively by suckers. Although most fruit fall from the plant, they are also dispersed by fruit-eating birds, mammals, and reptiles. Seeds can remain in a dormant phase in the soil for at least 10 years, and although germination is stimulated by light, the species can also tolerate shade (Hughes, 2002).

The combination of these factors makes control of blackberry difficult. Once it has produced seed and begun to form a seedbank, the species is very hard to remove from the environment. Just to prevent its spread requires repeated and frequent monitoring and control of new infestations. In addition the plants are hard to find amongst other vegetation and by the time they are spotted they are usually bearing fruit.

It is unclear when blackberry reached Santiago. Control began in 2006, with a systematic approach beginning in 2007. This has involved regular control of known infestations using an herbicide and systematic searching of surrounding areas to locate new plants. Helicopter surveying along transects has also been carried out several times and is proving to be an efficient method of detecting adult plants outside of known areas of distribution.

This paper reviews the distribution and abundance of the invasive blackberry in Santiago, evaluates whether eradication is still possible and whether there is still time to avoid another degradation event.

Methods

Systematic control of the known infestations and monitoring for new plants or infestations of blackberry were carried out during eleven field trips to Santiago in 2007.

The known infestations were controlled every three months. Intensive searching using equidistant points at a distance of 5 m apart were carried out in defined zones around each of the main infestations. In addition, a systematic helicopter search over part of the area was completed once. The plants located were subsequently controlled and areas around these new plants searched systematically. The life history stage of all plants found was also recorded.

Results

By the end of 2007, blackberry was known to cover 28 ha, located in four sites: La Naranja (15 ha), Pampa Larga (6 ha), La Reina (4 ha), and La Muela (3 ha) (Figure 1). Systematic searching of an additional 260 ha surrounding these zones resulted in 63 new plants, the majority of which were found immediately surrounding the four large infestations, although some were found at the maximum distance searched from each infestation (500 m).

A total of 2 760 plants were found and controlled over the five repeat visits of which 94 were adults bearing fruit. Plants both with and without fruit were found each time the areas were revisited, with

no trend of decreasing abundance over time, indicating the enormous size of the seedbank (Figure 2).

Of the 63 plants found surrounding the known infestations, 12 were with fruit. Most of the fruiting plants were first spotted at a distance or from the helicopter rather than during transect monitoring.

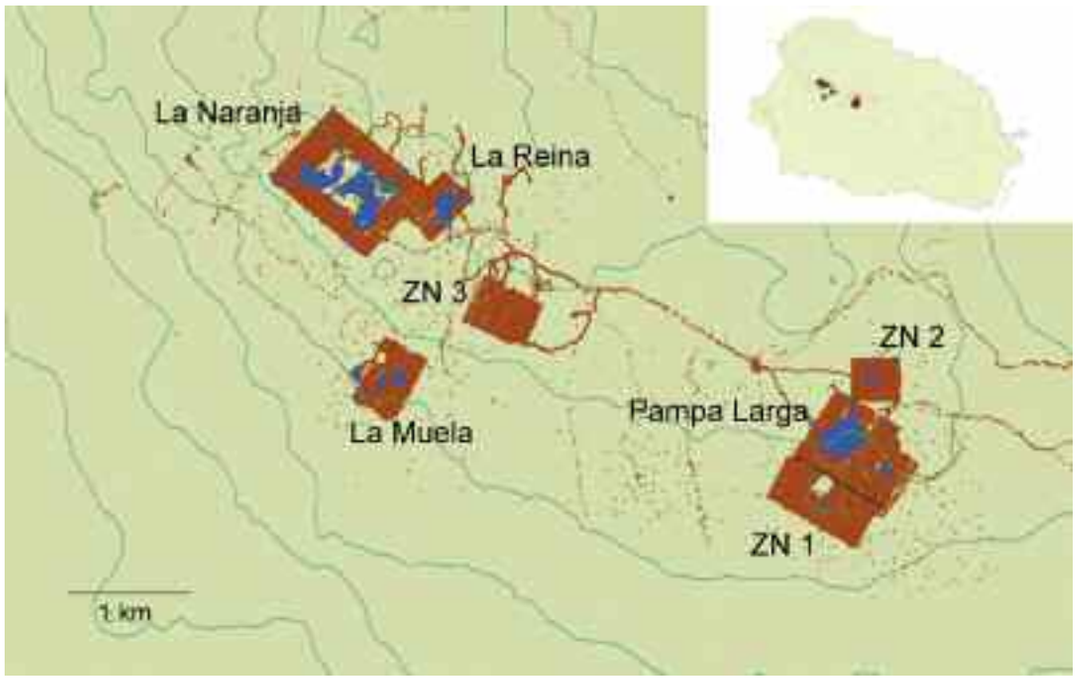

Figure 1. Zones of infestation of blackberry in the highlands of Santiago. Areas searched using equidistant points are in brown and blackberry locations in blue.

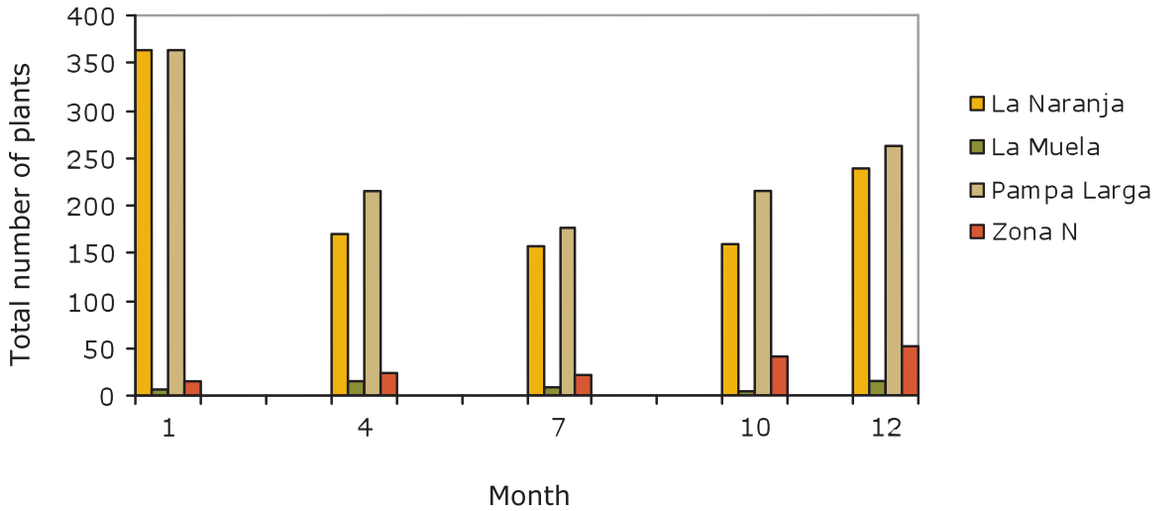

Figure 2. The number of plants found in each of the main infestations during the five controls carried out in 2007.

Discussion

While it is obvious that the eradication of introduced herbivores from Santiago has had a significant and positive effect, an alarming consequence has been the establishment of the introduced blackberry in the highlands of the island. The species is now known to cover at least 28 ha. It has a huge and viable seedbank in these areas and the presence of adult plants outside of the main infestations suggests that the species has a much wider and as yet unknown distribution that will continue to increase through seed dispersal.

On Santa Cruz and San Cristóbal, the

humid zone is nearly dominated by blackberry but it is rarely found in transition zone vegetation (CDF unpublished). Thus it can be predicted that all of the humid uplands of Santiago would be suitable for its growth, a potential area of about 4000 ha (Figure 3). Under climate change models it is likely that Galapagos will experience increased precipitation (Mitchell *et al.*, 2003). This will increase the potential area available for invasion by blackberry in the future.

Figura 3. Habitat zone predicted as suitable for blackberry expansion (shown in blue); based on maps by Pronareg, Orstom and Ingala (1987).

It is clear that if this species is going to be eradicated from Santiago, more intensive survey and control methods must be developed and implemented. These include surveying on horseback or helicopter to cover the whole of the humid zone every three to six months. This will ensure that every plant is detected before it produces fruit so that a seedbank does not become established. At the same time, the established infestations have enormous seedbanks that will continue to germinate over the next 10-15 years. Seedbank control methods that prevent germination or growth need to be implemented. This will help to reduce the persistence of this species in the ecosystem.

With this combination of techniques, it is estimated that eradication could be achieved within 15 years, at an estimated cost of US$150 000 per year, totalling US$2.25 million. Although this appears to be less costly than eradication of goats at US$5.5 million (Lavioe *et al.*, 2007), blackberry is only found in the humid zone. Thus, on a per hectare basis, its eradication will cost six times that of goat eradication.

The release of the introduced blackberry from herbivory clearly shows that the use of single-species eradications for ecosystem restoration is only a first step in a long-term process. Carrying out a risk analysis to predict any negative consequences of the eradication beforehand, developing a funded contingency plan, and monitoring the ecosystem after eradication has been completed are essential steps to ensure that a rapid response to any new threat can be instigated before the ecosystem begins to degrade again. This does not mean that single species eradications should not take place but that careful planning is necessary to avoid the negative consequences to restoration.