INVASIVE PLANTS IN THE *SCALESIA PEDUNCULATA* FOREST AT LOS GEMELOS, SANTA CRUZ, GALAPAGOS

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SUMMARY

Volunteers were used to map invasive plants in 25 ha of one of the best remnants of *Scalesia pedunculata* forest at Los Gemelos, Santa Cruz Island, Galapagos. The most dominant invaders were the trees *Cestrum auriculatum*, *Cedrela odorata* and *Cinchona pubescens*, a vine *Passiflora edulis*, and the shrub *Rubus niveus*. Forest structure at the site suggests that further cyclical stand-level dieback, reportedly characteristic of *S. pedunculata* forests, is unlikely to occur in the near future. Although the invasion at Los Gemelos is continuous, we conclude that dieback provides extra opportunity for the establishment of invasive plants. Management is required to reduce invasive species impacts on the forest.

RESUMEN

Plantas invasoras en el bosque de *Scalesia pedunculata* de Los Gemelos, Santa Cruz, Galápagos. Con el trabajo de voluntarios, se realizó mapas de plantas invasoras presentes en 25 ha del mejor remanente del bosque de *Scalesia pedunculata* de Los Gemelos, Isla Santa Cruz, Galápagos. Las especies invasoras dominantes fueron las especies arbóreas *Cestrum auriculatum*, *Cedrela odorata* y *Cinchona pubescens*, la trepadora *Passiflora edulis* y la arbustiva *Rubus niveus*. La estructura del bosque en el sitio sugiere que un episodio de muerte regresiva, que se sugiere es característico del bosque de *S. pedunculata*, es improbable en el futuro próximo. Aunque la invasión en Los Gemelos es proceso continuo, se concluye que los eventos de muerte regresiva crean más oportunidad para el establecimiento de especies introducidas. Un manejo es requerido para reducir el impacto de las plantas invasoras en el bosque.

INTRODUCTION

Scalesia (Asteraceae) is a genus endemic to Galapagos comprising *c.* 20 taxa. The tree *Scalesia pedunculata* Hook. f. is the tallest of the genus reaching up to 15 m in height and 15 cm in trunk diameter (Wiggins & Porter 1971). It is found in the humid zone on four high-altitude Galapagos islands: San Cristóbal, Floreana, Santiago and Santa Cruz. It forms dense forests 400–600 m above sea level on Santa Cruz (Itow 1965, Hamann 1979, 2001). Soft wooded, it can grow to 4 m in its first year and 7 m in its second (Itow 1995) and can reach reproductive maturity within two years, though it is short lived, at 20–30 years (Hamann 1979). It experiences periodic stand-level dieback and regeneration (Hamann 2001), so the presence of larger long-lived invasive tree species in *S. pedunculata* forest on Santa Cruz could result in potentially catastrophic changes in forest structure if a further mass die-back event were to occur.

Serious threats to the *S. pedunculata* forests are the expansion of agricultural activities and competition with introduced plants on inhabited islands (Santa Cruz, San Cristóbal and Floreana), and goat and donkey browsing on Santiago Island (Snell *et al*. 2002). Invasive species and direct modification via land use are the biggest agents of human mediated change in the Galapagos terrestrial ecosystem. Settlement and agriculture are restricted to designated areas on the inhabited islands, and the rest of the land area is National Park. Invasive species have been deliberately planted and have spread more widely on their own, even to uninhabited islands. Worldwide, invasive species are regarded as the second biggest threat to biodiversity after direct modification through land use (Williamson 1999).

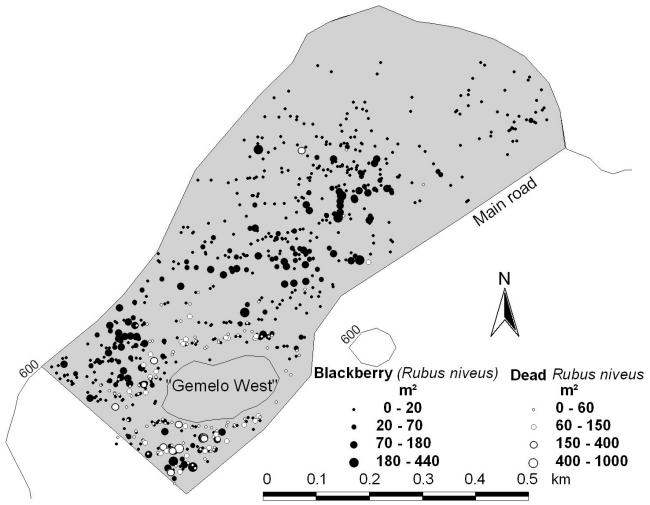
The biggest remnant of *S. pedunculata* forest is found on Santa Cruz, at the site Los Gemelos (*c.* 600 m above sea level). The forest extends over *c.* 140 ha and has been invaded by a number of introduced plant species including the trees Cuban Cedar *Cedrela odorata* L., Guava *Psidium guajava* L., Sauco *Cestrum auriculatum* L'Hér. and Quinine *Cinchona pubescens* Vahl, the shrub Hill Blackberry *Rubus niveus* Thunb., the passionfruit vine *Passiflora edulis* Sims. and the herbs *Tradescantia zebrina* hort. ex Bosse, *Hyptis pectinata* (L.) Doit., Elephant Grass *Pennisetum purpureum* Schumach., Guinea Grass *Panicum maximum* Jacq. and Molasses Grass *Melinis minutiflorus* P. Beauv. Hamann (2001) predicted that Cuban Cedar will replace *S. pedunculata* as the dominant species in the humid and transition vegetation zones (*sensu* Wiggins & Porter 1971), due to its longer life cycle, greater stature and shade tolerance. Quinine now dominates other parts of the island (Buddenhagen *et al.* 2004) and has started to invade Los Gemelos. Hamann (2001) suggests that, due to its stand-level dieback cycle, *Scalesia* forest is vulnerable to invasion by alien plants and should receive high priority for conservation management (Shimuzu 1997).

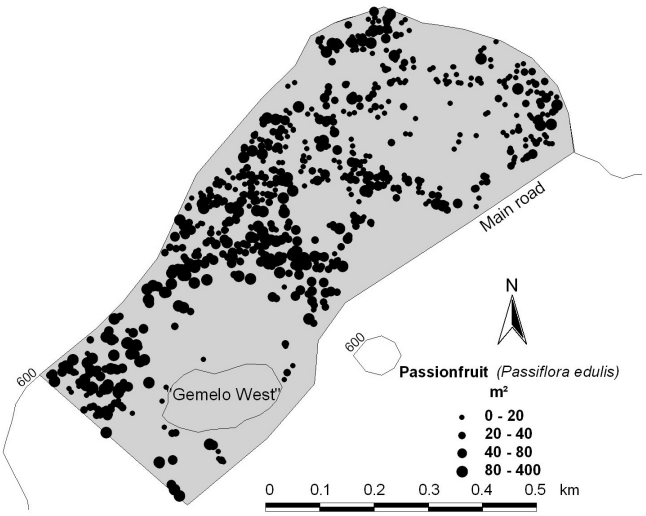
A project to restore the *S. pedunculata* forest at Los Gemelos was initiated in May 2005, using short-term volunteers to provide most of the labour required for control of the most important invasive plant species. Initially, 50 ha were selected for intensive management over two years. The impact of management on the forest will be monitored. As the main invasive species in Los Gemelos are widespread on Santa Cruz, reinvasion is likely and continued surveillance and control will be necessary. Although intermittent management of invasive species at Los Gemelos has been carried out previously, this project represents the first systematic attempt to document the extent of the invasive plant problem at this site before and after management. Here, we describe the distribution and abundance of invasive plant species in 25 ha of the *Scalesia* forest at Los Gemelos, in May–June 2005. This information will act as a baseline to monitor the long term success of management actions.

METHODS

The study area included 25 ha around the western of the two Los Gemelos craters and on the small volcanic cone Cerro Maternidad to the north (Fig. 1). We mapped individuals of the invasive species *Cedrela odorata*, *Cestrum auriculatum*, *Cinchona pubescens*, *Hyptis pectinata*. *Passiflora edulis*, *Psidium guajava*, *Rubus niveus* and *Tradescantia zebrina*. The grasses *Melinis minutiflorus*, *Panicum maximum*, *Paspalum conjugatum* Bergius (regarded as doubtfully native in Galapagos), *Pennisetum purpureum* and *Oplismenus* spp. (up to three species possible, introduced or doubtfully native) were grouped together without distinguishing species. Distribution and abundance were mapped by volunteers following 69 pre-established parallel transects 15 m apart, extending from the adjacent road *c.* 300 m into the forest. Transect lines were generated in GIS and uploaded to hand-held Global Positioning System (GPS) units. Transects were followed in the field by creating routes between points. Along each transect the location of each species was saved in the GPS. Abundance was recorded either as number of plants counted, or, where individuals could not be distinguished due to clumping and growth form, the length and width in meters of each infestation along the largest axes were estimated. For tree species, all stems were counted and for those over 2 m tall diameter at breast height (DBH) was measured. Volunteers were aware of the spacing between transects and tried to map only species that corresponded to their swath. However, some infestations may have been missed or others mapped twice. This type of error was minimized by checking for overlap when mapping the data in GIS.

The structure of the *S. pedunculata* population was also assessed to predict the likelihood of stand level die-back occurring in the near future. The size class distribution of *S. pedunculata* was measured in twenty 5 × 5 m quadrats





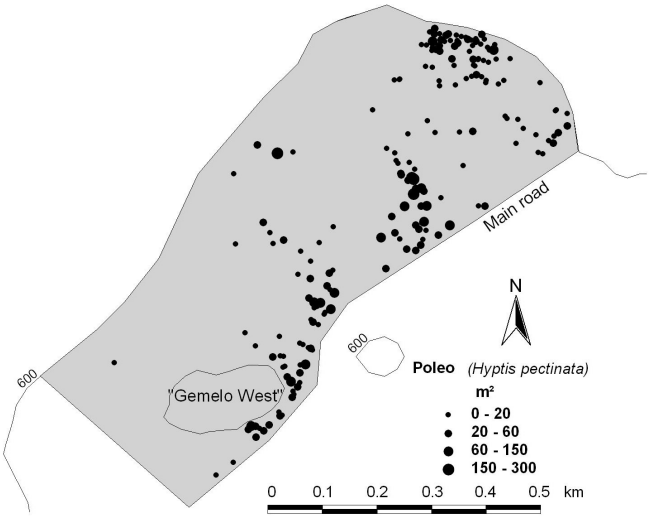


Figure 1 (a–c above, d–i opposite, reading from top left across then down on each page). Area (a–e) and point (f–i) distributions of nine invasive plants at the Los Gemelos site.

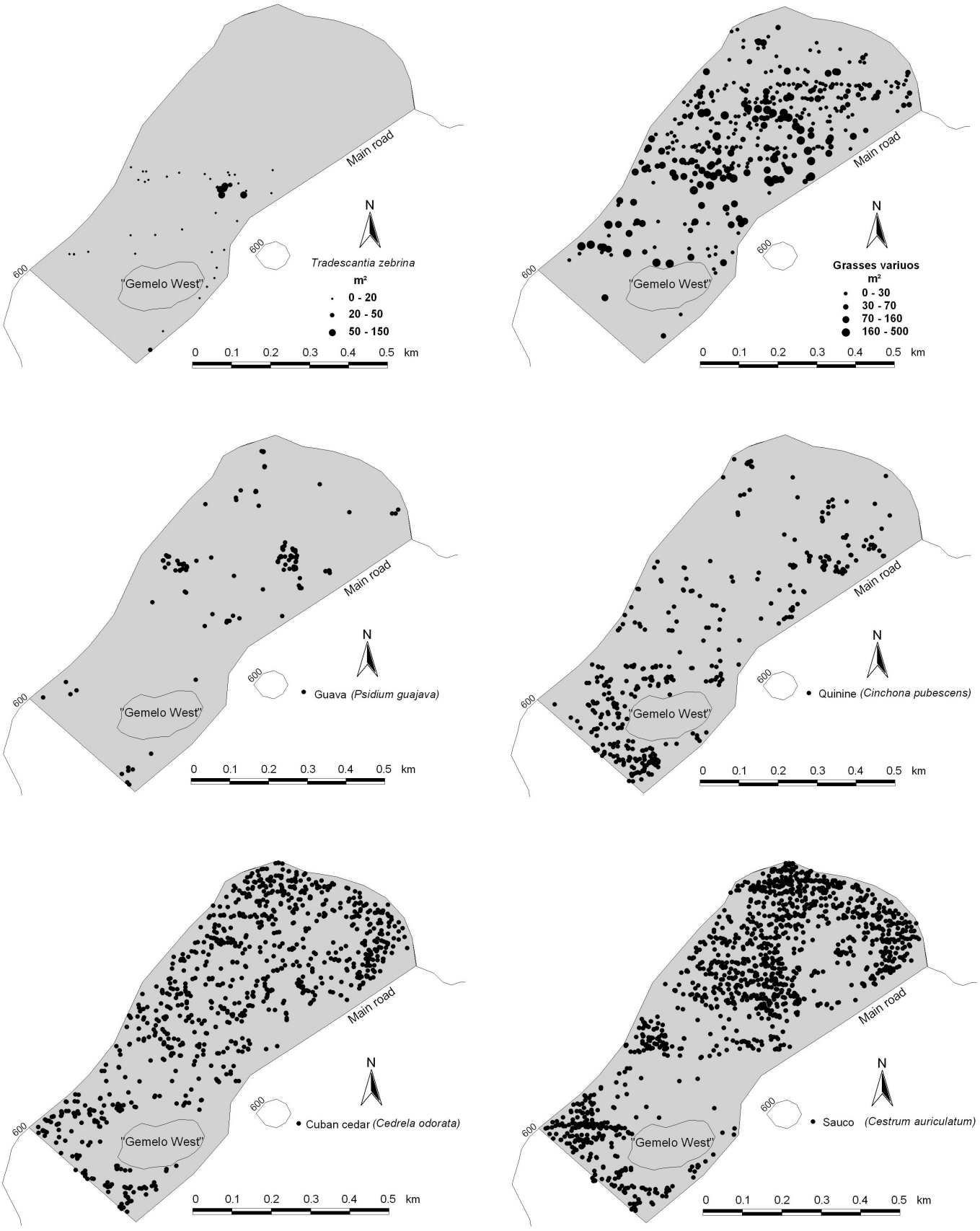


Figure 1 continued (caption opposite).

Table1. Size of infestations for thicket-forming invasive species at Los Gemelos. Data are n (%) of observations.

Area of infestation (m²)	*P. edulis*	*R. niveus*	Grasses	*H. pectinata*	*T. zebrina*	dead *R. niveus*
0–25	444 (62.4)	574 (79.6)	218 (52.1)	125 (66.5)	32 (72.7)	27 (21.4)
25–50	151 (21.2)	69 (9.6)	70 (16.7)	38 (20.2)	10 (22.7)	54 (42.9)
50–100	84 (11.8)	59 (8.2)	89 (21.3)	20 (10.6)	1 (2.3)	30 (23.8)
100–200	25 (3.5)	14 (1.9)	23 (5.5)	2 (1.1)	1 (2.3)	11 (8.7)
200–500	7 (1.0)	5 (0.7)	18 (4.3)	3 (1.6)	0	4 (3.2)
Total n	711	721	418	188	44	126
Total area (ha)	2.328	1.431	2.242	0.536	0.083	0.839

along parallel east to west transects spaced 100 m apart. The first quadrat along each transect was located at a random distance between zero and 100 m and subsequent quadrats were located 100 m apart. Total *Scalesia* stems were counted and DBH was measured of all stems over 2 m tall in each quadrat.

RESULTS

The whole of the 25 ha study area was heavily infested with the eight invasive species (Fig. 1). Dead *R. niveus* occupied 0.8 ha, in an area controlled by the Galapagos National Park service within the last 1–2 years (Fig. 1a). Most infestation patches of all patch-forming species were smaller than 25 m² (Table 1).

More than half the stems of all tree species were more than 2 m tall (Table 2). *C. odorata* included the largest individuals, which overtopped the 6–8 m *S. pedunculata* canopy when they attained *c.* 5 cm DBH. About 66% of *C. odorata* stems had DBH>5 cm. *C. auriculatum* was the smallest of the tree species with only 3% of stems > 5 cm DBH. *P. guajava* had a restricted number of foci (Fig. 1f).

The varied size class distribution of *S. pedunculata* trees suggests that there were multiple cohorts of trees present in 2005, rather than a single, even-aged stand (Figure 2).

DISCUSSION

The Los Gemelos forest appears at first glance to be completely native, due to the structural dominance of *Scalesia pedunculata*. However, the site is actually heavily invaded by at least ten alien plant species. J. Runkle (pers comm.) did not notice many invasive plants in his Los Gemelos study site in 1998, apart from the distinctive *Cinchona* (Runkle & Runkle 2005). However, we do not know whether this indicates that the invasive plant problem has recently become worse.

The cyclical stand-level dieback and regeneration supposedly typical of *Scalesia* forest has been suggested to occur every 20–30 years, linked to major El Niño events (Hamann 2001). The forest may be particularly vulnerable to invasion during canopy dieback. However, despite a suggested initiation of this cycle at Los Gemelos in 1985 exactly 20 years prior to our study (Hamann 2001) there was no evidence of mass dieback during the 1997–8 major El Niño event (Tye & Aldaz 1999) nor since, as the *S. pedunculata* size class distribution appears to be varied (Fig. 2). The typical size class distribution of trees with continuous regeneration is a curve with small individuals being most numerous and old large trees being relatively uncommon. Regeneration of *S. pedunculata* at Los Gemelos

Table 2. Height-diameter classes of four tree species in 25 ha at Los Gemelos. Data are n (%) of trees in each size class.

	Cinchona	*Cedrela*	*Psidium*	*Cestrum*
< 2 m height	106 (19.1)	54 (6.8)	74 (26.1)	1002 (20.4)
0.5–5 cm DBH	307 (55.3)	219 (27.6)	189 (66.8)	3746 (76.2)
5–10 cm DBH	94 (16.9)	214 (27.0)	15 (5.3)	133 (2.7)
10–25 cm DBH	48 (8.6)	195 (24.6)	5 (1.8)	34 (0.7)
25–50 cm DBH	0.0	106 (13.4)	0.0	0.0
50–100 cm DBH	0.0	6 (0.8)	0.0	0.0
Total stems	555	749	283	4915
Mean density (stems per ha)	22	30	11	196

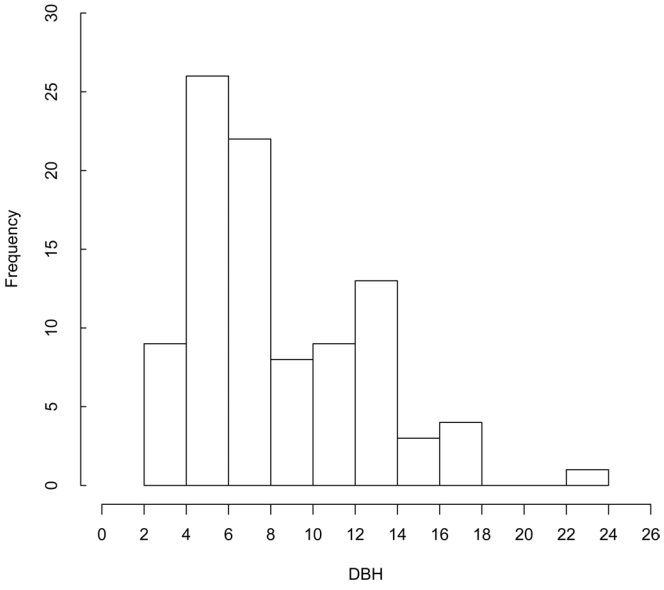


Figure 2. Size class distribution of 95 *S. pedunculata* trees in twenty 5 × 5 m plots.

has not been constant, and two distinctive cohorts have been formed (Fig. 2), possibly during the 1997–8 and 2002 El Niño events. However, the current size class distribution (Fig. 2) suggests that even if there were an extreme El Niño in the coming years, which could trigger death of senescent trees, the effect would be patchy since large old trees are not common.

All of the species in this study site except *Cestrum auriculatum* are known to be naturalized or invasive elsewhere (http://www.hear.org/pier/, 2006). It is likely that most of them had dispersed from the nearby agricultural zone. *C. odorata* and *C. pubescens* are wind dispersed, *R. niveus* and *C. auriculatum* are bird dispersed. *P. edulis*, *P. guajava* and grasses are also dispersed by birds (Buddenhagen & Jewell 2006, Guerrero 2002) and large animals including people, cattle, pigs and tortoises (pers. obs.). Apart from people, there was no sign of large animals at the site.

Some of the larger invasive trees may have established during the 1982–3 *Scalesia* dieback. Most individuals of the invasive trees in this study were large and long established with few seedlings < 2 m tall (Table 2). The largest *C. odorata* trees (up to >50 cm DBH) could have established at this time, since they can grow 2 m in height and add 2.5 cm of DBH per annum in good conditions (Citrón 1990) . However, even intact forest appears to be vulnerable to invasion at periods other than during diebacks. Our data suggest that there several more years are required before *Scalesia* trees reach senescence or self-thinning leads to loss of smaller trees. However, a patchy or extensive dieback at the site could lead to invasive species gaining a greater foothold than they would by the current gradual attrition.

Without intervention, this site is likely to transform into a forest of tall *C. odorata* with an understorey of *R. niveus*. Of the eight invasive species studied, these two will potentially cause the greatest impacts. *C. odorata* has huge potential to change the site because it is long-lived and can form a dense canopy up to 30 m high. A mature *C. odorata* forest would out-compete the smaller short-lived *S. pedunculata*. *R. niveus* is a scrambler that forms dense thickets up to 4 m high and will probably eventually take over the whole understorey, leaving little opportunity for the light-demanding *S. pedunculata* seedlings to establish.

Invasive species control is urgently required if we expect to maintain natural regeneration in this forest. Even with effective control, reinvasion is inevitable from surrounding areas, necessitating permanent control.

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