

Forest processes in the presence of wild ginger (*Hedychium gardnerianum*)

P.A. Williams¹, C. Winks², and W. Rijkse³

¹Landcare Research, Private Bag 6, Nelson, New Zealand (E-mail: WilliamsP@Landcareresearch.co.nz)

²Landcare Research, Private Bag 92 170, Auckland, New Zealand

³Landcare Research, Private Bag 3127, Hamilton, New Zealand

Abstract: Wild ginger (*Hedychium gardnerianum*) is a tall rhizomatous herb that invades forests and shrubland fragments in northern New Zealand. In order to determine the impacts of this invasive weed on forest processes, comparisons of conifer-broadleaved forest patches with different densities of ginger were made at Opononi and Whangarei in Northland. Soil properties, vegetation structure, floristics, and seed rain were recorded. Annual litterfall biomass and chemical composition were measured. There were no significant differences between soils under forest with sparse (< 5% cover) and dense (> 50% cover) ginger. A sparse subcanopy layer and fewer saplings were common factors in ginger plots. Forest canopy litterfall (c. 6.8 t ha⁻¹ yr⁻¹) and total N (45.1–56.2 kg ha⁻¹ yr⁻¹) were similar in plots with sparse or dense ginger. Species richness of adult trees and seedfall richness varied little. In contrast, seedling density and richness were lower in dense ginger stands and seedling composition was dominated by species with large (> 200 mg) seeds, i.e. *Corynocarpus laevigatus*, *Dysoxylum spectabile* and *Rhopalostylis sapida*. These seedlings may produce a different forest canopy from that currently found in areas where ginger is sparse.

Keywords: adventive species; *Hedychium gardnerianum*; litter composition; litterfall; weeds.

Introduction

Invasive plant species may have major effects on ecosystem processes (Schulze and Mooney, 1993), altering ecosystem structure, function and biodiversity (Cross, 1982; Vitousek and Walker, 1989; Fensham *et al.*, 1994). Species that acquire a disproportionate share of essential resources frequently have a great impact on indigenous communities and ecosystems. One such species is wild ginger (*Hedychium gardnerianum*, Zingiberaceae), hereafter termed ginger, which is a native of the Himalayan region of India. Ginger was first invasive in Jamaica (Grubb and Tanner 1976) and now invades tropical forests in Reunion I., South Africa, Azores, Madeira (Cronk and Fuller, 1995), and the Hawaiian Islands (Anderson and Gardner, 1999). Since the first collection in the wild in New Zealand, in Auckland in 1949 (Healy and Edgar, 1980), it has spread to become a major forest weed in northern New Zealand (Williams and Timmins, 1990; Porteous, 1993).

Ginger is a large rhizomatous herb with stems up to 2.0 m tall and leaves 0.5 m long. It can form dense patches covering at least a hectare, and exclude most other ground-cover plants. Whether there are differences in ecosystem function between forest

patches with and without ginger warrants examination if we are to understand the impacts of this invasive species (Parker *et al.*, 1999). We aimed to describe the forests invaded by ginger and determine whether there were differences in major soil nutrients, species composition and spatial distribution of the vegetation, and the amount and composition of canopy and subcanopy litterfall, between areas with sparse and dense ginger.

Methods

Study sites and plots

The study was undertaken at two sites in Northland, New Zealand. Ginger occupies a wide range of sites in Northland that are free from intensive grazing, ranging from indigenous forests to reverting pasture. We were limited to sites where ginger occupied forest understories over areas sufficiently large to sample and where equipment would be free from human interference. Only two sites satisfied these criteria, and they were on very different substrates. The most northern site was 7 km south of Opononi (35° 33' S, 173° 26' E) at 40–80 m a.s.l. in the Waioitemarama Valley, which lies in the Hokianga Ecological District of the Aupouri

Ecological Region (McEwen, 1987). The mean annual rainfall is approximately 1650 mm yr⁻¹ and mean annual temperature 15.1°C (New Zealand Meteorological Service, 1983). The site was located in a 14-ha forest patch on a steep hill of sandstone and mudstone within a Scenic Reserve managed by the Department of Conservation. There were old Maori fortifications on ridges and spurs. The area would have supported closed conifer-broadleaved forest that was partly cleared and burnt, perhaps in Maori times, and has since been replaced by regenerating tall scrub. The present canopy is predominantly secondary forest dominated by *Kunzea ericoides* and *Weinmannia silvicola*, with patches of primary forest represented by *Beilschmiedia tarairi* and scattered emergent podocarps. Ginger occupies most of the margins and canopy gaps within the stand, particularly on the lower slopes where there is a high proportion of *B. tarairi*. Department of Conservation files record that ginger had occupied much of the reserve by the mid-1980s, when it was manually cut, but not sprayed. Cattle were grazed in the reserve afterwards, but these have been removed and the area is now fenced (A. McCluggage, Department of Conservation, Whangarei, N.Z. pers. comm.).

The second site was 2.5 km south-west from the centre of Whangarei City (35° 45' S, 174° 18' E) at 60 m a.s.l. in the Raumanga Valley, on reserve land administered by the Whangarei City Council. It lies in the Eastern Northland and Islands District of the Eastern Northland Ecological Region (McEwen, 1987). The mean annual rainfall is approximately 1600 mm yr⁻¹ and mean annual temperature 15.4°C (New Zealand Meteorological Service, 1983). The site covered about 2 ha of steep hill of calcareous sandstones with characteristic limestone topography of hollows and outcrops. The site may have been partly burnt since human settlement, but it is mainly primary conifer-broadleaved forest dominated by emergent *Podocarpus totara*, *Dacrycarpus dacrydioides* with *Dysoxylum spectabile* and *Vitex lucens*. Ginger is scattered in varying densities throughout the stand and appears to be most dense in hollows of the limestone topography. The site has been protected from grazing by virtue of its peri-urban location. Possums (*Trichosurus vulpecula*) are present in unknown densities at both sites but appear to have little impact on the vegetation.

Patches of forest with nil or sparse (< 5%) ginger cover and dense (> 50%) ginger cover with similar landform features and canopy vegetation were selected at both sites. Three 20 m by 20 m plots were located by random coordinates within each site and cover combination. All plots were > 50 m in from the reserve margins to avoid areas of very dense ginger lacking a forest over-story.

Soils and vegetation

Representative soil profiles were described from two pits in each plot. Soil samples were taken from one profile in four 7.5-cm segments to 30 cm. Soil samples were collected for each soil layer separately. Ten additional soil cores, 3 cm diameter by 10 cm deep, were collected randomly from within each plot to form a bulk sample. Soil pH (in water), total carbon, total nitrogen, and exchangeable cations—calcium, magnesium, potassium and sodium—were measured as described by Blakemore *et al.* (1987).

Ground cover, litter, and vegetation cover at five tier heights (> 12 m, 5–12 m, 2–5 m, 2 m–30 cm, < 30 cm), were estimated by eye within each plot, and the presence of all vascular plant species noted. The number and diameter of all woody stems ≥ 2 cm diameter were measured in each plot, and the data averaged for each species. Woody seedlings (< 30 cm) were counted in 10 randomly located 1 m² quadrats in each plot.

Litterfall

Canopy and understory litterfall was collected in circular funnels, 0.1 m² catching area and 0.30 m deep, constructed of heavy nylon shade cloth (0.5 mm mesh) tied at the bottom for access. Nine funnels per plot were attached to three stakes 1 m above ground level, which was above the level of ginger crowns. Traps were set out in December 1997 and emptied approximately monthly until December 1998. Twigs in the traps were collected but the occasional branch resting across a trap was discarded. Litter samples were dried at 80°C for 2 days, and the fruit and seeds removed as per Williams and Karl (2002). Leaves and identifiable woody material were weighed to the nearest 0.01 g after being sorted into the following categories: *Beilschmiedia* spp., *Dacrycarpus dacrydioides*, *Podocarpus totara*, two large-leaved species *Dysoxylum spectabile* and *Vitex lucens*, *Weinmannia silvicola*, mixed broadleaved species, and “other” comprising non-leaf material and small amounts of unidentifiable leaves. Data for the two December collections were averaged and all data were combined into four periods of approximately equal length; spring (September–November), summer (December–February), autumn (March–May), and winter (June–August). Litter within each period was combined, subsampled, and analysed ($n = 16$) for total N, P, Ca, Mg, K, and Na (Blakemore *et al.*, 1987). A sample of recently dead ginger leaves from each plot was collected in December and treated similarly.

Statistical tests were made using the Mann-Whitney approximation of the chi-squared test for two groups (sparse ginger and dense ginger), and means presented with ± 1 standard deviation (S.D.). Significance for these tests was determined as $P < 0.01$ because of the large number of paired comparisons.

Results

Soil profiles

Despite the accumulation of ginger rhizomes at the surface, there were no morphological differences between sparse ginger (SG) and dense ginger (DG) topsoils. At Opononi, soil horizons beneath sparse ginger and dense ginger were variable because of the broken topography. Horizons with maximum organic accumulation were about 15 cm thick, comprising dark greyish-brown, sticky clay loam. Soil structure was weakly developed in the organic horizons but moderately firm beneath. The underlying horizons were 65 cm of olive-brown to yellowish-brown, sticky clay, over mottled clay down to at least 100 cm.

At Whangarei, soils were more uniform, other than in the bottoms of sink holes where there was often dense ginger. Organic horizons were 12–17 cm thick, with black to very dark grey, sticky clay loam. Soil structure was weakly developed in the organic horizons, grading to moderately firm in the underlying horizons of 40–55 cm of light yellowish-brown to greyish-brown sticky clay. The underlying horizons were light-coloured clay down to at least 100 cm.

Soil properties

Bulk densities were estimated at $1.2\text{--}1.4\text{ t m}^{-3}$ across all sites. Means of the three bulked samples from the 0–10 cm were compared, and the values from the three lower layers of the described profile averaged into a combined subsoil figure. At Opononi, there were no significant differences in the 0–10 cm layer in any soil properties between the sparse and dense ginger samples (Table 1). The soils were slightly acid (mean pH 5.4) in the topsoils, and the cations and base saturation

indicate a weak to medium level of leaching (Taylor and Pohlen, 1962). The C:N ratio was high, indicating the organic matter was not well decomposed.

The Whangarei soils were slightly acid to near neutral in the upper horizons with medium to high N and C levels (Table 1). There were differences in the 0–10 cm layers, with more carbon (% dry weight) in the dense ginger, 11.6, than in sparse ginger, 8.7, and a correspondingly higher cation exchange capacity in the dense ginger, although these were not significant ($P=0.05$). Base saturation (%) was higher in the dense ginger, 97.4, compared with the sparse ginger, 81.0, due to the higher amounts of Ca and K, all of which may indicate higher cations in the dense ginger plots, although again, these differences were non-significant ($P=0.05$) (Table 1).

Vegetation

Estimates of ginger cover at 2 m–30 cm in the Opononi plots were $1.5 \pm 1.5\%$ (S.D.) in the sparse ginger plots and $62.7 \pm 17.4\%$ in the dense ginger plots. All Opononi plots had a very similar cover of other vegetation in the upper >12 m and 12–5 m layers, 9% and 30% respectively. Cover in the sub-canopy 5–2 m layer was $29.5 \pm 10.3\%$ in the sparse ginger plots, and $12.5 \pm 6.3\%$ in the dense ginger plots. At Whangarei the 2 m–30 cm layer had only a trace of ginger in the sparse ginger plots, and 43% cover in the dense ginger plots. Cover in the >12 m layer was $41.2 \pm 16.4\%$ in the sparse ginger plots and $8.0 \pm 6.1\%$ in the dense ginger plots. Cover in the 5–12 m layer was about 35.0% in both sparse and dense ginger, and $34.2 \pm 6.6\%$ and $10.6 \pm 7.5\%$ respectively, in the 2–5 m layer. These differences in individual layers were non-significant, although several were almost significant at ($P=0.05$).

Table 1. Soil properties from forest sites at Opononi and Whangarei. The 0–10 cm layer is the mean \pm S.D. of bulked samples of 10 small cores from each of the three plots within sparse ginger (SG) and dense ginger (DG). Subsoil values are the mean of samples from a single profile, sampled in 3 layers between 7.5–30.0 cm, and averaged for the sparse ginger and dense ginger plots. Bulk density was estimated at $1.2\text{--}1.4\text{ t m}^{-3}$ all plots. Significance levels of the Mann-Whitney test comparing mean levels between the 0–10.0 cm layers in the SG and DG plots are all non-significantly different, $P > 0.01$.

Site	Depth (cm)	pH (water)	Total C (%)	Total N (%)	C/N ratio	CEC cmol(+)/kg	Base sat. (%)	Exchangeable cations cmol(+)/kg			
								Ca	Mg	K	Na
Opononi											
SG	0-10.0	5.2 \pm 0.5	7.6 \pm 1.3	0.4 \pm 0.1	19.3 \pm 2.4	37.3 \pm 4.0	51.1 \pm 16.4	8.1 \pm 3.9	8.6 \pm 1.9	1.0 \pm 0.3	0.7 \pm 0.1
DG	0-10.0	5.8 \pm 2.1	6.3 \pm 2.0	0.4 \pm 0.1	16.7 \pm 5.9	31.9 \pm 11.4	69.0 \pm 25.2	12.2 \pm 5.1	8.4 \pm 3.2	1.1 \pm 0.4	0.7 \pm 0.2
Subsoil	7.5-30.0	5.5	2.2	0.1	14.2	23.2	51.3	3.9	6.6	0.8	0.7
Whangarei											
SG	0-10.0	6.2 \pm 0.3	8.7 \pm 1.2	0.6 \pm 0.1	15.1 \pm 0.5	59.1 \pm 7.8	81.0 \pm 3.1	41.0 \pm 7.2	5.9 \pm 0.8	0.6 \pm 0.1	0.5 \pm 0.1
DG	0-10.0	6.7 \pm 0.2	11.6 \pm 0.9	0.8 \pm 0.1	14.4 \pm 1.5	80.9 \pm 1.8	97.4 \pm 4.7	70.3 \pm 5.9	7.2 \pm 0.9	0.9 \pm 0.1	0.5 \pm 0.1
Subsoil	7.5-30.0	6.0	2.6	0.2	11.1	44.9	74.3	27.9	4.9	0.4	0.5

The total vegetation cover (sum of all tiers %) of the non-ginger component of the vegetation was significantly negatively correlated with the total ginger cover (sum of lower 2 tiers %) at Opononi ($R^2 = 0.816$, $P = 0.05$), and almost significant at Whangarei ($R^2 = 0.704$, $P = 0.06$) (Fig. 1).

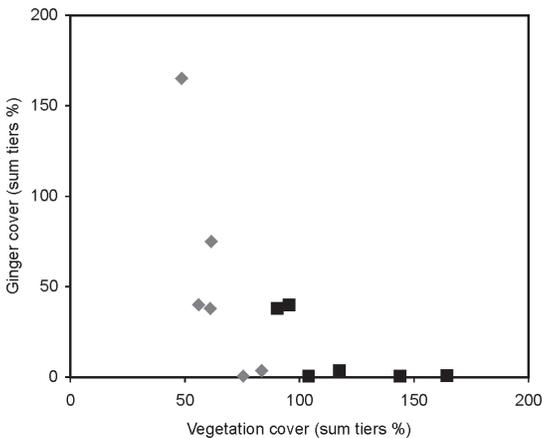


Figure 1. The relationship between the sum of ginger cover in 2 tiers, and the sum of cover of all other vegetation in 5 tiers from $> 12\text{ m} - < 0.3\text{ m}$ (Table 2). Data are from plots at Opononi (\blacklozenge), and Whangarei (\blacksquare).

The cover of litter was $> 90\%$ in sparse ginger plots at both sites, whereas in the dense ginger plots it was lower, $38.0 \pm 5.6\%$ and $72.6 \pm 24.5\%$ at both Opononi ($P < 0.01$) and Whangarei respectively. There was only a trace (0–2%) of bare ground in any group.

At Opononi, stand basal area (woody species > 2 cm diameter) was similar, $35 \pm 11.4\text{ m}^2\text{ ha}^{-1}$ and $45.2 \pm 10.4\text{ m}^2\text{ ha}^{-1}$, in dense ginger and sparse ginger plots respectively. Stems were noticeably smaller and more numerous in the sparse ginger plots, $2308 \pm 912\text{ ha}^{-1}$, than in dense ginger, $1075 \pm 319\text{ ha}^{-1}$, but not significantly so ($P = 0.05$). Basal area in the sparse ginger plots was distributed amongst many species, with *Cyathea* species, *Kunzea ericoides* and *Weinmannia silvicola*, in descending order of importance (Table 2), contributing a total of 34 % of live basal area. Vegetation in the dense ginger plots was dominated by *K. ericoides* and *Beilschmiedia tarairi* (Table 2), which contributed 38% of live basal area. All plots had substantial numbers and basal area of standing dead stems, especially in dense ginger, where $43.5\text{ m}^2\text{ ha}^{-1}$ of dead stems equalled the basal area of live stems.

Table 2. Frequency ($n = 3$) of all species in plots with sparse (SG) and dense ginger (DG), at Opononi and Whangarei. The rank order for stem basal area is indicated in brackets for the top 5 species in each location and ginger density combination.

	Opononi		Whangarei	
	SG	DG	SG	DG
Trees, shrubs, and climbers				
<i>Coprosma arborea</i>	3 (4=)	1	..	..
<i>Coprosma rhamnoides</i>	3	1	..	..
<i>Hedycarya arborea</i>	1	1	..	..
<i>Leucopogon fasciculatus</i>	1	1	..	..
<i>Weinmannia silvicola</i>	2 (3)	3 (3)	..	..
<i>Ackama rosifolia</i>	1	2	..	..
<i>Metrosideros excelsa</i>	1 (4=)	2 (5)	..	..
<i>Knightia excelsa</i>	1	1	1	..
<i>Dacrydium cupressinum</i>	1	..	..	1
<i>Kunzea ericoides</i>	3 (2)	3 (1)	2	1
<i>Myrsine australis</i>	3	2	1	2
<i>Melicytus ramiflorus</i>	1	3	2	1
<i>Geniostoma rupestre</i>	1	1	1	1
<i>Podocarpus totara</i>	2	1	3 (1)	2 (4)
<i>Dysoxylum spectabile</i>	1	1	3 (2)	3 (3)
<i>Beilschmiedia taraira</i>	1	1 (2)	2	3 (5)
<i>Dacrycarpus dacrydioides</i>	1	1	2 (4)	1 (2)
<i>Macropiper excelsum</i>	..	1	2	3
<i>Rhopalostylis sapida</i>	..	1	2	3
<i>Ripogonum scandens</i>	..	1	2	..
<i>Streblis heterophyllum</i>	..	..	2	..
<i>Corynocarpus laevigatus</i>	..	..	3	3
<i>Sophora tetraptera</i>	..	..	3 (5)	1
<i>Coprosma tenuicaulis</i>	..	..	1	1
<i>Vitex lucens</i>	..	..	1 (3)	1 (1)
<i>Coprosma robusta</i>	..	..	1	2
Ferns				
<i>Phymatosorus pustulatus</i>	3	1	..	..
<i>Lygodium articulatum</i>	2	1	..	..
<i>Asplenium flaccidum</i>	2	2	..	..
<i>Adiantum cunninghamii</i>	1	2	..	..
<i>Cyathea smithii</i>	3 (1)	3 (4)	3	..
<i>Asplenium oblongifolium</i>	2	2	1	..
<i>Blechnum filiforme</i>	3	2	2	1
<i>Adiantum hispidulum</i>	..	1	2	..
<i>Phymatosorus scandens</i>	..	..	3	1
<i>Pteris macilentia</i>	..	..	..	2
Others				
<i>Oplismenus imbecillis</i>	2	2	..	..
<i>Carex dissita</i>	1	1	..	..
<i>Uncinia banksii</i>	1	1	..	..
<i>Hedychium gardnerianum</i> *	3	3	3	3
<i>Collosporum hastatum</i>	1	1	1	3
Total species	38	36	29	24
No. species m⁻²	0.5±0.0	0.4±0.1	0.3±0.1	0.3±0.1

Species that occurred only once are as follows:

Opononi SG: *Coprosma grandifolia*, *Dicksonia lanata*, *Hymenophyllum* spp., *Metrosideros diffusa*, *Phyllocladus trichomanoides*, *Pseudopanax arboreus*, *Pseudowintera axillaris*, *Uncinia uncinata*; Opononi DG: *Asplenium polyodon*, *Coprosma spathulata*, *Lastreopsis hispida*, *Rubus australis*; Whangarei SG: *Elaeocarpus hookerianus*, *Elatostema rugosum*, *Lastreopsis glabellum*, *Ligustrum lucidum**, *Hoheria populnea*.

Whangarei DG: *Alectryon excelsum*, *Ligustrum sinense**, *Peperomia tetraphylla*.

*Naturalised species

At Whangarei, stand basal area was similar in the sparse ginger plots, $48.5 \pm 11.6 \text{ m}^2 \text{ ha}^{-1}$, and the dense ginger, $70.7 \pm 2.6 \text{ m}^2 \text{ ha}^{-1}$. The number of stems was highly variable and similar in sparse and dense ginger plots. *Podocarpus totara* and *Dysoxylum spectabile* dominated the basal area in sparse ginger. A few very large *Vitex lucens* trees dominated the dense ginger (Table 2). The sparse ginger and dense ginger plots had the same number of species at Opononi and the composition was very similar, although *Coprosma* spp. were more frequent in the sparse ginger. Species composition was also very similar in sparse and dense ginger plots at Whangarei, but ferns were more frequent in sparse ginger plots (Table 2).

Seedfall and seedlings

A total of 1571 seeds were identified from Opononi, and 1645 from Whangarei (Table 3). Birds were the main dispersal agents. At Opononi, total seed numbers were variable in both sparse and dense ginger, ranging from an average of 42 to 168 m^{-2} . In contrast, seed species richness was significantly higher in dense ginger, 7.9 species m^{-2} , than in sparse ginger, 3.1 species m^{-2} (Table 3). *Leucopogon fasciculatus* and *Myrsine australis* were the main seeds, followed by *Meliccytus ramiflorus*, which was significantly more common in the dense ginger, 123 m^{-2} , than in sparse

ginger, 1 m^{-2} . Woody seedling density in sparse ginger, 3.2 m^{-2} , was significantly higher than in dense ginger, 0.96 m^{-2} . Woody seedling species richness was also significantly lower in dense ginger, 0.58 m^{-2} , than in sparse ginger, 1.66 m^{-2} , in contrast to the high seed species richness noted earlier. The density of *Coprosma* spp. seeds averaged 5.5 m^{-2} and this was reflected in the low number of seedlings. The large number of *L. fasciculatus*, *M. australis* and *M. ramiflorus* seeds at Opononi were matched by few, if any, seedlings, particularly in dense ginger.

At Whangarei, total seed numbers were similar in sparse and dense ginger, averaging 47 to 113 m^{-2} (Table 3). Seed species richness was significantly greater in sparse ginger, 5.6 m^{-2} , than in dense ginger, 0.7 m^{-2} . *Podocarpus totara* and *Solanum aviculare* seeds were common, but neither was recorded as seedlings.

Woody seedling density was significantly higher in the sparse ginger than in dense ginger, 1.9 m^{-2} and 1.2 m^{-2} respectively. Species richness was significantly higher in the sparse ginger plots, 1.2 m^{-2} , than in the dense ginger, 0.7 m^{-2} . *Dysoxylum spectabile* was the most common seedling, with 0.9 m^{-2} in sparse ginger and significantly fewer, 0.4 m^{-2} , in dense ginger. *Corynocarpus laevigatus* seedlings were the next most common, at about 0.5 m^{-2} in both sparse and dense ginger (Table 3).

Table 3. Seedfall (no. m^{-2}) from all traps, December 1997 to August 1998, and woody seedlings (no. m^{-2}) of the most frequent species¹ in forest stands with sparse (SG) and dense ginger (DG) in Northland (mean \pm S.D). Significance level of the Mann-Whitney test comparing mean number of seed, or seedlings, in the ginger and non-ginger stands: $P < 0.01$, ***; $P = 0.01$, **; otherwise not significant, $P > 0.10$.

Species or group	Dispersal: (b, bird; w, wind; u, unspecialised)	Opononi				Whangarei			
		All seeds		Woody seedlings		All seeds		Woody seedlings	
		SG	DG	SG	DG	SG	DG	SG	DG
<i>Leucopogon fasciculatus</i>	b	213.4	1083.0	0.06	0.02	4.4			
<i>Myrsine australis</i>	b	187.0	80.3	0.46	0.22	25.3	17.6		
<i>Dacrycarpus dacrydioides</i>	b	2.2	2.2	0.01		85.0	94.6		
<i>Coprosma</i> spp. (n.= 4)	b	5.5	6.6	0.68	0.19	4.4	10.0	0.03	0.02
<i>Meliccytus ramiflorus</i>	b	1.1	123.2*	0.03			3.3	0.03	
<i>Corynocarpus laevigatus</i>	b		3.3			3.3	2.2	0.47	0.60
<i>Dysoxylum spectabile</i>	b			0.02	0.04		1.1	0.89	0.36
<i>Podocarpus totara</i>	b					935.0	125.4		
<i>Solanum aviculare</i>	b					126.5	255.2		
Total seeds or seedlings m^{-2}		42.2	168.8	3.2	0.96	47.7	113.0	1.89	1.22
		± 33.7	± 244.0	± 0.9	± 1.7	± 35.7	± 137.0	± 2.22	± 1.92
No. species m^{-2}		3.1	7.9	1.66	0.58	5.61	0.71	1.22	0.71
		± 1.3	± 1.3	± 1.07	± 0.75	± 1.6	± 0.81	± 0.96	± 0.8

¹Abbreviations: dispersal, b, w, u; Op, Opononi; Wh, Whangarei; A, All seeds; W, Woody seedlings; data for A and W are indicated only when there are data, and their presence in SG and DG are indicated by the numbers or (-) if absent. *Alseuosmia macrophylla* (b, Op, W, 0.04, -); Asteraceae (w, Op, A, 1.1, 1.1; Wh, A, 1.1, 3.3); *Beilschmiedia taraira* (b, Op, W, 0.11, 0.16; Wh, W, 0.01, -); *Beilschmiedia tawa* (b, Wh, A, -, 15.4); *Benula* sp. (w, Wh, A, 4.4, -); *Cordylina australis* (b, Wh, A, 4.4, 105.0); *Geniostoma rupestre* (u, Op, W, 0.13, 0.07; Wh, W, 0.12, -); *Hedycarya arborea* (b, Op, W, 0.10, -); *Hoheria* sp. (w, Wh, W, 0.02, -); *Knightsia excelsus* (u, Op, A, -, 2.2); *Laurelia novae-zelandiae* (u, Op, A, -, 2.2); *Litsea calicaris* (b, Op, A, -, 1.1); *Macropiper excelsum* (b, Wh, A, 0.04, 3.3, 0.1, 0.1); *Melicope ternata* (u, Op, A, 1.1, 1.1; Wh, A, 6.6, 4.4); *Muehlenbeckia australis* (b, Wh, W, 4.4, 1.1); *Phyllocladus trichomanoides* (b, Op, W, -, 0.02); *Pseudopanax* spp. (b, Op, A, -, 2.2); *Rhopalostylis sapida* (b, Op, W, 0.40, 0.24); *Rubus fruticosus* (b, Op, A, -, 1.1); *Sophora tetraptera* (u, Wh, A, 3.3, 3.3); 2 unidentified spp. (Op, A, 2.2, 9.7; Wh, W, 1.1, 27.5).

Litterfall

Annual litterfall from the canopy and subcanopy was similar in sparse and dense ginger plots. At Opononi, the means ranged from 5.58 t ha⁻¹ yr⁻¹ to 7.58 t ha⁻¹ yr⁻¹, and at Whangarei from 7.19 t ha⁻¹ yr⁻¹ to 9.27 t ha⁻¹ yr⁻¹ (Table 4). Peak litterfall was during the summer, i.e. December to February. At Opononi, *Weinmannia silvicola* and *Dacrycarpus dacrydioides* were prominent individual species in the litter of sparse ginger and dense ginger, and *Beilschmiedia tarairi* in the dense ginger plots. The significantly greater amount of "others" in the dense ginger (Table 5) derived from stem material from the greater number of standing dead stems.

At Whangarei, *Dysoxylum spectabile* and *Vitex lucens* dominated litter production, with *Dacrycarpus dacrydioides* in second place in all plots, and *Podocarpus totara* in sparse ginger plots. The significantly greater "mixed broadleaved" litter type in the sparse ginger reflects the greater cover in the upper tiers.

Litter chemistry

Element concentrations in the bulked litterfall, and in the ginger litter, were in the order Ca>N>K=Mg>P in both sparse and dense ginger (Table 6). The high concentrations of Ca in ginger leaves and forest litter at Whangarei reflects differences in soil chemistry within the top 10 cm (Table 1), resulting from the calcareous soil parent material. There were no significant differences in concentrations between litter from sparse ginger and dense ginger at either site. There were significantly greater N inputs in sparse ginger at Opononi compared with dense ginger, while at Whangarei there were greater Ca inputs in the dense ginger. These differences result primarily from differences in litterfall (Table 5).

Comparisons between ginger leaf litter and forest litter from the same plots are not strictly valid because there was no control on their respective ages, and hence the amount of leaching. It is noticeable, however, that concentrations of K, Ca, and Mg are higher in ginger leaf litter than in forest litter at both Opononi and Whangarei.

Table 4. Seasonal and annual total litterfall (t ha⁻¹) during 1997/1998 in forests at Opononi and Whangarei, with sparse ginger (SG) and dense ginger (DG). Mann-Whitney tests comparing mean total litterfall in the sparse ginger and dense ginger plots are not significant, $P > 0.01$.

Location	Spring (Sep.–Nov.)		Summer (Dec.–Feb.)		Autumn (Mar.–May)		Winter (Jun.–Aug.)		Annual	
	SG	DG	SG	DG	SG	DG	SG	DG	SG	DG
Opononi	0.93	1.02	2.33	3.53	1.03	1.39	1.29	1.64	5.58	7.58
									± 1.40	± 2.70
Whangarei	1.72	1.48	4.16	2.95	2.14	1.68	1.23	1.10	9.27	7.19
									± 2.47	± 1.80

Table 5. Litterfall (t ha⁻¹) composition during 1997/1998 in forests at Opononi and Whangarei, with sparse ginger (SG) and dense ginger (DG). Many species are grouped, and non-leaf material is included in "other". The significance level of the Mann-Whitney test comparing mean total litterfall in the sparse ginger and dense ginger plots: $P < 0.001$, ***; $P = 0.01$, **; otherwise comparisons are not significant, $P > 0.01$.

Species/group	Opononi		Whangarei	
	SG	DG	SG	DG
<i>Beilschmiedia</i> spp. ¹	0.03±0.08	0.29±0.44	0.53±0.84	0.59±0.57
<i>Dacrycarpus dacrydioides</i>	0.32±0.52	0.75±0.11	1.19±1.19	0.95±1.28
<i>Dysoxylum spectabile</i> and <i>Vitex lucens</i>	0.01±0.02	0.12±0.18	2.05±1.16 ^d	1.85±1.61
<i>Podocarpus totara</i>	IO ⁴	IO ⁴	2.61±1.04	0.15±0.20***
<i>Weinmannia silvicola</i>	1.09±0.69	0.63±0.34	IM ⁵	IM ⁵
Mixed broadleaved ²	0.55±0.24	2.20±0.98	0.94±0.67	0.29±0.35**
Others ³	0.33±0.41	3.12±1.34***	1.92±0.75	3.30±1.80

¹Mainly *Beilschmiedia tarairi* with some *B. tawa*

²Mainly *Carpodetus serratus*, *Collospermum hastatum*, *Coprosma* spp., *Corynocarpus laevigatus*, *Griselinia littoralis*, *Hedycarya arborea*, *Kunzea ericoides*, *Meliclytus ramiflorus*, *Myrsine australis*, *Sophora tetraptera*, *Weinmannia silvicola*

³All non-leaf material plus small amounts of some species from "mixed broadleaved"

⁴IO = Included in "others"

⁵IM = Included in "mixed broadleaved."

Table 6. Chemical composition ($\text{mg}^{-1} \text{gm}^{-1}$) of ginger leaf litter and forest litterfall, and total elements ($\text{kg ha}^{-1} \text{yr}^{-1}$) of forest litter in sparse (SG) and dense ginger (DG) plots at Opononi and Whangarei. Significance level of the Mann-Whitney test comparing mean concentrations or weights of elements in the SG and DG plots: $P < 0.01$, **; otherwise not significant, $P > 0.01$.

Location	N	P	K	Ca	Mg
	Ginger leaves ($\text{mg}^{-1} \text{gm}^{-1}$) ¹				
Opononi DG	5.7±1.0	0.5±0.1	7.2±0.5	15.7±1.9	9.7±0.8
Whangarei DG	7.5±1.3	0.8±0.2	6.7±1.4	22.9±1.8	5.7±1.2
	Forest litter ($\text{mg}^{-1} \text{gm}^{-1}$) ²				
Opononi SG	6.4±1.1	0.4±0.0	2.5±0.5	9.2±0.3	2.5±0.3
Opononi DG	6.7±0.9	0.5±0.1	3.4±0.8	11.9±1.8	2.5±0.3
Whangarei SG	9.9±1.5	0.7±0.2	3.5±1.2	12.6±3.2	1.7±0.2
Whangarei DG	8.2±1.3	0.7±0.1	5.2±1.5	15.6±0.8	1.6±0.1
	Forest litter ($\text{kg ha}^{-1} \text{yr}^{-1}$)				
Opononi SG	35.7±6.1	2.2±0.1	13.9±2.8	51.3±1.7	13.9±1.6
Opononi DG	50.7±6.8 **	3.8±0.8	25.7±6.0	90.2±13.6 **	18.9±2.2
Whangarei SG	91.7±13.9 **	6.5±1.8	32.4±11.1	116.8±29.6	15.7±1.8
Whangarei DG	58.9±9.3	5.0±0.7	37.3±10.7	112.1±5.7	11.5±0.7

¹Mean ± standard deviation of 3 replicates

²Mean ± standard deviation of analyses of summer, autumn, and winter samples.

Discussion

Determining the effects of weeds by comparing different sites, in the presence and absence of weeds, is problematic because of confounding influences of other site factors (Adair and Groves, 1998). Prioritising the management of weed species should nevertheless proceed even though their impacts are uncertain, and while costs are still relatively low (Williams, 1997). Resolution of the effects of dense ginger or other weeds requires long-term experiments (Williams and Karl, 2002), but our Northland study indicates the ecosystem processes that may be affected within a few decades of the establishment of ginger.

The soils under dense ginger at Whangarei had relatively higher organic matter (total C) and base status than under sparse ginger as a result of their being associated with colluvial portions of a pitted limestone landscape; whereas at Opononi there were no differences in soil physical or chemical properties beneath the stands. Overall, ginger invasion within the forests appeared unrelated to variation in soil nutrient availability.

Total litterfall in dense ginger plots was similar to that in sparse ginger, ranging from $7.2 \text{ t ha}^{-1} \text{yr}^{-1}$ to $7.6 \text{ t ha}^{-1} \text{yr}^{-1}$, which is slightly higher than a range of North Island conifer-broadleaved forests (4.5 to $6.5 \text{ t ha}^{-1} \text{yr}^{-1}$) (Wardle, 1991), but in the centre of the 5-year range (6.77 – $8.79 \text{ t ha}^{-1} \text{yr}^{-1}$) reported from *Agathis australis*-broadleaved forests near Auckland (Enright, 1999). It followed the usual pattern for New Zealand angiosperm-broadleaved forests by peaking in early

summer (Cowan *et al.*, 1985; Enright and Ogden, 1987; Enright, 1999). Nutrients showed a similar trend in the ginger plots; using N as an example, the $50.7 \text{ kg ha}^{-1} \text{yr}^{-1}$ at Opononi and $58.9 \text{ kg ha}^{-1} \text{yr}^{-1}$ at Whangarei are similar or higher than 31.0 – $44.0 \text{ kg ha}^{-1} \text{yr}^{-1}$ of N reported for South Island conifer-broadleaved forests (Daniel and Adams, 1984; Levett *et al.*, 1985). These comparisons indicate that forest penetrated by ginger, at least in terms of dry weight of litter and litterfall nutrient inputs, is similar to that of other forests of the region. The dense ginger crowns and rhizomes represent a substantial pool of nutrients on the forest floor, but there is no evidence ginger has affected ecosystem nutrient cycling as other weeds have, especially legumes (Vitousek and Walker, 1989).

There were few differences in forest composition between sparse and dense ginger patches as determined from vegetation cover, stem basal area, and composition of litterfall. The structural feature common to dense ginger plots in both forests was a sparse sub-canopy layer leading to lower overall crown density (Fig. 1) and presumably greater light for ginger growth. At Opononi, the sparse subcanopy in the dense ginger may reflect the response of the forest to the earlier attempts to control ginger or to grazing, but it may also reflect patterns of wind throw, or stand edge effects (e.g. Mucia, 1995; Davies-Colley *et al.*, 2000).

Overall species richness of trees, shrubs, and ferns varied little between sparse and dense ginger plots. However, woody seedling richness was lower in the dense ginger sites. This pattern was exhibited where the seed species richness was both higher and lower in

dense than in sparse ginger. The most abundant seedlings amongst dense ginger at Whangarei, relative to seedfall, were large-seeded *Corynocarpus laevigatus* (270 mg; Wardle, 1991). This is one of the few species seen emerging through dense *Tradescantia fluminensis* in Northland (P.A. Williams, *unpubl.*), a species commonly associated with reduced densities of native woody seedlings (Kelly and Skipworth, 1984; Smale and Gardner, 1999; Standish *et al.*, 2001). Over all sparse ginger plots, the abundant seedfall from the small-seeded species produced most of the seedlings, in order of relative frequency *Coprosma* spp. (mean seed weight 7.7 mg; Wardle, 1991) then *Myrsine australis* (c. 3 mg; P.A. Williams, *unpubl.*). There were a few seedlings of the large-seeded *Dysoxylum spectabile* (288 mg; Standish *et al.*, 2001). In contrast, similarly abundant small seeds in ginger plots produced only a few seedlings, whereas large-seeded species that were uncommon in the seedfall produced most of the seedlings, in the order *Corynocarpus laevigatus* > *Dysoxylum spectabile* > *Rhopalostylis sapida* (244 mg; Wardle, 1991). This suggests that seedlings derived from large seeds are favoured in establishing amongst dense layers of invasive forest floor weed species (Standish *et al.*, 2001). This is primarily due to large seeds being correlated with an element of shade tolerance (Grime and Jeffrey, 1965; Grime, 1979; Leishmann and Westoby, 1994; Walters and Reich, 2000), although the correlation is not universal (Augsburger, 1984; Grubb and Metcalfe, 1996).

Numerous studies summarised by Adair and Groves (1998) have shown non-indigenous plant species reduce indigenous species diversity and alter successional pathways. Ginger appears to be another example. Reduced densities of small seedlings and saplings in the critical regeneration phase at both localities, and the differing composition of seedling populations in the presence of ginger, suggest ginger is altering successional pathways in these forests and thus future canopy composition. Furthermore, these interactions may be influenced by forest mutualisms, as two of the three seedlings most abundant in the ginger, *Corynocarpus laevigatus* and *Dysoxylum spectabile*, have seeds so large as to be dependant on the native kereru (*Hemiphaga novaeseelandiae*) for their dispersal (Clout and Hay, 1989). Kereru is not endangered (Mander *et al.*, 1998), but should it become so, through increased predation by introduced mammalian pests (Clout *et al.*, 1995; Pierce and Graham 1995) or hunting (Pierce *et al.*, 1993), these northern forests would lack means of dispersing the main plant species capable of regenerating through the invasive ginger. This could lead to accelerating impacts on native ecosystems that Simberloff and Holle (1999) termed "meltdown" processes.

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