

Prospects for biological control of
Tradescantia fluminensis Vell.
(Commelinaceae)

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ABSTRACT

The feasibility of biological control of *Tradescantia fluminensis* in New Zealand was investigated. There are no native or naturalised relatives of *T. fluminensis* in New Zealand, nor a significant trade of related plants, that would preclude the use of a biocontrol agent with a genus- or family-specific host range. *Tradescantia fluminensis* contains flavonoids that may deter generalist insect feeders but could foster host-specific interactions that are likely to be endemic to its native range (i.e. Brazil and other regions within South America). *Phakosora tecta*, a fungus which causes leaf spot, is the only record of a disease of *T. fluminensis* from South America. It has potential as a classical biological control agent, though its efficacy needs to be demonstrated. Within the native range of *T. fluminensis*, southern Brazil has a climate similar to that of northern New Zealand, and so may contain additional suitable potential biocontrol agents. There are undescribed mirids (Hemiptera: Miridae) recorded from *Tradescantia* and *Commelina* spp. in the USA that have potential as classic biological control agents. Their climate limitations, effectiveness against *T. fluminensis* and specificity need to be assessed. *Septoria tradescantiae*, a fungus from central USA which causes leaf spot, is another potential biocontrol agent. It is specific to *Tradescantia*, although an association with *T. fluminensis* has not been demonstrated. If it is already present in New Zealand, it could be developed as a mycoherbicide. Re-invasion of other weeds could hamper the success of a biological control programme for *T. fluminensis*. There is a 'middle zone' beyond the forest margin that is too dark for a majority of light-demanding weeds which would likely benefit from the removal of *T. fluminensis*. For native forest regeneration to occur, the biological control agent needs to reduce the standing biomass of weed to less than 200 g/m². This goal is realistic in the light of the success of previous biological control programmes.

Keywords: *Tradescantia fluminensis*, wandering Jew, biological control, invasive weeds, plant-feeding insects, plant pathogens.

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1. Introduction

Tradescantia fluminensis Vell. (Commelinaceae) is an invasive mat-forming weed of lowland forest remnants throughout the North Island and northern South Island of New Zealand. The feasibility of biological control of *T. fluminensis* in New Zealand was investigated by R. Standish on behalf of Landcare Research for the Department of Conservation (DOC).

2. Background

2.1 GLOBAL DISTRIBUTION

Tradescantia fluminensis (syn. *T. albiflora*) is native to South America (Esler 1978), and has naturalised in New Zealand (Kelly & Skipworth 1984a), eastern Australia (Dunphy 1991), Spain (Landcare Research 1998), Russia (Tolkach et al. 1990) and the south-eastern USA (Farr et al. 1989; Wunderlund 1998). Within its native range, *T. fluminensis* is considered to be an agricultural weed (Dos Santos & De Araujo 1971 cited in Kelly & Skipworth 1984a; Robert Barreto, pers. comm.).

2.2 *Tradescantia fluminensis* IN NEW ZEALAND

Tradescantia fluminensis was first introduced to New Zealand in 1910 by a Manawatu farmer (Kelly & Skipworth 1984a), and was recorded as being naturalised in Awanui, Northland, soon after (Carse 1916). While it is not known to set seed in New Zealand (Healy & Edgar 1980), *T. fluminensis* has dispersed widely by the spread of fragments that have been dumped in forest remnants in garden refuse or naturally via streams (Esler 1978). Livestock and road machinery have also been known to disperse fragments (Ogle & Lovelock 1989; Department of Conservation 1998). Fragments as small as 10 mm can successfully establish new plants (Kelly & Skipworth 1984a).

The distribution of *T. fluminensis* within New Zealand is restricted by its intolerance of frost (Bannister 1986) and, arguably, by its reliance on streams, people or animals for dispersal. The absence of *T. fluminensis* from large tracts of forest may be due to either of these limitations. Currently, the distribution of *T. fluminensis* spans 11 of the 13 DOC Conservancies (Susan Timmins, pers. comm.). Tongariro/Taupo, Otago and Southland Conservancies do not list *T. fluminensis* as a problem weed. It has also spread to some offshore islands, e.g. Stephens Island (Brown & Rees 1995), Matiu and Mana Islands (Howell et al. 2000), the Chatham Islands and Rangitoto Island (Susan Timmins, pers. comm.). *Tradescantia fluminensis* continues to invade new sites within the Northland, Bay of Plenty, East Coast/Hawke's Bay, Wanganui and Nelson/ Marlborough

Conservancies (Owen 1997). It has a weed ranking of 25 (0 indicates minimal impact and 34 indicates maximal impact), based on its 'effects on the system' and 'biological success', compared with scores of 22 (*Vinca major*) and 23 (*Selaginella kraussiana*) for other mat-forming weeds (Owen 1997).

Tradescantia fluminensis invasion is symptomatic of degradation of lowland forest remnants. Once it is introduced to a site, available light is the primary factor limiting its spread and biomass accumulation (Kelly & Skipworth 1984a; Maule et al. 1995; Standish et al., in press) which, in turn, determines its impact on native forest regeneration (Standish et al., in press). In addition, there is some evidence that *T. fluminensis* is drought sensitive (Standish et al., in press), which may limit its biomass accumulation or, perhaps, its ability to establish (e.g. eastern Wairarapa, Howell et al. 2000). Its greatest impact on forest regeneration occurs in parts of those forest remnants where canopy cover is reduced and at the forest margins, where it grows most vigorously. At high biomass, *T. fluminensis* increases litter decomposition and alters nutrient cycling (Standish et al., unpubl. data). The particular characteristics of *T. fluminensis* enable it to affect the long-term viability of the lowland forest remnants it invades.

2.3 CURRENT CONTROL METHODS

Currently, chemical control by herbicides is considered the only practical means of controlling large infestations of *T. fluminensis* (McCluggage 1998; Tony McCluggage, pers. comm.; Chris Buddenhagen, pers. comm.). Manual weed removal is considered suitable for small infestations (Porteous 1993; Chris Buddenhagen, pers. comm), if care is taken to remove every last piece. A combination of physical and chemical removal methods has been used with success in Kitchener Park, Feilding, but has required repeated efforts to ensure continued control (Anon 1995). In heavily infested forest remnants, gaps left by manual or chemical removal of *T. fluminensis* are likely to be filled by other invasive species, which will hinder regeneration of native plants (Standish, unpubl. data). Invasion by other species on removal of a well-established invasive species is a common problem in ecological restoration of native communities (see examples in Hobbs & Mooney 1993). An alternative method that has been suggested to suppress *T. fluminensis* is shading by artificial or natural means (i.e. restoration planting) (Kelly & Skipworth 1984b; Stockard 1991; Maule et al. 1995; Standish et al., in press). In separate field trials, artificial shading was more effective than manual removal and herbicide application for sustained control of *T. fluminensis*, without invasion of other weeds; and restoration planting of three of four species tested showed potential as a means to enhance canopy cover over large areas (Standish, unpubl. data).

2.4 ADVANTAGES OF BIOLOGICAL CONTROL

Biological control could offer some advantages over current methods for the management of *T. fluminensis* (Fowler et al. 2000). Firstly, use of a host-specific biological control agent would reduce impacts on native flora, compared with the detrimental impacts of chemical herbicides (Chris Buddenhagen, pers. comm.). Secondly, once established at a site, a classical biological control agent is 'always on the job' and so may reduce the incidence of re-invasion (e.g. via streams) that hampers current control efforts (Michael Greenwood, pers. comm.; Gavin Scott, pers. comm.). Thirdly, in the event that a biological control agent became widespread, it would affect far more *T. fluminensis*-infested sites than the number able to be managed with chemical and manual removal methods (Chris Buddenhagen, pers. comm.) or for which restoration planting could be achieved.

3. Objectives

The objectives of this study were to:

- List the members of the Commelinaceae present in New Zealand that may be affected by a biological control programme against *T. fluminensis*.
- Summarise the literature and current information available from researchers worldwide on the potential for biological control of *T. fluminensis*.
- Assess the likelihood of success of a biological control programme for *T. fluminensis* in New Zealand, and review the steps and costs associated with such a programme.

4. Sources of information

Information for this report was obtained by searching computer databases (CAB abstracts, Current Contents) and Internet sites for information on *T. fluminensis*; cross-referencing; and contact with:

Dr Bruce Auld, Orange Agricultural Institute, Australia

Dr Robert Barreto, Departamento de Fitopatologia, Universidade Federal de Viçosa, (central east coast) Brazil

Chris Buddenhagen, Department of Conservation, Wellington

Prof. Raghavan Charudattan, Plant Pathology Department, University of Florida, USA

Dr John Dugdale, Landcare Research, Nelson

Dr Alan C. Eyles, Paraparaumu Beach

Clayson Howell, Department of Conservation, Wellington

Tony McCluggage, Department of Conservation, Whangarei

Dr Eric McKenzie, Herbarium, Landcare Research, Auckland

Michael Priest, Plant Pathology Herbarium, Orange Agricultural Institute,
Australia
John Sawyer, Dept of Conservation, Wellington
Dr Kálmán Vánky, Herbarium Ustilaginales Vánky (HUV), Germany
Dr Alfred Wheeler, Jr., Department of Entomology, Clemson University, USA
Dr Peter A. Williams, Landcare Research, Nelson
Dr Gregor Yeates, Landcare Research, Palmerston North.

5. Results

5.1 RELATIVES OF *Tradescantia fluminensis* IN NEW ZEALAND

The Commelinaceae belong to the Order Commelinales, which contains a further three families (Hutchinson 1959). There are no native Commelinales recognised in New Zealand (Moore & Edgar 1970), and the Liliales are the closest relative of the Commelinales with native representatives, e.g. *Astelia*, *Collospermum*, *Ripogonum* (Hutchinson 1959; Moore & Edgar 1970), though these are morphologically quite different from *T. fluminensis*.

Tradescantia fluminensis is the only species of the genus to have become established in New Zealand. *Tradescantia virginiana* L. has been collected as a 'persistent garden outcast on wasteland in Christchurch' but has not established in native communities (Healy & Edgar 1980; Landcare Research Herbarium 2001). Similarly, *T. cerinthoides* Kunth. is listed as an exotic species of New Zealand but is not naturalised (Landcare Research Herbarium 2001).

Ornamental *Tradescantia* spp. are available from at least eight retail outlets within New Zealand (Gaddum 1997). The plant most commonly available is *T. × andersoniana* W. Ludwig & Rohw. (Gaddum 1997), which is likely to have originated from *T. virginiana* L. × *T. obiensis* Raf. (Mabberley 1987). *T. spathacea* Sw. (syn. *Rhoeo discolor*), *T.* spp. "pale blue" and "Wilmot Rose" (Gaddum 1997) and, *T. zebrina* Bosse (syn. *Zebrina pendula*) (pers. obs.) are also available as ornamentals. Other Commelinaceae for sale as ornamentals are *Commelina coelestis*, *C. dianthifolia* and *Dichorisandra thyrsiflora* (Gaddum 1997).

In summary, there are no native or naturalised relatives of *T. fluminensis*, nor a significant trade of plants, that would preclude the use of a control agent with a genus- or family-specific host range.

5.2 POTENTIAL AGENTS FOR BIOLOGICAL CONTROL OF *Tradescantia fluminensis*

5.2.1 Vertebrates

Cattle and chickens are known to eat *T. fluminensis* (Timmins & Mackenzie 1995; Wilfred Henson, pers. comm.). *Tradescantia fluminensis* can disperse via cattle hooves (Ogle & Lovelock 1989) and, probably, chicken feet. This, coupled with the damage to other forest plants and to the soil that would result from their feeding, makes domestic stock unsuitable candidates for biological control.

5.2.2 Insects: pests and virus vectors

There are no reports of insect pests (in the sense that they cause damage to the plant) of *T. fluminensis* in New Zealand or Australia (Table 1), or field observations of damage to the plant in either country (pers. obs.; John Dugdale, pers. comm.; Bruce Auld, pers. comm.; Michael Priest, pers. comm.; query to the Ecological Society of Australia list server; query to the Australian Entomological Society list server). Leaves of *T. fluminensis* contain flavonoids (del Pero Martínez & Martínez 1993) which may deter generalist insect herbivores (Harborne & Williams 2000), but lead to adaptation of host-specialists. It is likely that any insect-plant association will be endemic to South America (the plant's natural range). We may expect to find Lepidoptera feeding on *T. fluminensis*, as a majority of this family are adapted to the flavonoids present in their food plants, and some even require them as a stimulant for oviposition (Harborne & Williams 2000). No information was found on insects associated with *T. fluminensis* from its native range, which may simply reflect a lack of research.

The most promising known insect candidate/s for biological control of *T. fluminensis* are several undescribed mirids (Hemiptera: Miridae) recorded on *Tradescantia* and *Commelina* spp. in the USA (Alfred Wheeler Jr., pers. comm.) but not recorded on *T. fluminensis* in New Zealand (Alan Eyles, pers. comm.) (Table 1). Their climate restrictions are unknown. The likely damage caused by mirids feeding on *T. fluminensis* would be malformation of new shoots (Eyles 1999) and so a reduction of biomass. The identified mirid listed in Table 1, *Pycnoderes medius*, is attracted to leaves damaged by a chewing insect (Johnson 1997); its success as a biocontrol agent may therefore depend on the actions of the chewing insect. Lastly, given that there are no economically significant Commelinaceae in New Zealand, the chrysomelids (Table 1) offer potential as biocontrol agents if damage to *T. fluminensis* was demonstrated.

5.2.3 Parasitic nematodes

The parasitic nematodes associated with *Tradescantia* (Table 2) have the potential to cause significant damage if the host is stressed (Gregor Yeates, pers. comm.). *Tradescantia fluminensis* may become stressed during dry summers (pers. obs.), but such conditions are probably unsuitable for a nematode population explosion (Gregor Yeates, pers. comm.). At three lowland forest remnants in the lower North Island, none of the plant-feeding nematodes associated with *T. fluminensis* appeared to damage the weed significantly (Yeates & Williams, in press). This evidence suggests that a successful biocontrol program for *T. fluminensis* using nematodes is unlikely.

TABLE 1. INSECTS REPORTED AS PESTS (i.e. CAUSE DAMAGE TO PLANT) OR VIRUS VECTORS ON COMMELINACEAE.

ORDER: FAMILY	SPECIES	LOCATION	REPORTED COMMELINACEAE HOST	SOURCE	DAMAGE	HOST RANGE	PRESENT IN NZ?
Coleoptera: Chrysomelidae	<i>Lema conctinnipennis</i>	Korea	<i>Commelina communis</i>	Choo et al. 1992	Leaf-feeding	?	No (Kusche1 1990)
	<i>Lema scutellaris</i>	China	<i>C. communis</i>	Zhang et al. 1996; Liu et al. 1999	Leaf-feeding	<i>C. communis</i>	No (Kusche1 1990)
	<i>Noelema sexpunctata</i>	New York	<i>C. communis</i>	Morton & Venc1 1998	Leaf-feeding	<i>Commelinaceae</i>	No (Richard Leschen, pers. comm.)
Diptera: Agromyzidae	<i>Liriomyza commelinae</i>	Jamaica	<i>C. diffusa</i>	Freeman & Smith 1990	Leaf-miner	<i>Commelina</i> spp. (Smith 1990)	No (Richard Toft, pers. comm.)
Hemiptera: Aphididae	<i>Myzus persicae</i>	Minnesota; Soviet Far East	<i>Tradescantia albiflora</i> , <i>T. blossfeldiana</i> , <i>T. fluminensis</i> , <i>T. navicularis</i> , <i>T. zebrina</i> & <i>Rhoeo discolor</i>	Lockhart et al. 1981; Tolkach et al. 1990	Deceminates potyvirus'—refer to Table 3	Polyphagous	Yes, vector for potato Y potyvirus in potato seed crops and in field tomato crops in NZ (Fletcher 1989; Cameron et al. 1992)
	<i>Rhopalosiphum padi</i>	Minnesota	<i>T. albiflora</i> , <i>T. blossfeldiana</i> , <i>T. fluminensis</i> , <i>T. navicularis</i> , <i>T. zebrina</i> & <i>Rhoeo discolor</i>	Lockhart et al. 1981	Deceminates potyvirus'—refer to Table 3	Polyphagous	Yes, vector for barley yellow dwarf luteovirus, which infects cereal crops in NZ (Farrell & Sward 1989; Farrell & Stufkens 1992)
Hemiptera: Berytidae	<i>Jalysus spinosus</i>	South Carolina	<i>T. hirsuticaulis</i>	Wheeler 1994	Feed on glandular hairs	Specialist on hairy plants	Not checked
Hemiptera: Miridae	<i>Pycnoderes medius</i>	Central Virginia	<i>C. communis</i>	Johnson 1997	Tissue necrosis	Native to northern midwest USA	No (Alan Eyles, pers. comm.)
	Spp. of two undescribed, related mirid genera	USA	<i>Tradescantia</i> and <i>Commelina</i> spp.	Alfred Wheeler Jr, pers. comm.	Tissue necrosis	<i>Tradescantia</i> and <i>Commelina</i> spp.	No mirids recorded on <i>T. fluminensis</i> in NZ (Alan Eyles, pers. comm.)
Lepidoptera: Arctiidae	<i>Estigmene acraea</i>	Nebraska	<i>T. occidentalis</i>	Wythers et al. 1993	Leaf-feeding	Polyphagous	No (Dugdale 1988)
Lepidoptera: Noctuidae	<i>Mouralia tinctoids</i>	USA	<i>T. fluminensis</i> , <i>T. zebrina</i>	Landolt 1993	Leaf-feeding, makes cocoons from leaves	Commelinaceae	No (John Dugdale, pers. comm.)

TABLE 2. PARASITIC NEMATODES ASSOCIATED WITH *Tradescantia*, PATHOGENICITY NOT DEMONSTRATED.

ORDER: SUBORDER	SPECIES	<i>Tradescantia</i> HOST, LOCATION*	SOURCE	POTENTIAL DAMAGE	DISTRIBUTION, HOST RANGE
Tylenchida: Aphelenchina	<i>Apbelenchoides fragariae</i>	<i>T. virginiana</i>	Goodey et al. 1965	Leaf damage, causes leaf malformation of strawberry (Choi et al. 1994)	Widespread pest of economic plants, e.g. ornamentals, strawberry (CAB Abstracts). Many plant-hosts in NZ, e.g. hen & chicken fern, orchid, lavender, strawberry (CAB Abstracts). Genus recorded under <i>T. fluminensis</i> in NZ (Yeates & Williams, in press)
	<i>Apbelenchoides ritzemabosi</i>	<i>T. albiflora</i> , NSW	Michael Priest, pers. comm.	Leaf damage	As for <i>A. fragariae</i>
Tylenchida: Tylenchina	<i>Meloidogyne incognita</i>	<i>T. fuscata</i>	Goodey et al. 1965	Root-knot	Many plant-hosts in NZ, e.g. onion, tomato, cyclamen, carrot, kumara (CAB Abstracts). Genus recorded under <i>T. fluminensis</i> in NZ (Yeates & Williams, in press)
	<i>M. spp.</i>	<i>T. dracaenoides</i> , <i>T. fluminensis</i> , <i>T. sp.</i>	Goodey et al. 1965	Root-knot	Genus recorded under <i>T. fluminensis</i> in NZ (Yeates & Williams, in press)
Various plant feeding		<i>T. fluminensis</i> , lower North Island, NZ	Yeates & Williams, in press	Root damage	

*The host list of Goodey et al. (1965) is a summary of worldwide information at the time.

5.2.4 Pathogens

Plant pathogens offer the most promising candidates for biocontrol of *T. fluminensis*, particularly fungal pathogens (Table 3; Raghavan Charudattan, pers. comm.; Robert Barreto, pers. comm.). Specifically, the rust *Phakosora tecta* (syn. *Physopella tecta*) has potential as a classical biological control agent (Raghavan Charudattan, pers. comm.), as it is specific to the Commelinaceae (Gjaerum 1984) and has been recorded on *T. fluminensis* in Hawaii, Puerto Rico & South America (Farr et al. 1989; Raghavan Charudattan, pers. comm.). It is likely that *P. tecta* would prosper in the New Zealand climate as it is similar to its cooler climate environs (i.e. northern Asia and southern South America) (Fullard & Darby 1979). *Uromyces commelinae* also has potential as a classical biological control agent, although its requirement for a second host to complete its life cycle may be a problem (Table 3; Jane Fröhlich, pers. comm.).

If a species-specific isolate of *Botrytis cinerea* exists on *T. fluminensis* in New Zealand, then it may offer potential as a biocontrol agent (Table 3), with the particular advantage that it is likely to persist in the New Zealand climate. *Septoria tradescantiae*, a fungus which causes leaf spot, is another potential biocontrol agent. It is specific to *Tradescantia*, although an association with *T. fluminensis* has not been demonstrated. *Septoria* species have proven ability as biocontrol agents for forest weeds, e.g. as classical biological control agents (Trujillo & Norman 1995) or mycoherbicides (Norman & Trujillo 1995). *Septoria tradescantiae* is found in inland regions of the United States (Farr et al. 1989) that experience temperature extremes (Skarratt et al. 1995), so the fungus could be expected to prosper in New Zealand's milder climate (Jane Fröhlich, pers. comm.).

Mycoherbicides are highly concentrated inoculums of fungal pathogen that are used against weeds in a similar manner to chemical herbicides (Hasan 1988). A fungus that does not offer potential as a classical biocontrol agent because it spreads slowly or is only effective under a narrow range of environmental conditions may offer potential as a mycoherbicide. A mycoherbicide can be applied where it is needed and it may be possible to formulate the fungus to persist in the environment until environmental conditions become suitable for infection and disease development. The Deuteromycotina (e.g. *Septoria*, *Alternaria*, *Cercospora*, *Fusarium* and *Colletotrichum* for use against *T. fluminensis*; Table 3) are particularly amenable to development as mycoherbicides as they are mostly facultative and can be grown easily on artificial media, which facilitates the mass production of the infective stage of the fungus (Hasan 1988). Improved efficacy of mycoherbicides can be achieved through experimentation with the method of application, e.g. plant wounding (Klein & Auld 1996), and/or integration with other methods of weed control, e.g. herbicides (Auld et al. 1997; Hoagland 1990) or restoration planting.

Of the viruses known to infect *T. fluminensis* (Table 3), the *Tradescantia albiflora* virus is the most suitable candidate for development as a biocontrol agent. However, the source of the virus is south-eastern Russia, which has a cool temperate climate (Fullard & Darby 1979), so the virus may not thrive in northern New Zealand. The use of viruses may also be prohibited by the lack of a known host-specific insect for transmission (Table 3).

TABLE 3. PLANT PATHOGENS OF *Tradescantia*.

PLANT PATHOGEN	CLASSIFICATION	SPECIES	<i>Tradescantia</i> HOST, LOCATION	SYMPTOMS	DISTRIBUTION, HOST RANGE—NOTES	SOURCE
Bacteria		<i>Pseudomonas andropogonis</i>	<i>T. sp.</i>	Leaf spot, can lead to reduced vigour	Wide host range (e.g. maize, clover, chickpea) but isolates have narrow host range (Kobayashi et al. 1995). Recorded on <i>Dianthus caryophylls</i> in NZ (Pennycook 1989)	Bradbury 1986
Fungi	Mastigomycotina - Chytridiomycetes	<i>Cladochytrium replicatum</i> (syn. <i>C. nowakowskii</i>)	<i>T. fluminensis</i> , Florida	Grows on leaves	N & S America, Europe; <i>Eriocaulon</i> , <i>Tradescantia</i>	Farr et al. 1989
	Mastigomycotina - Oomycetes	<i>Phytophthora sp.</i>	<i>T. spathacea</i> , Florida	Root and stem rot. <i>Phytophthora</i> literally means 'plant destroyer'	<i>Phytophthora palmivora</i> active ingredient of the commercial mycoherbicide 'De Vine' (Hasan 1988)	Farr et al. 1989
		<i>Pythium aphanidermatum</i>	<i>T. zebrina</i> , Florida	Root rot	Cosmopolitan; wide host range	Farr et al. 1989
		<i>Pythium sp.</i>	<i>T. fluminensis</i> , Hawaii; <i>T. spathacea</i> and <i>T. sp.</i> , Florida	Root rot		Farr et al. 1989
	Zygomycotina	<i>Actinomucor elegans</i>	<i>T. zebrina</i> , Montana	?	Widespread; <i>Zea</i> , <i>Zebrina</i> (syn. <i>Tradescantia</i>)	Farr et al. 1989
	Basidiomycotina - Uredinales	<i>Uromyces commelinae</i>	<i>T. sp.</i> , Texas; <i>T. zebrina</i> , Florida	Rust	Cosmopolitan (Farr et al. 1989), but not present in NZ (McKenzie 1998; Eric McKenzie, pers. comm.); heteroecious (2 hosts): telial host Commelinaceae, aecial host <i>Cissus</i> and <i>Vitis</i> spp. (Gjaerum 1984; Farr et al. 1989). A potential biocontrol agent for <i>Commelina erecta</i> , a weed of vegetable crops in Argentina (dal Bello et al. 1995)	Farr et al. 1989
		<i>Pbkosora tecta</i> (syn. <i>Physopella tecta</i>)	<i>T. fluminensis</i> , Hawaii, Puerto Rico and South America	Rust	Widespread in Asia, Central and South America (Gjaerum 1984), not present in NZ (McKenzie 1998; Eric McKenzie pers. comm.); Commelinaceae (Gjaerum 1984)	Farr et al. 1989; Raghavan Charudattan pers. comm.

Table 3 *continued.*

PLANT PATHOGEN	CLASSIFICATION	SPECIES	<i>Tradescantia</i> HOST, LOCATION	SYMPTOMS	DISTRIBUTION, HOST RANGE—NOTES	SOURCE
	Basidiomycotina - Ustilaginales	Various <i>Ustilago</i> spp.	Various Commelinaceae excl. <i>T.</i> spp.	Seed damage	First descriptions of these spp.	Vanky 1994; Kalman Vanky, pers. comm.
	Deuteromycotina - Eumycota	<i>Epicoccum nigrum</i> (syn. <i>E. purpurascens</i>)	<i>T. albiflora</i> , NSW	Leaf spot	Wide host range, saprophytic & can inhibit growth of other fungi (CAB Abstracts)	Michael Priest pers. comm.
	Deuteromycotina - Hyphomycetes	<i>Alternaria</i> sp.	<i>T. fluminensis</i> , <i>T. spathacea</i> and <i>T. sp.</i> , Florida	Leaf spot	<i>Alternaria</i> spp. are reputed potential biocontrol agents (Aneja & Sing 1989; Nehl & Brown 1992; Winder & Watson 1994; Hoagland 1995; Lawrie et al. 2000)	Farr et al. 1989
		<i>Botrytis cinerea</i>	<i>T. fluminensis</i> , Alaska; <i>T. sp.</i> , Florida	Gray mold leaf blight	Cosmopolitan; many of the morphologically indistinct conidia states are plurivorous, while others have restricted host ranges	Farr et al. 1989
		<i>Cercospora</i> sp.	<i>T. fluminensis</i> , Florida	Leaf spot	Some evidence for <i>C.</i> spp. as potential biocontrol agents (Grossman 1989; Martinez-Jimenez 1996; Ribeiro 1997; Barreto et al. 1999)	Farr et al. 1989
		<i>Cercospora zebrina</i>	<i>T. zebrina</i> , Florida	Leaf spot	Northern Hemisphere to Africa, South America; <i>Agropyron</i> , <i>Medicago</i> , <i>Melilotus</i> , <i>Trifolium</i> , <i>Zebrina</i> (syn. <i>Tradescantia</i>)	Farr et al. 1989
		<i>Curvularia eragrostidis</i>	<i>T. spathacea</i> , Florida	Tan leaf spot	Subtropical and tropical regions; <i>Alysicarpus</i> , <i>Gossypium</i> , <i>Opuntia</i> , <i>Oryza</i> , <i>Pennisetum</i> , <i>Tradescantia</i> , <i>Zea</i>	Farr et al. 1989
		<i>Curvularia</i> sp.	<i>T. pallida</i> , Florida	Leaf spot		Farr et al. 1989
		<i>Fusarium</i> sp.	<i>T. sp.</i> , Florida	Root rot	<i>F. tumidum</i> isolate a candidate mycoherbicide for gorse and broom in NZ (Morin et al. 2000), also <i>F. moniliforme</i> for jimsonweed in USA (Abbas et al. 1991)	Farr et al. 1989
		<i>Myrothecium</i> sp.	<i>T. sp.</i> , Florida	Leaf spot	<i>Myrothecium</i> infects vegetable crops in India (Srivastava 1997)	Farr et al. 1989

Table 3 continued.

PLANT PATHOGEN	CLASSIFICATION	SPECIES	<i>Tradescantia</i> HOST, LOCATION	SYMPTOMS	DISTRIBUTION, HOST RANGE—NOTES	SOURCE
		<i>Ramularia</i> sp.	<i>T.</i> sp., Florida	Leaf spot		Farr et al. 1989
	Deuteromycotina - Coelomycetes	<i>Colletotrichum falcatum</i>	<i>T. zebrina</i> , Florida	Anthracnose	Subtropical and tropical regions; wide host range, including sugar cane	Farr et al. 1989
		<i>Colletotrichum</i> sp.	<i>T. fluminensis</i> , <i>T. spatbacea</i> , <i>T. zebrina</i> and <i>T.</i> sp., Florida. <i>T. fluminensis</i> , Texas and <i>T. virginiana</i> , New Jersey	Anthracnose, crown rot, leaf spot	<i>Colletotrichum</i> sp. have been developed as mycoherbicides (Hoagland 1990; Winder & Watson 1994; Norman & Trujillo 1995)	Farr et al. 1989
		<i>Phyllosticta</i> sp.	<i>T. spatbacea</i> and <i>T.</i> sp., Florida. <i>T. subaspera</i> , Wisconsin	Leaf spot		Farr et al. 1989
		<i>Septoria tradescantiae</i> (syn. <i>Cylindrosporium tradescantiae</i>)	<i>T.</i> sp. in states of Central USA, Iowa and South Dakota; <i>T. virginiana</i> , states of Central USA and South Dakota	Leaf spot	Temperate North America; <i>Tradescantia</i> only known host. <i>Septoria</i> spp. are potential biological control agents (Giannopolitis & Chrysayi 1989; Hershenhorn et al. 1993), including three for forest weeds in Hawaii (Trujillo et al. 1994; Trujillo & Norman 1995; Gardner 1999). <i>S. tradescantiae</i> not recorded in NZ (Pennycook 1989)	Farr et al. 1989
	Deuteromycotina - Agonomycetes	<i>Rhizoctonia solani</i>	<i>T. spatbacea</i> , <i>T. zebrina</i> and <i>T.</i> sp., Florida	Leaf blight, basal stem, stem and root rot	Cosmopolitan; wide host range	Farr et al. 1989
		<i>Rhizoctonia</i> sp.	<i>T. fluminensis</i> , North Carolina	Root rot		Farr et al. 1989
		<i>Sclerotium rolfsii</i>	<i>T. tricolour</i> , Nagaland, India; <i>T. zebrina</i> , Hawaii	Stalk rot	Widespread. Fungi are placed in this genus because they only produce sterile mycelium (hyphae mass) and sclerotia (Farr et al. 1989)	Daiho et al. 1988; Farr et al. 1989

Table 3 continued.

PLANT PATHOGEN	CLASSIFICATION	SPECIES	<i>Tradescantia</i> HOST, LOCATION	SYMPTOMS	DISTRIBUTION, HOST RANGE—NOTES	SOURCE
Viruses	potyvirus	Bean yellow mosaic virus-BV	<i>T. albiflora</i> / <i>T. fluminensis</i> , manual inoculation Virginia	Vein-clearing, necrotic lesions, stunting	Wide host range. This virus infects lentil crops in NZ (Fletcher 1993)	Hunst & Tolin 1982
	potyvirus	Clover yellow vein virus	<i>T. albiflora</i> (syn. <i>T. fluminensis</i>), manual inoculation USA	?	This virus infects clover (<i>Trifolium repens</i>) in NZ (Bryan et al. 1992)	Baker & Zettler 1988
		Cucumber mosaic cucumovirus (syn. Cucumber mosaic virus)	<i>T. elongata</i> , Brazil	?	Species-specific isolate? Virus present in tomato, broad-bean and lentil crops in NZ (Cameron et al. 1992; Fletcher 1993)	Duarte et al. 1994
	nepovirus	Tomato ringspot virus	<i>T. andersoniana</i> , Lithuania	Mosaic, yellow stripe	Widespread and wide host range (e.g. grapes)	Navalinskiene & Samuitiene 1999
	potyvirus	<i>Tradescantia albiflora</i> virus	<i>T. albiflora</i> (syn. <i>T. fluminensis</i>), Russia (naturally)	Mosaic, mottling	Recently described	Tolkach et al. 1990; Gnutova & Tolkach 1998
	potyvirus	<i>Tradescantia</i> / <i>Zebrina</i> potyvirus	<i>T. albiflora</i> , <i>T. blossfeldiana</i> , <i>T. fluminensis</i> , <i>T. navicularis</i> and <i>T. zebrina</i> , manual inoculation Minnesota; <i>T. albiflora</i> and <i>T. fluminensis</i> , Florida (naturally)	Mosaic, leaf distortion and stunting	<i>Rhoeo discolor</i> suitable host, other Commelinaceae not suitable hosts in laboratory trials: <i>Setcreasea pallida</i> , <i>Chlorophytum comosum</i> , <i>Commelina elegans</i> and <i>C. diffusa</i> (Lockhart et al. 1981)	Lockhart et al. 1981; Baker & Zettler 1988

5.3 PROSPECTS FOR ACHIEVING SUCCESSFUL BIOLOGICAL CONTROL OF *Tradescantia fluminensis*

At first glance, the inadequacy of pests and pathogens evident within its native range, and the apparent lack of any significant invertebrate or pathogen associations with *T. fluminensis* in New Zealand or eastern Australia, indicate little immediate prospect for achieving successful biological control of *T. fluminensis*. Experience with other weed biological control programmes, however, indicates that it is unusual for there to be immediate prospects (Pauline Syrett, pers. comm.). There are no active biological control programmes for *T. fluminensis* overseas, though Dr R. Barreto has indicated his intent to instigate such a programme in Brazil using pathogens (Robert Barreto, pers. comm.), and people and agencies in eastern Australia and Florida may be interested in a collaboration with New Zealand. Several prospects are available that require further research for development as biological control agents against *T. fluminensis* in New Zealand. The rust-causing pathogen *Phakosora tecta*, and undescribed mirid/s offer potential as classical biological control agents. If *Septoria tradescantiae*, a fungus which causes leaf-spot, does not occur in New Zealand (as the literature suggests) then it could be introduced as a classical biocontrol agent. If, however, *S. tradescantiae* was found during a survey of pathogens in New Zealand, then it could be developed as a mycoherbicide.

6. Conclusions and recommendations

The next step in assessing the potential for biocontrol of *T. fluminensis* would be to survey the invertebrate and pathogen fauna associated with the weed in New Zealand, and to record any damage to the plant resulting from these associations. It seems unlikely that a highly virulent, widespread pathogen already exists in New Zealand, but a less conspicuous fungal pathogen may be present and could be developed as a mycoherbicide. The survey would also ensure that agents that have already established in New Zealand were not considered for importation as classical biological control agents (Jane Fröhlich, pers. comm.).

The next step would be to survey *Tradescantia* species in Brazil, and to record any damage to the plants resulting from pathogens and insects. One aim of this survey would be to describe the damage caused by *Phakosora tecta*. This survey would require a minimum of two researchers (i.e. a plant pathologist and an entomologist) and would cost approximately \$75 000–100 000. Climate may be an important determinant of the success of a pathogen or insect biological control agent sourced elsewhere and released in New Zealand (Williams 1985; McClay 1996; Maywald & Sutherst 1997), though there are exceptions (McFadyen 1985). The climate, including total rainfall, rain pattern, maximum,

minimum and mean temperature, of southern Brazil matches northern New Zealand (Skarratt et al. 1995). As central and northern Brazil experience higher temperatures than New Zealand, the initial focus of the survey could be southern Brazil. The identification of the insects and pathogens collected is likely to cost more, take longer and require additional researchers (i.e. taxonomists). Costs would be reduced if a collaboration with Dr R. Barreto was initiated.

An alternate option is to visit the United States to identify and determine the suitability of the mirid/s and the pathogen, *S. tradescantiae*, as biocontrol agents. The states in which *T. fluminensis* has been recorded (Farr et al. 1989; Wunderlund 1998) and which experience a similar climate to New Zealand, include the coastal regions of north-west Florida and North Carolina (Skarratt et al. 1995). These regions could be the focus of a search for the mirid/s, to identify the species and document the host-plant associations and the damage it/they caused. An association of *S. tradescantiae* with *T. fluminensis* needs to be demonstrated and also its virulence. Their distributions, based on present records, do not overlap, but it would be worth searching inland populations of *T. fluminensis* in north-west Florida and North Carolina for *S. tradescantiae*. In total, this option would also require a plant pathologist and an entomologist and would cost approximately \$100 000–125 000, unless a student project was funded on site.

For the overseas biocontrol candidates, an assessment of their efficacy as potential biocontrol agents *in situ* should allow fairly accurate predictions to be made regarding their likely success in New Zealand (Hasan 1988). Such assessments would eliminate all but the most likely candidate/s and so reduce the number of imports into New Zealand. Beyond these early stages, the costs of developing a biocontrol programme will depend on the candidate selected, e.g. the development and use of a commercial standard mycoherbicide is likely to be more costly than development and use of a classical biocontrol agent.

There are two matters to consider regarding the prospects for successful biological control of *T. fluminensis*. First, like chemical and manual control methods, biological control addresses the symptom rather than the cause of weed invasion. Therefore, biological control may effectively manage *T. fluminensis* but not the problem of other weeds that are likely to invade with a reduction of *T. fluminensis* (e.g. *Hedychium gardnerianum*, *Selaginella kraussiana*). However, the gradual reduction of *T. fluminensis* that is likely to occur with biological control (Fowler et al. 2000; Jane Fröhlich, pers. comm.), may reduce the chance of re-infestation by other weeds. Moreover, an integrated approach to weed control (Groves 1991) by using, for example, biological control and restoration planting, may assure greater success than application of either method in isolation.

In general, the margins of forest remnants are likely to remain weedy unless 'armoured' with vegetation (Peter Williams, pers. comm.), so it may be pointless to remove *T. fluminensis* from this zone of the forest remnant, other than to ensure it does not spread further. Further into the forest, where light levels are reduced relative to the edges, *T. fluminensis* does not prevent seedling establishment (Standish et al., in press), and so it is unnecessary to remove it from this zone. However, there is a 'middle' zone between the margin

and the middle of the forest where the removal of *T. fluminensis* could improve forest regeneration without invasion of other weeds (Peter Williams, pers. comm.). Where extensive canopy damage leads to dense *T. fluminensis*, the middle zone extends throughout the forest remnant.

The second matter to consider is that a biological control agent needs to be able to reduce the standing biomass of *T. fluminensis* to less than 200 g/m² to allow regeneration of tolerant native species (e.g. *Dysoxylum spectabile*) and, ideally, to lower levels, as native seedling species richness and abundance increase with decreasing *T. fluminensis* biomass (Standish et al., in press). *Tradescantia fluminensis* attains a biomass of 800 g/m² at maximum, i.e. at forest margins, and less than this in the 'middle' zone. This reduction of 75% of plant mass seems a realistic goal for a biological control programme in view of the documented success in biological control of weeds by arthropods. For example, the apionid weevil, *Trichapion lativentre*, caused a 60% reduction in the vegetative growth of the perennial legume *Sesbania punicea*, by feeding on the leaflets and meristems (Hoffmann et al. 1990). The chrysomelid beetle, *Leptinotarsa texana*, completely curtailed the vegetative growth of silver-leaf nightshade, *Solanum elaeagnifolium*, resulting in reduced shading of crops (Hoffmann et al. 1998).

In conclusion, *T. fluminensis* is a good candidate for biological control because it is widespread, and the risk of non-target effects are minimal to non-existent. Several prospects are available that require further research for development as biological control agents against *T. fluminensis* in New Zealand. Reducing both the weed's biomass and re-invasion by other weeds are the biggest challenges for a biocontrol programme to overcome.

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