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Impact of *Sphagneticola trilobata* on Plant Diversity in Soils in South-East Viti Levu, Fiji

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Abstract: Wedelia (*Sphagneticola trilobata* (L.) Pruski) has become one of the most dominant invasive plant species in Fiji. However, the soil seed bank of its monospecific stand and its ability to reproduce by seed is relatively unknown. A soil seed bank study was undertaken in a monospecific stand of *S. trilobata* in Sawani, Natavea and Wainivesi in south-east Viti Levu, Fiji in March 2012. The soil samples were collected from within 1.0 m^2 quadrat taken at 10 spots in each of the study areas and spread thinly over a base of Yates Thrive Premium potting mix in seedling trays and placed in a glasshouse at Koronivia Research Station, Fiji. A total of 23, 26 and 33 plant species were found in the soil seed bank in Wainivesi, Sawani and Natavea respectively which may have succumbed to *S. trilobata* invasiability. There were ca. 3,800 (17%), 2,100 (11%) and 2,600 (6%) germinable *S. trilobata* seeds·m^{-2} in the soil seed bank in Wainivesi, Sawani and Natavea areas respectively. This study has demonstrated that *S. trilobata* seeds may have a role in the spread of the invasive species in Fiji and movement of soil to *S. trilobata* free areas should be restricted.

Key words: *Sphagneticola trilobata*, wedelia, Fiji, soil seed bank, quadrat, invasive.

1. Introduction

((*Spagneticola trilobata* (L.) Pruski); Asteraceae) is native to Mexico, Central America, and the Caribbean and has been introduced widely to tropical and sub-tropical regions of the world including the Pacific Islands [1, 2]. In the Pacific Island countries and territories, *S. trilobata* is established in American Samoa, Northern Mariana Islands, Cook Islands, Federated States of Micronesia, Fiji, French Polynesia, Guam, Hawaii, Kiribati, Kingdom of Tonga, Marshall Islands, Nauru, New Caledonia, Niue, Palau, Samoa and Tokelau [2]. *S. trilobata* is commonly known as wedelia, creeping ox-eye, Singapore daisy and trailing daisy [2]. It is usually introduced as an ornamental plant, attributed to its fleshy green leaves and bright yellow flowers [3]. It is a perennial creeper that forms dense thickets of inter-winning stems that shoots and roots at the nodes [4]. The invasive species spreads vegetatively and encroach the neighbouring area easily and at a rapid rate. According to Batianoff & Franks [5], the highest rate of spread of *S. trilobata* in Australia was recorded at 167 km·$year^{-1}$.

From an observation on cultivated *S. trilobata* in Hawaii, it was reported that *S. trilobata* matured achenes were 4-5 mm long [4]. Similarly, the risk assessment for *S. trilobata* prepared for Australia was silent on the seed reproduction capability of the species [2]. Based on a published literature on biology of non-native plants in natural areas in Florida, *S. trilobata* fruit is a tiny, brown, pimpled achene, ca. 5 mm in length [6]. All these authors neither reported the production capacity nor the fertility of *S. trilobata* achenes. This suggests that there is a gap in knowledge on the seed biology of *S. trilobata*. However, the reproductive potential of *S. trilobata* may have played a substantial role in the success of its naturalization and invasion as occurred in a related species, *Mikania micrantha* H.B.K. [7]. Furthermore, factors influencing the number of propagules

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produced, mode of spread and rate of recruitments and deaths contribute in the spread of invasive species [8].

S. trilobata was thought to have been introduced into Fiji in mid-1970s [9]. However, it did not take long to colonise road sides, river banks, drains, pasture fields and vacant lands in major islands in Fiji [9] (personal observation). *S. trilobata* has extended its boundary to cropping areas and was found as a new weed of taro (*Colocasia esculenta* L. Schott) in the taro production areas in south-east Viti Levu [10]. In Taveuni Island Fiji, *S. trilobata* was found infesting a taro farm in the southern side of the island in October 2012 (personal observation). It has very wide ecological tolerance range and found to be equally suited to dry and moist sites and seemed to grow very well on almost all soil types [2]. Based on its ecological significance, *S. trilobata* was considered one of the "100 World's Worst Invasive Alien Species" [11].

According to Meyer 2000 [3], wedelia is one of the most significant dominant invasive plant species in most of the Pacific islands. The presence of invasive plant species such as *S. trilobata* in the islands terrestrial ecosystem poses a major threat to the biodiversity of a given community and ecosystem functions [12, 13]. *S. trilobata* was found to prevent regeneration of co-occurring species and damage riverbanks and wastelands [14]. This could have been attributed to the allelopathic effect of *S. trilobata* leachates and residues that caused substantial reduction in germination and growth rate of tested crop and native plants in China [15, 16]. Furthermore, the high concentration of CO_2 found to cause greater growth stimulation in *S. trilobata* as compared to its native congener, (*Wedelia chinensis* (Osbeck.) Merr.) in southern China [17].

One of the reasons *S. trilobata* is more aggressive and dominant in the invaded region is because of the lack of natural enemies which are capable of controlling its population growth [18-20]. However, *Cuscuta australis* R. Brown, a holoparasitic rootless annual plant found to decrease the growth and nutrient content of *S. trilobata* in a field study in China had been recommended as a potential biological control for the invasive species [14]. *Cuscuta* species have been observed on *S. trilobata* in some sites in Viti Levu Fiji (personal observation). According to Englberger [21], *S. trilobata* is controlled by repeated physical removal of the plants but this method is labor intensive. Herbicide found to be effective on *S. trilobata* was metsulfuron methyl herbicide (600 g/kg) and has been registered for controlling the weed in Australia [22]. In Fiji, metsulfuron methyl herbicide has been recommended for the control of *S. trilobata* [23]. Other herbicides found to have had some effect were dicamba and 2,4-D [24], triclopyr (Garlon 4) and glyphosate (Roundup) [21].

There is insufficient data on impacts of invasive species in the PICs and strong recommendation was made for research to be undertaken on the assessment of the impacts of invasive species on the biodiversity of island ecosystems [25]. *S. trilobata* is a threat to the ecosystem because of its ability to easily colonise an area however, the soil seed bank of a monospecific stands of *S. trilobata* and its effect on plant diversity is relatively unknown.

The presence of a seed bank is essential for the life cycle of many plant species [26, 27]. The soil seed bank is "plant biodiversity in storage" and provides the future re-establishment of variation back into the ecosystem [28]. However, the dominance of a particular invasive plant would deplete seed production of other neighboring species and may reduce the genetic diversity of the community [29, 30]. Therefore, the aim of this study was to determine if *S. trilobata* is present and if it does, its density relative to co-occurring plant species in the soil seed bank community, underneath monospecific stands of *S. trilobata*, with a view to better understand its invasiveness and to identify better management practices in cropping areas of Fiji. A positive outcome is evidence that *S. trilobata* can produce fertile seeds.

This study may also reveal plant species that *S. trilobata* may have displaced, i.e., the history of the site and the potential future plant community if *S. trilobata* is controlled.

2. Materials and Methods

2.1 Study Site

Three *S. trilobata* infested fields in Sawani (18°02'S; 178°28'E), Natavea (18°04'S; 178°34'E) and Wainivesi (17°47'S; 178°31'E) in south-east Viti Levu were identified. Each study site has a measurement of approximately 50 m × 50 m of > 95% monospecific stand and > 30 cm dense thickets of *S. trilobata*. A zig-zag method of sampling and the use of quadrats (1.0 m^2) (method modified from that described by Colbach et al. [31] and Mehdi et al. [32] was employed to collect soil samples for soil seed bank assessment. The first quadrat was placed on a spot ca. four walking paces from the top left-hand corner towards the central part of the study site. Within the quadrat, the weed spectrum was assessed and recorded before soil was collected using a soil corer (each 5.5 cm in diameter and 8 cm deep), from each of the four corners and one from the centre of the quadrat. The same were done on the remaining nine quadrats on spots c. 20 walking paces from the preceding spot along a zig-zag imaginary line covering the central and the edges of the study site. The soil samples collected from each quadrat were placed into separate plastic bag and transported to Koronivia Research Station (KRS) where they were processed immediately.

2.2 Data Collection

The soil samples in each bag were thoroughly mixed and spread thinly (< 1 cm deep) over a base of “Yates Thrive Premium” potting mix (> 2 cm deep) on paper towels in seedling trays (52 cm × 36 cm × 10 cm; l/w/h) that were marked and placed on the benches in a glasshouse at KRS. The soil seed bank in these samples was estimated by counting the viable seeds germinating from the soil seed bank tray. The soil samples were subjected to conditions favorable for seed germination. Five additional trays, filled only with “Yates Thrive Premium” potting mix, were used as controls to detect any seed in the potting compost or in the glasshouse environment.

The thin layering of the soil sample spread over the potting mix in the tray was undertaken to enhance the possibility of germination of the viable seeds present in the sample. Daily observations made on newly emerged seedlings and all trays were watered to field capacity when required. The emerged seedlings were counted, identified and then removed from the seedling tray. Unidentified seedlings were removed from the trays and transplanted into separate pots and grown to maturity so that they could be identified at a later date using taxonomical keys and field guides (Plants of the Fiji Islands [33], Flora Vitiensis Nova [34], Wayside Plants of the Islands [35], Pacific Island Ecosystem at Risk [2]). In the first two months, daily inspection of newly emerged seedlings were undertaken to ensure no plants died between counting periods. Two months later, soil in the trays were allowed to dry, then their contents stirred to stimulate the germination of any remaining deeply buried seeds. At the end of the sixth month, the experiment was terminated as three months was considered sufficient for most viable seeds to germinate [36].

2.3 Data Analysis

The species richness (that is, the number of species present) and density were analysed for each rep in each site. To test if there was any variation in germinable seeds and species richness in the soil seed bank of the three study sites, a one way ANOVA was undertaken. The data were analysed using STATISCA 10.0-2010. The mean values were separated by using the Fisher’s Least Significant Difference test at $P < 0.05$.

3. Results and Discussion

3.1 Sphagneticola trilobata Germinable Seed Bank

The germinable *S. trilobata* seed in the soil seed bank under *S. trilobata* monospecific stand in the three study sites were significantly different ($F_{2,27}$ = 3.97; $P < 0.05$) (Fig. 1). The germinable *S. trilobata* seed in Wainivesi (3,839 m^{-2}) was significantly greater than those recorded in Natavea (2,551 m^{-2}) and Sawani (2,088 m^{-2}) sites (Fig. 1). There was no significant difference between the germinable *S. trilobata* seed in Natavea and Sawani (Fig. 1). The greater size of the *S. trilobata* seed bank in Wainivesi suggests that this species may have been introduced and established in this site earlier than in Sawani and Wainivesi. Similar results have been demonstrated on other species [36]. This is supported by the fact that the *S. trilobata* infestation in Wainivesi was much denser and has colonized a larger area than the other two sites.

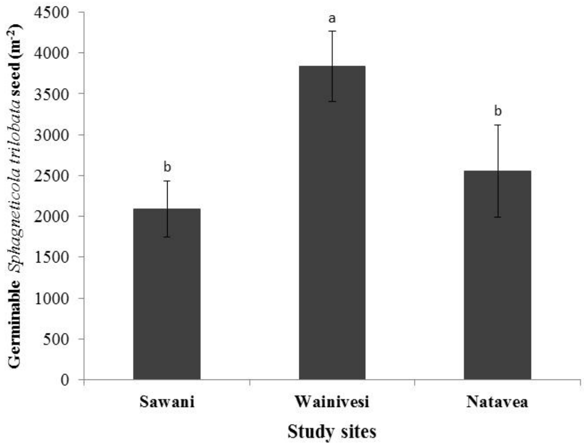

Fig. 1 The germinable *S. trilobata* seed in the soil seed bank under *S. trilobata* monospecific stand in Sawani, Wainivesi and Natavea in south-east Viti Levu. Samples were collected in March 2012. Vertical bars with same letters are not significantly different at *P* < 0.05 and error bars show two standard errors around the mean from ten replicates.

3.2 S. trilobata vs Overall Seed Bank

There was a significant difference between the study sites in the proportion of *S. trilobata* seed in the overall germinable seed bank (m^{-2}) ($F_{2,27}$ = 4,059; $P <$ 0.05). The proportion of *S. trilobata* germinable seed in the overall germinable seed bank (m^{-2}) in Wainivesi and Sawani were both significantly greater than the one in Natavea (Fig. 2). It appeared that there was an inverse correlation between the proportion of *S. trilobata* germinable seeds in the overall seed bank and the species richness in the three study sites (Fig. 2). This relationship may have been attributed to the variation in residence time of *S. trilobata* in the three sites [37]. This implies that long residence time of *S. trilobata* reduces species richness of the infested site.

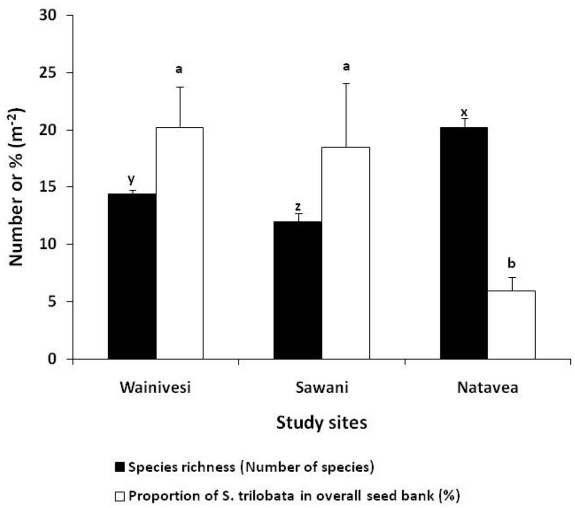

Fig. 2 The species richness (mean number of species present) and the proportion (%) of germinable *S. trilobata* seed in the overall seed bank (m^{-2}) under *S. trilobata* monospecific stand in Wainivesi, Sawani, and Natavea in south-east Viti Levu. Vertical bars with same letters are not significantly different at *P* < 0.05 and error bars show two standard errors around the mean from ten replicates.

The plant species found in the study site at Natavea belonged to 17 families and 16 families each were found in Sawani and Wainivesi study sites respectively (Table 1). The germinability of the soil seed bank in Natavea was the highest (42,376 seeds·m^{-2}), followed by Wainivesi (22,585 seeds·m^{-2}) and then followed by Sawani site (19,925 seeds·m^{-2}). The greater size of the seed bank in Natavea suggests that most of these species may have been present in this site longer than in Sawani and Wainivesi as demonstrated in other studies [37]. The Natavea site is located closer to the mouth of the river than the other two sites. Most invasive plant species establishment is more pronounced at the bottom than the upper part of the river system [36]. In addition, the probability of spread and establishment of an invasive species is much greater in older than newly invaded sites [37].

Apart from *S. trilobata*, none of the species found in the present soil seed bank study were observed on the above-ground plant community in the three study sites. This suggests that the dense thickets of *S. trilobata* stems, foliages and litter may have prevented the growth of species in the soil seed bank. In other studies, plant litters have contributed to the patterns of establishment and growth of species in the soil seed bank by reducing their germination and seedling growth [38, 39]. In addition, the allelopathic effect of *S. trilobata* residues may have contributed to the demise of several species from the three study sites as occurred on tested native and crop plant species in China [15, 16].

S. trilobata was thought to have been introduced into Fiji via Suva (Capital) in mid-1970s and later spread to other parts of Fiji [9]. Majority of other species found in the soil seed bank have been reported in Fiji much earlier [34]. This suggests that some of the plant species found in the current soil seed bank study may have been members of the above ground plant community before the invasion of *S. trilobata*. This study has demonstrated that *S. trilobata* has a strong negative impact on plant diversity by displacing up to 33 plant species from an area. Furthermore, it provides an additional scientific evidence to justify the need to prevent the introduction of *S. trilobata* into non-infested areas in Fiji and eradicate it from areas with low infestations.

3.3 Predominant Species

Pilea microphylla (L.) Liebm. was the most dominant species in the soil seed bank under *S. trilobata* monospecific stand in the three study sites followed by *Ludwigia octovalvis* (Jacq.) Raven., *S. trilobata* and *Cyperus rotundus* L. (Table 1). However, *Oldenlandia corymbosa* L. recorded the highest density of ca. 14,800 germinable seeds m^2 (35%) in Natavea site. *L. octovalvis* and *S. trilobata* were the two most frequently occurring species as they were present in all the 30 quadrats sampled in the three sites (Table 1). In a similar study conducted on taro crops in south-east Viti Levu, *Ludwigia* sp. was the most dominant species and one of the most frequently occurring species in the above ground weed survey in taro and banana cultivation areas in the south-east region of Viti Levu [40]. This suggests that *Ludwigia* spp. is widespread in both cultivated and non-cultivated areas in Viti Levu.

Habitat disturbance is the major cause of biodiversity degradation [41], and non-native species found to invade disturbed areas rather than the undisturbed areas [42, 43]. Conservation of plant biodiversity in many parts of the world have been threatened by the invasion of non-native plants [36]. This concurs with result of the current study that the soil seed bank under monospecific stands of *S. trilobata* in the three sites have been exclusively dominated by non-native species. However, this may be attributed to the nature of the study sites which is near the river and prone to occasional flooding, the result is expected. In addition, the soil seed bank in the three study sites is supported by a variety of life forms ranging from very small sized herbs and vines to shrubs (Table 1). Unless *S. trilobata* is controlled, these species would find it very difficult to survive and complete their life cycle underneath the dark and dense thickets of *S. trilobata* stand as found in other dominant species in the islands ecosystem [43, 44].

4. Conclusions

The current study has not only revealed that *S. trilobata* produces viable seed but also demonstrated that the invasive species has a large seed bank in the soil it has invaded. In its invasion process, *S. trilobata* has displaced many plant species in the study sites. This study has demonstrated that *S. trilobata* seeds

Table 1 The top ten germinable soil seed bank in each of the *Sphagneticola trilobata* monospecific stand in Sawani, Wainivesi and Natavea in south-east Viti Levu Fiji. Samples were collected in March 2012 and the data are the means of 10 replicates.

Plant species	Family	Sawani	Wainivesi	Natavea	Frequency (%)	Life form*	Reproduction*[a]	Origin*
		Mean density (m^{-2})						
Oldenlandia corymbosa L.	Rubiaceae			14,799	57	A herb	S	Tropical Africa, Madagascar, India
Pilea microphylla (L.) Liebm.	Urticaceae	9,748	5,590	5,320	97	A herb	S, V	Florida (USA), West Indies & Mexico, South America
Ludwigia octovalvis (Jacq.) Raven.	Onagraceae	3,401	3,788	4,217	100	P shrub	S, V	Micronesia
Cardamine hirsuta L.	Brassicaceae	3,224			27	A herb	S	Europe, African, Asia
Sphagneticola trilobata (L.) Pruski)	Asteraceae	2,088	3,839	2,551	100	P herb	V, S	Mexico, Central America & Caribbean
Mikania micrantha H.B.K.	Asteraceae	337	909		83	P herb	S, V	Central & South America
Cyperus rotundus L.	Cyperaceae	269	3,569	1,650	97	P sedge	S, V	Eurasia
Clidemia hirta (L.) D.Don	Melastomataceae	168			53	P shrub	S	Tropical America
Kylinga polyphylla Willd. Ex Kunth	Cyperaceae	126			73	P sedge	S, V	Tropical eastern Africa
Ageratum conyzoides L.	Asteraceae	101			37	A herb	S	Central & South America
Eleusine indica (L.) Gaertn.	Poaceae	101		1,490	50	A grass	S	Africa
Phyllanthus urinaria L.	Phyllathaceae		1,591		43	A herb	S	Tropical eastern Asia
Cuphea carthagenensis (Jacq.) MacBr.	Lythraceae		1,204	1,642	50	A herb	S	Tropical America
Acmella uliginosa (Sw.) Cass.	Asteraceae		598		60	A herb	S	Tropical America
Solanum torvum Sw.	Solanaceae		564		60	P shrub	S	West Indies
Barcopa procumbens (Mill.) Greenm.	Plantaginaceae		194		57	A herb	S	Tropical America
Spermacoce exilis (L.O. Williams) C.D. Adams.	Rubiaceae			4,571	33	A herb	S	Africa
Phyllanthus amarus Sch. & Thon.	Phyllantha ceae			1,010	37	A herb	S	New World
Euphorbia hypericifolia (L.) Millsp.	Euphorbiaceae			1,002	43	A herb	S	South America, West Indies

*Source: Ref. [2]; [a] Mode of reproduction: S – reproduction by seed, V – reproduction by vegetative means

have a role to play in the spread of the invasive species in Fiji and movement of soil to *S. trilobata*-free areas should be restricted.

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