The invasive *Parthenium hysterophorus* L. has limited impact on soil chemistry and enzyme activities but influences above and below ground biodiversity

Olusegun O. Osunkoya[1], Boyang Shi[1], Kerri Moore[2] and Kunjithapatham Dhileepan[1]
[1] Invasive Plant and Animal Science Unit, Biosecurity Sciences, Department of Agriculture and Fisheries, Eco-sciences Precinct, Brisbane, Queensland 4102, Australia
[2] CSIRO, Eco-sciences Precinct, Brisbane, Queensland 4102, Australia
(Olusegun.osunkoya@daf.qld.gov.au)

Summary The invasive *Parthenium hysterophorus* L., a Weed of National Significance, is pervasive in agriculture, conservation and disturbed lands of central Queensland. In recent years, it has spread to the eastern and southern parts of the State and has the potential for incursion to the neighbouring States of New South Wales and Northern Territory, especially in view of climate change. However, very little work (most done overseas with inconsistent findings) has been reported on the weed's impact on soil processes and native biodiversity. The work reported herein (involving soil sampling across multiple sites in central Queensland in parthenium weed infested and non-infested habitats) showed that due to the weed's annual growth habit, a null effect was detected for soil chemistry (both micro- and macro-nutrients) and enzyme activities (β-glucosidase, fluorescein diacetate (FDA) hydrolysis and total microbial nitrogen and carbon). In contrast, significant negative impacts of parthenium weed infestation were observed for both below-ground (soil seed bank) and above-ground composition and diversity of co-occurring plant species. The results are discussed in terms of sampling methodology, adaptive pasture management, the weed's growth habit and its 'perceived' position on Queensland weed list for risk assessment (based on impact, abundance and spread) and management.

Keywords Australia, biological invasion, soil chemistry, soil enzymes activity, biodiversity, weed impact.

INTRODUCTION

Parthenium hysterophorus L (henceforth parthenium weed) is an annual herbaceous plant with its origin in the Gulf of Mexico and/or central south America (Dhileepan and McFadyen 2012). This weed now has a pantropical distribution and is found in more than 80 countries (Shi *et al.* 2015). It is a major weed in Australia especially in Queensland. Parthenium weed has substantial negative impacts on many natural and managed ecosystems, including open grassland, roadsides, and agricultural lands as well as health costs to grazing animals and humans.

Several studies have reported on the pervasive negative impacts of plant invasions on above ground communities (Pyšek *et al.* 2012, Mollot *et al.* 2017). In contrast, few studies have examined the impact of plant invasions on below-ground processes, including seed bank diversity, soil chemistry and nutrient cycling, and soil enzyme activities (Osunkoya and Perrett 2011, Giora and Pyšek 2016, Osunkoya *et al.* 2017). For parthenium weed, the findings on its ecological impact have been inconsistent. We had earlier reported that its invasion across varying land–use type (n = 3) and sites (n = 12) had minimal impact on soil physico-chemical properties (Osunkoya *et al.* 2017). We then hypothesised that perhaps other ecosystem properties, such as above-ground biota, may be more impacted by parthenium weed invasion. Additionally, the null effect was attributed, amongst other factors, to a large environmental variation (idiosyncrasies of site and land-use factors) and low sample size (n = 3–6 per treatment) used in the previous study. Consequently, a larger sample size per site was advocated to increase the power of the test and thus limit committing type II error (i.e. declaring a significant result non-significant when in actual fact there is a difference). In this study, in view of logistical constraints, we limited the number of sites surveyed (from n = 12 to n = 4) and increased substantially the sample size (n = 15 per treatment per site) to assess parthenium weed impact on above and below ground processes. Our ecological markers were below-ground (soil seedbank, soil chemistry and enzyme activities) and above-ground (plant species identity and assemblages) processes.

MATERIALS AND METHODS

The four field survey and soil collection sites are in central Queensland, Australia. All these sites have been heavily invaded by parthenium weed for at least 10 years. These sites are representative of grazing grassland (Gracemere and Hutton creek), cropping

(Morebridge) and riparian (Moolayamber Creek) lands typicality infested by parthenium weed in the region (see Osunkoya *et al.* 2017). The data for above-ground (standing vegetation) and below ground (seed bank and soil chemistry) assessments were collected from paired parthenium weed infested and parthenium weed free patches (5–10 m apart) using a standardised procedure (Osunkoya *et al.* 2017). Each site has 15 replicates of each vegetation (or soil) patch type sampled, except for Hutton Creek site which consisted of only five replicates. For assessment of above-ground species plant composition, we used 0.25 m × 0.25 m quadrats. Soils from both infested and non-infested patches were collected using a 10 cm diameter × 7 cm depth soil corer. Each replicated soil sample was made up of five randomly selected cores in a 1 m^2 area that were subsequently combined into a composite sample. Soil seedbank was evaluated in germination trays under adequate moisture and temperature (17°C to 32°C) for nine months at Ecosciences Precinct glasshouse in Brisbane, (Queensland, QLD) Australia. Germinated seedlings of parthenium weed and other plant species were identified and counted monthly. Soil moisture and a series of chemical traits (pH, electrical conductivity, total carbon, total nitrogen, microbial biomass carbon and microbial carbon nitrogen) and enzyme activities (fluorescein diacetate [FDA] hydrolysis and β-glucosidase – two major enzymes involve in the first phase of plant cell tissue decomposition) were assayed (see details of analytical procedures in Osunkoya *et al.* 2017).

We normalised that data and used common parametric analyses (ANOVA and generalised linear modelling) and multivariate ordination techniques to detect differences in mean performance of infested and uninfested (control) patches. For species assemblages we converted the abundance data to presence-absence data, and used non-metric multidimensional scaling ordination (NMDS) involving Bray-Curtis dissimilarity matrix to explore general trends in the data sets. For soil chemistry and soil enzyme data, values were log transformed prior to NMDS ordination. All ordinations were performed via PRIMER version 7.0.

RESULTS

A higher number of seedlings of parthenium weed germinated from the soil of infested compared with those from non-infested patches (Figure. 1). Also, the greater abundance of the parthenium weed in the soils of the infested patches had a detrimental effect on the seed bank composition of other species (both native and non-native species, Figure 1).

Above ground plant species diversity varied across land use type ($F_{2, 194} = 98.58$, $P<0.001$) or site

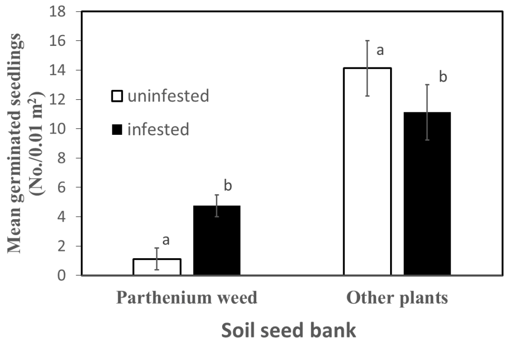

Figure 1. Mean (±SE) seed bank population in parthenium weed infested and uninfested vegetation patches. Data have been pooled across the four sites surveyed. Within paired vegetation patches, bars with different letters are significantly different at P≤0.05.

($F_{3, 192} = 66.55$, $P<0.001$). Standing plant density (no. $0.0625m^{-2}$) of parthenium weed was significantly ($P<0.0001$) higher in the infestation plots (14.49 ± 1.27) compared to the parthenium weed free areas (3.90 ± 1.20). In all and across the four sites surveyed, 33 plant species were identified from the above ground vegetation, with greater species number (Figure 2) and significant difference in species composition in uninfested (control) compared to infested vegetation patches (Figure 3). The depressing effect of the parthenium weed infestation on species diversity was of the order cropping > riparian ≥ grazing and there were no significant differences in soil chemistry and enzyme activities both within and across sites and land use type (Figure 4).

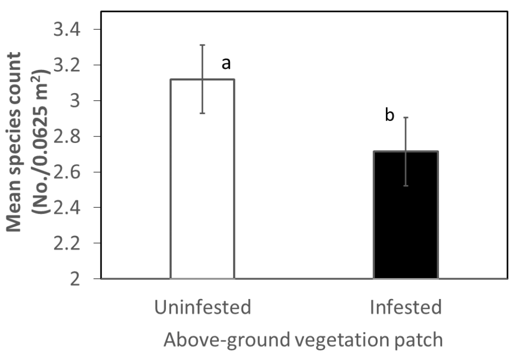

Figure 2. Mean (±SE) species richness in parthenium weed infested and uninfested vegetation patches. Data pooled across the four sites surveyed. Bars with different letters are different at P≤0.05.

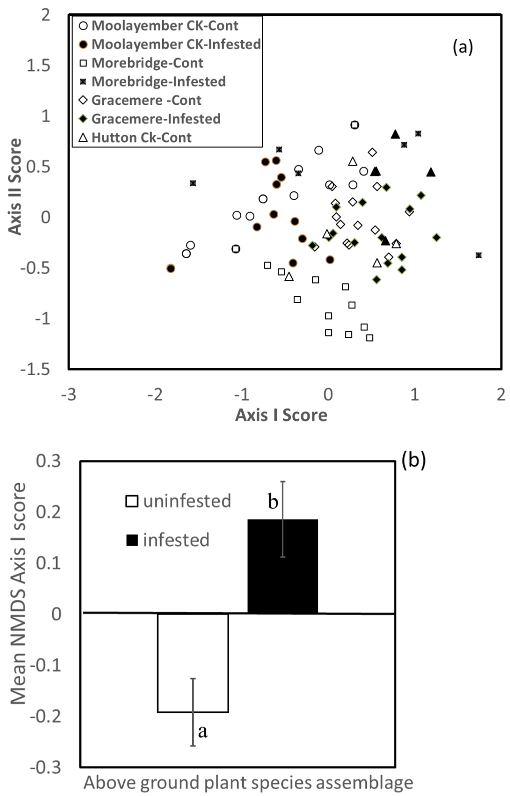

Figure 3a,b. NMDS ordination on the first two principal axes of above-ground vegetation patches based on presence-absence species data. Each data point represents a parthenium infested (closed symbol) or uninfested (open symbol) vegetation patch (2D stress = 0.07) (Figure 3a). A significant difference (P<0.02) exists between the two vegetation patches in species composition, especially along Axis I scores and this difference is summarised (±SE) in Figure 3b.

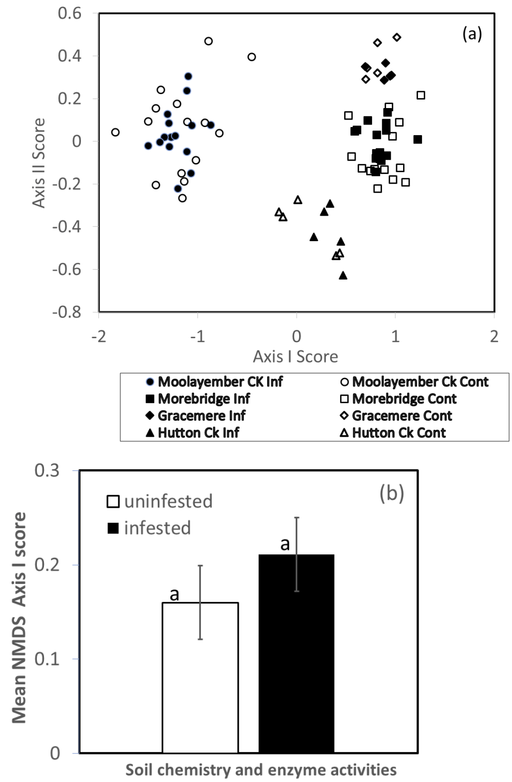

Figure 4a,b. NMDS ordination on the first two principal axes of parthenium infested (closed symbol) and uninfested (open symbol) soil patches across the four sites surveyed in Central QLD, Australia based on chemical traits and enzyme activities (2D stress = 0.03) (Figure 4a). No significant differences were detected in soil chemical traits and enzyme activities both within and across sites/land use type between the two vegetation patches as indicated by the mean (±SE) score for Axis I (Figure 4b).

DISCUSSION

It is interesting to note the presence of seeds of parthenium weed in the soil seed bank from some of the so called 'non-infested' (control) patches (the seeds are minor in abundance and detected in ~35% of weed-free soil patches surveyed). This suggests that parthenium weed-free habitat patches that we sampled may have, in the immediate past seasons, been infested by the weed but unknown to us due to its the annual life form. This could mask any soil differences we expected to observe between infested and non-infested patches, especially if a legacy effect of parthenium weed invasion persists under such ephemeral conditions (Gioria and Pyšek 2016). The finding also reinforces the belief that a 'good' cultural/pasture management with minimal tillage may help to suppress germination of buried parthenium seeds, hereby limiting its competitive impact on native plants and/or crop productivity.

Impact studies of invasive species are becoming increasingly available, and will contribute immensely towards a better estimation of pest risk assessment and management. Parthenium weed has always been ranked highly in terms of invasiveness and management needs in QLD Australia (see Osunkoya *et al.* 2018). While this assertion maybe correct, we have shown in previous work (Osunkoya *et al.* 2017), and in this study, that parthenium weeds overall (ecological) effect may be context- and trait-of-interest-specific.

The detrimental effect on above-ground native and non-native species and below-ground soil seed bank assemblage is real (Figure 1), but its influence as driver of soil processes (e.g. nutrient cycling) is minimal.

Sample size was substantially increased in this work compared to that of our previous study (Osunkoya *et al.* 2017; from n = 3–6 to n = 15), and we could still only detect minimal influence of parthenium weed on soil processes (i.e., a change was only detected in the soil seed bank assemblage). This is in contrast to many invasive plant species that we have worked on, including *Lantana camara* L. and cat's claw creeper vine (*Dolichandra unguis-cati* (L.) L.G.Lohmann) (Osunkoya and Perrett 2011, Perrett *et al*. 2012). Parthenium weeds annual growth habit with minimal ephemeral litter input may be a contributing factor to its limited influence on soil processes. In a review of the global assessment of invasive plant impacts of more than 150 species, Pyšek *et al*. (2012) reported that short-statured plants (<4.8 m), including many annuals like parthenium weed (but excluding grasses) were least likely to exert significant impacts on outcomes related to species diversity and soil attributes. Additionally, rather than invoking a change in major nutrients *per se*, the mode of action of parthenium weed on soil processes could be indirect via the release of allelopathic phytotoxic exudates (e.g. phenols) from its roots and/or residue decomposition. These phytotoxins are known to interact with soil chemistry, can suppress seed germination and growth of native and other weedy species, and can potentially lead to the establishment of monocultures of parthenium weed (Belz *et al*. 2007, Shi *et al.* 2015). Phytotoxins can also impact negatively on soil food-web structures of nematodes, insects, and mammals (Van der Putten *et al.* 2013). Assuming the phytotoxicity hypothesis is real, there is a need for microcosm and controlled laboratory trials to explore further and explicitly the impact of the parthenium weed on soil processes, including possible feedback effects (Van der Putten *et al*. 2007).

ACKNOWLEDGMENTS

We thank the Queensland Government, through the Land Protection Trust Fund, for travel support that greatly assisted in field work and accommodation during the course of the study. The assistance of Christine Perrett in the seed bank germination trials is appreciated.

REFERENCES

Belz, R.G., Reinhardt, C.F., Foxcroft, L.C. and Hurle, K. (2007). Residue allelopathy in *Parthenium hysterophorus* L.—Does parthenin play a leading role? *Crop Protection* 26, 237-45.

Dhileepan, K. and McFadyen, R.E. (2012). *Parthenium hysterophorus* L. – parthenium. *In* 'Biological control of weeds in Australia' eds M. Julien, R.E. McFadyen and J. Cullen, pp. 448-62. (CSIRO Publishing, Melbourne)

Gioria, M. and Pyšek, P. (2016). The legacy of plant invasions: changes in the soil seed bank of invaded plant communities. *BioScience* 66, 40-53.

Mollot, G., Pantel, J., and Romanuk, T. (2017). The Effects of invasive species on the decline in species richness: A global meta-analysis. *Advances in Ecological Research* 56, 61-83.

Osunkoya, O.O. and Perrett, C. (2011) *Lantana camara* L. (Verbenaceae) invasion effects on soil physicochemical properties. *Biology and Fertility of Soils* 47, 349-55.

Osunkoya, O.O., Akinsanmi, O.A., Lim, L.S., Perrett, C., Callander, J., and Dhileepan, K. (2017). *Parthenium hysterophorus* L. (Asteraceae) invasion had limited impact on major soil nutrients and enzyme activity: Is the null effect real or reflects data insensitivity? *Plant and Soil* 420, 177-94.

Osunkoya, O.O., Perrett, C., Moore, K., Nicol, S., Froese, J., Gooding, K. and Campbell, S. (2018). An inventory of Queensland prioritised invasive plant species for management and research. Proceedings of the 21st Australasian Weeds Conference, 9–13 September, Sydney, New South Wales, eds S. Johnson, L. Weston, H. Wu and B. Auld, pp. 392-96. (Weed Society of NSW).

Perrett, C., Osunkoya, O.O. and Clark, C. (2012) Cat's claw creeper vine, *Macfadyena unguis-cati* (Bignoniaceae), invasion impacts: Comparative leaf nutrient content and effects on soil physicochemical properties. *Australian Journal of Botany* 60, 539-48.

Pyšek, P., Jarošík, V., Hulme, P.E., Pergl, J., Hejda M., Schaffner, U. and Vilà, M. (2012). A global assessment of invasive plant impacts on resident species, communities and ecosystems: The interaction of impact measures, invading species' traits and environment. *Global Change Biology* 18, 1725-37.

Shi, B., Aslam, Z. and Adkins, S. (2015). The invasive potential of parthenium weed. A role for allelopathy. *In* 'New Developments in Allelopathy Research', ed. J.E. Price, pp. 135-73. (Nova Science Publishers, United States of America).

van der Putten, W.H., Bardgett, R.D., Bever, J.D., Bezemer, T.M., Casper, B.B., Fukami, T., Kardol, P., Klironomos, J.N., Kulmatiski, A., Schweitzer, J.A., Suding, J.A., van de Voorde, T.F.J. and Wardle J.A. (2013). Plant-soil feedbacks: the past, the present and future challenges. *Journal of Ecology* 101, 265-76.