The Economic Implications of Robinia pseudoacacia L. (black locust) on Agricultural Production in South Africa.

Fraser G[1], Martin G[1], Humphrey L[1]

[1]Rhodes University

Corresponding author email: g.fraser@ru.ac.za

Abstract:

Robinia pseudoacacia L. (black locust) is an invasive deciduous, broad-leaved tree that has the potential to be widely distributed across South Africa. It has invaded all nine of South African provinces. The potential economic impacts of R. pseudoacacia on agricultural production stem from the tree's ability to reduce the carrying capacity for livestock. This study estimated the potential economic implications of R. pseudoacacia on agricultural production in South Africa, specifically the livestock sector. R. pseudoacacia's potential distribution was calculated by using a maximum-entropy predictive habitat model, MaxEnt. The distribution of livestock, based on grazing capacity (ha/large stock unit), in South Africa was then determined. The potential direct economic impacts were estimated by assessing the impact of the potential distribution of R. pseudoacacia on the carrying capacity for livestock. The results showed that an infestation of R. pseudoacacia has the potential to reduce the total gross margin in the livestock sector by between approximately R135 million and R674 million, dependent on the level of invasion. The potential levels of foregone income and business activity found in this study reaffirm the need to devote resources to develop a viable, economical and effective control.

Keywords: Invasive alien plants, livestock, grazing capacity, MaxEnt, economic impact.

#4

The Economic Implications of *Robinia pseudoacacia* L. (black locust) on Agricultural Production in South Africa.

ABSTRACT

Robinia pseudoacacia L. (black locust) is an invasive deciduous, broad-leaved tree that has the potential to be widely distributed across South Africa. It has invaded all nine of South African provinces. The potential economic impacts of *R. pseudoacacia* on agricultural production stem from the tree's ability to reduce the carrying capacity for livestock. This study estimated the potential economic implications of *R. pseudoacacia* on agricultural production in South Africa, specifically the livestock sector. *R. pseudoacacia's* potential distribution was calculated by using a maximum-entropy predictive habitat model, MaxEnt. The distribution of livestock, based on grazing capacity (ha/large stock unit), in South Africa was then determined. The potential direct economic impacts were estimated by assessing the impact of the potential distribution of *R. pseudoacacia* on the carrying capacity for livestock. The results showed that an infestation of *R. pseudoacacia* has the potential to reduce the total gross margin in the livestock sector by between approximately R135 million and R674 million, dependent on the level of invasion. The potential levels of foregone income and business activity found in this study reaffirm the need to devote resources to develop a viable, economical and effective control.

Keywords: Invasive alien plants, livestock, grazing capacity, MaxEnt, economic impact.

1. INTRODUCTION

In many parts of the world, tree invasions have become more widespread in recent decades (Richardson et al., 2014) and of all the invasive species, trees are increasingly recognised as one of the largest threats to biodiversity and ecosystem functioning (Rejmánek and Richardson 2013) and human livelihoods (Shackleton et al. 2014). It is these effects which are currently driving the criteria for prioritising efforts to remove and manage them (Sieg et. al. 2010).

The management of invasive trees globally varies from small-scale private initiatives to large-scale national programmes, such as the internationally recognised “working for water” programme in South Africa (Rejmánek and Richardson 2013; Van Wilgen et al. 2012; Brundu and Richardson 2016). However, the success of tree management also varies dramatically and examples of large scale, long term control are limited (Van Wilgen et al. 2012; Kraaij et al. 2017, Richardson et al. 2014). Additionally, as with many introduced invasive species, invasive trees often provide some form of benefits along with their associated cost, leading to conflicts of interests surrounding their use and or their management (Dickie et al. 2014; Van Wilgen and Richardson 2014) which can compromise management options (Kull et al. 2011; Richardson et al. 2014). Therefore, investigations into the impacts of invasive trees as well as potential conflicts of interest can be used to drive and prioritise management.

In South Africa, the adverse impacts of alien plant invasions on water flows have been a prime motivation for prioritisation of trees within South Africa’s Working for Water Programme (Le Maitre et al. 2016). However, it is increasingly recognised that many invasive trees have other significant impacts that should be considered when prioritising for management. Richardson et al. (2014) suggest investigations into a number of impacts including conflict, control, costs, distribution and economic impacts, to name only a few.

There is an increasing recognition of the effect IAPs have on the agricultural sector (Cullen & Whitten 1995; Leitch et al. 1996; Pimentel et al. 2001; Acquaye et al. 2005; De Neergaard et al. 2005; Eagle et al. 2007; Dube 2010). IAPs have substantial impacts on forage quantity and quality, increasing management costs, imposing land use changes, and thereby reducing agricultural production, output and profitability (Eagle et al. 2007). IAPs have the potential to have an impact on the livestock sector, as a reduction in the carrying capacity for livestock disrupts agricultural production. They also pose a threat to livestock production by lowering yield and quality of forage, interfering with grazing patterns, poisoning livestock, restricting access to grazing lands, and increasing costs of managing and producing livestock (Ditomaso 2000). One such IAP in South Africa, *R. pseudoacacia*, which has the potential to have significant impacts on the agricultural sector.

The agricultural sector’s significance in South Africa is large because of its potential to create jobs and is a key focus of the New Growth Path (Republic of South Africa 2013). In South Africa, there are approximately 100 million hectares of agricultural land, of which 72% is used for extensive grazing. Therefore, agricultural land in South Africa is primarily livestock-based (Meissner et al. 2013). Livestock production not only contributes substantially to food security in South Africa (Meissner et al. 2013), but forms a critical part of South Africa's socio-economic and socio-political stability (Tibane and Vermeulen 2014). Furthermore, livestock is the primary driver underpinning sustainable rural agriculture (Palmer et al. 2010). The grassland biome is one of the most valuable biomes in South Africa, in terms of agricultural production. Much of the increasing demand for meat and dairy products is supplied from the grassland biome (Boval and Dixon 2012).

2. *ROBINIA PSEUDOACACIA*

Robinia pseudoacacia, an invasive deciduous tree (Cierjacks et al. 2013), is ranked as a problematic invader (Kurokochi et al. 2010). Although native to south-eastern United States of America, the broad-leaved tree has been widely planted and become naturalised elsewhere in temperate North America, Europe, Australia and south Africa (Sheppard et al. 2006; Carbutt 2012) (Figure1). In South Africa, the plant is listed as a Category 1B invader species –under the *National Environmental Management: Biodiversity Act 2004* regulations. *Robinia pseudoacacia* is known to have negative environmental and socio-economic impacts.

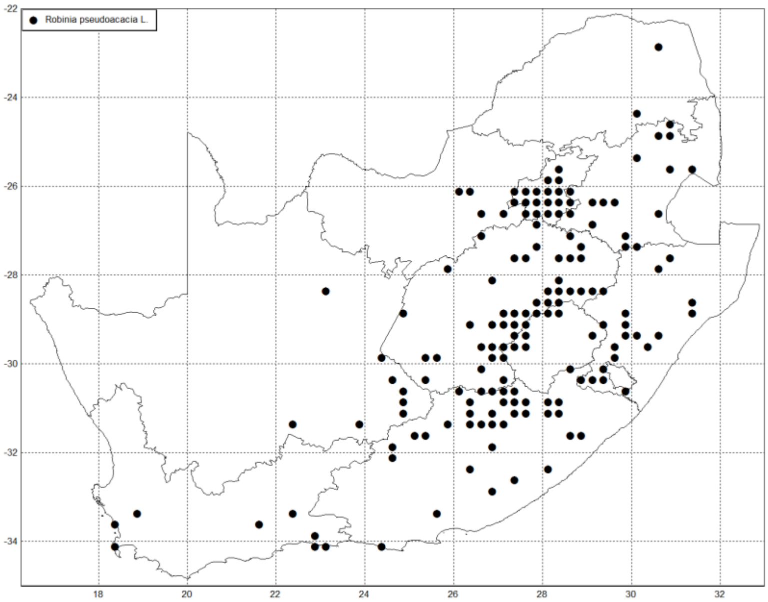

Figure 1. Distribution map of *Robinia pseudoacacia* in South Africa in quarter degree squares as of March 2015. Source: SAPIA (2015).

The tree is a threat to existing ecosystems as it spreads rapidly from suckering roots and seeds creating monocultures that displace native species (Sabo 2000). It is a prolific water user, capable of invading pristine environments, and its seeds, leaves and bark are toxic to both humans and animals (Kumar 1992; Vanschandevijl et al. 2010; Sabo 2000; Van Wyk et al. 2002; Sheppard et al. 2006). Thus, *R. pseudoacacia* possesses most of the characteristics associated with “weediness” (Sabo 2000). In South Africa, *R. pseudoacacia* is potentially causing extensive negative ecological and economic effects: it impacts on native biodiversity (Van Wilgen et al. 2001, Carbutt 2012). The implementation of control measures to combat the spread of *R. pseudoacacia* have proven difficult due to its rapid growth and clonal spread (Akamatsu et al. 2014). Considering the economic importance of agricultural production in

South Africa, the potential impact *R. pseudoacacia* has on agricultural production needs to be determined. Therefore, the aim of this study is to estimate the potential economic implications of the uncontrolled spread of *R. pseudoacacia* on agricultural production in South Africa.

3. BIO-ECONOMIC MODEL

The bio-economic model (Figure 2) was first developed to guide research efforts from the biological aspects through to the economic impacts (Leitch et al. 1996). The bio-economic was used by Leitch (1996) to estimate the economic impacts of *Euphorbia esula* L. (leafy spurge) infestations. The model identifies key relationships between the changes in the level of leafy spurge infestation and changes in land output (e.g. carrying capacity for grazing livestock). Bio-economic modelling, according to Knowler (2002), is typically used by economists to describe models that have both economic and biophysical components. The model was used to address the relationship(s) which exist between them. More specifically, bio-economic models are capable of simultaneously addressing the various dimensions of an agricultural system (Flichman 2011).

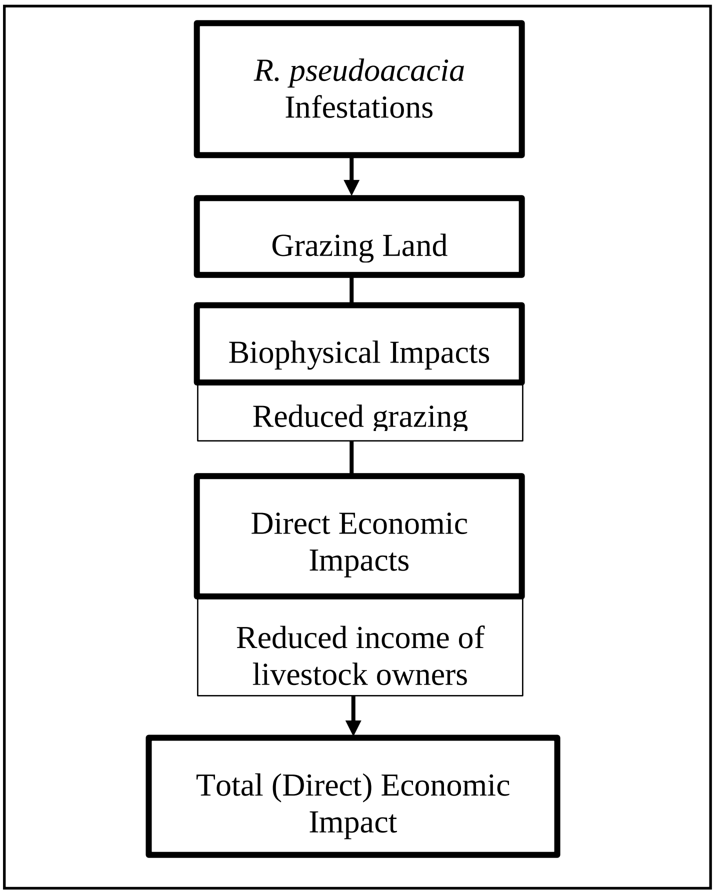

Figure 2. A conceptual bio-economic model of the economic impacts of *Robinia pseudoacacia* infestations.

Figure 1 describes the relationships between the biological aspects and the economic impacts if an infestation of *R. pseudoacacia* occurred. This would impact the available grazing capacity in several ways. Firstly, *R. pseudoacacia's* toxic components would deplete livestock numbers. Secondly, due to the clonal spread, specific areas of the grazing land would become restricted. The biophysical impacts would be a reduction in grazing capacity, ultimately reducing the carrying capacity of an area. The economic impacts of this would result in a reduction in income for livestock owners. In the last stage of the model, the total (direct) economic impact will be determined.

4. POTENTIAL DISTRIBUTION OF *R. PSEUDOACACIA*

The MaxEnt model (See Appendix for the Spatial Distribution Modelling) indicates that the regions of highest suitability for *R. pseudoacacia* are generally distributed towards the eastern portion of South Africa (Figure 3)[1]. This includes the Free State and Gauteng provinces, while there is a low probability of establishment of *R. pseudoacacia* into the western portion of the country (largely in the Northern Cape Province). The regions of highest probability coincided with those regions where the IAP had been recorded in the SAPIA database (SAPIA 2015) and the grassland biome. Most of South Africa's surface water originates from the high altitude grasslands of South Africa (Turpie et al. 2008). The area of highest suitability for *R. pseudoacacia*, the mountain catchments within the grassland biome occupy a mere 8% of the surface area of South Africa but yield 49% of the runoff (Wilson 1984 cited by Snaddon 1999). The grassland biome also harbours a rich species, community and ecosystem diversity (Reyers & Tosh 2003), supplying essential ecosystem services and supporting crop and livestock agricultural activities (O'Connor and Kuyler 2009). Thus, grasslands are central to the livelihoods and economies for both small-scale/communal and commercial farmers as well as a number of rural communities (Boval and Dixon 2012).

Areas of moderate probability exist in the north and north-western portions of the Eastern Cape Province, as well as along the south-western coastline. Furthermore, there is a low probability in the northern tip of the country, in the Limpopo province, as well as along the eastern coastline.

Approximately 37.52% or 45 million ha of the total land coverage in South Africa has zero probability for *R. pseudoacacia* establishment. Slightly over 25% or 30 million ha of land are vulnerable to low levels of establishment (1-3), with approximately 18% or 22 million ha of land vulnerable to moderate levels of invasion (4 and 5). Although the highest probability of invasion (7) is only 5.95% of total land in South Africa, this represents over 7 million ha of land (mainly within the Gauteng and Free State provinces), which are extremely suitable for establishment. Furthermore, the second highest probability of invasion (6) suggests that approximately 13.10% or almost 16 million ha of land is highly suitable for establishment by

[1] The potential distribution of *R. pseudoacacia* was ranked by MaxEnt on a scale from 1-7 (Figure 3). Higher probability (values closer to 7) represents areas most suitable for *R. pseudoacacia*, while zero or lower probability indicates areas less suitable for *R. pseudoacacia*.

R. pseudoacacia. Overall, based on the MaxEnt model, *R. pseudoacacia* has the potential for establishment in 62.48% of all land in South Africa.

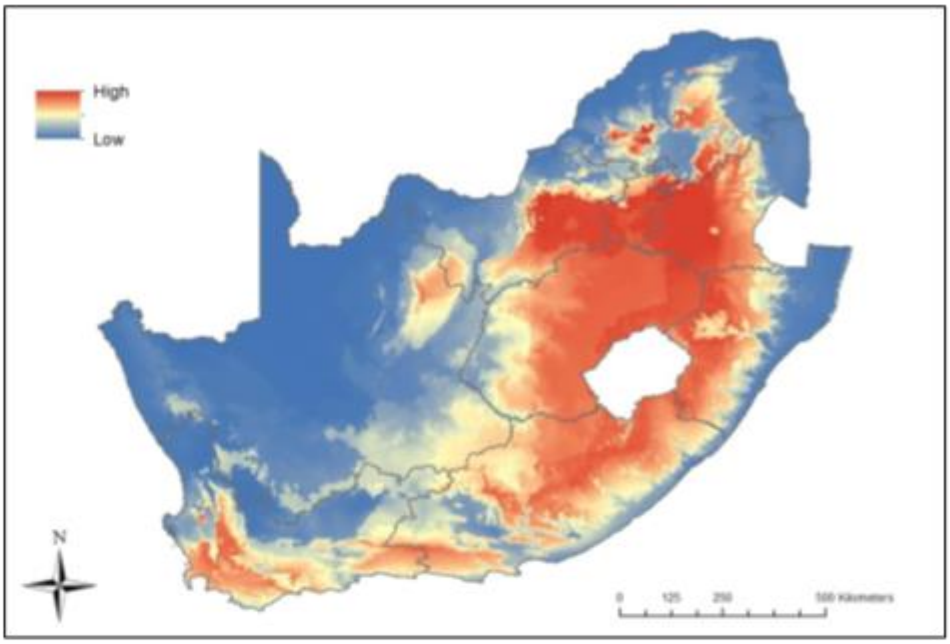

Figure 3: The potential distribution of *Robinia pseudoacacia* in South Africa

Table 1. The potential distribution of *Robinia pseudoacacia* in South Africa.

Probability of Invasion	Area (ha)	Land Cover (%)
0	45,816,900	37.52
1	10,494,600	8.60
2	11,749,000	9.62
3	8,341,620	6.83
4	11,893,400	9.74
5	10,287,300	8.43
6	15,992,000	13.10
7	7,268,170	5.95
Total	121,842,990	

5. ESTIMATING THE IMPACT OF *ROBINIA PSEUDOACACIA* ON LIVESTOCK

Estimating the economic impact of infestations requires consideration of both biological and economic parameters (Leistritz et al. 1993). A change in an area's agricultural production practices can affect agribusiness firms, local trade and service sectors (Leistritz and Murdock 1981; Leistritz and Ekstrom 1986). The potential economic impacts of *R. pseudoacacia* on agricultural production stems from the tree's ability to reduce livestock grazing capacity

(Bangsund et al. 1999). The establishment of the invasive tree restricts access to grazing lands and the seeds, leaves and bark of the tree are toxic to livestock[2] (Kumar 1992; Van Wyk et al. 2002; Vanschandevijl et al. 2010). A critical step in estimating the economic impact of an invasion into grazing lands was to estimate the potential reduction in the number of large stock units (LSUs).

The impact of the potential distribution of *R. pseudoacacia* at different invasion probabilities was determined in terms of livestock units (LSUs) in South Africa. In ARC-MAP, the ARC grazing capacity data layer was overlaid with the potential distribution data layer (ARC 2009). This data provided the impact of the potential distribution of *R. pseudoacacia,* at different invasion probabilities (high, moderate and low), on LSUs in South Africa. However, MaxEnt only predicts the potential distribution of *R. pseudoacacia*, and does not predict the canopy cover of the growth-areas where *R. pseudoacacia* was predicted (at any probability level). According to the MaxEnt model, the cover could range from a single tree to a large infestation. Thus, one could not assume that intermittent patches of *R. pseudoacacia* or a *R. pseudoacacia* monoculture would have the same impact on LSUs (Hirsch and Leitch 1996). A large infestation of *R. pseudoacacia* would have a greater effect on LSUs, compared to that of a single tree.

To combat the problem of the unknown canopy cover of the potential invasion, three canopy cover invasion possibilities were constructed. The possibilities were based on guidelines developed by Le Maitre and Versfeld (1994), which provide for a range of density classes from rare (<0.01%) to closed (100% canopy cover) (Table 2).

Table 2. Summary of the canopy cover invasion possibilities.

Probability of Invasion	Canopy cover assumption	Impact on LSU
High (5-7)	>20%	50%
Moderate (3-4)	5-20%	25%
Low (1-2)	<5%	12.5%

Based on the relevant assumptions for each possibility, the total number of LSUs potentially effected by an invasion of *R. pseudoacacia* were determined. The total number of LSUs within each probability of invasion possibilities, which was previously calculated, was multiplied by the canopy cover assumption and the impact on LSUs assumption. This was done for the whole of South Africa as well as for the grassland biome (Table 2).

The potential impact on the gross margin in the livestock sector was estimated, within each probability of invasion scenario. The total number of LSUs within each probability of invasion possibility was multiplied by the gross margin. Gross margins for livestock were

[2] Other economic impacts of invasions, which were not included in this study, are lowering yield and quality of forage, increasing costs of managing and producing livestock, foregone livestock sales and potential decreases in land values (Ditomaso 2000).

obtained from the livestock enterprise budget, compiled by VKB in the eastern Free State. An average gross margin per LSU of R1000 was assumed[3]. Gross margins per LSU vacillated quite significantly, depending on the size and weight of the animals. Therefore, a gross margin of R1000 per LSU was chosen as it represents an average gross margin per LSU.

6. THE POTENTIAL ECONOMIC IMPLICATIONS

The potential economic impacts of *R. pseudoacacia* on agricultural production stem from the tree's ability to reduce livestock carrying capacity (Bangsund et al. 1999). This is because an infestation of the tree potentially restricts access to grazing lands as the seeds, leaves and bark of the tree are toxic to livestock. Meissner et al. (2013) stated that grazing capacity may deteriorate because of an invasion by alien vegetation. A critical step in estimating the economic impact of an invasion into grazing lands is to estimate the potential reduction in the number of LSUs. The total potential number of LSUs within each biome was determined (Figure 4).

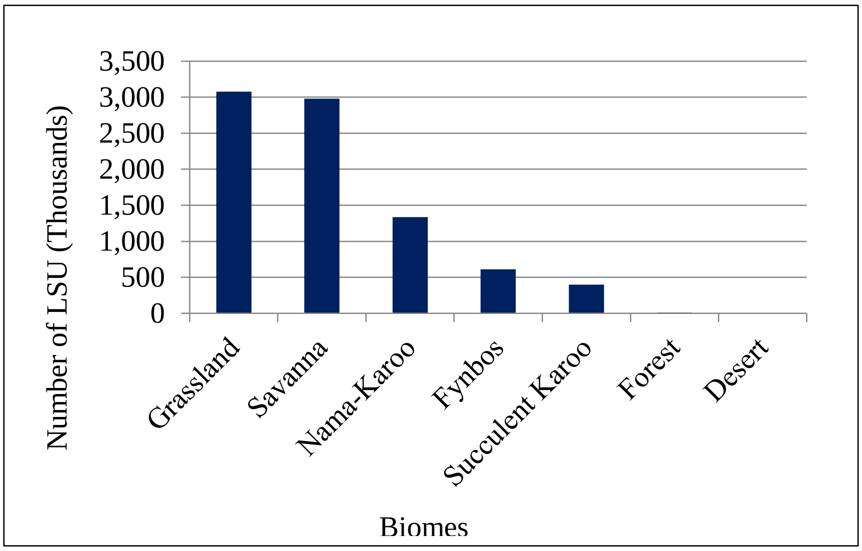

Figure 4. Potential number of LSU's within each of the seven South African biomes.

The results indicate that the grassland biome potentially contains the largest number of LSUs, at slightly over 3 million. This is followed closely by the savanna biome, which potentially contains approximately 3 million LSUs. The nama-Karoo biome contains approximately half the number of potential LSUs of the grassland and savanna biomes. The fynbos and the succulent Karoo biomes contain relatively smaller numbers of potential LSUs of approximately 600 000 and 400 000, respectively. The forest and the desert biomes contain relatively few potential LSUs, relative to the other biomes.

[3] For more information on the classification of livestock, see Soji et al. (2015).

7. IMPACT OF *ROBINIA PSEUDOACACIA* ON LIVESTOCK IN SOUTH AFRICA

Recognising that livestock is an important component in agriculture production in South Africa, the impact of the potential distribution of *R. pseudoacacia*, at different invasion probabilities, on LSUs in South Africa was determined (Table 4). Table 4 illustrates high (5-7), moderate (3-4) and low (1-2) probabilities of *R. pseudoacacia* invasions and the corresponding potential reductions in the number of LSUs in South Africa.

Table 4. The impact of the potential distribution of *Robinia pseudoacacia* on LSUs in South Africa.

Probability of Invasion	Number of LSU
High (5-7)	1 922 717
Moderate (3-4)	1 047 292
Low (1-2)	1 037 499

The results suggest that at a high probability of invasion, there would be a reduction of approximately 1.9 million LSUs. At moderate and low probabilities of invasion, there would be reductions of approximately one million LSUs each.

However, MaxEnt only predicts the potential distribution of *R. pseudoacacia*, and does not predict the canopy cover of the invasion. To combat the problem of the unknown canopy cover of the potential invasion, canopy covers were estimated, and three canopy cover scenarios were constructed.

Based on our canopy cover and impacts on LSUs assumptions, the total number of LSUs that could potentially be impacted by an invasion of *R. pseudoacacia* were estimated at different invasion probabilities (Table 5). This allowed for a more accurate and realistic estimation.

Table 5. Number of LSUs potentially impacted by an invasion of *Robinia pseudoacacia* in South Africa, based on the relevant assumptions.

Probability of Invasion	Number of LSUs Impacted
High (5-7)	961 359
Moderate (3-4)	261 823
Low (1-2)	129 687

The results suggest that at a high probability of invasion, *R. pseudoacacia* has the potential to affect 961 359 LSUs (assuming a dense canopy cover of >20% and a reduction of LSUs by 50%). This represents just less than one third of the total number of LSUs within the grassland biome (see figure 4). At a moderate probability of invasion, the invasive tree has the potential to affect 261 823 LSUs (assuming a medium canopy cover of 5-20% and a reduction of LSUs by 25%). Lastly, at a low probability of invasion, the invasive tree has the potential to affect 129 687 LSUs (assuming a light canopy cover of <5% and a reduction of LSUs by 12.5%). These figures for the number of LSUs affected in the three probability zones assumes that the total area in each of the zones is invaded. However, it is unlikely that each of the zones will be totally invaded by *R. pseudoacacia.* To determine the impact of the potential invasion, in monetary terms, three scenarios were developed to cover high (50%), moderate (25%) and low (10%) levels of invasion (Table 6).

Table 6. Number of LSUs and total gross margin potentially affected by *Robinia pseudoacacia* in South Africa at various invasion levels.

	Scenarios – levels of invasion		
Probability of invasion	50%	25%	10%
High	480680	240340	96136
Moderate	130912	65456	26182
Low	64844	32422	12969
LSUs Affected	676436	338218	135287
TGM reduced (R)	676.4 mil	338.2 mil	135.3 mil

Using the worst-case scenario, with an invasion rate of 50% in the three zones, the impact on the total gross margin of the livestock sector of approximately R676 million. It was estimated that an invasion at a moderate invasion level (25%) could potentially cause a reduction in gross margin in the livestock sector of approximately R338 million and a low invasion level (10%) could potentially cause a reduction in total gross margin in the livestock sector of approximately R130 million. This suggests that the uncontrolled spread of *R. pseudoacacia* has the potential to have significant economic implications on the South African agricultural industry.

As the grassland biome is the most likely biome to be invaded, the same scenarios used for the determination of the economic impact of *R. pseudoacacia* on the country can be used for the grassland biome. In monetary terms, the impact of the potential invasion of *R. pseudoacacia* at a high invasion rate on LSUs in the grassland biome, could potentially cause a reduction in total gross margin in the livestock sector of approximately R410 million. At moderate and low invasion rates, the potentially reduction in total gross margin in the livestock sector would be R205 million and R82 million respectively. This means that approximately 60% of the reduction in total gross margin would be incurred on the grassland biome.

8. DISCUSSION

The spread of *R. pseudoacacia* has the potential to cause extensive damage to the agricultural sector, specifically to livestock as seen in the study. Although this study only looked at one element - the impact on grazing capacity - the potential economic impacts are significant. There remains a role for public intervention to control *R. pseudoacacia,* as this will yield public benefits for a diverse array of other natural resource service flows negatively impacted by *R. pseudoacacia* (Eagle et al. 2007). Thus, to prevent the potential negative impacts from occurring, a solution to the problem is needed.

Mechanical and herbicidal control methods have proven to be unsuccessful, as seen in the literature (Brown et al. 2001; Edgin 2007; Cierjacks et al. 2013) and in a case study where, in total, approximately R9 million was spent attempting to control *R. pseudoacacia* in the eastern Free State (Humphrey 2016). The costs of control rise exponentially as each control attempt only aggravates the spread. Mechanical control methods result in prolific root suckering (Zimmerman 1984) and clonal spread (Czarapata 2005) and no complete or long-term herbicidal solution exists (DeLoach 1997; Weitzenberg and Zentner 1997; Sabo 2000; Edgin 2007; Cierjacks et al. 2013). However, one control option, which has not yet been attempted, is biological control.

Biological control is the most environmentally friendly, cost effective and self-sustaining control method used to supress IAPs (Zimmermann et al. 2004). This method of control has been used as a powerful tool for reducing the costs of management of IAPs worldwide as well as in South Africa (Van Wilgen et al. 2004). A variety of biological control agents has been released on a variety of IAPs in South Africa which have proven to be successful (Olckers and Hill 1999; Cruttwell McFadyen 2000; Van Wilgen et al. 2004; Hill and Coetzee 2017). Biological control using seed-attacking insects is the most cost-effective, long-term option for limiting seed production into catchments (Richardson and Kluge 2008; Van Wilgen et al. 2013). For example, Holmes et al. (1987) showed that stopping seeding of *Acacia saligna* resulted in an 80% decline in its seed bank after 4–6 years. Additionally, benefit:cost ratios of the seed attacking biological control programmes of A. *longifolia* and *A. pycnantha* have been calculated to be 1465:1 and 4433:1, respectively (Van Wilgen et al. 2004). Potential biological control agents exist for *R. pseudoacacia* (Sheppard et al. 2006). The implementation of biological control has the potential to reduce the rate of spread of *R. pseudoacacia* and potentially the density within populations.

Economic studies such as this have the potential to inform the use of scarce funds and resources to be allocated for the effective control of invasive alien plants. Implications for both policy makers and researchers can be drawn from this effort to estimate the economic impacts of *R. pseudoacacia*. Insight and awareness for policy makers has been provided concerning the economic implications of the current and potential situations. Implementing more effective control measures should be an issue of concern to policymakers generally, rather than just to those representing the livestock sector.

ACKNOWLEGEMENTS

The South African Working for Water (WfW) Programme of the Department of Environmental Affairs: National Resource Management is acknowledged for providing funding. The South African Research Chairs Initiative of the Department of Science and Technology and the National Research Foundation of South Africa also provided funding for this work. Any opinion, finding, conclusion or recommendation expressed in this material is that of the authors and the NRF does not accept any liability in this regard.

LIST OF REFERENCES

Acosta LE (2008) Distribution of Geraeocormobius sylvarum (Opiliones, Gonyleptidae): Range modelling based on bioclimatic variables. J Arachnol 36(3): 574-582.

Acquaye AK, Alston JM, Lee H, Sumner DA (2005) Economic consequences of invasive species policies in the presence of commodity programs: theory and application to citrus canker. Appl Econ Perspect P 27(3): 498-504.

Akamatsu F, Makishima M, Taya Y, Nakanishi S, Miwa J (2014) Evaluation of glyphosate application in regulating the reproduction of riparian black locust (Robinia pseudoacacia L.) after clear-cutting, and the possibility of leaching into soil. Landsc Ecol Eng 10(1): 47-54.

ARC (Agricultural Research Council) (2009). Grazing capacity data. Available: Dr A Palmer (Agricultural Research Council, Grahamstown, South Africa). [Accessed 12 August 2015].

Bangsund DA, Leistritz FL, Leitch JA (1999) Assessing economic impacts of biological control of weeds: the case of leafy spurge in the northern Great Plains of the United States. J Environ Manage 56(1): 35-43.

Bhengu S, Schulz C, Grobler J (2009) South African National Biodiversity Institute (SANBI): National Land Cover (NLC) 2009: GIS Metadata. Pretoria, South Africa.

Boval M, Dixon RM (2012) The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. Animal 6(5): 748-762.

Brown WT, Krasny ME, Schoch N (2001) Volunteer monitoring of nonindigenous invasive plant species in the Adirondack Park, New York, USA. Nat Area J 21(2): 189-196.

Brundu G, and Richardson DM (2016) Planted forests and invasive alien trees in Europe: A Code for managing existing and future plantings to mitigate the risk of negative impacts from invasions. NeoBiota, 30: 5-47.

Carbutt C (2012) The emerging invasive alien plants of the Drakensberg Alpine Centre, southern Africa. Bothalia 42(2): 71– 85.

Cierjacks A, Kowarik I, Joshi J, Hempel S, Ristow M, Lippe M, Weber E (2013) Biological flora of the British Isles: Robinia pseudoacacia, J Ecol 101(6): 1623-1640.

Cruttwell McFadyen RE (2000) Successes in biological control of weeds. In: Proceedings of the X International Symposium on Biological Control of Weeds, Montana State University–Bozeman, Bozeman, MT. 3-14.

Cullen JM, Whitten MJ (1995) Economics of classical biological control: a research practice. In: Hokkanen H, Lynch J (Eds) Biological Control–Benefits and Risks. Cambridge University Press, Cambridge, pp 270–276.

Czarapata EJ (2005) Invasive plants of the Upper Midwest: An illustrated guide to their identification and control. The University of Wisconsin Press, Madison, WI. p 215.

De Meyer M, Robertson MP, Peterson AT, Mansell MW (2008) Ecological niches and potential geographical distributions of Mediterranean fruit fly (Ceratitis capitata) and Natal fruit fly (Ceratitis rosa). J Biogeogr 35(2): 270-281.

De Neergaard A, Saarnak C, Hill T, Khanyile M, Berzosa AM, Birch-Thomsen T (2005) Australian wattle species in the Drakensberg region of South Africa–An invasive alien or a natural resource? Agr Syst 85(3): 216-233.

Deloach CJ (1997) The biological control of weeds in the United States and Canada. In: Luken JO, Thieret JW (Eds) Assessment and management of plant invasions. Springer Science & Business Media. https://link.springer.com/article/10.1023/A:1010084724526.

Dickie IA, Bennett BM, Burrows LE, Nuñez MA, Peltzer DA, Porté A, Richardson DM, Rejmánek MM, Rundel PW, van Wilgen BW 2014 Conflicting values: ecosystem services and invasive tree management. Biol Invasions 16: 705-719.

Ditomaso JM (2000) Invasive weeds in rangelands: species, impacts, and management. Weed Sci 48(2): 255-265.

Dube N (2010) The economic evaluation of possible loss of prosopis pods as a result of increased biological control in the Northern Cape Province, South Africa. Unpublished Master of Science (Agric) Thesis, Department of Agricultural Economics and Extension, University of Fort Hare, Alice.

Eagle AJ, Eiswerth ME, Johnson WS, Schoenig SE, Cornelis van Kooten G (2007) Costs and losses imposed on California ranchers by Yellow starthistle. Rangeland Ecol Manag 60(4): 369-377.

Edgin B (2007) Vegetation Management Guideline Black Locust (Robinia pseudoacacia L.). Illinois Nature Reserve Commission, 1(4): 1-7. [Online]. Available: http://www.dnr.illinois.gov/INPC/Documents/VMG/VMG%20Black%20locust%20revised%202007%20-%20Copy.pdf [Accessed 24 April 2015].

ESRI (Environmental System Research Institute) (2011) ArcGIS Desktop: Release 10. Environmental Systems Research Institute, Redlands, CA.

Flichman G (Ed) (2011) Bio-economic models applied to agricultural systems. Springer Science & Business Media, New York.

Forsyth GG, Le Maitre DC, O'Farrell PJ, Van Wilgen BW (2012) The prioritisation of invasive alien plant control projects using a multi-criteria decision model informed by stakeholder input and spatial data. J Environ Manage (103): 51-57.

GBIF (Global Biodiversity Information Facility) (2015) GBIF Secretariat: GBIF Backbone Taxonomy. Robinia pseudoacacia L. [Online]. Available: http://www.gbif.org/species/5352251 [Accessed 09 June 2015].

Guisan A, Thuiller W (2005) Predicting species distribution: offering more than simple habitat models. Ecol Lett 8(9): 993-1009.

Hirsch SA, Leitch JA (1996) The effect of knapweed on Montana's economy. Ag. Econ. Rep. No. 355. p43.

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25(15): 1965-1978.

Hill MP, Coetzee J (2017) The biological control of aquatic weeds in South Africa: Current status and future challenges. Bothalia 47(2): 1-12.

Holmes PM, Dennill GB, Moll EJ (1987) Effects of feeding by native alydid insects on the seed viability of an alien invasive weed, Acacia Cyclops. S Afr J Sci 83: 580-581.

Humphrey L (2016) The potential economic implications of black locust (Robinia Pseudoacacia L.) on agricultural production in South Africa. Unpublished Master of Commerce thesis, Department of Economics and Economic History, Rhodes University, Grahamstown.

Knowler D (2002) A review of selected bioeconomic models with environmental influences in fisheries. Journal of Bioeconomics 4(2): 163-181.

Kraaij T, Baard JA, Rikhotso DR, Cole NS, Van Wilgen BW (2017) Assessing the effectiveness of invasive alien plant management in a large fynbos protected area. Bothalia 47(2), pp.1-11.

Kull CA, Shackleton CM, Cunningham PS, Ducatillon C, Dufour Dror J-M, et al. (2011) Adoption, use, and perception of Australian acacias around the world. Divers Distrib 17: 822–836.

Kumar R (1992) Anti-nutritional factors, the potential risks of toxicity and methods to alleviate them. In ‘Legume trees and other fodder trees as protein source for livestock’. FAO Animal Production and Health Paper no. 102, pp.145-160. http://www.fao.org/3/a-t0632e/T0632E10.htm (accessed December 2015).

Kurokochi H, Toyama K, Hogetsu T (2010) Regeneration of Robinia pseudoacacia riparian forests after clear-cutting along the Chikumagawa River in Japan. Plant Ecol 210(1): 31-41.

Leistritz FL, Ekstrom BL (1986) Interdependencies of Agriculture and Rural Communities: An Annotated Bibliography. New York, NY: Garland Publishing Co.

Leistritz FL, Murdock SH (1981) Socioeconomic Impact of Resource Development: Methods for Assessment. Westview Press Boulder.

Leistritz FL, Leitch JA, Bangsund DA, Wallace NM (1993) Economic Impact of Leafy Spurge on Grazing Land and Wildland in North Dakota. Great Plains Research: A Journal of Natural and Social Sciences. Paper 83.

Leitch JA, Leistritz FL, Bangsund DA (1996) Economic effect of leafy spurge in the upper Great Plains: methods, models, and results. Impact Assessment 14(4): 419-433.

Le Maitre DC, Versfeld DB (1994) Field manual for mapping populations of invasive plants for use with the Catchment Management System. Report FOR-DEA, Department of Environment Affairs, Pretoria.

Le Maitre DC, Kotze IM, O’Farrell PJ (2014) Impacts of land-cover change on the water flow regulation ecosystem service: Invasive alien plants, fire and their policy implications. Land Use Policy 36: 171-181.

Le Maitre DC, Forsyth GG, Dzikiti S, Gush MB (2016) Estimates of the impacts of invasive alien plants on water flows in South Africa. Water SA 42(4): 659-672.

Li G, Xu G, Guo K, Du S (2014) Mapping the global potential geographical distribution of Black Locust (Robinia Pseudoacacia L.) using herbarium data and a maximum entropy model. Forests 5(11): 2773-2792.

Mau-Crimmins TM, Schussman HR, Geiger EL (2006) Can the invaded range of a species be predicted sufficiently using only native-range data? Lehmann lovegrass (Eragrostis lehmanniana) in the southwestern United States. Ecol Model 193(3): 736-746.

Meissner HH, Scholtz MM, Palmer AR (2013) Sustainability of the South African Livestock Sector towards 2050 Part 1: worth and impact of the sector. S Afr J Anim Sci 43(3): 282-297.

Mgidi TN, Le Maitre DC, Schonegevel L, Nel JL, Rouget M, Richardson DM (2007) Alien plant invasions-incorporating emerging invaders in regional prioritization: a pragmatic approach for Southern Africa. J Environ Manage 84(2): 173-187.

Moran VC, Hoffmann JH, Zimmermann HG (2005) Biological control of invasive alien plants in South Africa: necessity, circumspection, and success. Front Ecol Environ 3(2): 71-77.

Mucina L, Rutherford M (2006) The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria.

O'Connor TG, Kuyler P (2009) Impact of land use on the biodiversity integrity of the moist sub-biome of the grassland biome, South Africa. J. Environ. Manage 90: 384-395.

Olckers T, Hill MP (1999) Biological control of weeds in South Africa (1990–1998), Entomological Society of Southern Africa, Memoir No. 1, pp 1-182.

Palmer AR, Short A, Yunusa IA (2010) Biomass production and water use efficiency of grassland in KwaZulu-Natal, South Africa. Afr J Range For Sci 27(3): 163-169.

Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connel C et al. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agr Ecosyst Environ 84: 1-20.

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modelling of species geographic distributions. Ecol Model 190(3): 231-259.

Republic of South Africa (2013). South Africa Yearbook 2013/14: Agriculture. Department Government Communications and Information System. 31-59.

Rejmánek M, Richardson DM (2013) Trees and shrubs as invasive alien species — 2013 update of the global database. Divers and Distrib 19(8):1093-1094.

Reyers B, Tosh CA (2003) National Grasslands Initiative: Concept Document. Gauteng Department of Agriculture, Conservation and Land Affairs, Johannesburg.

Richardson DM, Van Wilgen BW (2004) Invasive alien plants in South Africa: how well do we understand the ecological impacts? S Afr J Sci 100(1): 45–52.

Richardson DM, Hui C, Nunez M, Pauchard A (2014) Tree invasions — patterns and processes, challenges & opportunities. Biol Invasions 16: 473-481.

Richardson DM, Kluge RL (2008) Seed banks of invasive Australian Acacia species in South Africa: role in invasiveness and options for management. Perspect Plant Ecol 10(3): 161-177.

Robertson MP, Caithness N, Villet MH (2001) A PCA-based modelling technique for predicting environmental suitability for organisms from presence records. Divers Distrib, 7(1-2): 15-27.

Robertson MP, Villet MH, Fairbanks, DHK, Henderson L, Higgins SI, Hoffmann JH et al. (2003) A proposed prioritization system for the management of invasive alien plants in South Africa: research in action. S Afr J Sci 99(1 & 2): 37-43.

Sabo AE (2000) Robinia pseudoacacia invasions and control in North America and Europe. University of Minnesota, Restoration and Reclamation Review 6(3): 1-9.

SAPIA (Southern African Plant Invaders Atlas). (2015). SAPIA database. [Online]. Available: http://www.arc.agric.za/arc-ppri/Pages/Weeds%20Research/Geographical-distribution-of-IAPs-in-southern-Africa-(SAPIA)-.aspx [Accessed 09 June 2015].

Shackleton, R.T., Le Maitre, D.C., Pasiecznik, N.M. and Richardson, D.M., 2014. Prosopis: a global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. AoB Plants 6: plu027.

Sheppard AW, Shaw RH, Sforza R (2006) Top 20 environmental weeds for classical biological control in Europe: a review of opportunities, regulations and other barriers to adoption. Weed Res 46(2): 93-117.

Sieg CH, Denslow JS, Huebner CD, Miller JH (2010) The role of the Forest Service in nonnative invasive plant research. In: Dix ME, Britton K (eds) A dynamic invasive species research vision: opportunities and priorities 2009–29. Gen. Tech. Rep. WO–79. Washington, DC: U.S. Department of Agriculture Forest Service pp 35–42.

Snaddon C (1999) Degradation of Surface Water Resources. In: Hoffman T, Todd S, Ntshona Z, Turner S (eds) Land degradation in South Africa. Plant Conservation Unit, University of Cape Town, Cape Town pp 37-60.

Soji Z, Chikwanda D, Chikwanda AT, Jaja IF, Mushonga B, Muchenje V (2015) Relevance of the formal red meat classification system to the South African informal livestock sector. S Afr J Anim Sci 45(3): 263-277.

Steiner FM, Schlick-Steiner BC, Vanderwal J, Reuther KD, Christian E, Stauffer C et al. (2008). Combined modelling of distribution and niche in invasion biology: a case study of two invasive Tetramorium ant species. Divers Distrib 14(3): 538-545.

Thompson GD, Robertson MP, Webber BL, Richardson DM, Le Roux JJ, Wilson JR (2011) Predicting the subspecific identity of invasive species using distribution models: Acacia saligna as an example. Divers Distrib 17(5): 1001-1014.

Tibane E, Vermeulen A (Eds) (2014) South Africa Yearbook 2013/14. Department of Government Commination and Information System. Republic of South Africa. [Online].

Available: http://www.gcis.gov.za/content/resourcecentre/sa-info/yearbook2013-14 [Accessed 07 September 2015].

Trethowan PD, Robertson MP, McConnachie AJ (2011) Ecological niche modelling of an invasive alien plant and its potential biological control agents. S Afr J Bot 77(1): 137-146.

Turpie JK, Marais C, Blignaut JN (2008) The Working for Water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa, Ecol Econ 65: 788-798.

Vanschandevijl K, Van Loon G, Lefère L, Deprez P (2010) Black locust (Robinia pseudoacacia) intoxication as a suspected cause of transient hyperammonaemia and enteral encephalopathy in a pony. Equine Vet Educ 22(7) 336-339.

Van Wilgen BW, Richardson DM, Le Maitre DC, Marais C, Magadlela D (2001) The economic consequences of alien plant invasions: Examples of impacts and approaches to sustainable management in South Africa. Environ Dev Sustain 3(2): 145-168.

Van Wilgen BW, De Wit M, Anderson H, Le Maitre DC, Kotze IM, Ndala S, Brown B, Rapholo MB (2004) Costs and benefits of biological control of invasive alien plants: case studies from South Africa. S Afr J Sci 100: 113–122.

Van Wilgen BW, Forsyth GG, Le Maitre DC, Wannenburgh A, Kotzé JD, Van Den Berg E, Henderson L (2012) An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. Biol Conserv 148(1): 28-38.

Van Wilgen BW, Moran VC, Hoffmann JH (2013) Some perspectives on the risks and benefits of biological control of invasive alien plants in the management of natural ecosystems. Environ Manage 52(3): 531-540.

Van Wilgen BW, Richardson DM (2014) Challenges and trade-offs in the management of invasive alien trees Biol Invasions 16: 721-734.

Van Wyk B-E, Van Heerden F, Van Oudtshoorn B (2002) Poisonous plants of South Africa. Briza Publications, Pretoria, South Africa.

Weitzenberg J, Zentner J (1997) Herbicide spray provide best control of black locust saplings (California). Restoration and Management Notes 15(1): 94-103.

Zimmerman RW (1984) Growth and development of black locust coppice stands in eastern Kentucky. PhD Thesis, University of Kentucky, Lexington, KY.

Zimmermann HG, Moran VC, Hoffmann JH (2004) Biological control in the management of invasive alien plants in South Africa, and the role of the Working for Water programme. S Afr J Sci 100(1 & 2): 34-40.

Appendix

SPECIES DISTRIBUTION MODELLING (SDM)

Species Distribution Models (SDM) are a popular method used to predict the potential geographic distribution of an organism (Robertson et al. 2001, 2003; Mau-Crimmins et al. 2006; Steiner et al. 2008) and to predict the environmental suitability of regions not yet invaded by invasive species (Mgidi et al. 2007; De Meyer et al. 2008). This is done by quantifying the species-environment relationship, so that the correlation between the occurrence of the species and the environmental parameters within a specific region are determined (Guisan and Thuiller 2005). A maximum-entropy predictive habitat model (MaxEnt-Version 3.3.0), which is regarded as one of the premier distribution-modelling software packages available (Thompson et al. 2011), was used to simulate its potential distribution. Predicting the potential distribution of *R. pseudoacacia* followed a similar method to that of Trethowan et al. (2011), who sought to determine the potential distribution of *Campuloclinium macrocephalum* (Less.) DC.) (Pompom weed) in South Africa. The current distribution data of *R. pseudoacacia,* was obtained from herbaria, GBIF (GBIF 2015) and SAPIA (SAPIA 2015) databases, and was used to model the potential distribution of *R. pseudoacacia*. Input layers, which act as environmental variables, are used in the software to generate a probability distribution, starting from the uniform distribution and repeatedly improving the fit to the data (Phillips et al. 2006). Suitable bioclimatic predictor variables were selected and downloaded from the WorldClim database (Hijmans et al. 2005). The 19 BioClim variables have been widely used in SDM studies (Steiner et al. 2008; Trethowan et al. 2011; Li et al. 2014), as the data can be easily downloaded from the WorldClim database with no further calculations required (Acosta 2008; Li et al. 2014).

The MaxEnt model was calibrated using the obtained records for *R. pseudoacacia* to predict the potential invaded ranges in South Africa. *R. pseudoacacia* has the potential to be distributed across a substantial portion of the country (Fig 3). The distribution results are similar that of Li *et al.* (2014), who sought to determine the global potential geographical distribution of *R. pseudoacacia*.

ARC-MAP 10.2 (ESRI, 2011) was used to overlay different environmental layers onto the model to refine the data. These layers included the MaxEnt layer, the National Land Cover (NLC) 2009 (Bhengu et al. 2009), the Mucina and Rutherford (2006) biome layer and the Agricultural Research Council (ARC) (2009) grazing capacity layer.