Current and potential distributions of *Nassella neesiana* (Chilean needle grass) in Australia and New Zealand

Graeme W. Bourdôt[1], Shona L. Lamoureaux[1], Darren J. Kriticos[2], Michael S. Watt[3] and Matthew Brown[4]
[1] AgResearch, Lincoln, Private Bag 4749, Christchurch 8140, New Zealand
[2] CSIRO Entomology, GPO Box 1700, Canberra, ACT 2601 Australia
[3] Scion, PO Box 29237, Fendalton, Christchurch, New Zealand
[4] AgResearch, Invermay, Private Bag 50034, Mosgiel 9053, New Zealand
Corresponding author: graeme.bourdot@agresearch.co.nz

Summary *Nassella neesiana* (Trin. & Rupr.) Barkworth, var. *neesiana* (Chilean needle grass) is an invasive weed in Australia and New Zealand where it is the subject of management programmes to reduce its impacts (downgrading of wool, skins, hides and carcasses, reduced stock carrying capacity, reduced grassland biodiversity) and spread. Inferring the species' climate preference from its distribution in its native range in South America using CLIMEX, we estimate that 180 and 15 million ha respectively are climatically suitable in Australia and New Zealand under current climate. We also estimate that 0.24 and 0.52% respectively of this suitable area has been invaded in Australia and New Zealand. These results imply that *N. neesiana* could become a much greater problem in both Australia and New Zealand and that management to limit its spread is justified.

Keywords Climate, CLIMEX, niche model, weed management.

INTRODUCTION

Nassella neesiana (Trin. & Rupr.) Barkworth, var. *neesiana* (synonym *Stipa neesiana*) or Chilean needle grass (family *Gramineae*; sub-family *Pooideae*; tribe *Stipeae*) is a tufted perennial grass of temperate South America origin. It has naturalised in both Australia and New Zealand, being first recorded in Australia in 1935, in Melbourne (McLaren *et al.* 1998), and in Auckland in New Zealand sometime before 1940 (Bourdôt and Hurrell 1989). It reduces the livestock carrying capacity of pastures due to the production of masses of unpalatable flower stalks (Anon. 2003, Gardener *et al.* 2003) and its sharp penetrating seeds injure livestock and result in the downgrading of wool, skins, hides and carcasses (Bourdôt and Ryde 1986). The weed also reduces the biodiversity of native grasslands in Australia (Anon. 2003).

In both Australia and New Zealand *N. neesiana* is the subject of community-level management initiatives aimed at local control and prevention of spread. It is a 'Weed of National Significance' (WoNS) in Australia (Snell *et al.* 2007) and is a prohibited species under the Quarantine Act 1908, preventing its sale and distribution. In ACT and parts of NSW it is a 'Declared Pest Plant' requiring its control by landholders (Anon. 2003). In New Zealand *N. neesiana* is a 'Total Control Plant' in Hawke's Bay (HBRC 2009) and a 'Containment Plant' in Marlborough (MDC 2009) requiring landholders to eradicate and contain the species respectively. Two assumptions underpinning these measures are that the species has not yet realised its potential range and therefore its potential ecological or economic impact in either Australia or New Zealand, and that without control it will spread to occupy more of its potential range in both countries.

Here we test the first of these assumptions by initially defining the potential geographic ranges of *N. neesiana* in Australia and New Zealand and then comparing the size of each of these potential ranges with the size of their invaded parts.

MATERIALS AND METHODS

CLIMEX version 3 (Sutherst *et al.* 2007), a dynamic climate model integrating weekly growth and survival (stress) responses of a species to temperature and soil moisture into an annual index of climatic suitability, the Ecoclimatic Index (EI) (ranging from 0 for locations where the species cannot persist to 100 for optimal locations), was parameterised for *N. neesiana*. The parameters (Table 1) were fitted to the species' native and introduced ranges in South America by iteratively changing their values (informed by published literature and anecdote) until the model's projected distribution of EI closely corresponded to the 90 known occurrences in South America. The draft model was verified by projecting it onto the UK and Western Europe. This comparison revealed that the model predicted EI ≥1 for all but three occurrences (all in Scotland). By reducing the tolerable length of the growing season (PDD) in the model from 900 to 650°C days, these three points were encompassed with a slight, but ecologically reasonable increase in the suitable area in South America. This model was then used without further modification to project the species' potential distribution in Australia and New Zealand where it was validated by comparison with all known occurrences.

A 0.5° of arc (*c*. 50 × 50 km) climate dataset generated by Kriticos *et al*. (2006) from the 1961–1990 climate normals provided by the Climatic Research Unit, University of East Anglia (described by New *et al*. 1999) was used to construct the model. Finer-scale climate data sets (0.05° arc, *c*. 5 × 5 km) used to project the model onto Australia and New Zealand were generated by Kriticos and Leriche (2010) and by Kriticos using data from Leathwick and Stephens (1998) respectively.

The percentage of the climatically suitable land area infested by *N. neesiana* in Australia and in New Zealand was calculated using a GIS as the sum of the land areas of the 0.05° arc climate cells with EI ≥1 that contained one or more occurrences of *N. neesiana* divided by the total land area of all of the 0.05° arc cells with EI ≥1 in each of the countries. Climate grid cells were clipped to fine-scale coastlines prior to summarising the areas of climate habitat suitability.

CLIMEX was chosen as the modelling system for this study because its process-oriented approach enables ecological interpretation of the results and because it provides greater confidence (than other models) when projecting into novel climates (e.g. from native to exotic range) (Kriticos and Randall 2001).

Table 1. Values of the CLIMEX model parameters (Sutherst *et al*. 2007) fitted for *Nassella neesiana*.

Index	Parameter	Value	Units
Growth			
Temp.	Lower threshold	8	°C
	Lower optimum	20	°C
	Upper optimum	25	°C
	Upper threshold	28	°C
Moisture	Lower threshold	0.1	
	Lower optimum	0.7	
	Upper optimum	1.1	
	Upper threshold	1.3	
Stresses			
Cold	Threshold	0	°C
	Accumulation rate	−0.01	Wk^{-1}
Heat	Threshold	33	°C
	Accumulation rate	0.005	Wk^{-1}
Dry	Threshold	0.1	
	Accumulation rate	−0.02	Wk^{-1}
Wet	Threshold	1.3	
	Accumulation rate	0.002	Wk^{-1}
H-W	Temp. threshold	25	°C
	Moist. threshold	1.2	
	Accumulation rate	0.01	Wk^{-1}
Growing season	Degree-day threshold for persistence	650	°C days

RESULTS

The parameters for the CLIMEX model for *N. neesiana* are in Table 1. The inferred optimal temperature for population growth is 20–25°C and the optimal soil moisture is 0.7–1.1 (70–110%) field capacity. In addition, *N. neesiana* is inferred to accumulate cold stress at temperatures below 0.0°C, heat stress above 33°C, dry stress at soil moisture levels below 0.1, wet stress above 1.3 and hot-wet stress when temperature and soil moisture exceed 25°C and 1.2 field capacity respectively (Table 1). These parameter values imply that *N. neesiana* has a wide ecological amplitude, tolerating drought-prone and seasonally waterlogged soils, supporting field observations to this effect (McLaren *et al*. 1998).

This model, when projected onto Australia and New Zealand, reveals that *N. neesiana* is potentially able to naturalise in both countries over geographic ranges that greatly exceed the known current distributions of the species (Figures 1 and 2).

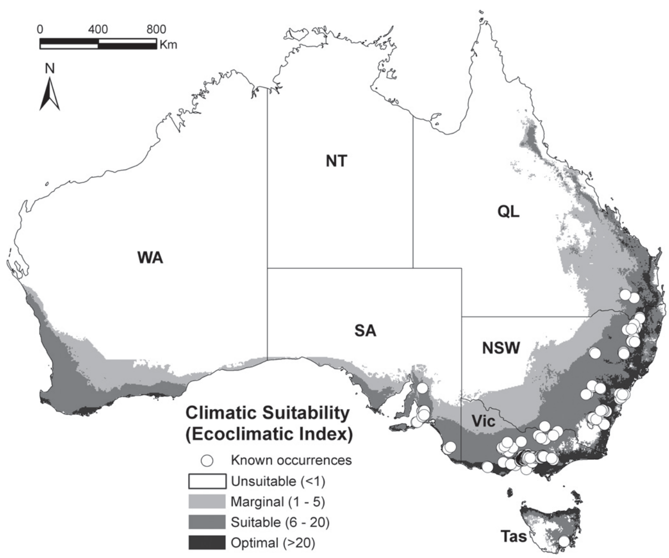

Figure 1. Potential distribution and known occurrences of *N. neesiana* in Australia.

In Australia, large tracts of land in the south west of Western Australia are climatically suitable as are parts of south-eastern Queensland, regions from which the species is currently unknown, apart from two occurrences in southern Queensland (Figure 1). The model also suggests that *N. neesiana* could naturalise further north in these regions of Australia than claimed in a previous study (McLaren *et al.* 2004). The model projects that there are 180 million ha (1.8 m. km^2) in Australia with EI ≥1.0, and that 432,157 ha (4322 km^2) are currently occupied by *N. neesiana*. Thus it is estimated that only 0.24% of the climatically suitable land area in Australia has been invaded to date (Table 2).

In New Zealand also, large tracts of land beyond the currently invaded areas are projected to be climatically suitable (Figure 2). In the North Island, large parts of the regions of Northland, Auckland, Waikato, Gisborne, Hawke's Bay, Manawatu-Wanganui and Wellington are climatically suitable. In the South Island, large parts of the Nelson, Marlborough and Tasman regions are climatically suitable, as are eastern Canterbury, eastern Otago and much of Southland. Only a small fraction of this climatically suitable area in New Zealand has been invaded. The model projects that there are 15 million ha (149,916 km^2) in New Zealand with EI ≥1.0, and that 78,173 ha (782 km^2) are currently occupied by *N. neesiana*. Thus it is estimated that only 0.52% of the climatically suitable land area in New Zealand has been invaded to date (Table 2).

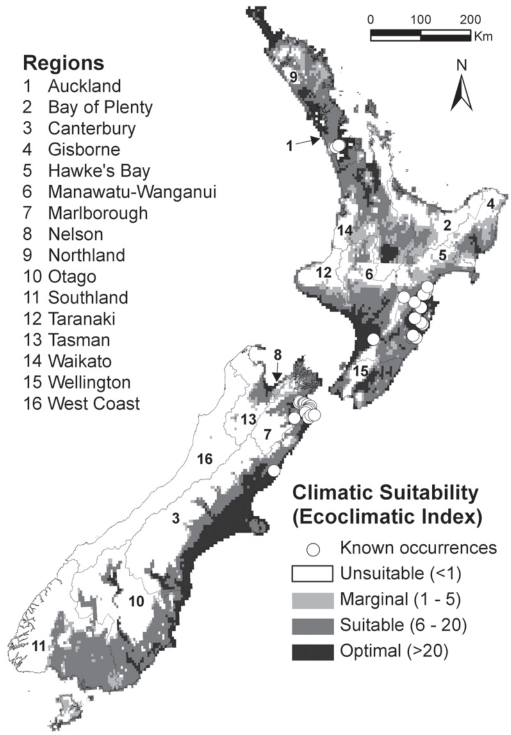

Figure 2. Potential distribution and known occurrences of *N. neesiana* in New Zealand.

Table 2. Comparison of the land area (million ha) climatically suitable for *Nassella neesiana* (EI ≥1) with the land area invaded.

Country	Suitable area	Invaded area	% invaded
Australia	180	0.432	0.24
New Zealand	15	0.078	0.52

DISCUSSION

The CLIMEX model for *Nassella neesiana* presented here, in combination with the known occurrences of the species in Australia and New Zealand, reveals that it has occupied less than 1% of the land areas that are currently climatically suitable in these two countries. This result indicates that this weed, approximately 70 years after being first recorded as naturalised (Bourdôt and Hurrell 1989, McLaren *et al.* 1998), remains in the early stages of its invasion in both countries. Therefore much wider geographic distributions, and hence much greater ecological and economic impacts, are possible in the future.

The realisation of these projected future impacts will depend upon the extent to which the propagules of the species are dispersed to climatically suitable areas. The natural dispersal of this species by wind appears to be limited by the bigeniculate awn (Conner *et al.* 1993) that results in the mature spikelets (fruits) tangling and dropping to the ground in a mass near the parent plant rather than dispersing away from the originating panicle. In contrast, long-distance human-mediated dispersal of the seeds of *N. neesiana* appears to have driven the invasion of this species in its exotic ranges. Its occurrences are commonly associated with tanneries and the transport of animals and/or their hides or fleeces (Haywood and Druce 1919, Stace 2001, Snell *et al.* 2007). Mechanical control of roadside populations and use of earthmoving machines are implicated in its spread in Australia (Anon. 2003). As a result, programmes that prevent the transport of animals, hides and fleeces from infested areas to the climatically suitable areas projected by this CLIMEX model can be expected to limit the spread of the species and thereby reduce its future impacts. Similarly, adherence to strict hygiene measures with respect to machinery used in *N. neesiana*-infested areas such as roadsides and sports fields can be expected to reduce the risk of spread. To this end, regionally or nationally-coordinated management programmes such as the WoNS in Australia may be justified in New Zealand.

In New Zealand, despite the current management programmes in Hawke's Bay and Marlborough, local scale, farm to farm spread of *N. neesiana* is ongoing. Evidence of this is apparent in Marlborough where the number of farms known to support populations of the weed has increased exponentially from 18 in 1987, to 96 in 2005 (Bell 2006). Additionally, the discovery of *N. neesiana* in Canterbury in 2008 apparently originating as seeds on livestock transported from Marlborough, *c.* 200 km away (Laurence Smith, ECan, pers. comm.) (Figure 2) provides evidence that long distance human-mediated dispersal is occurring. This recent spread of the species into Canterbury, a region that is projected by the model to be optimally suitable climatically throughout its eastern districts, highlights the threat posed by the species and the utility of the model as a tool to guide its management.

ACKNOWLEDGMENTS

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