NASSELLA TUSSOCK: CURRENT AND POTENTIAL DISTRIBUTIONS IN NEW ZEALAND

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ABSTRACT

Nassella tussock (*Nassella trichotoma*) occurs most frequently in drought-prone grasslands in several areas of New Zealand where it is the subject of surveillance and/or regional management strategies. The potential range of nassella tussock in New Zealand was estimated using a climate model developed from global distribution data (excluding the known distribution for New Zealand). The climate suitability of New Zealand for nassella tussock was estimated using a gridded climate dataset with a spatial resolution of 10 minutes of arc. The model projections encompassed all areas of current occupation, as determined from the records of ten Local Authorities, and revealed vast tracts of land, particularly in southern Canterbury and Otago, which are currently climatically suitable yet unoccupied by the weed. This map will enable regional authorities to recognise sites most at risk of invasion (those with high climatic suitability that are nearby current or historical infestations), and factor this into their management programmes.

Keywords: CLIMEX, fundamental niche, nassella tussock, *Nassella trichotoma*, serrated tussock.

INTRODUCTION

Nassella trichotoma (Nees) Hack. ex Arechav is native to central South America in the Argentine pampas and southern Uruguay (Torres 1996; Torres 1997) and at least one location in Brazil. There have also been unconfirmed reports of *N. trichotoma* being native to Chile, Peru and Patagonia (Patterson 1994). Known in New Zealand and South Africa as nassella tussock, this invasive species is highly unpalatable to livestock, particularly sheep, and has been in New Zealand since about 1860 (Healy 1945), though it wasn't identified scientifically until 1935 (Allen 1935). It has also been introduced to Australia, England, Italy and the USA, though no plants have been reported as growing in the USA. Reports of nassella tussock in Scotland, Germany and France were not verified by the citations in the papers we had access to (Moggi 1971; Campbell 1982; Westbrooks 1991; Westbrooks & Cross 1993; McLaren et al. 1998). This is because (1) the citation did not contain the information cited, (2) we could not find the cited information due to incorrect referencing or (3) due to antiquity we could not obtain a copy of the cited information.

In New Zealand, nassella tussock spread rapidly during the early 1900s to occupy vast tracts of pasture land, especially in North Canterbury and Marlborough, where many farms soon supported extensive monocultures of up to 34,000 plants/ha (Healy 1945). Because of the perceived national threat and the high costs of control, central Government intervention was deemed necessary. In 1946 the Nassella Tussock Act was passed, legislating for the formation of the North Canterbury and Marlborough Tussock Boards to coordinate control programmes. Programmes involving cultivation, herbicides and destocking, topdressing and oversowing, were employed to reduce population densities, and afforestation, fire and grazing with cattle were used to reduce seeding (Bourdôt et al. 1992). Infestations of scattered plants, many of which arose in newly sown pastures, were manually grubbed, and this technique remains the primary control method in New Zealand. During the 22-year period from 1966 until 1988, data collected in North Canterbury revealed a pronounced reduction in the population density of the weed to apparent equilibria of 2 and 5 plants/ha on "developed" and "undeveloped" land respectively (Bourdôt et al. 1992). Recent monitoring by Environment Canterbury shows the population density of nassella tussock has remained at these low levels under a continued annual grubbing regime (Environment Canterbury Draft Community Plan 2004-2014).

Although these densities are currently well below economically damaging levels the perceived threat of population increase and spread is a strong incentive for ongoing regional management programmes, particularly in Canterbury and Marlborough. This paper describes a climate-based model of nassella tussock that provides an objective estimate of the potential distribution and relative abundance of the species in New Zealand under current climatic conditions.

METHODS

A CLIMEX model (version 2.0) of nassella tussock was developed by fitting parameters to its native range in South America, and also to its introduced range in South Africa, the United Kingdom and Italy. The distribution of nassella tussock in Australia was used to verify and validate the model before using it to predict the species potential distribution in New Zealand. This predicted distribution was then compared to its current and historical distribution in New Zealand.

The methods for deriving CLIMEX model parameters from geographic distributions are described in Sutherst et al. (1999) and Sutherst (2003). The parameter-fitting procedure is a manual process of iteratively adjusting parameters and comparing model results with known distribution information, whilst considering any eco-physiological knowledge about the species.

The native range of nassella tussock was ascertained from field delimitation surveys in Argentina undertaken by one of us (W. Pettit, unpubl. data), from the data of Gardener (1998) and from herbarium records across Argentina, Uruguay and Brazil (Pretoria herbarium, Torres 1996; Torres 1997; Barkworth & Torres 2001) (Fig. 1). The exotic range of nassella tussock was compiled from published records and survey data: Australia (D. McLaren, Department of Natural Resources, Victoria, pers. comm.), Italy (Moggi 1971), South-east England (Stace 1997), South Africa (extract from the Southern African Plant Invaders Atlas (SAPIA) database supplied by Lesley Henderson; additional records supplied by Ben Viljoen, Plant Protection Research Institute, and Piet Theron, National Department of Agriculture, Republic of South Africa) and New Zealand (Taylor (1987) and records provided by the Regional and District Councils that are listed in the acknowledgements). Reports of *Nassella trichotoma* from Scotland, France, Germany and the USA (e.g. Campbell 1982; Westbrooks & Cross 1993; McLaren et al. 1998) are thought to be erroneous, probably based on a confused interpretation of Ridley (1973) and Stace (1997), who discuss the presence of both *Nassella* syn *Stipa neesiana* and *S. trichotoma* in Europe, and of Westbrooks (1991) and Westbrooks & Cross (1993), who report on the introduction of *N. trichotoma* seed into the USA, but who also note that no plants have been reported there. The distribution of nassella tussock in Australia, South Africa and Europe was used to verify and validate the model.

The climate surfaces used for modelling were derived from the 10' of arc resolution gridded climatology from the University of East Anglia described by New et al. (2002). The slight differences between the 10' CRU climate dataset and the standard meteorological station dataset provided within CLIMEX means that the fitted parameters for this model are valid only for use with the 10' CRU dataset and should not be used with the standard dataset without first checking and re-fitting the parameters. Version 2.0 of CLIMEX was used for this modelling work. This version employs a new means of calculating the rate of stress accumulation compared with previous versions. The hot-wet stress accumulation rate (PHW) would need to be re-fitted if the model is to be used in version 1.x of CLIMEX.

RESULTS AND DISCUSSION

The fitted model parameters and their values are given in Table 1. Nassella tussock prefers cool, moist Mediterranean climates (Table 1, Fig. 1). In the native range, nassella tussock reaches no further south than approximately 100 km south of Bahia Blanca on the coast of Argentina, since low temperatures become limiting. In the north, hot-wet stress limits nassella tussock to Uruguay, and a single outlying location at Porto Alegre, whose climate is anomalously drier compared with its immediate surroundings. In the west, soil moisture becomes limiting. Wet stress *per se* does not appear to be limiting, and the restriction on growth under excessively moist conditions appears to be sufficient to explain the distribution pattern of nassella tussock.

TABLE 1: CLIMEX parameters used for modelling the distribution of nassella tussock.

Index	Parameter	Value	Units[1]
Temperature	DV0 = lower threshold	6	ºC
	DV1 = lower optimum temperature	15	ºC
	DV2 = upper optimum temperature	25	ºC
	DV3 = upper threshold	31	ºC
	PDD = degree-day threshold (minimum annual total no. degree-days above 6ºC (DV0) needed for population persistence	1 200	ºC Days
Moisture	SM0 = lower soil moisture threshold	0.15	
	SM1 = lower optimum soil moisture	0.2	
	SM2 = upper optimum soil moisture	0.9	
	SM3 = upper soil moisture threshold	1.25	
Cold Stress	TTCS = temperature threshold	-2	ºC
	THCS = stress accumulation rate	-0.05	$week^{-1}$
Heat Stress	TTHS = temperature threshold	31	ºC
	THHS = stress accumulation rate	0.02	$week^{-1}$
Dry Stress	SMDS = threshold soil moisture	0.15	
	HDS = stress accumulation rate	-0.055	$week^{-1}$
Hot-Wet Stress[2]	TTHW = temperature threshold	25	ºC
	MTHW = threshold soil moisture	0.9	
	PHW = stress accumulation rate[2]	0.02	$week^{-1}$

[1]Cells without unit values are a dimensionless index of soil moisture availability.
[2]In version 2 of CLIMEX, it is assumed that all stresses accumulate exponentially over time, reflecting the progressive increase in severity of the same amount of stress stimulus as time goes by as the population exhausts its resources. In previous versions of CLIMEX the calculations for the interaction stresses did not include the week number term. For example, the hot-wet stress is now calculated as: {Weekly Stress = PHW x (TTHW – average weekly Temperature) x (MTHW – average weekly Soil Moisture) x week number}. These parameters should therefore not be used in versions of CLIMEX prior to 2.0 without re-fitting of the stress accumulation rate.

At the global scale, the CLIMEX model of nassella tussock (Fig. 2) closely agrees with the available distribution data (Fig. 1), with no obvious anomalies. The potential for additional spread into the cooler regions of Queensland accords with the northern limits of nassella tussock in South America. The lack of records in Queensland could be expected due to the less favourable environment there compared with more southern regions. It might therefore be expected that the invasion front would slow here due to increasing hot-wet stress, so it may be that the lack of records from that region is due simply to invasion history rather than a lack of climatic suitability.

FIGURE 1: The worldwide distribution of *Nassella trichotoma*. Filled triangles indicate locations at which *N. trichotoma* has been positively identified. See text for sources of data.

The potential distribution of nassella tussock in New Zealand is given in Figure 3. There are three anomalies, Whangarei, Coromandel Peninsula (Te Puru Bay and Waitete Stream) and western Canterbury (Tasman River; Upper Rakaia River; Waimakariri River, Craigieburn; and Clarence River, St Bernard), where the model does not correctly predict the potential occurrence of nassella tussock. The Whangarei sites are located outside the climate dataset, and may otherwise be correctly predicted. The Coromandel Peninsula sites are apparently the wettest sites that nassella tussock is found globally. Possible reasons for the anomaly include errors in the climate dataset or the model formulation, or the possibility that these infestations are in relatively dry microsites, or a combination of these factors. The heavily dissected landscape on the western coast of the Coromandel peninsula and the proximity of the central mountain range, mean that it is possible that the nassella tussock in this area is located in rain shadow areas. The fact that there is no other infestation worldwide that is located in such apparently wet locations suggests that the model formulation may be correct in respect of the moisture index. The four western Canterbury sites are projected by the model to be marginally too cold for nassella tussock. This anomaly is likely to be due to the climate in the corresponding climate grid cells not being representative of the valley floor sites from which the records were taken. However, it is also possible that nassella tussock is able to tolerate conditions slightly colder that those from where it has been found in its native range. Irrespective of the cause, warmer microsites along the western Canterbury foothills to the Southern Alps should be considered at risk of invasion by nassella tussock.

FIGURE 2: The modelled global potential distribution of *Nassella trichotoma*. The CLIMEX ecological index (EI) ranges for each climate suitability class are indicated in parentheses. Higher EI values indicate greater climatic suitability and therefore relative abundance of nassella tussock.

Compared with the historical distribution, the modelled potential distribution in New Zealand indicates that nassella tussock has the ability to invade a great deal more territory, particularly in the southern third of the North Island, and southern Canterbury and Otago on the South Island (Fig. 3). When interpreting the CLIMEX suitability classes in Figure 3, the best indicator of the invasive potential of nassella tussock within each region will be gained from consideration of on-the-ground examples of present or historical infestations within each of the climate suitability classes. That is, to understand the meaning of the suitability classes it is necessary to look beyond the present state of the pastures under the present grubbing regime. Historical photographs or other evidence of nassella tussock infestations in Canterbury taken prior to the concerted control efforts that followed the establishment of the control boards in 1946 should serve as a basis for interpreting the "optimal" class. Similarly, the present state of the southern highlands of New South Wales in Australia provides a stark reminder of what could happen if control measures were to be relaxed in New Zealand. Badly infected paddocks in that region are frequently barely able to support any livestock grazing activity due to the dominance of nassella tussock.

Whilst the effect of climate change on the potential distribution of nassella tussock was outside the scope of this modelling project, it might be expected that as temperatures rise, the suitability of southern regions would increase considerably (particularly those areas of southern Canterbury and Otago that are projected to be too cold and those parts of Southland that are marginal due to cold). Higher altitude areas such as the southern highlands will also likely increase in suitability, though the steep thermal gradients in these mountains means that further invasion will be limited in areal extent.

The inclusion of the exotic distributions in South Africa, United Kingdom and Italy allows the model to capture any range expansion in climatic terms that may have occurred as a function of release from natural enemies or competition in the native range (Kriticos & Randall 2001). The model may therefore approximate the fundamental niche (Hutchinson 1957), which is the most appropriate indicator of likely performance of an organism in an exotic environment. Whilst it is generally accepted that climate is the primary determinant of the potential distribution of plants and poikilothermal animals (Andrewartha & Birch 1984; Woodward 1987), non-climatic factors frequently modify the suitability of habitat within the climatic limits, and favourable microsites may exist beyond the limits predicted by climate measurements. Within the climatically suitable zone in Figure 3, site-specific factors such as soils, land use and control measures, will influence whether any given location is suitable for the persistence of nassella tussock.

This CLIMEX model is highly consistent with the known distribution of nassella tussock, and appears valid compared with the independent dataset. This tool should prove valuable to Regional and District Councils and others looking to control this invasive species. It places current infestations in context with their potential to increase in abundance and their potential for further spread. The use of finer-scale climate datasets may address the anomalies noted in Canterbury and the Coromandel Peninsula. Exploring the effects of climate change on this climatic suitability map is the next obvious step in providing land managers with useful information tools for managing nassella tussock.

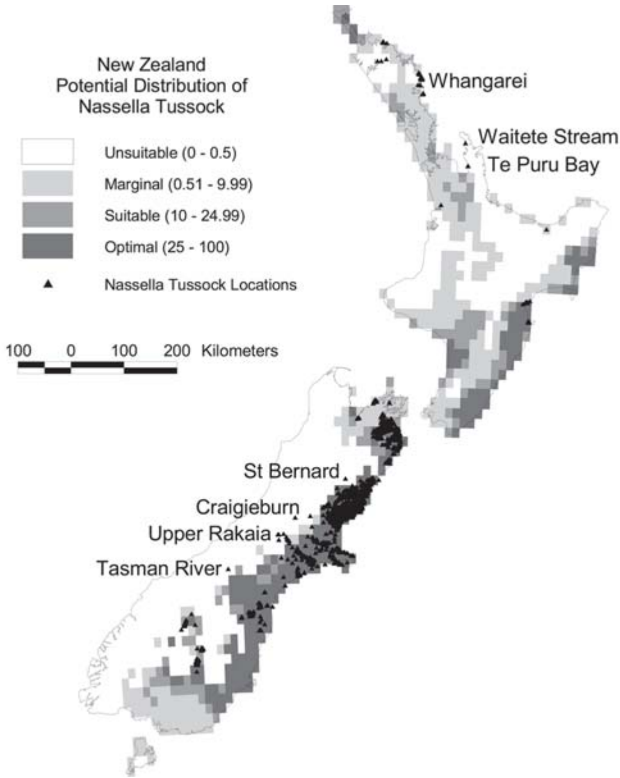

FIGURE 3: The historical and modelled potential distribution of *Nassella trichotoma* in New Zealand under current climate conditions. Filled triangles indicate locations at which *N. trichotoma* has been positively identified. See text for sources of data. The CLIMEX ecological index (EI) ranges for each climate suitability class are indicated in parentheses. Higher EI values indicate greater climatic suitability and therefore relative abundance of nassella tussock

ACKNOWLEDGEMENTS

David McLaren, of DNRE in Victoria, kindly provided distribution data on nassella tussock in Australia. Thanks to Ben Minehan (Marlborough District Council), Robin Vanzoelen (Tasman District Council), Tim Senior (Environment Bay of Plenty), Jack Craw (Auckland Regional Council), David Stephens (Environment Waikato), Ken Massey (Northland Regional Council), Robin Packe (Hawke's Bay Regional Council), Don Robson (Otago Regional Council), Doug Gordon (ex Otago Regional Council), Laurence Smith, Fiona Nicol and Ryan Elley (Environment Canterbury) and Dave Saville (AgResearch) for providing data on the current and historical occurrences of nassella tussock. Thanks also to Rob Phillips (Environment Canterbury) for co-ordinating our request for data across the local authorities throughout New Zealand. We thank John Scott (CSIRO Entomology) and Peter Williams (Landcare Research) for helpful comments on the manuscript.

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