The potential distribution of yellow bristle grass (*Setaria pumila*) in New Zealand

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Abstract Yellow bristle grass (*Setaria pumila*), an invasive annual grass weed in North America, Africa, Australia and New Zealand, has become a problem on dairy farms in the upper North Island. To define its potential distribution in New Zealand, an eco-climatic model was constructed using CLIMEX. The model was parameterised using the known distribution of the species in its native range in Eurasia and validated against its invaded range in North America. The model predicted all known occurrences in New Zealand and revealed extensive tracts of land in both the North and South Islands that are currently climatically suitable yet, according to current records, unoccupied by the weed. Under climate change, this potential distribution increases substantially. These results imply that yellow bristle grass could become a much wider problem on dairy farms throughout New Zealand and that management to limit its spread is justified.

Keywords climate change, CLIMEX, *Setaria pumila*, weed invasion, yellow bristle grass, yellow foxtail.

INTRODUCTION

Setaria pumila (Poir.) Roem. et Schult., (yellow bristle grass) is a C₄ annual summer grass thought to have originated in China and then spread westward through Asia into Europe as both a weed and a crop (koral) (Dekker 2003). It is now widely distributed in North America, Argentina, Uruguay, Africa, the Middle East, Europe, Asia, Australia and many Pacific Islands (Wang et al. 1995). It is considered an important agricultural weed in North America (Wang et al. 1995; Dekker 2003). It was first recorded in New Zealand in 1905 (Allan 1940) and has spread through Waikato dairy pastures (James et al. 2009; Tozer et al. 2012). Because of its poor nutritive value and avoidance by cows when seeding, losses in farm production can be substantial (James et al. 2009).

While yellow bristle grass is currently known to be affecting dairy farms in the Upper North Island and coastal Taranaki, its sporadic occurrence throughout the North and upper South Island could portend a wider ecological and economic impact. As a first step toward quantifying the potential national impact, this paper presents a climate-niche model for yellow bristle grass and projects it onto New Zealand to identify the weed's potential distribution.

MATERIALS AND METHODS

The CLIMEX model

CLIMEX is a dynamic model (Sutherst et al. 2007) that integrates the weekly growth and survival (stress) responses of a species to climate and

biotic variables into an annual index of climate suitability, the Ecoclimatic Index (EI) that ranges from 0 for locations where the species cannot persist to 100 for optimal locations. In this study only the climate variables, air temperature and soil moisture, are used. In addition, EI is classified into four classes of climatic suitability for yellow bristle grass: unsuitable (EI = 0), marginal (EI = 1-5), suitable (EI = 6-20) and optimal (EI > 20).

Current distribution

The known occurrences of yellow bristle grass globally (n=4264) (Figure 1) were determined from published literature (full reference list available on request) found by searching CAB Abstracts and the Global Biodiversity Information Facility (Global Biodiversity Information Facility 2011) using the search terms "*Setaria pumila*" and "*Setaria glauca*". Additional records for New Zealand were provided by Trevor James and Katherine Tozer (AgResearch Limited, Ruakura, New Zealand). All occurrence records were verified where possible using site descriptions and Google Earth 7.0 and those with incomplete or missing locality information were excluded as were any duplicate records.

Fitting model parameters

The 'Climond 10' spatial resolution climate dataset (Kriticos et al. 2012) was used within

CLIMEX v3 for fitting the parameters. This dataset was used to infer the climatic requirements of yellow bristle grass from its known occurrences first in China (n=30), the native range of the species (Dekker 2003), and then in the rest of Asia (n=130) where the genetic diversity of the species is extensive, suggesting that Asia is where invasive yellow bristle grass originated (Dekker 2003). The model was fitted by iteratively changing the parameter values (informed by published literature) from the default "temperate" model (Sutherst et al. 2007) until the projected distribution (where EI≥1) closely corresponded to the Chinese records. In the remainder of Asia, further adjustments were needed in the temperature and soil moisture indices and stresses to allow persistence in areas with dry summers and temperatures regularly in excess of 30°C. To verify the model, its projected distribution of EI≥1 was compared with the occurrences of yellow bristle grass in Europe (n=3253). The model included all occurrences except for a few in Norway and Austria that were initially excluded due to very low number of degree days. To include these points, PDD (thermal accumulation) was omitted from the model allowing the model to include these records without changing the model's projection in Asia.

Figure 1 The global distribution of known occurrences of yellow bristle grass.

This final model was validated against the naturalised occurrences of yellow bristle grass in Africa (n=63), North America (n=532), South America (n=5), Australia (n=169) and Oceania (n=57) before finally projecting it onto New Zealand (n=25). In North America and Africa, all but a few occurrences were within the predicted range of suitable climate. All those occurrences that fell outside of the model (n=10 in North America and n=3 in Africa) were in locations where fatal dry stress predicted by the model was overcome either by irrigation or gardening or the occurrences were in micro-habitats such as drainage ditch or stream banks of a scale below the resolution of the climate data used for the model's projections. In all other regions all occurrences were modelled as having suitable climate, providing confidence that the model is an adequate representation of the climate preference of yellow bristle grass.

Climate change scenarios

Four climate change scenarios were used as meteorological input for the validated CLIMEX

model to project future potential distributions of yellow bristle grass. These scenarios were developed from two Global Climate Models (GCMs), CSIRO Mark 3.0 (CSIRO, Australia) and MIROC-H (Centre for Climate Research, Japan), each run using two standard emission scenarios (medium (A1B) and high (A2)) (IPCC 2007). The data for each climate change scenario were from the CliMond database and are fully described in Kriticos et al. (2012).

RESULTS

The parameters for the CLIMEX model are in Table 1. The inferred optimal temperature for population growth is 18–24°C and the optimal soil moisture is 0.8–1.5 field capacity (FC). In addition, yellow bristle grass is inferred to accumulate cold stress at temperatures below 8°C, heat stress above 35°C, dry stress at soil moisture levels below 0.08 FC and wet stress above 2.5 FC. These values suggest that yellow bristle grass has a wide ecological amplitude tolerating drought prone and seasonally water logged soils as well as periods of extreme heat, supporting the idea that

Table 1 Parameters fitted to define the Growth and Stress Indices for yellow bristle grass in the CLIMEX model

Index	Parameter	Value	Units ¹
Temperature	DV0 = lower threshold	8	°C
	DV1 = lower optimum temperature	18	°C
	DV2 = upper optimum temperature	24	°C
	DV3 = upper threshold	35	°C
Moisture	SM0 = lower soil moisture threshold	0.08	
	SM1 = lower optimum soil moisture	0.8	
	SM2 = upper optimum soil moisture	1.5	
	SM3 = upper soil moisture threshold	2.5	
Cold Stress	TTCS = temperature threshold	8	°C
	THCS = stress accumulation rate	-0.00006	Week ⁻¹
Heat Stress	TTHS = temperature threshold	35	°C
	THHS = stress accumulation rate	0.0005	Week ⁻¹
Dry Stress	SMDS = threshold soil moisture	0.08	
	HDS = stress accumulation rate	-0.0005	Week ⁻¹
Wet Stress	SMWS = threshold soil moisture	2.5	
	HWS = stress accumulation rate	0.002	Week ⁻¹

¹Cells without unit values are a dimensionless index of soil moisture availability.

the species can readily adapt to local conditions (Dekker 2003).

Potential distribution in New Zealand under current climate

The model, when projected onto New Zealand encompasses all known occurrences of yellow bristle grass and has the highest EI values in those regions where the plant is currently most invasive (Figure 2a). Evidently, large tracts of land throughout New Zealand beyond the currently invaded areas are climatically suitable. Most of the North Island is highly suitable with unsuitable areas occurring only in the Central Plateau. In the South Island, much of the Tasman district, East Coast, the northern part of the West Coast and parts of Southland are suitable or optimal. All unsuitable areas are a result of cold stress.

Potential distribution in New Zealand under future climate

All four future climate scenarios gave remarkably similar projections and the CSIRO Mark 3.0 model with the A1B emission scenario has been selected to illustrate the climate change effect. Under climate change, there was an increase in climate suitability in both islands (Figure 2b). In the North Island under future climate, suitable areas extended into the central plateau and the whole island becomes suitable in all but the illustrated climate change scenario where a small portion of the central plateau remains unsuitable. In the South Island, climatic suitability extends further inland on both the east and west coasts and south down the West Coast. The increase in suitability for both islands is due to an increase in temperatures.

DISCUSSION

The occurrence records show that global distribution of yellow bristle grass is wide and encompasses all climatic regions except the polar ice cap and tundra and dry steppe and desert regions (Figure 1). The ability of the species to inhabit such an array of climatic regions is reflected in the wide range of suitable

Figure 2 Potential distribution and known occurrences (circles) of yellow bristle grass in New Zealand under (a) current climate and (b) future climate (CSIRO Mark 3.0 model with the A1B emission scenario).

temperatures for growth (temperature thresholds of 8°C and 35°C for lower and upper limits respectively). This response is probably due to its genotypic diversity, which allows it to invade, colonise and adapt to a wide range of habitats (Dekker 2003). Its ability to grow quickly and produce seed in a short period of time (Tozer et

al. 2012) suggests that populations can persist in colder climates and this is reflected in the slow rate of cold stress accumulation (THCS).

The potential distribution of yellow bristle grass in New Zealand as modelled here by CLIMEX reveals that it has, to date, occupied very little of the land area that is climatically suitable. This indicates that this weed, 110 years after first being recorded as naturalised (Allan 1940), remains in the early stages of its invasion. Furthermore, under climate-change the area of climatically suitable land increases considerably. The increase is due to greater temperatures, which reduce cold stress on the species.

The extent to which the species realises its potential distribution in New Zealand dairy pastures will depend on the extent to which its seeds are dispersed. Yellow bristle grass is dispersed mainly by human activities (mowing, farm machinery, hay, etc.) (James et al. 2009; Tozer et al. 2012), and prudent on-farm biosecurity measures will be required to limit its spread. The potential distribution maps presented here for yellow bristle grass may be used by regional authorities and the dairy industry to identify areas at greatest risk of infestation and formulate strategic control plans to mitigate further spread of this weed.

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