COMMERCIAL IN CONFIDENCE

Client Report No. XXXX

THE CURRENT AND POTENTIAL DISTRIBUTION OF SCOTCH BROOM (*CYTISUS SCOPARIUS* (L.) LINK) IN NEW ZEALAND

Authors Karina Potter, Darren Kriticos and Samantha Alcaraz

Date: 29 June 2007
Client: New Zealand Site Management Cooperative

THE JOINT FORCES OF CSIRO & SCION

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EXECUTIVE SUMMARY

Objective

The objective of this study was to collect *C. scoparius* presence and absence data from the national plantation estate and to project the potential distribution of *C. scoparius* in New Zealand.

Key Results

Cytisus scoparius is present in all 16 administrative regions of the country, infesting land at a range of altitudes and of varying land use. It has been recorded from sea level to over 1300m, on both the dry land sites on the east coast of the South Island where annual rainfall can be as low as 609 mm $year^{-1}$ and in Fjordland on the west coast where rainfall can be over 4000 mm $year^{-1}$.

The modelled distribution projects the entire North Island and the majority of the South Island to be of suitable or optimal climate for the persistence of *C. scoparius*. Areas of marginal or unsuitable climate occur in the Southern Alps and in Fiordland in the South West where the number of degree days and cold stress limit persistence.

Application of Results

The synoptic view of the potential distribution of *C.* scoparius indicates that there is still potential for further range expansion of this weed in New Zealand. Hence the forestry sector needs to consider the management of this weed an integral part of their business plan in order to mitigate its impact on production both now and in the future.

Further Work

Modification of Figure 4 - the potential distribution of *C.* scoparius in New Zealand, would be valuable in order to better display the variation in the climate suitability of locations within New Zealand. New and innovative management strategies are required in order to mitigate the threat posed by this weed. In order to carry out this research, financial and in-kind support from industry and other funding bodies will need to be sourced.

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Information for Ensis abstracting:

Report ID number	
Weed species worked on	*Cytisus scoparius* (Scotch Broom)
Key words	CLIMEX, Scotch broom, potential distribution, New Zealand, *Cytisus scoparius,* forestry, risk assessment

INTRODUCTION

Cytisus scoparius (L.) Link is widely distributed throughout the Temperate and Mediterranean climatic zones (Fig 1). It is native to western and central Europe, North Africa and Western Asia (Holm *et al.*, 1979; Wheeler *et al.*, 1987; Hosking *et al.*, 1996; Luken & Thieret, 1997) and is considered an introduced weed in New Zealand (Williams, 1981), Australia (Parsons & Cuthbertson, 1992; Downey & Smith, 2000), South Africa, Canada, Chile, Iran (Smith *et al.*, 2000), the United States of America including Hawaii (Holm *et al.*, 1979; Bossard, 1991; Hosking *et al.*, 1996; Luken & Thieret, 1997), the Canary Islands and parts of Asia including India (Smith *et al.*, 2000), Japan (Nemoto *et al.*, 1993; Dobashi, 1995; Smith *et al.*, 2000) and China (Fowler *et al.*, 1996). *Cytisus scoparius* is recorded as a specific threat to commercial forestry operations in New Zealand, Australia, the USA and Canada (Zielke *et al.*, 1992; Prasad & Peterson, 1997; Peterson & Prasad, 1998).

In New Zealand, *C. scoparius* is widespread and abundant over large areas of the country, invading open grasslands on both production and conservation lands, large areas of wasteland, roadsides, river beds, and plantation forests (Syrett, 1989; Syrett *et al.*, 1999). It has the ability to grow and set seed over a wide altitudinal range (Syrett, 1986), on land of varied topography (Syrett, 1989) and grows all year round under adequate moisture and mild temperature conditions (Williams, 1981; Richardson & Davenhill, 1996). In plantation forests, *C. scoparius* often appears as a dense mat of seedlings after cutover or site preparation operations. Infestation can be particularly severe during site preparation for second and third rotation planting as seed in the seed bank is stimulated to germinate. Many studies have demonstrated that the survival and growth rates of *Pinus radiata* crop trees can be reduced by competition with other plant species for water, light, and nutrients (Richardson *et al.*, 1993). This has been shown to be the case with *C. scoparius* in a number of studies (Richardson, 1993; Richardson *et al.*, 1996; Kimberley & Richardson, 2001; Watt *et al.*, 2004) and a reduction in tree growth rates, particularly in the early years of tree establishment, can have a significant impact on site productivity. Significant costs are associated with *C. scoparius* control, with the application of herbicides both prior to and post planting the most common method employed (see Isaacson *et al.*, 2000; Potter, 2007). The risk of spreading *C. scoparius* to new, currently uninfested areas is also high due to the potential for human, vehicle and machine-assisted dispersal as part of the monitoring, maintenance and harvest of the forest estate.

This study was a component of the project titled "A Case Study of Broom Management in Forestry" funded by the New Zealand Site Management Cooperative. Its aims were to collect *C. scoparius* presence and absence data from the national plantation estate and to project the potential distribution of *C. scoparius* in New Zealand. The potential distribution and relative abundance of *C. scoparius* in New Zealand was projected using the computer programme, CLIMEX Version 3 (Sutherst *et al.*, 2007). CLIMEX (Sutherst & Maywald 1985) is a modelling tool designed to explore the potential distribution and relative abundance of species using climate databases to infer the responses of a taxon to climate. The value of CLIMEX for weed risk assessment has been described by Kriticos & Randall (2001). The outcome of this approach is the identification of areas that are climatically suitable for persistence of the organism, independent of the effect of factors such as dispersal, competition, predators and land-use that can prevent a species from expanding into climatically suitable environments. The production of a synoptic view of the potential distribution of *C. scoparius* in New Zealand facilitates an assessment of the risk posed by this weed to the forestry sector. The results can be used to motivate a more objective assessment of current vegetation management practises and stimulate the development of new, innovative management strategies.

MATERIALS AND METHODS

The Current Distribution

The known distribution of *C. scoparius* in New Zealand was collated from many institutions and individuals including members of the New Zealand Site Management Cooperative, District and Regional councils and the Department of Conservation (see the list of sources at the end of this report).

The Potential Distribution

CLIMEX is applied to a species by selecting values for a set of parameters that describe its response to temperature, moisture and light (Sutherst *et al.*, 2007). These are integrated to form the Ecoclimatic Index (EI) which gives an overall measure of the potential of a given location to support a permanent population of the species (Sutherst *et al.*, 1995). The EI is potentially scaled between 0 and 100, though in practice, maximum values can only be attained in highly stable environments such as near the equator. Sutherst (2004) provided a suggestion that an EI close to zero indicates that a location is poorly favourable for a species, and that an EI of more than 30 represents a very favourable climate for the species. However, the range of EI values is a species and model specific function, and, therefore, interpreting EI values requires consideration of the relationship between the modelled EI values and the abundance of the species at known locations.

The *C. scoparius* CLIMEX model was based upon the known native distribution as a means of estimating the realised niche of *C. scoparius* in the presence of its natural enemies and under competition with other plant species. The world-wide distribution of *C. scoparius* was determined from records in the literature and a survey of locality data held by various institutions (Figure 1, see the list of sources at the end of this report). World gazetteers (www.nla.gov.au/map/worldgazetteers.html) were used to derive estimates of coordinates for localities where coordinates were not given in original sources. Where mapped distributions were located, maps were scanned, rectified and georeferenced, and a series of points were manually generated.

The model developed using the known native distribution was verified by adjusting parameters to allow for persistence at locations on the fringe of the native distribution and in areas of the known range where climate conditions where extreme. The known distribution in North and South America were used as validation data to examine how well the model projected the potential distribution in a country within the introduced range where the known distribution was well documented. Finally, the model was used to project the potential distribution of *C. scoparius* in New Zealand.

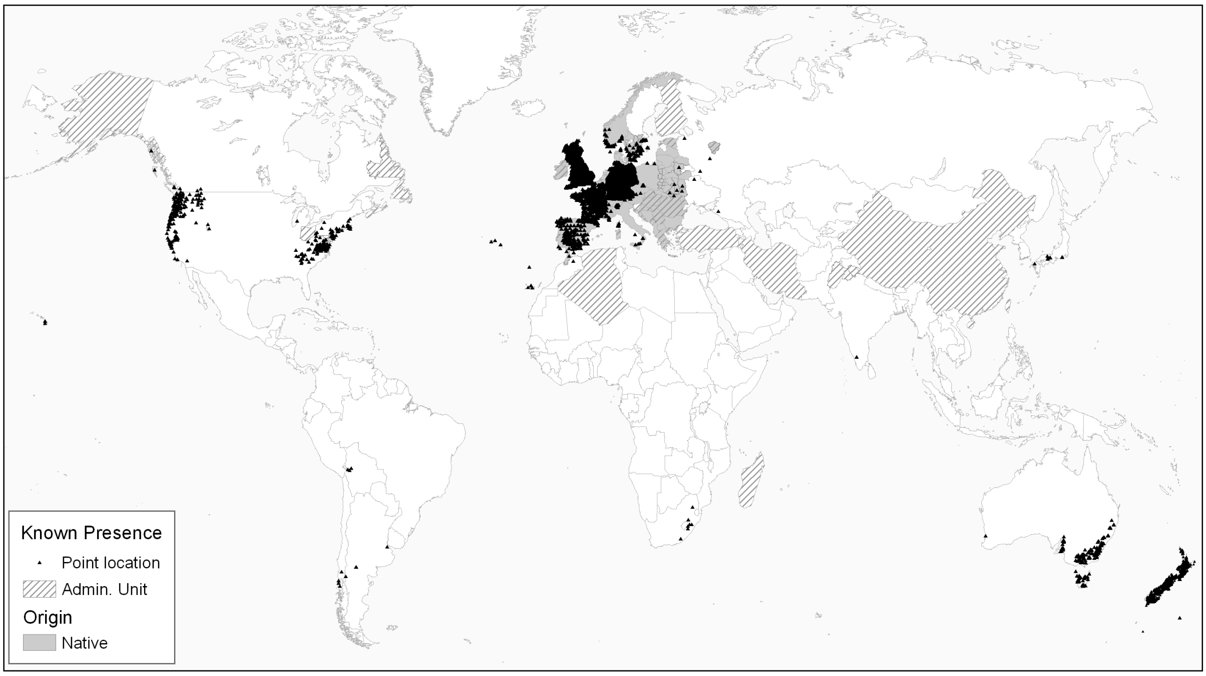

Figure 1 Worldwide distribution of *C. scoparius.* Grey *s*hading indicates native distribution, cross hatch indicates administrative units where *C. scoparius* has been recorded and triangles indicate historical point locations.

Fitting Parameters in the Native Range

The climate dataset used for the parameter-fitting was a 0.5 degree of arc dataset generated by Stephens et al. (in press) from the 1961-1990 climate normals provided by the climate research unit (Mitchell *et al.*, 2004). The genetic algorithm function in CLIMEX provided the starting set of parameter values for the "Compare Locations" module. Parameters were then manually interatively adjusted until the EI indicated suitable climatic conditions at sites within the known native distribution and unsuitability at sites outside of the known native distribution (Table 1, Fig. 2a,b).

Table 1 CLIMEX parameters values used for modelling the distribution of *Cytisus scoparius* based on the native distribution. The role and meaning of parameters are described in Sutherst *et al*. (2004).

Index	Parameter	Values
Temperature	DV0 = lower threshold	5 °C
	DV1 = lower optimum temperature	14 °C
	DV2 = upper optimum temperature	25 °C
	DV3 = upper threshold	28 °C
Moisture	SM0 = lower soil moisture threshold	0.1
	SM1 = lower optimum soil moisture	0.6
	SM2 = upper optimum soil moisture	1
	SM3 = upper soil moisture threshold	2
Cold stress	TTCS = temperature threshold	-12 °C
	THCS = stress accumulation rate	-0.01 $Week^{-1}$
	DTCS = degree-day threshold	10 °C days
	DHCS = degree-day stress accumulation rate	-0.00014 $Week^{-1}$
Heat stress	TTHS = temperature threshold	30 °C
	THHS = stress accumulation rate	0.001 $Week^{-1}$
Dry stress	SMDS = soil moisture dry stress threshold	0.1
	HDS = stress accumulation rate	-0.05 $Week^{-1}$
Wet stress	SMWS = soil moisture wet stress threshold	2.5
	HWS = stress accumulation rate	0.002 $Week^{-1}$
PDD	Number of degree-days above DV0 necessary to complete one generation	652°C days

NB. Values without units are dimensionless indices.

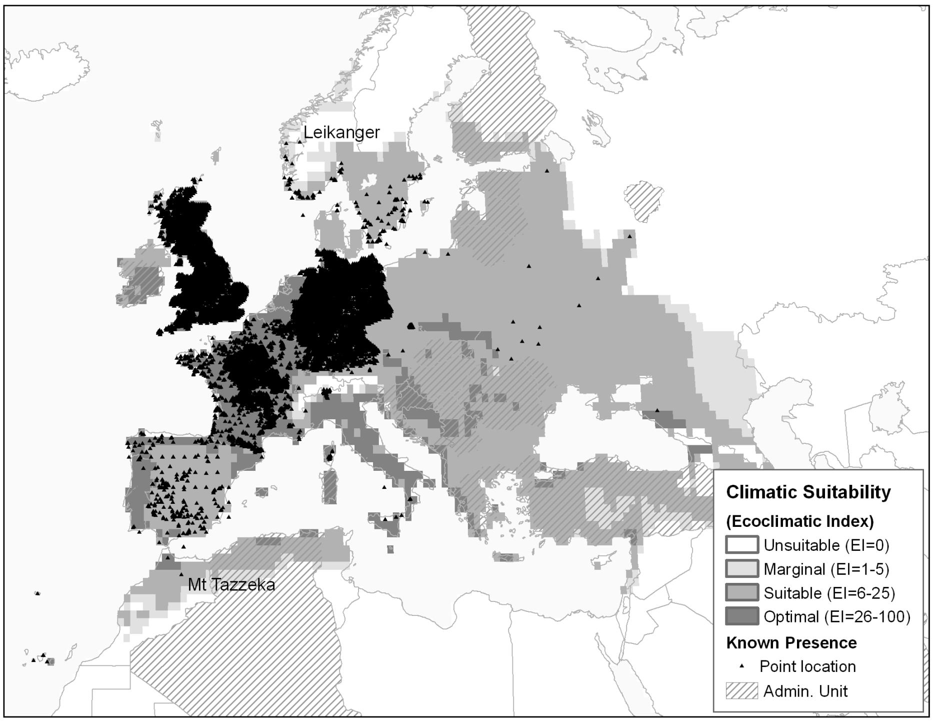

Figure 2 The known and potential distribution of *C. scoparius* in the native range in Europe. CLIMEX climate suitability (ecoclimatic index, EI) indicated by grey scale, cross hatch indicates administrative units where *C. scoparius* has been recorded and triangles indicate historical point locations.

Dry stress was used to limit the southern distribution of *C. scoparius* in both northern Africa and into the eastern European countries including Turkey and the Middle East. This corroborates comments by Wardle (1971) and other authors that the southern distribution of the weed is limited by drought. The dry stress threshold was set to 0.10 with an accumulation rate of -0.05 week^{-1}. These values reflect *C. scoparius'* reputed adaptations for surviving dry conditions such as its deep tap root system, reduced leaf surface area, photosynthetically active stems bearing sunken stomata beneath a thick epidermal wax covering and the ability to abscise its leaves when necessary (Zielke *et al.*, 1992). The selected parameter values allow it to barely persist at the only North African location within the known distribution, Jabel Tazzeka, in the Atlas Mountains in Morocco.

Cytisus scoparius survives in many locations that experience standing snow (e.g. Russia, Scotland and New Zealand) and the species is not frost tender (Plants for a Future, www.pfaf.org/). Both the degree-day model and cold stress temperature threshold were necessary to adequately describe the known cool climate boundary. A cold stress degree-day threshold (DTCS) of 10 °C days and a stress accumulation rate (DHCS) of -0.00014 week^{-1} controlled the northern European distribution, allowing persistence in Scotland and the southern parts of Scandinavia, while a lethal cold stress temperature threshold (TTCS) of -12 °C and accumulation rate (THCS) of -0.01 assisted in restricting the distribution east into Russia. Moscow was accepted as the eastern limit of the native distribution as the source was considered reliable and updated in 1994 (International *et al.*, Legume Database). The number of degree-days above DV0 necessary to complete one generation (PDD) of 652 °C days allows persistence of *C. scoparius* at all the known locations in Scotland and at Leikanger, the northern most point in Norway.

Heat stress was used to restrict the distribution of *C. scoparius* in the north of Africa and parts of southern Spain and Turkey. The heat stress threshold temperature, TTHS, was initially set at the temperate template setting of 30°C while the accumulation rate (THHS) was set to 0.005. The accumulation rate was reduced to 0.001 week^{-1} to barely allow persistence in southern Spain.

Wet stress does not appear to limit the distribution of *C. scoparius* anywhere within the native range. Hence wet stress indices were set at the temperate settings of wet stress threshold (SMWS) of 2.5 and an accumulation rate (HWS) of 0.002 week^{-1}.

The temperature index was fitted to account for the climate at sites within the native distribution of *C. scoparius*. The limiting low temperature (DV0) was set to 5°C, a common base temperature for development of temperate species. The limiting high temperature (DV3) was set to match the heat stress threshold (30°C). The lower and upper optimal temperatures (DV1 and DV2) were set to biologically reasonable values between the developmental extremes of DV0 and DV3.

The moisture index parameter values were adjusted after consideration of evidence in the literature and an examination of the climate at sites within and outside of the known distribution of *C. scoparius.* The limiting low moisture parameter (SM0) was set to 0.1 which equates to permanent wilting point for most plants (Kriticos *et al.*, 2003a; Kriticos *et al.*, 2003b). SM2, the upper optimal moisture parameter was set to 1 indicating soil moisture content was at field capacity. SM3, the limiting high moisture content was set to 2. This indicates water content greater than the soil water holding capacity (i.e. run-off). These values were set to reflect the broad range in average annual rainfall at sites within the known distribution, with some of the wettest sites in Scotland and Norway, and the driest in northern Africa.

RESULTS

The known distribution of *C. scoparius* in New Zealand is displayed in Figure 3. Note that the density of records in a specific area is a reflection of the sampling regime with some data collected through intensive ground surveys and other data sourced from more general databases held by various institutions. Similarly, while considerable effort was made to clarify the absence of the weed in areas poorly represented on Figure 3, we were unable to initiate comprehensive on ground searches as part of this project.

Cytisus scoparius is present in all 16 administrative regions of the country, infesting land at a range of altitudes and of varying land use. The distribution reflects a species that has a very broad climatic tolerance, persisting in the subtropical conditions experienced in Northland, the cool temperate conditions experienced in Southland and the harsh alpine conditions experienced in the Southern Alps. It has been recorded from sea level to over 1300m, on both the dry land sites on the east coast of the South Island where annual rainfall can be as low as 609 mm year^{-1} and in Fjordland on the west coast where rainfall can be over 4000 mm year^{-1}.

The potential distribution of *C. scoparius* in New Zealand is presented in Figure 4. The modelled distribution projects the entire North Island and the majority of the South Island to be of suitable or optimal climate for the persistence of *C. scoparius*. Areas of marginal or unsuitable climate occur in the Southern Alps and in Fiordland in the South West where the number of degree days and cold stress limit persistence.

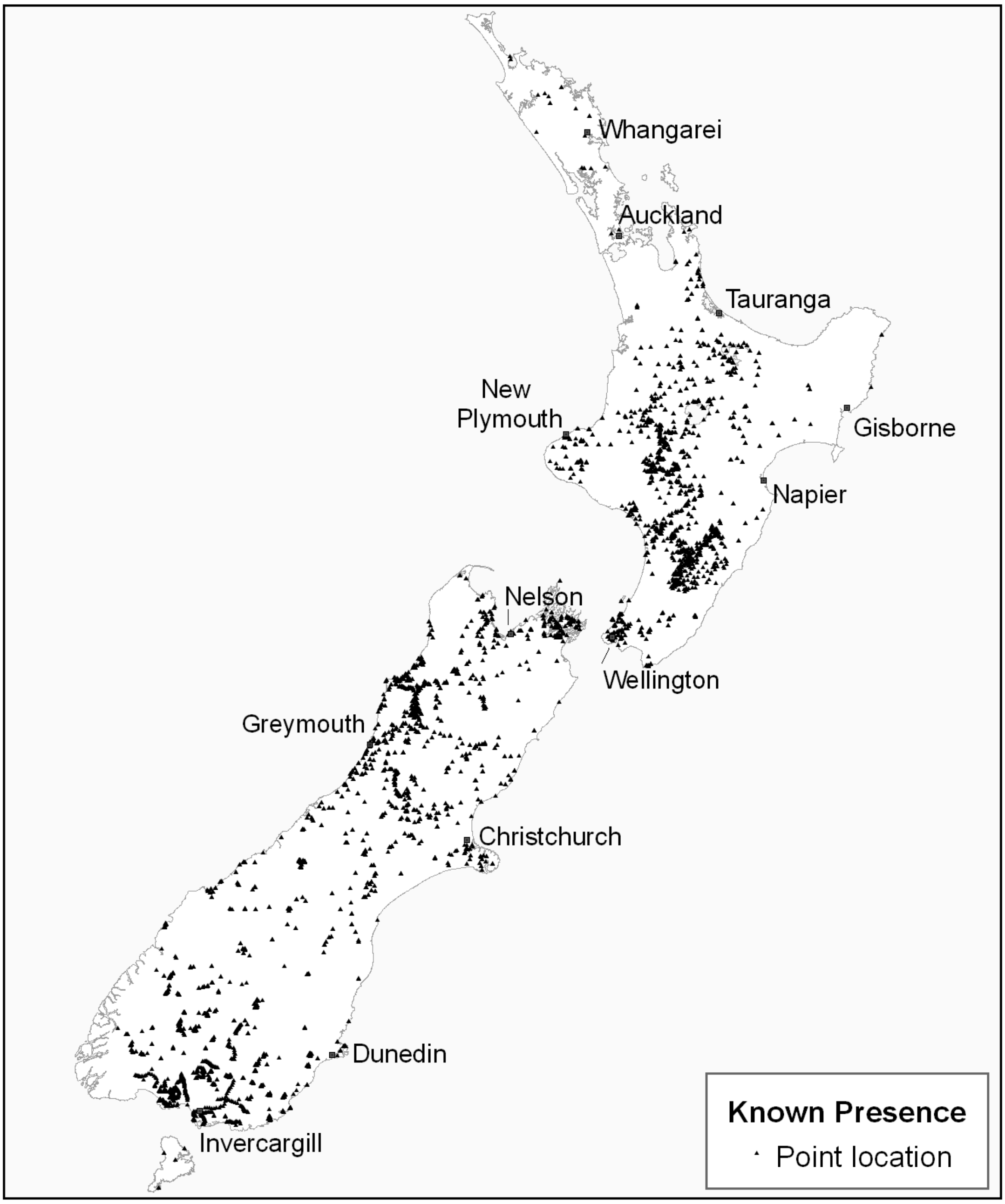

Figure 3 Distribution of *C. scoparius* in New Zealand. Data provided by the sources listed at the end of this report.

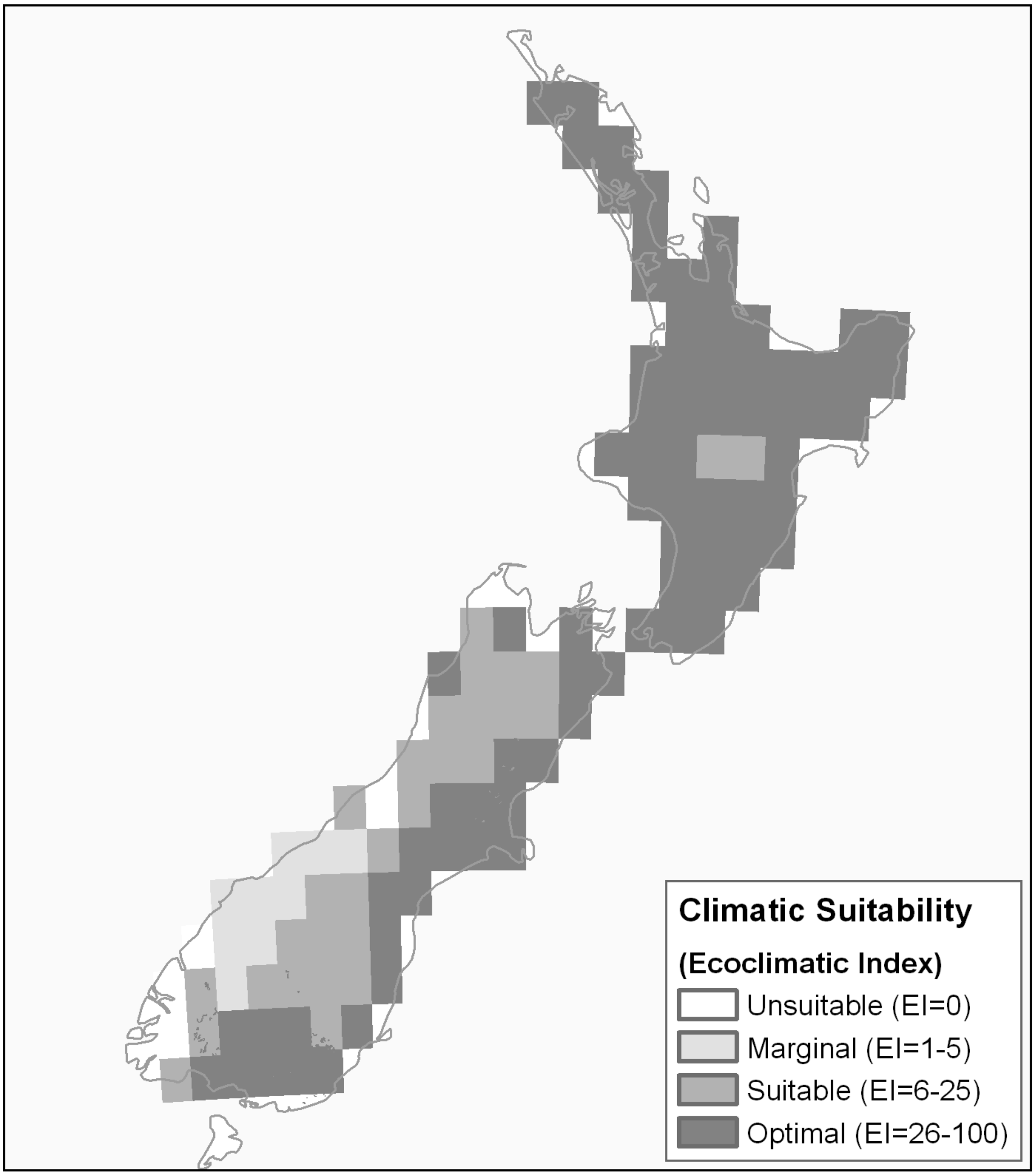

Figure 4 The potential distribution of *C. scoparius* in New Zealand. CLIMEX climate suitability (ecoclimatic index, EI) indicated by grey scale.

DISCUSSION

The development of a CLIMEX "Compare Locations" model allows the modeller to examine the climatic constraints of the weed and explore how these constraints impact on the potential distribution of the species being modelled, both in the native range of the weed and world-wide. The primary factors restricting the world-wide distribution of *C. scoparius* are cold stress and dry stress. For example the easterly distribution of this weed in Russia is limited by the extreme cold conditions experienced at locations east of Moscow where temperatures can be below 0 °C for 6 months of the year with minimum temperatures reaching -15°C and below for extended periods. Similarly, the southern distribution of *C. scoparius* in Spain and northern Africa is restricted by dry stress with sites further south experiencing less than 300mm of rainfall/annum. The New Zealand climate, when compared to the regions of the world mentioned above, is relatively mild. Consequently, the model indicates that there are large areas of New Zealand that are climatically suitable for the persistence of *C. scoparius*. Cold stress accumulated at only a small number of locations in the Southern Alps and dry stress did not accumulate at any of the New Zealand sites included in the model.

It is clear from a comparison of the known and potential distribution of *C. scoparius* in New Zealand that there are large areas of New Zealand that are climatically suitable for the persistence of this weed that are currently not infested. In fact almost all of the North Island of New Zealand is climatically optimal for *C. scoparius.* Based on the synoptic view produced by this model and reports that *C.* scoparius is still increasing its range (Fowler & Syrett, 2000), the forestry sector needs to consider the management of this weed an integral part of their business plan in order to mitigate its impact on production both now and in the future.

As mentioned in the introduction, the potential distribution of an organism forecasted using CLIMEX indicates areas that are climatically suitable for persistence of the organism, independent of the effect of factors such as dispersal, competition, predators and land-use. In the context of forestry, the high levels of soil and vegetation disturbance associated with harvesting, planting and forest maintenance provides an extremely favourable environment for both the persistence and spread of this weed. In the short term, it is recommended that forest managers focus on reducing the spread of the weed, particularly into areas that are geographically isolated and are currently uninfested. This can be achieved by the regular monitoring and removal of *C. scoparius* along transport corridors, the control of plants prior to them becoming reproductively mature and setting seed (2-5 years of age, (Smith & Harlen, 1991; Sheppard *et al.*, 2002)) and the implementation of vigilant hygiene practices when people, vehicles and machinery move between infested and uninfested areas. In the longer term, the cost: benefit of a range of *C. scoparius* management options on sites of differing productivity should be assessed. This would be assisted through the expansion of the height growth model used by VMAN (Vegetation Manager) to include sites in locations of contrasting climate and an investigation into the relationship between a sites climatic suitability (the ecoclimatic index - EI) calculated by CLIMEX and the rate of *C. scoparius* growth. Ultimately, innovative research and the uptake of new management practices by the industry will be necessary to mitigate the threat posed by this weed.

RECOMMENDATIONS AND CONCLUSIONS

The synoptic view of the potential distribution of *C.* scoparius indicates that there is still potential for further range expansion of this weed in New Zealand. Hence the forestry sector needs to consider the management of this weed an integral part of their business plan in order to mitigate its impact on production both now and in the future.

It is recommended that forest managers reduce the spread of the weed, particularly into areas that are geographically isolated and are currently uninfested by:

- the regular monitoring and removal of *C. scoparius* along transport corridors
- the control of plants prior to them becoming reproductively mature and setting seed (2-5 years of age, (Smith & Harlen, 1991; Sheppard *et al.*, 2002)) and
- the implementation of vigilant hygiene practices when people, vehicles and machinery move between infested and uninfested areas.

Ultimately the funding of novel research and the uptake of new management practices by the industry will be required to mitigate the threat posed by this weed.

LIST OF DATA SOURCES

Lucy Roberts (DoC Turangi / Taupo Area), Lynely Hayes (Landcare Research), Ben Minehan (Marlborough Regional Council), Graeme Miller (DoC Murihiku Area), Catherine Law (Taranaki Regional Council), Clayson Howell (DoC Wellington), Ines Schönberger (Landcare Research), Jake Overton (Landcare Research), Rod Randall (Department of Agriculture and Food, Western Australia), H. Brisse, Sophy database, Randall Milne, (Environment Southland - Land Resource Inventory, NZ Survey 1999/2000, Pest Workshop DoC and ES), Phil Karaitiana (Gisbourne District Council), Tony McCluggage (DoC Northland), Jamie (Snyder) Nielsen (UAF Cooperative Extension Service, Invasive Plants Program), Tom Belton (DoC West Coast/ Tai Poutini), Peter Joynt (Biosecurity Officer Northland Regional Council), Sarah Crump (DoC BOP), Matthew Baker (Tasmanian Herbarium), Elaine Birk and staff (Rayonier Asia Pacific), Nigel Herron and staff (Kaingaroa Timberlands), Mark Bryant and staff (Weyerhaeuser Ltd.), Dave Coe and staff (Pan Pac Forest Products Ltd.), Ensis: Forest Health Database, International Legume Database and Information Service 2003 (http://www.ildis.org/LegumeWeb), www.jucn.org, www.mobot.org, www.lehigh.edu, Germplasm Resources Information Network (http://www.ars-grin.gov/cgi-bin/npgs/html/taxon.pl?13019), www.ildis.org, BioWeb database (developed and maintained by www.doc.gov.nz), R. Prasad (Canadian Forest

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