Spatial Prediction of the Potential Range of Three Threatened Plant Species in the Waikato Region

Daniel Rutledge, Merilyn Merrett, and Bruce Burns

Manaaki Whenua
Landcare Research

Spatial Prediction of the Potential Range of Three Threatened Plant Species in the Waikato Region

Daniel Rutledge, Merilyn Merrett, and Bruce Burns
Landcare Research
Private Bag 3127
Hamilton, New Zealand

Landcare Research Contract Report: LCR0304/113

PREPARED FOR:

Environment Waikato
PO Box 4010
Hamilton, 2001

DATE: June 2004

Reviewed by:

Dr Susan Walker
Scientist
Landcare Research

Approved for release by:

Dr David Choquenot
Biodiversity & Ecosystem Processes
Science Manager
Landcare Research

Disclaimer

The findings in this report are specific to this project. Landcare Research accepts no responsibility where information in the report is used for any other purpose, and will not be liable for any loss or damage suffered as a result of such other use.

Contents

Summary

Project and Client

This report to Environment Waikato documents an investigation of models to predict the potential range of threatened plant species in the Waikato Region. Environment Waikato would like to use such models to help them identify potentially significant natural areas as part of their responsibilities under the Resource Management Act.

Objective

Model the potential range of three threatened plants species across the Waikato Region: *Dactylanthus taylorii*, *Marattia salicina*, and *Myriophyllum robustum.*

Methods

We modelled the potential range for each species using an environmental envelope based on associations between the species and three successively more restrictive criteria:

- Level 1: LENZ 1.0 Level IV environments and the 15 underlying variables
- Level 2: Level 1 + land cover from the 1996/97 Land Cover Database Version 1
- Level 3: Level 2 + native vegetation from the 1995 Current Vegetation of the Waikato Region.

Results

For *D. taylorii*, 8 of 8 records withheld from model development fell in the Level I potential range, 7 in Level 2, and 6 in Level 3. For *M. salicina*, 6 of 6 records withheld from model development fell in the Level I potential range, 5 in Level 2, and 5 in Level 3. *M. robustum* had no records withheld for evaluation.

Conclusions

Potential range modelling worked well for *D. taylorii* and *M. salicina.* As species associated with indigenous forest, environmental envelopes using LENZ (designed for canopy tree species) should prove robust. With no records withheld for comparison, model results for *M. robustum* were inconclusive. Because *M. robustum* is a wetland species, the modelled potential range is likely less accurate than for the other two species.

Recommendations

Potential range modelling appears to work well and could inform management decisions for threatened plant species associated with indigenous forest. For species occurring in other environments such as wetlands or coastal areas, additional factors could be included to help delineate potential range. With further development, models of potential range could serve as highly effective screening tools to aid conservation and resource management.

1. Introduction

Environment Waikato (EW) has responsibility for sustainable resource management in the Waikato Region under the Resource Management Act. To that end, EW developed policies and criteria to identify significant natural areas and to facilitate their protection from adverse effects (Environment Waikato 2002). EW designed the policies and criteria to reduce the need for field surveys for which data quickly become outdated, and now apply the criteria on an as-needed basis.

The criteria for significant natural areas include references to sites with threatened species. Remote sensing cannot yet readily identify many individual plant species including threatened species. Therefore EW sought an alternative method that uses existing information to screen broad areas and identify sites that are potentially suitable for threatened plant species. Knowing how many sites exist and where they occur would help Environment Waikato prioritise funding decisions regarding land protection (legal and physical, e.g., pest/stock control) and would act as initial 'red flags' for consent processing under the Resource Management Act.

Areas that lie within the suitable range for a threatened species would be treated as 'potentially significant' when considering applications for resource consent under the Resource Management Act or funds for forms of assistance. Classifying a site as potentially significant would trigger a requirement for intensive surveys for the indicated threatened species. In addition, sites that fall within potentially suitable areas could be targeted as likely locations for restoration, regardless of their current land cover.

The Department of Conservation has also expressed an interest in the project and has provided records of locations of three threatened plant species, a summary of life history characteristics, and potential factors affecting the historical distribution of the three species subject to this contract.

2. Background

Recent research advances allow for the spatial depiction of the potential range of a species based on analyses of species-environment relationships (Leathwick 2001). The potential range of a species delimits the geographic area (or areal extent) that satisfies a species' life history requirements. The spatial depiction of potential range can vary from a binary assessment of suitable/unsuitable areas to perfect knowledge where we would know exactly where a species occurs. Between those two extremes exist intermediate levels of depiction, such as suitability categories (e.g., unsuitable, low, medium, high), to mapping the probability of occurrence at each location in the landscape (Figure 1). For many species, particularly threatened species, we typically hold at most a few records that provide data on suitable environmental conditions. The challenge becomes how to predict potential distribution over a broader area given such low levels of information.

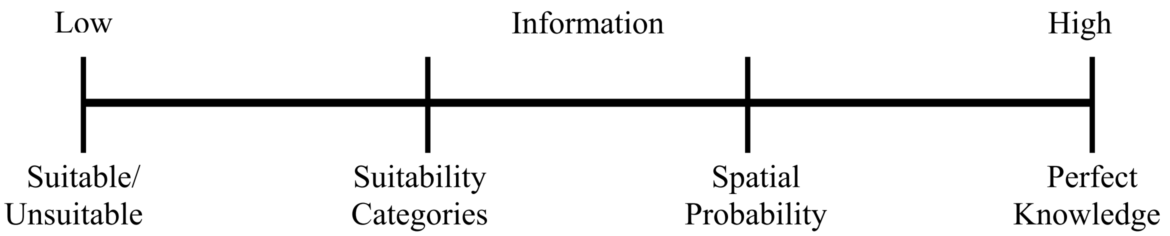

Fig. 1 Conceptual scale of potential distribution depiction.

Climate matching is a very common method used to predict the potential range of a species, particularly for invasive species when the number of records in the invaded area is very small (Sindel & Michael 1991; Mack 1996; Welk et al. 2002). The methodology is motivated by niche theory, which states that species need particular combinations of abiotic and biotic factors at particular levels to fulfil their life history requirements. The climate matching process has five steps (Figure 2).

Step 1: Identify climatic factors that may influence native distribution.
Step 2: Determine what data exists.
Step 3: Examine species distribution records and determine the minimum and maximum acceptable values for each factor.
Step 4: Combine acceptable values for all factors. = ENVIRONMENTAL ENVELOPE (Nix 1986)
Step 5: Map areas where values fall within the environmental envelope. = POTENTIAL RANGE

Fig. 2 Steps in the climate matching process to determine the potential range of a threatened species.

Many factors could be considered, although the exact choice often depends on data availability (Walker & Cocks 1991). For plants, climate variables such as average, minimum, and/or maximum temperature are almost always included, as is information on water availability, rainfall, or derived parameters (e.g., water deficit, humidity) if available. More robust analyses may be possible if data are available for edaphic factors (e.g., fertility, drainage) or landform (e.g., slope, aspect). We can further refine the prediction of suitable range by including biotic information, such as current vegetation (e.g., land cover) or the distribution of known competitors or predators (e.g., Leathwick 2002).

As indicated in Figure 2, the intersection of the various factors generates an environmental envelope within which conditions are suitable for the threatened species. At its most basic, this process produces a binary map classification showing areas inside (1) and outside (0) the potential range (value of 1). Within the environmental envelope, a species can survive and reproduce; outside the envelope it cannot. BIOCLIM (Busby 1986) is a popular programme that is used to perform this analysis (Sindel & Michael 1991; Lindemayer et al. 1997; Jackson & Claridge 1999). While relatively straightforward, this method has several limitations. First, it can underestimate the environmental envelope if the number of known records is low (e.g., less than 15). Second, it can underestimate the envelope if known records only come from a portion of a species range (Panetta & Dodd 1987; Claridge 2002). Third, it can under- or over-estimate the potential range because it does not consider biological factors (Mack 1996).

We can use several different approaches to overcome these limitations. When dealing with small sample sizes, we can apply information on similarity of conditions at the record locations to conditions at other locations to predict potential range. For example, we can use similar environments as defined by Land Environments of New Zealand or LENZ (Leathwick et al. 2003a, 2003b) to help predict potential range. Because LENZ environments define areas with similar abiotic conditions, we assume a species can occur anywhere within the range of values of the associated abiotic factors for that environment. Based on that assumption, we can construct an environmental envelope using the range of values spanned by all the environments associated with records of the species. We can then use the resulting envelope to predict the potential range of the species in question.

Perhaps the biggest limitation of the environmental envelope method is that it does not consider relevant biological information, particularly present and possible future conditions, both of which could strongly influence a species range (Mack 1996). Again, a number of methods can be used to overcome these drawbacks.

The simplest and often most feasible method to overcome this limitation involves associations between a species and land cover information. Land cover information provides basic information on the biotic conditions at a site and can help spatially refine the potential range. For example, Richardson et al. (1994) showed a gradient of susceptibility of sites to pine invasion based on land cover, with forest < shrubland < grassland < < dunes < bare ground. Inclusion of such information often substantially reduces the prediction of potential range.

The ability to predict potential range ultimately depends on the available data. For many species, this can be quite limiting, including a low number of observed records, lack of absence records, limited information on conditions in the native range, and poor understanding of the species biology. Despite these limitations, data are becoming available to allow us to begin predicting, even at a simple level (suitable/unsuitable – left end of Figure 1) the potential range of a species.

3. Objectives

Environment Waikato wishes to develop methodologies to predict the environmental suitability for threatened plant species in the Waikato Region. Environment Waikato requires the assessment to be performed as a desktop exercise, without intensive field survey, by utilising existing information on species locations and known relationships with environmental factors.

Using existing environmental information housed at Landcare Research and known distributional data supplied by Environment Waikato and the Department of Conservation, we developed models to predict spatially the potential range of three threatened plant species within the Waikato Region. The three threatened species have differing environmental requirements (Table 1).

The models predicted the potential range of locations within the Waikato Region at three levels of increasing specificity:

- Level 1: Potential range based on an environmental envelope calculation using relationships between known threatened species locations and the 15 underlying variables used in LENZ
- Level 2: Level 1 + analysis of land cover suitability
- Level 3: Level 2 + analysis of current vegetation suitability

Each level of the analysis provides an increasingly more restricted potential range of the threatened species primarily because the species require relatively natural conditions such as indigenous forest or wetlands.

Table 1 Information on the three threatened plant species used in the analysis.

	Dactylanthus taylorii	*Marattia salicina*	*Myriophyllum robustum*
Common	Wood rose	King or potato fern	Stout water-milfoil
Máori	Pua o te reinga	Para	
Description	NZ's only fully parasitic plant; wide variety (~ 30) host species; dioecious, root parasite with above-ground parts restricted to small flowers clustered in inflorescences	Fern with large, twice divided (2-pinnate) fronds, 1.5–2 m in length, smooth & leathery to touch; frost tender; sporangia on under surface	Aquatic perennial plant with finely pinnate whorled leaves with acute tips. Stems may be pink contrasting with yellow-green emergent leaves
Range & Status	Historic distributions possibly limited by short-tailed bat Mice may act as effective pollinators now, thus removing range limitations	Once common throughout northern NZ; starchy roots were an important food source in pre-European times	Scattered throughout New Zealand from Kaitaia in the north to Fiordland in the south
Suitable conditions	Generally found on mid-sized trees and shrubs, always native and broadleaved; often on edge of podocarp forests; never found on gymnosperms or exotics; needs suitable pollinators, e.g., short-tailed bats, mice; possibly rats, weta, honeybees, and wasps	Shaded and sheltered sites with rich moist soils	Peaty ponds, lagoon or lake margins in swampy lowlands with standing water 0.5–2 m deep.
Pressures	Herbivory – mostly by possums that remove all flowers and leave only the inflorescent bracts; some by rats but they may also act as pollinators; without measures to prevent flower loss, recruitment is nil and plants are functionally extinct	Herbivory – highly palatable (deer, goats, pigs) Collecting by people	Peat harvesting, wetland drainage, eutrophication from altered hydrology; herbivory by invasive fish species; competition by invasive aquatic weeds (e.g., parrot's feather)
Protection	Exclusion cages to prevent herbivory & increase recruitment	Prevent grazing and collection	Wetland protection

4. Methods

Environment Waikato provided 25 records from a Department of Conservation database for each of the three threatened plant species used in the analysis. EW also reserved additional records to check the ability of the analysis to predict the potential range of the three threatened plant species.

We used the following GIS layers in the analysis:

1) LENZ 1.0 Underlying Data Layers (15 in total) (Leathwick et al. 2003b)
2) LENZ 1.0 Level IV Classification (500 Groups) (Leathwick et al. 2003b)
3) NZ Land Cover Database Version 1 (1996/1997)
4) 1995 Current Vegetation of the Waikato Region (Leathwick et al. 1995)

Using these layers, we developed a GIS-based methodology to generate spatial predictions of the potential range for the three threatened plant species within the Waikato Region. The methodology consisted of 12 steps (Table 2) and produced a map for each of the three threatened species that showed the predicted potential range within the Waikato Region.

Table 2 Methodology used to predict the potential range of the threatened plant species in the Waikato Region.

Step	Description
1	Plot records (NZ Map Grid Easting and Northing) for the species in the GIS
2	For each record, determine the associated LENZ Level IV environment
3	For each record, determine the minimum and maximum value for each of the 15 LENZ underlying variables for the associated LENZ Level IV environment
4	For each of the 15 LENZ underlying variables, determine the absolute minimum and absolute maximum from the set of all records
5	For each of the 15 LENZ underlying variables, create a mask coded 0 for points outside and coded 1 for points inside the absolute minimum and maximum range
6	Union the 15 masks created from the analysis of the LENZ underlying variables and create a new mask of unsuitable (where *any* mask = 0) and suitable (where *all* masks = 1) areas **Level 1 Mask** = Environmental Envelope =
7	For each record, determine the associated land cover class from the Land Cover Database
8	Create a mask of unsuitable (0) and suitable (1) land cover based on Step 7 and the life history characteristics of the species
9	Union the land cover mask and the environmental envelope to create a Level 2 mask **Level 2 Mask** = Level 1 Mask + Land Cover Mask =
10	For each record (where possible), determine the associated vegetation class from the 1995 vegetation layers for the Waikato Region (Leathwick et al. 1995)
11	Create a mask of unsuitable (0) and suitable (1) vegetation classes based on Step 10 and life history characteristics of the species
12	Union the Level 2 mask and the suitable vegetation mask to create a Level 3 mask **Level 3 Mask** = Level 2 Mask + 1995 Current Vegetation Mask =

5. Results

5.1. Dactylanthus taylorii

Environment Waikato provided 25 records for *D. taylorii*. Seven records fell outside the Waikato Region. We used these records for the Level I analysis but not the Level 2 or Level 3 analysis.

The Level 1 potential range for *D. taylorii* occurred primarily in higher elevation hill country of the Waikato Region (Figure 3). These areas were generally cooler but not cold, had low to moderate slopes, and were moderately to well drained. In particular, slope provided the highest degree of discrimination, as no record of *D. taylorii* was associated with slopes < 5° or > 25° (Table 3). The total area of Level 1 potential range for *D. taylorii* was 1 000 600 ha or about 40% of the region.

Sixteen of the Waikato records were associated with the indigenous forest class from the Land Cover Database, while two records were associated with the pasture class. The Level 2 potential range included those Level 1 areas that also had indigenous forest (Figure 3). The total area of the Level 2 potential range for *D. taylorii* was 325 750 ha or about 13% of the region.

All 16 records associated with indigenous forest were also associated with a conifer-broadleaved forest class, either existing or logged, from the 1995 vegetation layer (Leathwick et al. 1995). The Level 3 potential range included Level 2 areas with conifer-broadleaved, montane conifer-broadleaved, or logged conifer-broadleaved forest classes. The total area of the Level 3 potential range for *D. taylorii* was 180 575 ha or about 7% of the region.

Eight records for *D. taylorii* were withheld from the analysis for model validation. All of these records fell within the Level 1 potential range, 7 in Level 2, and 6 in Level 3.

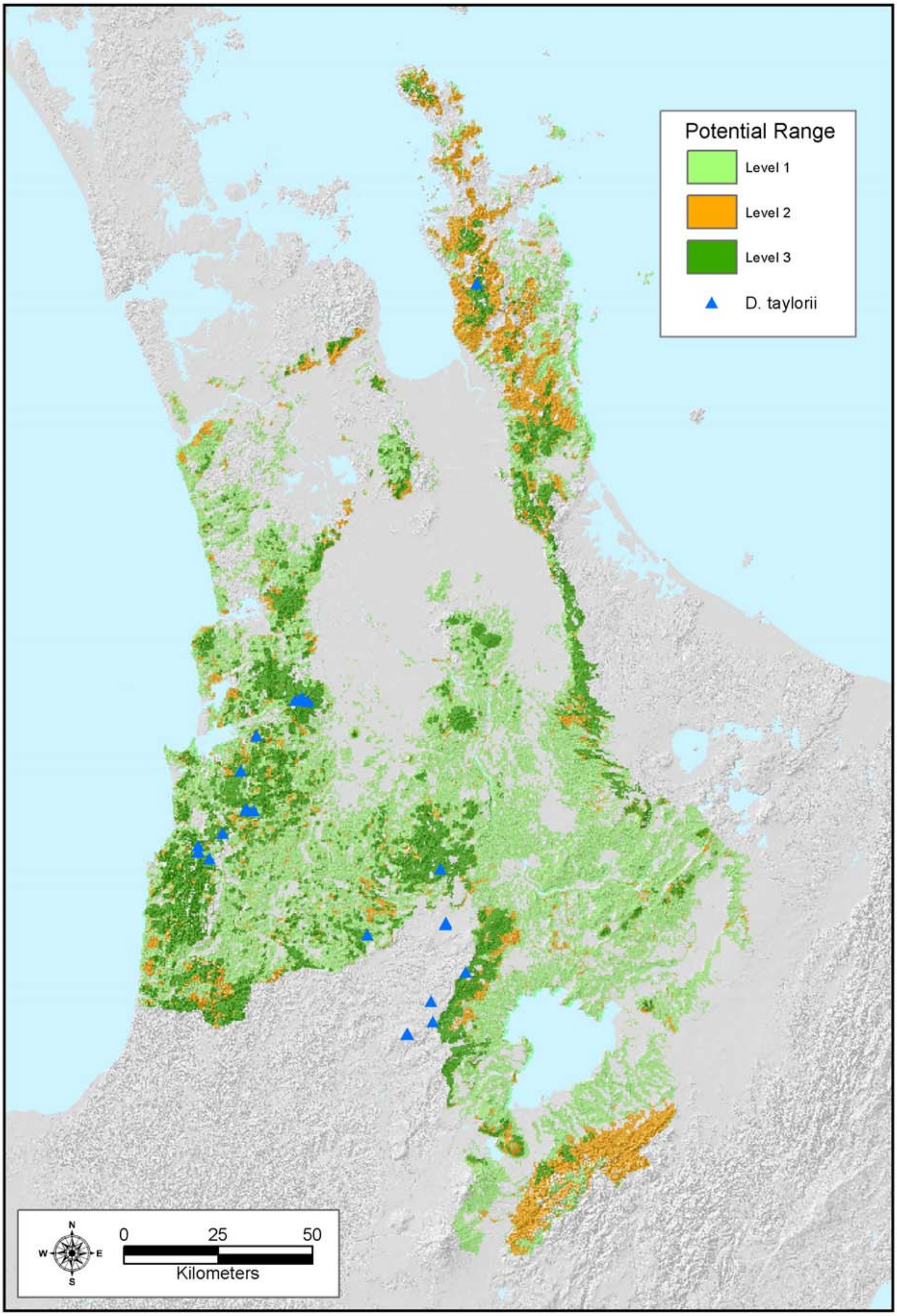

Fig. 3 Level 1, 2, and 3 potential range for *Dactylanthus taylorii* in the Waikato Region.

Table 3 Comparison of LENZ underlying variable range values for the Waikato Region and the three threatened plant species used in the potential range analysis.

LENZ Underlying Variable	Waikato Range	Potential Range		
		D. taylorii	*M. salicina*	*M. robustum*
Mean Annual Temperature	-0.7–15.3	4.5–14.6	8.9–14.7	5.8–15.0
Mean Minimum Winter Temperature	-4.7–7.3	-2.2–6.7	1.1–6.7	-1.0–7.3
Mean Annual Solar Radiation	13.8–15.4	13.6–15.3	14.1–15.3	14.0–15.3
Minimum Winter Solar Radiation	4.9–6.5	4.4–6.5	4.8–6.5	4.4–6.4
October Vapour Pressure Deficit	0.00–0.45	0.02–0.47	0.15–0.53	0.14–0.55
Monthly Water Balance	2.0–13.3	1.8–14.3	2.1–8.6	1.9–6.0
Annual Soil Water Deficit	0–118	0–107	0–96	0–118
Slope	0–55	5–25	2–20	0–20
Soil Drainage	1–5	4–5	3–5	1–5
Acid Soluble Phosphorus	1–5	1–4	1–4	1–3
Calcium	1–4	1–2	1–2	1–3
Particle Size	1–5	1–5	1–5	1–5
Induration	1–4	2–4	1–4	1–4
Soil Age	1–2	1	2	1–2
Chemical Limitations to Plant Growth	1–2	1	1	1

5.2. Marattia salicina

Environment Waikato provided 25 records for *M. salicina*, all of which occurred inside the Waikato Region.

The Level 1 potential range for *M. salicina* occurred from low-lying foothills to mid-slopes throughout the Waikato region (Figure 4). This distribution was similar to the Level 1 potential range for *D. taylorii* but tended to slightly warmer, wetter environments on gentler slopes of 2–20° (Table 3). The total area of Level 1 potential range for *M. salicina* was 1 263 700 ha or about 51% of the region.

Eighteen records were associated with the indigenous forest class from the Land Cover Database. Six records were associated with pasture, and one was associated with scrub. Two of the records associated with pasture were very close to forest or scrub (< 10 m). Three records were approximately 110 m from scrub or forest, and the remaining record was ~550 m from the nearest forest or scrub. Given that *M. salicina* prefers shaded and sheltered sites, we considered only those areas with indigenous forest as potentially suitable. The Level 2 potential range included those Level 1 areas that also had indigenous forest (Figure 4). The total area of the Level 2 potential range for *M. salicina* was 478 400 ha or about 19% of the region.

The 18 records associated with indigenous forest were also associated with various conifer-broadleaved forest classes (17 records) or a secondary forest class (1 record) from the 1995 vegetation layer (Leathwick et al. 1995). In addition, one record associated with pasture was also associated with secondary forest. Therefore the Level 3 potential range included Level 2 areas with conifer-broadleaved, montane conifer-broadleaved, or logged conifer-broadleaved, kauri-conifer-broadleaved, or secondary forest classes. The total area of the Level 3 potential range for *M. salicina* was 241 400 ha or about 10% of the region.

Six records for *M. salicina* were withheld from the analysis for model validation. Five records occurred within the Level 3 potential range, while the remaining record occurred in the Level 2 potential range.

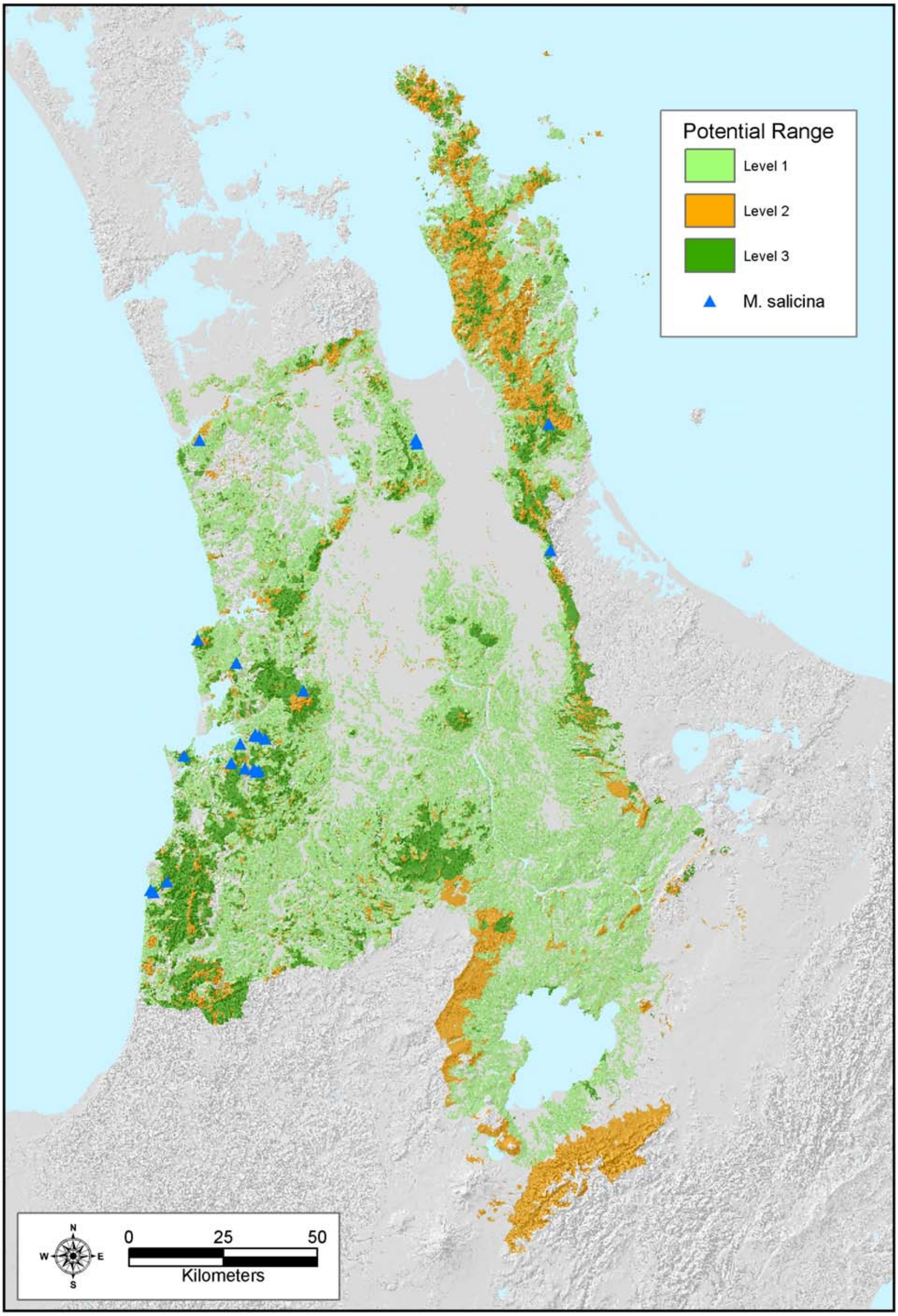

Fig. 4 Level 1, 2, and 3 potential range for *Marattia salicina* in the Waikato Region**.**

5.3. Myriophyllum robustum

Environment Waikato provided 25 records for *M. robustum*, all of which occurred inside the Waikato Region.

The Level 1 potential range showed that *M. robustum* has the potential to be very widespread in low-lying areas throughout the Waikato Region (Figure 5). The Level 1 potential range excluded only cooler, steeper hilltops (Table 3). The total area of Level 1 potential range for *M. robustum* was 2 040 300 ha or about 83% of the region.

Twelve records were associated with the inland wetlands class from the Land Cover Database, including a cluster within a wetland complex along the Maramarua River near Mercer. Ten records were associated with the pasture class, including one that occurred in a depression noted on the topographic maps and a cluster of three along the Mangapu River near the Waitomo Caves. Two records were associated with the indigenous forest class near Mangakino, including one that lies near the Mangaongaonga Stream in a location marked as wetlands on topographic maps but listed as indigenous forest in the Land Cover Database. One record was associated with the scrub class. Because *M. robustum* is a wetland species, we only considered those areas with inland wetlands as potentially suitable. The Level 2 potential range included those Level 1 areas that also had inland wetlands (Figure 5). The total area of the Level 2 potential range for *M. robustum* was 26 300 ha or about 1% of the region.

The associations with the current vegetation cover (Leathwick et al. 1995) were as follows: 10 were associated with freshwater wetlands (including 1 listed as pasture in the LCDB); 3 with induced scrub and shrubland (including 1 listed as pasture in the LCDB); and 2 with conifer forest (Leathwick et al. 1995). Unlike the other two species, we generated the Level 3 potential range by combining the Level 1 potential range and suitable classes from the 1995 vegetation classification. We did not include the Level 2 potential range, as too many records that fell outside that range were still associated with a 1995 vegetation class. We considered the following 1995 vegetation classes as potentially suitable: conifer forest, freshwater wetland, and induced shrub/scrubland. The total area of the Level 3 potential range for *M. robustum* was 89 300 ha or about 4% of the region.

No records for *M. robustum* were withheld from the analysis for model validation.

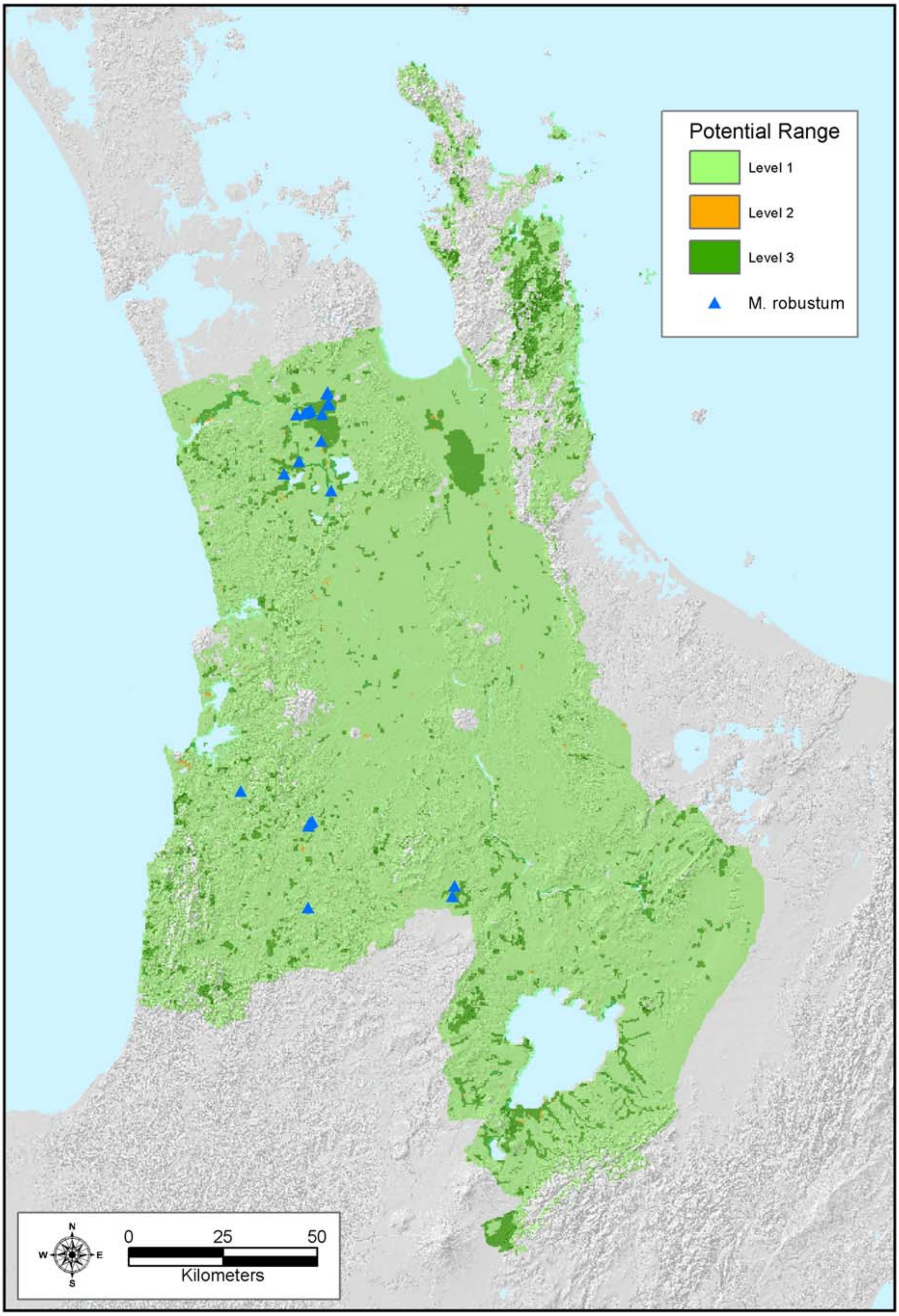

Fig. 5 Level 1, 2, and 3 potential range for *Myriophyllum robustum* in the Waikato Region.

6. Conclusions

The potential range modelling performed extremely well for *D. taylorii* and *M. salicina* (Table 4). This is not surprising given that the analysis relies on associations between species and LENZ environments (Leathwick et al. 2003a, b). The 15 underlying environmental variables used in LENZ were chosen as being strong physiological drivers of the growth and distribution of forest canopy tree species. Other species associated with indigenous forest communities, such as *D. taylorii* and *M. salicina*, could be expected to have similarly strong correlations with LENZ environments, either directly with the underlying variables themselves or through their association with other species. This was evident based on the analysis of withheld records for both species. The majority of records for both species fell within the Level 3 potential range, and all fell within the Level 1 potential range.

The predicted range modelling for *M. robustum* is inconclusive because no reserved records were available for the analysis. According to Department of Conservation staff with local knowledge of *M. robustum*, the Level 3 potential range does not appear to be reasonable. The Level 3 mask predicted the majority of the Kopuatai peat bog as being environmentally suitable for *M. robustum*. However, that is extremely unlikely given that nutrient levels in the peat bog are too low. Also, DOC staff feel the likelihood that *M. robustum* occurs in the Coromandel ranges is very low, although Johnson and Brooke (1989) described *M. robustum* as ranging from Kaitaia to Fiordland, and therefore the Coromandel Peninsula may be a suitable location.

Table 4 Number of withheld threatened species plant records occurring within estimated potential range.

Species	Number of Withheld Records	Number of Withheld Records in Potential Range		
		Level I	Level II	Level III
D. taylorii	8	8	7	6
M. salicina	6	6	6	5
M. robustum	-	-	-	-

7. Recommendations

Potential range modelling based on associations with LENZ environments appears to discriminate areas of potential suitability for certain types of species. Therefore the method would work well as a screening tool to help Environment Waikato assess natural significance under the Resource Management Act or target restoration efforts for certain species. Further work would be needed to determine how many records are required for an adequate analysis.

The potential exists to develop more sophisticated models to predict the suitability of different areas for threatened plants or even other species. Additional variables such as topographic indices, slope, aspect, etc., may improve the ability of the model to discriminate potential site suitability. Similarly, we could investigate the use of logistic regression or generalised additive models (e.g., GRASP – Lehmann et al. 2002) to estimate probability of occurrence rather than simple presence/absence as in the current analysis (Figure 1).

In particular, the coarse resolution of the LCDB is problematic. Several sites that fell within apparently unsuitable areas such as pasture may actually occur within suitable areas that are below the detection resolution of the LCDB. Use of additional remotely sensed imagery with finer resolution or higher levels of discrimination, such as ECOSAT, could improve the land cover classification and identify generally small and isolated areas that could be suitable for the various plant species.

8. Acknowledgements

The authors wish to thank Karen Denyer at Environment Waikato and Andrea Brandon at the Department of Conservation for providing the threatened plant data and for providing feedback on modelling results. The authors also wish to thank Anne Austin for editorial oversight and Brenda Hall for reporting formatting. Environment Waikato funded this contract under Environment Waikato Contract LC009 1.1.

9. References

Busby, J.A. 1986: A biogeoclimatic analysis of *Nothofagus cunninghamii* (Hook.) Oerst. in southeastern Australia. *Australian Journal of Ecology 11*: 1–7.

Claridge, A. 2002: Use of bioclimatic analysis to direct survey effort for the long-footed potoroo (*Potorous longipes*), a rare forest-dwelling rat-kangaroo. *Wildlife Research 29*: 193–202.

Environment Waikato. 2002: Waikato Regional Policy Statement. Environment Waikato (www.ew.govt.nz/policyandplans/rpsintro/index.htm)

Jackson, S.M.; Claridge, A. 1999: Climatic modelling of the distribution of the mahongany glider (*Petaurus gracilis*), and the squirrel glider (*P. norfolcensis*). *Australian Journal of Zoology 47*: 47–57.

Johnson, P.N.; Brooke, P.A. 1989: Wetland plants in New Zealand. Wellington, DSIR Publishing. 228 pp.

Leathwick, J.R. 2001: New Zealand's potential forest pattern as predicted from current species-environment relationships. *New Zealand Journal of Botany 39*: 447–464.

Leathwick, J.R. 2002: Intra-generic competition among *Nothofagus* in New Zealand's primary indigenous forest. *Biodiversity and Conservation 11*: 2177–2187.

Leathwick, J.; Clarkson, B.D.; Whaley, P. 1995: Vegetation of the Waikato Region: Current and historical perspectives. Landcare Research Contract Report LC9596/022 to Environment Waikato. 54 p.

Leathwick, J.: Morgan, F.; Wilson, G.; Rutledge, D.; MacLeod, M.; Johnson, K. 2003a: Land Environments of New Zealand – Nga Taiao o Aoeteroa. Auckland, David Bateman Ltd. 278 p.

Leathwick, J.: Wilson, G.; Rutledge, D.; Morgan, F.; MacLeod, M.; Johnson, K.; Kirkpatrick, R. 2003b: Land environments of New Zealand – Nga Taiao o Aoeteroa – Technical Guide. Wellington, Ministry for the Environment. 237 p.

Lehmann, A.; Overton, J.McC.; Leathwick, J.R. 2002: GRASP: generalised regression analysis and spatial prediction. *Ecological Modelling 157*: 189–207.

Mack, R.N. 1996: Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation 78:* 107–121.

Nix, H.A. 1986: A biogeographic analysis of Australian elapid snakes. *In*: Longmore, R. *ed.* Atlas of Australian Elapid snakes. Canberra, Bureau of Flora and Fauna. Pp. 4–15.

Panetta, F.D.; Dood, J. 1987: Bioclimatic prediction of the potential distribution of skeleton weed *Chondrilla juncea L.* in western Australia. *The Journal of the Australian Institute of Agricultural Science 53*: 11–16.

Richardson, D.M.; Willliams, P.A.; Hobbs, R.A. 1994: Pine invasions in the Southern Hemisphere: Determinants of spread and invadability. *Journal of Biogeography 21*: 511–527.

Sindel, B.M.; Michael, P.W. 1991: Spread and potential distribution of *Senecio madagascariensis Poir.* (fireweed) in Australia. *Austrailan Journal of Ecology 17*: 21–26.

Walker, P.A.; Cocks, K.D. 1991: HABITAT: a procedure for modeling a disjoint environmental envelope for a plant or animal species. *Global Ecology and Biogeography Letters* 1:108–118.

Welk, E.; Schubert, K.; Hoffman, M.H. 2002: Present and potential distribution of invasive garlic mustard (*Alliaria petiolata*) in North America. *Diversity and Distribution 8*: 219–233.

Manaaki Whenua
Landcare Research

www.landcareresearch.co.nz