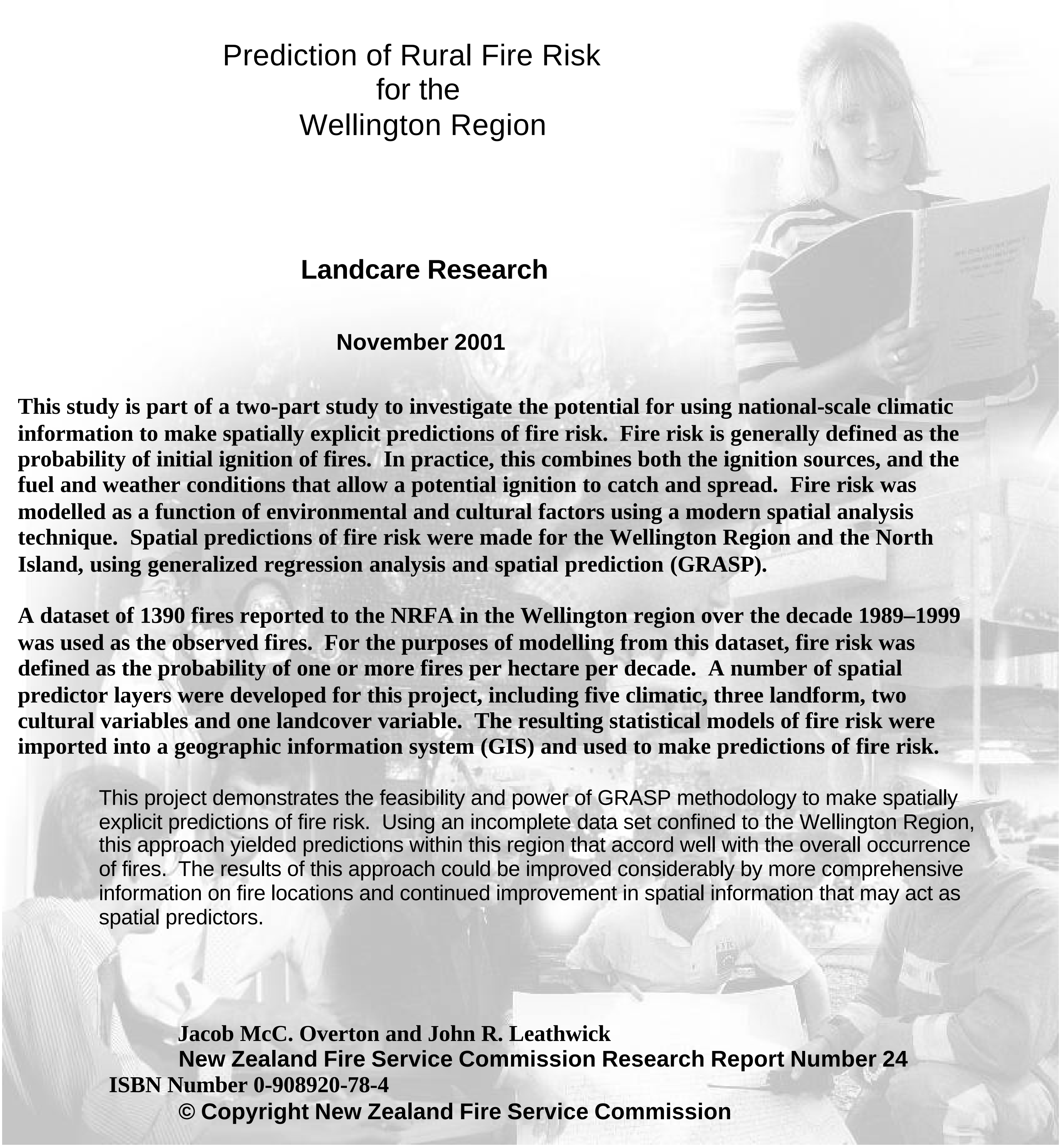
Fire Researc
Report



Prediction of Rural Fire Risk for the Wellington Region

Landcare Research

November 2001

This study is part of a two-part study to investigate the potential for using national-scale climatic information to make spatially explicit predictions of fire risk. Fire risk is generally defined as the probability of initial ignition of fires. In practice, this combines both the ignition sources, and the fuel and weather conditions that allow a potential ignition to catch and spread. Fire risk was modelled as a function of environmental and cultural factors using a modern spatial analysis technique. Spatial predictions of fire risk were made for the Wellington Region and the North Island, using generalized regression analysis and spatial prediction (GRASP).

A dataset of 1390 fires reported to the NRFA in the Wellington region over the decade 1989–1999 was used as the observed fires. For the purposes of modelling from this dataset, fire risk was defined as the probability of one or more fires per hectare per decade. A number of spatial predictor layers were developed for this project, including five climatic, three landform, two cultural variables and one landcover variable. The resulting statistical models of fire risk were imported into a geographic information system (GIS) and used to make predictions of fire risk.

This project demonstrates the feasibility and power of GRASP methodology to make spatially explicit predictions of fire risk. Using an incomplete data set confined to the Wellington Region, this approach yielded predictions within this region that accord well with the overall occurrence of fires. The results of this approach could be improved considerably by more comprehensive information on fire locations and continued improvement in spatial information that may act as spatial predictors.

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The Prediction of Rural Fire Risk for the Wellington Region

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Disclaimer

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Executive Summary

Project and Client

Fire risk was modelled as a function of environmental and cultural factors using a modern spatial analysis technique. Spatial predictions of fire risk were made for the Wellington Region and the North Island. Research was carried out by Landcare Research, Hamilton, in between July 2000 and June 2001 for the National Rural Fire Authority (NRFA).

Objectives

- To investigate the feasibility of modeling fire risk using a statistical approach
- To make preliminary predictions of fire risk
- To highlight the strengths and weaknesses of existing data

Methods

We used generalized regression analysis and spatial prediction (GRASP) to spatially predict fire risk in the Wellington region.

A dataset of fires reported to the NRFA in the Wellington region over the decade 1989–1999 was used as the observed fires. For the purposes of modelling from this dataset, fire risk was defined as the probability of one or more fires per hectare per decade.

A number of spatial predictor layers were developed for this project, including five climatic, three landform, two cultural variables and one landcover variable.

Modern regression analysis was used to establish the observed relationships between fire risk and environmental and cultural variables. The resulting statistical models of fire risk were imported into a geographic information system (GIS) and used to make predictions of fire risk for the Wellington region. The models developed for the Wellington region were then used to extrapolate fire risk to the entire North Island.

Results

The dataset included 1390 fires, of which 725 had a useable spatial location and were included in the analyses. These 725 fires were at 635 locations (Figure 1). Three variables were found to be significant predictors of fire risk for the Wellington region. These variables were mean annual temperature, human density, and distance to the closest road (Figure 2).

The regression approach provided a significant model of fire risk (Figure 4). Based on this model, the probability of fire increased as mean annual temperature increased. The effect of distance from road is a consistent decrease with increased distance. The effect of human density increases to moderately high densities, declining at the highest densities. The relative contributions of each significant explanatory variable to the regression model are shown in Figure 5. Distance to road is the most important variable, with temperature and human density showing similar, but lower importance.

The predicted probability of one or more fires is shown for the Wellington region in Figure 6. This prediction has an overall mean very close to that expected from the number of fires and the size of the Wellington region. This prediction is extrapolated to the entire North Island (Figure 7).

Conclusions

- This project demonstrates the feasibility and power of GRASP methodology to make spatially explicit predictions of fire risk.
- Using an incomplete data set confined to the Wellington Region, this approach yielded predictions within this region that accord well with the overall occurrence of fires.
- The results of this approach could be improved considerably by more comprehensive information on fire locations and continued improvement in spatial information that may act as spatial predictors.

The advantages to fire management of this approach to the prediction of fire risk management are several, including:

1) Point locations of fires are combined with spatial information to produce spatially explicit predictions of fire risk (e.g., Figures 6 and 7).
2) Relationships between fire risk and environmental or cultural fire factors and their relative importance are determined (Figures 4 and 5). Since individuals experience phenomena at more local scales, these statistical analyses over large spatial scales play an important role in understanding the factors that influence fire risk at regional or national scales.
3) Data requirements and deficiencies can be highlighted. This can lead to much more focused efforts to provide data needed for fire management, resulting in huge potential gains in the efficiency of data reporting and collecting.

Recommendations

This study highlights the need for continued improvement in the underlying information, especially the development of a coherent database on the spatial distribution of fires and their characteristics, as well as on the development of spatial information that will predict these fires. Continued investment in improving both sorts of information will substantially improve the ability of this approach to predict fire risk.

While this study employed a purely spatial analysis using average climatic conditions, a more sophisticated analysis could utilize a spatio-temporal analysis of both the locations of fires, and the climatic conditions at the time of the fire. Such an approach would have major advantages, since it would produce a data-defined, spatio-temporal model that could predict a dynamic pattern of fire risk across the landscape that would depend on local, current weather conditions and could be used to highlight both specific locations and specific climate conditions leading to high fire risk.

1. Introduction

This study is part of a two-part study to investigate the potential for using national-scale climatic information to make spatially explicit predictions of fire risk. Fire risk is generally defined as the probability of initial ignition of fires. In practice, this combines both the ignition sources, and the fuel and weather conditions that allow a potential ignition to catch and spread. By nature, fire locations will be highly stochastic and generally rare.

The underlying climatic information and spatial modeling techniques have been developed in a coordinated program to capture large-scale ecosystem patterns by combining spatial surfaces of climate and landform with biotic information. Environmental domains (Leathwick et al. 2001) have been used as an ecosystem classification and are currently being implemented nationally in conjunction with the Ministry for the Environment Environmental Performance Indicators Programme.

Climatic and landform factors that influence natural ecosystems patterns also influence the human use of ecosystems. In addition, they influence many risk factors, such as erosion and pollution, as well as disturbances, such as landslips, storms and fires. Fire can, of course, be either a natural disturbance, a purposefully used tool, or a human and environmental hazard resulting from human ignition sources. In this study, we predict fire risk using a statistical approach that we have also used to predict species distributions and ecosystems characteristics.

Such an approach is strictly data-defined, and the outcome will be only as good as the underlying data. Here, we model fire risk as the probability of one or more fires per hectare per decade. However, it is important to remember that what we are actually modeling and predicting is the probability that there are one or more fires per hectare per decade *that appear in the dataset and have spatial locations.* This distinction is important because the dataset does not include all fires in the region in the decade, but is instead a *sample* of the total fire population.

Unfortunately, this sample was not drawn with a defined sampling scheme, but instead results from the vagaries of fire reporting and data collation. Therefore, we can really only make informed guesses as to how the dataset represents the total fire population. However, we do know some of the characteristics of the dataset. For a fire to end up in this dataset, several events had to occur:

- The fire was responded to by the local fire authority (fires attended by the Fire Service are NOT included in this dataset);
- The fire was reported by the local authority to the NRFA;
- The spatial location (grid coordinates) of the fire was reported.

While there is no information that allows us to estimate the probabilities of the first two events occurring, the probability of the third event occurring can be estimated by the proportion of fires in the dataset that have spatial locations. This is reported in the *Results* section.

The spatial predictors used in this study include human population density from census data, road distributions, and climatic surfaces developed for the national domains implementation (Leathwick, unpublished ms.).

2. Methods

A dataset of fires provided by the NRFA was used in these analyses. This database consisted of fires in the Wellington Region reported to the NRFA in the 10-year period 1989–1999. Only those fires with spatial locations were used in these analyses.

Fire risk was modelled as the probability of one or more fires per hectare per decade. While the population of fires that the data represent is subject to question (see Introduction and Discussion sections), the data were treated as if they were all the fires in this population. A 1% uniform random sample of 1 ha squares (pixels) across the region (a total of 8051 pixels) were chosen as non-fire locations, with no attempt made to exclude the rare pixels with fire events. These points were included as fires and non-fire points in the analyses. Each point was weighted according to the inverse of the probability of it being chosen. For fire locations, this was 1/1. For non-fire locations, this was (805100–635)/8051 = 99.92.

For both fire and non-fire points, the points were overlain onto environmental predictors, resulting in estimates of environmental predictors for each point. The probability of one or more fires was modelled as a multiple logistic regression using Generalized Additive Models (GAMs) in Generalized Regression Analysis and Spatial Prediction (GRASP) (Lehmann, et al. 2001) to model the relationships between the presence of fires and environmental variables. The final model was chosen using backwards, stepwise regression, using AIC criteria to select variables for inclusion in the model.

The following environmental variables were available for selection by the model process:
Climatic Variables:

- Mean annual temperature
- Ratio of rainfall to potential evapotranspiration,
- Mean annual solar radiation
- Vapor pressure deficit
- Annual moisture deficit

Landform Variables:

- Elevation
- Slope
- Aspect

Cultural Variables:

- Distance to road
- Human Density

Land Cover Variable:

- Land Cover Data Base (LCDB).

A spatial prediction of fire risk was made by importing results from the statistical model into a geographic information system (GIS). The final model was exported as a lookup table

(Since GAMs are non-parametric models, they do not produce regression equations. Instead, tables are used to approximate the smoothed additive contribution of each variable, e.g., Figure 4). The lookup tables were then imported into Arcview, and the predicted probability of one or more fires was calculated for the entire North Island at 100 m resolution. To avoid predicting outside the range of mean annual temperature (MAT) observed in the Wellington Region, the values for MAT were truncated in the prediction grid to either the minimum or maximum observed in the Wellington Region. Truncation was not required for human density and distance to road, because the Wellington Region had contained the entire range of those variables.

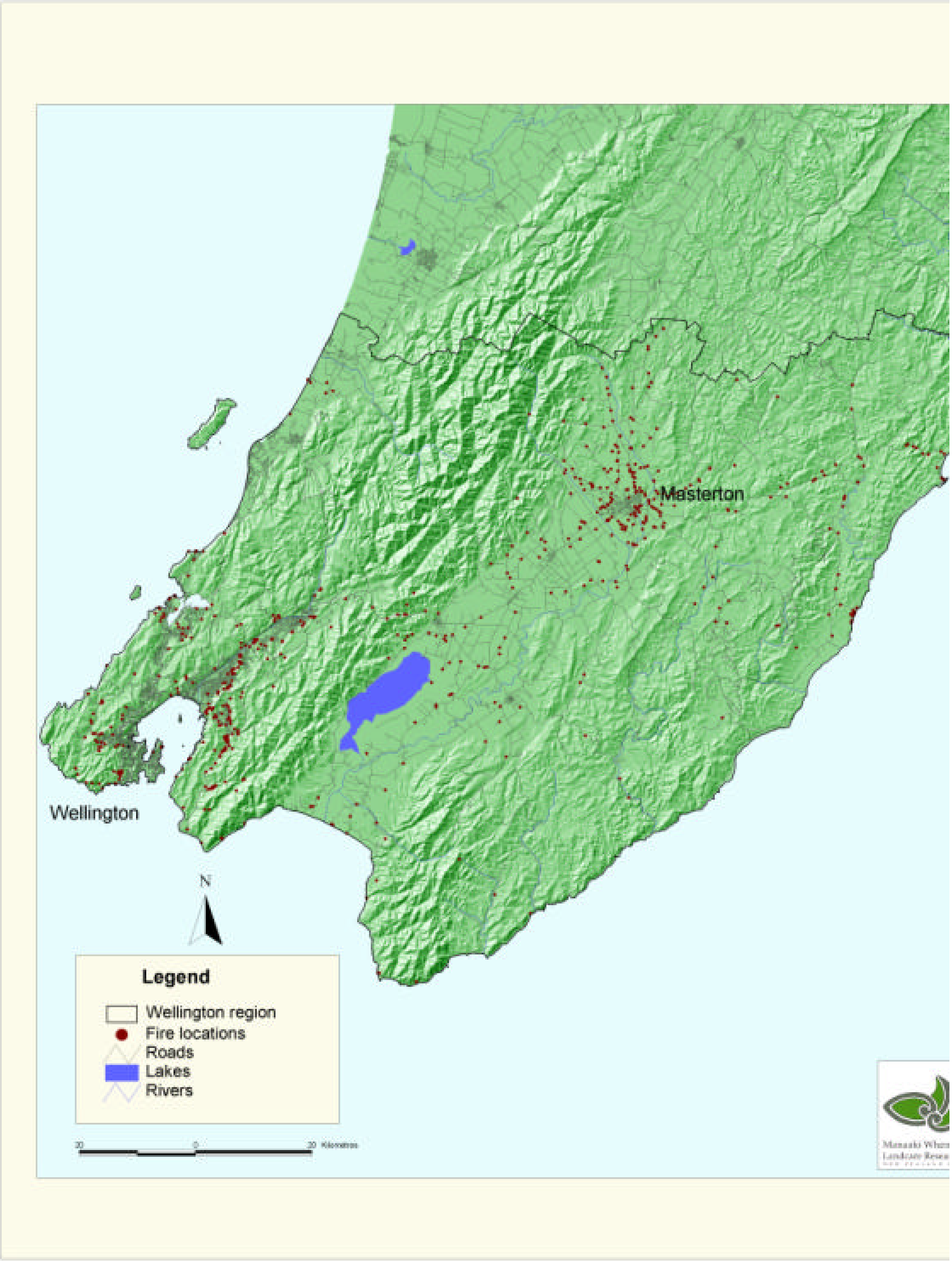

Fig. 1 The fires with spatial locations used in the analyses. For modelling purposes, this was assumed to be the entire population of rural fires. See text for a discussion of how this assumption may affect the results, and how the reported fires might relate to total fires.

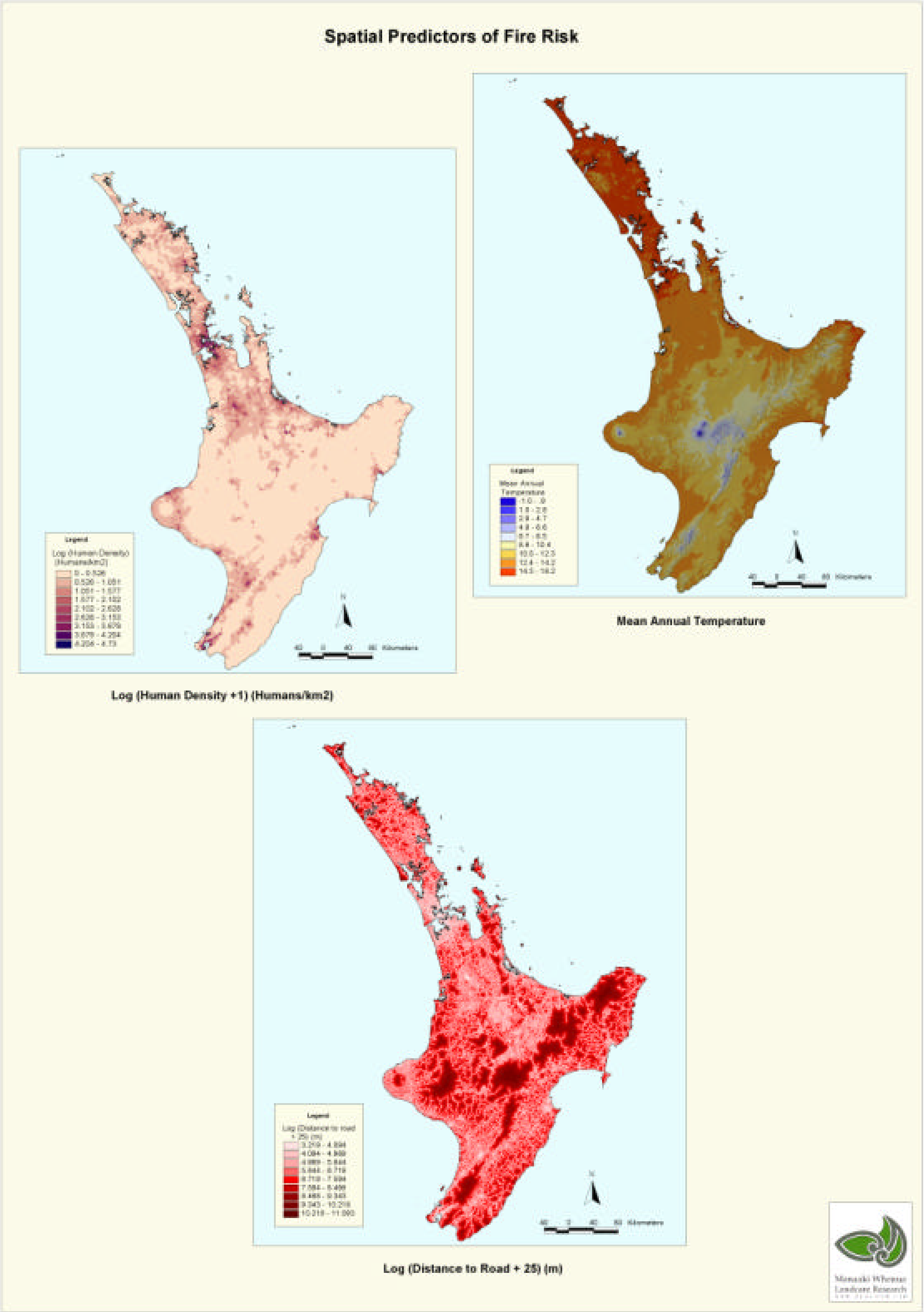

Fig. 2 Spatial predictors selected as significant predictors of fire risk. The predictors are: 1) Mean Annual Temperature in degrees centigrade; 2) Human Density, in humans per km^2 and transformed by adding one and taking the natural logarithm; and 3) Distance to roads mapped on the NZMS 260 series, in metres, transformed by adding 25 and taking the natural logarithm. All spatial predictors are mapped on a grid with 100-m pixels.

3. Results

The dataset of reported fires included 1390 fires, of which 725 had a useable spatial location and were included in the analyses. These 725 fires were at 635 locations (Figure 1). Fifty - five locations had more than one fire, with most having only two, but with one location having 11 fires. With approximately 805100 pixels (= hectares) in the Wellington study area, the overall probability of one or more fires per pixel is 0.0007887.

Three variables were found to be significant predictors of fire risk for the Wellington region (Figure 2). These variables were mean annual temperature, human density on a natural log scale, and distance to road on a natural log scale. The histograms of these significant predictors, and the distributions of fires across each variable are shown in Figure 3. It is clear that the distribution of fires is higher in higher mean annual temperatures, peaks and declines with human densities, and decreases with distance from roads. These effects are also apparent in the partial contribution of each of these variables to the GAM model in Figure 5.

The Generalized Additive Model of fire risk is shown in Figure 4. The effect of temperature on the model is a general increase of the probability of fire at higher temperatures. The probability of fires shows a consistent decrease with increased distance from roads. The effect of human density peaks at intermediately high human densities, and declines at the highest densities.

The relative contributions of each significant explanatory variable are shown in Figure 5. Distance to road is the most important variable, with temperature and human density showing similar amounts of deviance explained.

The predicted probability of one or more fires is shown for the Wellington region in Figure 6. This prediction has an overall mean for the region of 0.000773, which is close to the mean calculated non-spatially as the (number of fires)/(number of pixels) (0.000789). The minimum predicted value for the Wellington grid is 0.00000621, and the maximum is 0.0124. A prediction formed from this regression is shown for the entire North Island in Figure 7. The minimum predicted value for the North Island grid is 0.00000527, and the maximum is 0.0180, with an overall mean of 0.00130, which is almost twice the mean for the Wellington Region alone. With 11 443 617 hectares in the North Island grid, this translates to 14 900 locations with one or more fires per decade for the North Island. In the Wellington dataset, there were 725 fires at 635 locations, for an average of 1.14 fires per location. Furthermore, these 725 fires with spatial locations represent a total of 1390 fires in the dataset, so that each fire in the dataset can be seen to represent 1390/725=1.92 fires. This leads to an extrapolation to the North Island of 14 900*1.14*1.92 = 32 700 fires per decade, or 3270 fires per year.

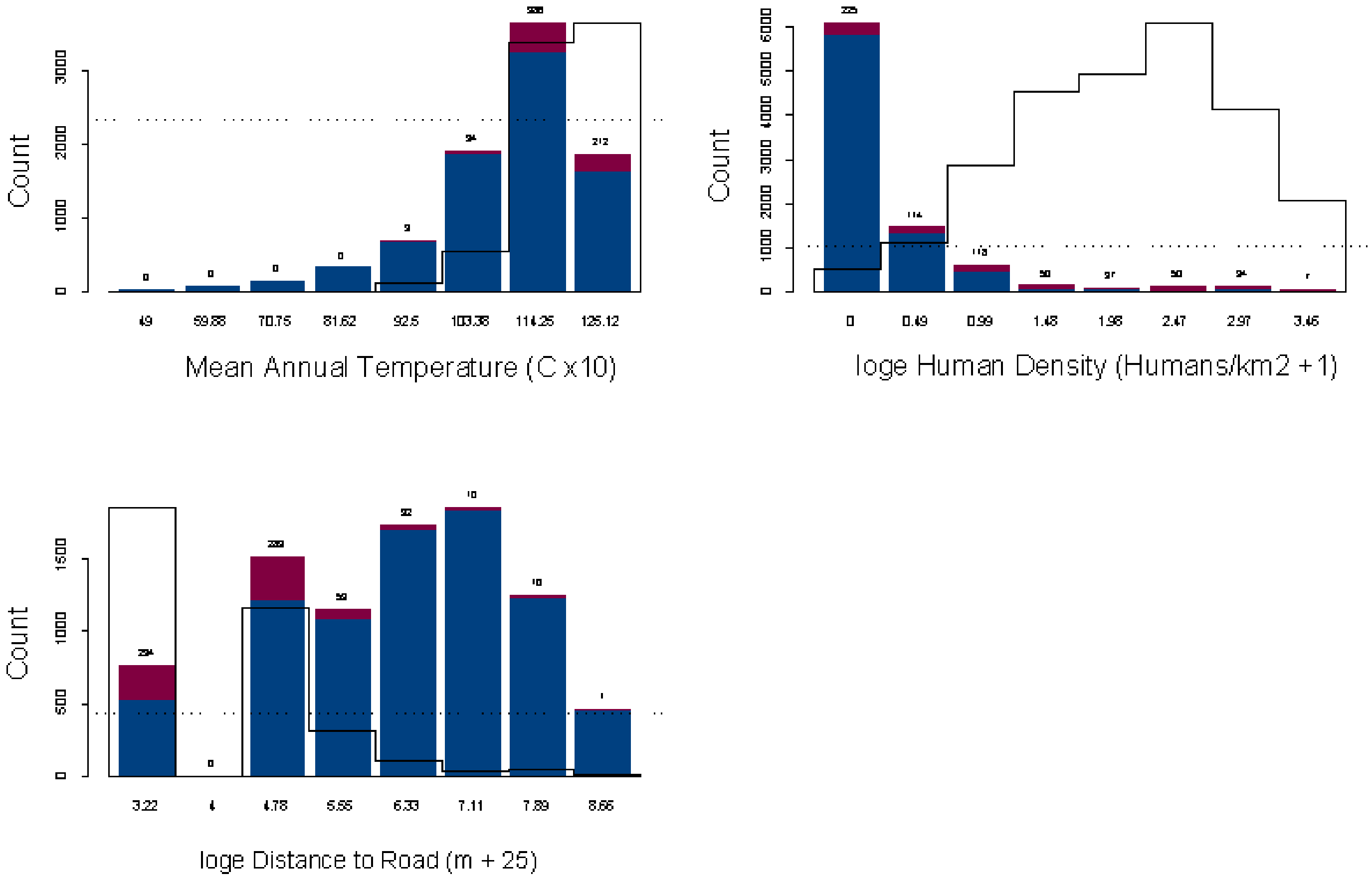

Fig. 3 Histograms of predictor variables included in model. The dark blue portion of the bar shows the non-fire points, and the red portion shows the fire points. The solid line shows the proportion of the pixels in each bar that have one or more fires relative to the overall average proportion of pixels with fires, which is depicted by the horizontal dashed line. Thus, when the solid line is above the dashed line, fires are more common in that portion of the environmental variable.

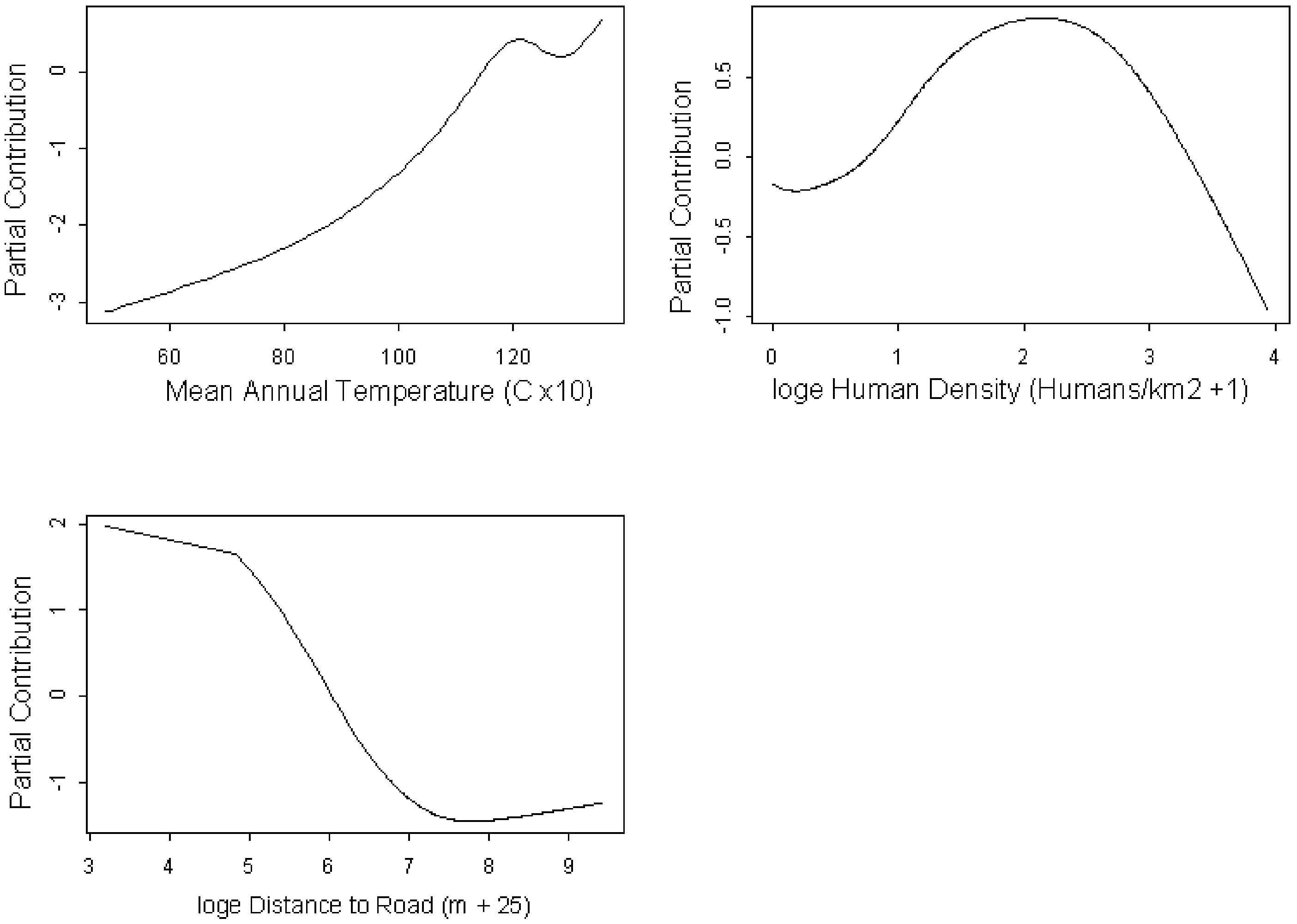

Fig. 4 Generalized Additive Model (GAM) of fire risk. These graphs show the smoothed fits of the partial contribution of each variable. The overall model is the overall mean plus the partial contribution of each variable.

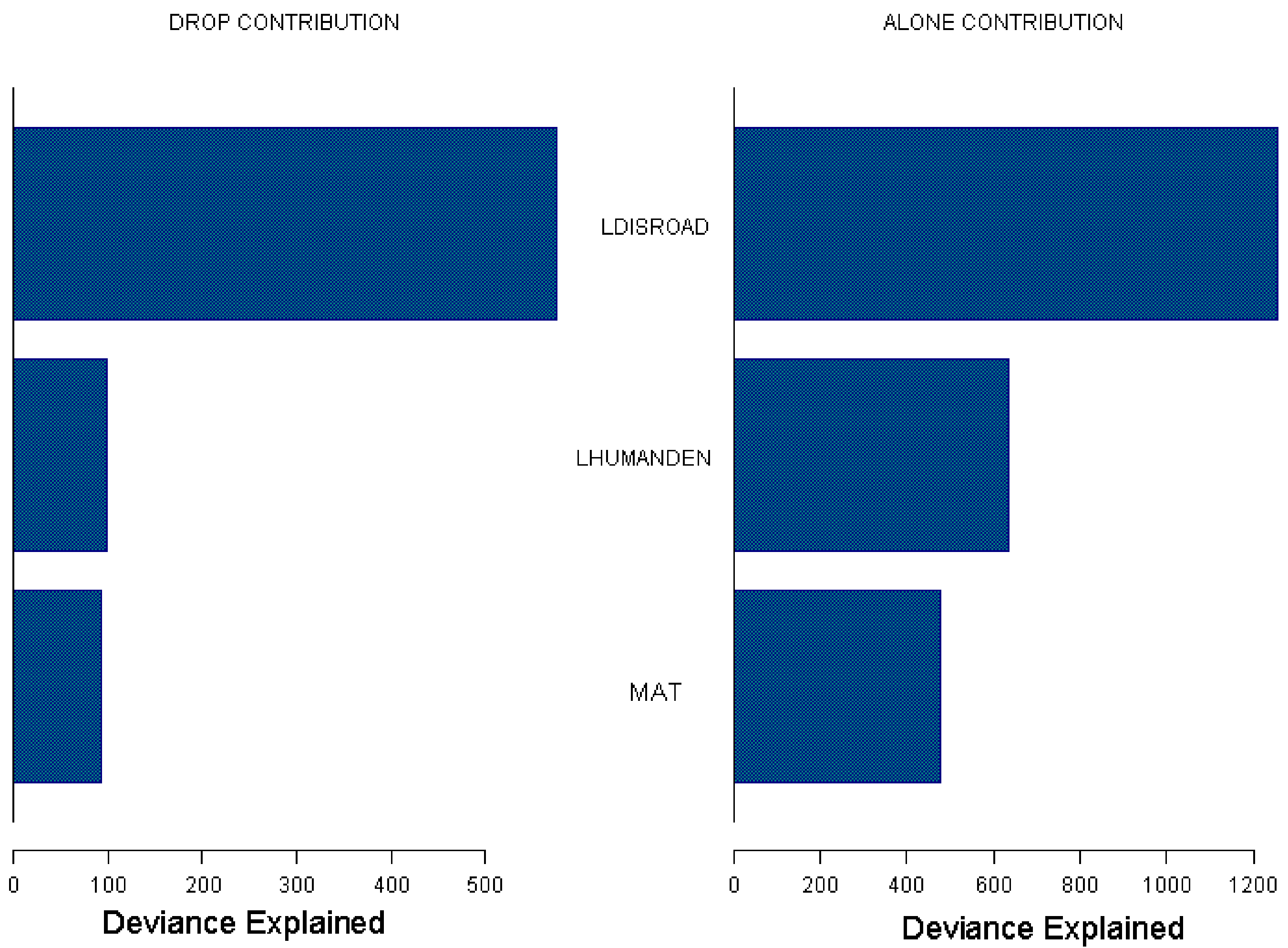

Fig. 5 The contributions of predictor variables to the GAM in Figure 4. These graphs show the deviance explained by each variable. The right-hand graph shows the amount of deviance explained by each variable when it is alone (the only variable) in the model. The left graph shows the drop in the total deviance explained by the model when all three variables are in the model, and one is dropped out. Notice the approx two-fold difference in scaling between the two graphs.

4. Discussion

The results of this project demonstrate the power of GRASP methodology to make spatially explicit predictions of fire risk by combining fire occurrence data with environmental and cultural information. Using an incomplete dataset confined to the Wellington Region, this approach yielded good predictions within this region. Even when extrapolated to the entire North Island, the predictions were not unreasonable.

The advantages of such an approach for fire management are several, including:

- Point locations of fires are combined with spatial information to produce spatially explicit predictions of fire risk (e.g., Figures 5 and 6).
- Relationships between fire risk and environmental or cultural fire factors and their relative importance are determined (Figures 4 and 5). Since individuals experience phenomena at more local scales, these statistical analyses over large spatial scales play an important role in understanding the factors that influence fire risk at regional or national scales.
- Data requirements and deficiencies can be highlighted. This can lead to much more focused efforts to provide data needed for fire management, resulting in huge potential gains in the efficiency of data reporting and collecting.

This study highlights the need for continued improvement in the underlying information. The information used in this pilot includes both the spatial locations of fires, as well as the spatial predictors, such as the climatic and landform surfaces and cultural information. Continued investment in improving information on both fires and spatial predictors will substantially improve the results gained from implementing this approach.

There is an unknown bias in the predictions based on the potential biases in the fire location data noted in the Introduction. In the present study, we can only say that what we are actually predicting is not fire risk per se, but is instead the probability that a fire is reported in our database and has a spatial location. However, this is insufficient for wider purposes, and the bias eventually needs to be understood or corrected. It is possible to gain an understanding of this bias by an analysis of the factors that contribute to the steps that lead up to a fire being reported to the NRFA with a spatial location. However, a much better solution is to develop data reporting and capturing systems that provide either complete or representative records of the fires across New Zealand.

Of the variables chosen by the stepwise process, the two factors relating to human fire risk are most easily interpretable. Human sources of ignition are a primary contributor to fire risk. Human density overall predicts the major patterns of human activity, while the distance to closest road predicts the places where people are travelling and providing sources of ignition. The fact that this method “chose” mean annual temperature as the only climatic variable to include is interesting. While predictions of fire risk often focus on moisture variables, the importance of temperature in determining fire risk is entirely reasonable. Temperature is a fundamental component of the speed of any chemical reaction, as well as the heat budget of an exothermic reaction. In addition, temperature is an important component of both rainfall and evaporation, and thus is correlated with the moisture balance variables used in this analysis. It is quite likely that if the study area had encompassed a wider range of climatic conditions, such as drier rainshadow areas near Napier, Christchurch or Alexandra, or warm moist areas such as Northland, there would have been an independent contribution of moisture variables. However, this somewhat counterintuitive result is an example of the strength of this approach to provide new insight into the behaviour of fires at large spatial scales.

The predictions of fire risk produced here need to be treated with caution for two main reasons: 1) the (unknown) bias of the sample points and 2) the extrapolation outside the geographic and environmental range of the data. The degree to which the fires that end up in the database represent the overall population of fires in the Wellington region is unknown. Clearly, most urban fires are not included in this dataset, along with an unknown number of rural fires. There could also be a bias produced by the fact that of the 1390 fires in the dataset, only 725 had accurate spatial locations. If there was a pattern to the reporting of spatial locations of fires, for example if a particular fire authority in a particular area did not report spatial locations, then these 725 fires will be a biased sample of the overall 1390 fires in the database.

While modeling of fire risk can be done from a priori techniques in the absence of data on fire risk, one has to question the rigour of such an approach. If the statistical models developed here for the Wellington region are questionable when applied to the rest of the North Island, then process-based models developed overseas must surely be even more questionable when applied to New Zealand. Operating in a data-free environment provides the luxury of not having anything to tell you that you are wrong! If there are no data in New Zealand, then there is no basis for a rigorous, empirical estimation of fire risk by any method. Fortunately, there does not need to be a choice made between process-based models and statistical models. As long as the foundation of data exists, it can be utilized in complementary ways.

While this study employed a purely spatial analysis using average climatic conditions, a more sophisticated analysis could utilize a spatio-temporal analysis of both the locations of fires, and the climatic conditions at the time of the fire. Such an approach would have important advantages, since it would produce a data-defined, spatio-temporal model that could predict a dynamic pattern of fire risk across the landscape that would depend upon current and recent weather patterns. The drawbacks of such an approach are mainly the difficulties of accurately estimating the appropriate weather variables for the time when and space where that each fire occurred. Such an estimation would require climate station data across the entire region of interest, measured at high temporal frequencies, all in a carefully prepared database with an efficient algorithm for interpolating the weather conditions at the time and location of each fire. The use of the resulting model to provide a dynamic prediction of fire risk would require that current weather conditions be used to produce the surfaces of current weather conditions needed to make the predictions.

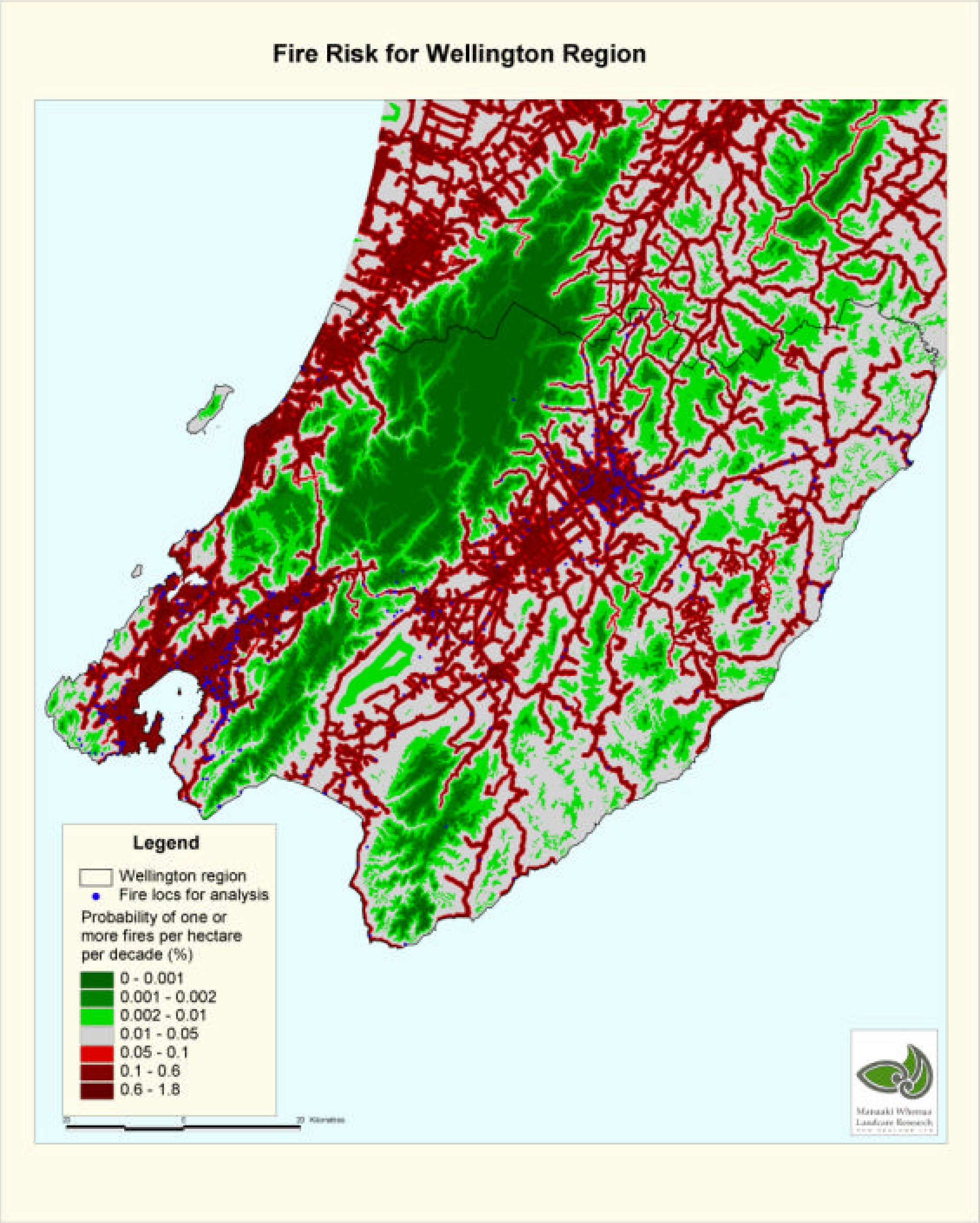

Fig. 6 Predicted fire risk for the Wellington region. Fire risk is given as the probability of one or more fires per hectare per decade, and is multiplied by 100 to convert to percentages. The observed fire locations from Figure 1 are shown for reference.

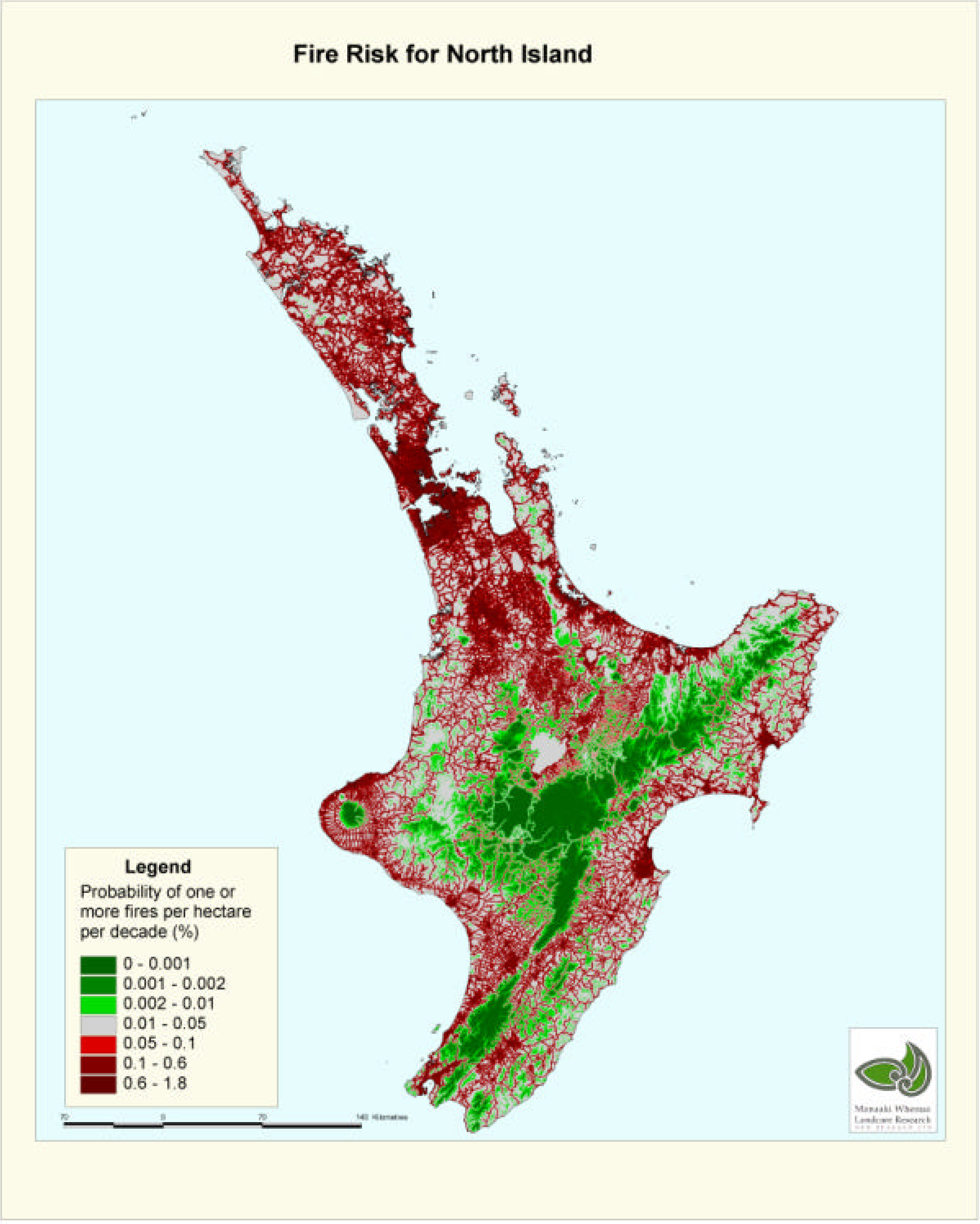

Fig. 7 Predicted fire risk for the entire North Island.

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