Wilding Conifer Risk Mapping in the Canterbury Region;

a Modelling Approach

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Project and Client

This report documents the research activity carried out under Objective 1, Milestone 4 of the Ministry of Agriculture and Forestry's Sustainable Farming Fund (SFF) project "The prevention, management and control of wilding conifers" (Grant 06\147). The work was carried out as a sub-contract to Scion, who in turn have been contracted to undertake the SFF project by the South Island Wilding Conifer Management Group.

Objectives

The objective is to map spread risk and control prioritisation in the Canterbury region. Under Objective 1 of the project, Milestone 3 requires the construction and validation of a Decision Support System (DSS) to assess the risk of wilding establishment. Milestone 4 requires this DSS to be implemented in map form. This report describes the computer-based method used for mapping the wilding risk DSS, and provides examples of its use in the Canterbury region.

Methods

Information was gathered from a national Digital Elevation Model of New Zealand, the Land Cover Database 2, and a wilding database gathered in the first year of this project. The three databases were converted from vector to raster datasets with 25m postings in the New Zealand Map Grid projection, covering the South Island. Using these databases, a selected area of Canterbury was mapped as an example.

The model used for mapping wilding spread risk was a DSS designed by Nick Ledgard of Scion, to assess the risk of wilding establishment at a given point on the landscape (Objective 1, Milestone 3); this DSS is referred to as DSSb. An electronic version of DSSb has been implemented in map form, referred to as eDSSb, by coding in the Matlab simulation and computation software environment. The eDSSb model yields an ordinal risk value for every point on the landscape, similar to DSSb, and hence estimates the risk of wilding tree spread into any site.

eDSSb has attempted to include the effects of topography and wind on seed dissemination and deposition, but this has proved difficult to model with precision.

Results

The wilding risk assessment tool, DSSb, has been implemented into an electronic version (eDSSb) to create computer-based maps. The model has been tested on an 80-by-60 km area of Canterbury high country. The resulting maps show the risk score from DSSb due to (a) the vegetation type, land use (principally grazing intensity), and altitude, and (b) combining these with the risks associated with the location of adjacent conifer species (seed sources) and the species involved – some being of higher spread risk than others.

Conclusions

The implementation of eDSSb attempts to reproduce the logic in DSSb, as described by (Ledgard 2008). The resulting maps do give a good 'first order' representation of the risk of wilding invasion, but there are a number of areas where the output from eDSSb will differ from that of an expert assessment using DSSb. The major reason is that the spatial data bases used, particularly relative to land use, are not of sufficient accuracy. In addition, the wilding information gathered (Objective 1, Milestone 1) is variable in quality due to the wide range of data sources, and wind has been modelled in a single flow direction, for simplicity reasons. Finally, while the logic of DSSb is followed closely in eDSSb, there may be some differences of interpretation to that used by an expert.

As a result of the above considerations, the eDSSb wilding risk maps should be carefully communicated to end users, since the quality of land use information, and that involving the potential conifer seed sources, has considerable impact on the overall risk result. Given time and further effort, the variable seed source data can be corrected, but the poor quality of the land use information will not be easy to overcome in the near future.

1. Introduction

This report documents the research activity for the 2007/2008 year, carried out under Objective 1, Milestone 4 of the Ministry of Agriculture and Forestry's Sustainable Farming Fund (SFF) project "The prevention, management and control of wilding conifers" (Grant 06\147). The work was carried out as a sub-contract to Scion, who in turn have been contracted to undertake the SFF project by the South Island Wilding Conifer Management Group.

2. Background

The natural regeneration of introduced conifers, or wilding spread, has been occurring in this country for over 100 years (Smith, 1903), but has received increasing attention during the last decade (well covered in Hill *et al*, 2004). Land management and administrating agencies such as regional and district councils and the Department of Conservation now proactively address wilding tree risk and control in their planning, policies and prioritisation of field operations (Bowman, 2004; DOC, 2001; Woods, 2004). As with the management of any weed or pest, good prevention can save significant funds having to be spent on control. Fortunately, the process of spread is predictable (Ledgard & Langer, 1999), which makes prevention and risk estimation easier than for many other pest plants.

One of the tools available to assess the risk of wilding spread is a decision support system (DSS), which can be defined as a set of tests that enables a person to make a reasoned judgement similar to that an expert would make in the same circumstances. A DSS is intended to circumvent the need for an expert to make an assessment on every occasion when a judgement is required, but still retain the balanced judgement of that expert. A DSS can take one of many forms, such as a set of rules in a computer program or a questionnaire.

A DSS for assessment of the risk of wilding spread into a given site, termed DSSb is described by Ledgard (2008), and is presented in Appendix 1. DSSb uses information on wilding species, topographic classification, wind flow, distance from wilding sources, land cover, and land use.

This report describes the computer implementation of DSSb for mapping the risk of wilding establishment onto a new site. The computerised version of DSSb is referred to as eDSSb.

2.1 General approach to modelling

The computer modelled version of DSSb, termed eDSSb in this report, is designed to implement the decision steps in DSSb as close as possible to the original. Inevitably, however, the interpretive nature of DSSb means that some decision steps are more difficult to implement than others. For instance, land use information on grazing pressure is an important element of DSSb that determines whether wilding seed spread to a site is likely to take hold.

However, land use information is difficult to obtain in eDSSb for the South Island as a whole, although it can usually be determined for a local site by local surveying, talking with local land owners, or in some circumstances by inference from other land information (North *et al* 2002).

Four of the six decision steps in DSSb require information on the relationship between the wilding source and downwind (or sometimes, upwind) conditions. Since the topographic information used by eDSSb is in raster form, moving in a downwind or upwind direction generally requires traversal of the raster dataset in some arbitrary direction defined by the prevailing strong winds, generally from the North-West. This type of data traversal can be computationally demanding, and in eDSSb a transformation is carried out to make this process simpler. In those steps of eDSSb that require downwind or upwind data traversal, the relevant datasets, such as the digital elevation model, are rotated in map space so that the wind direction flows along the lines of the raster dataset. Traversing downwind or upwind is then simply a process of moving along lines in the raster image, which is considerably less computationally demanding. Once the processing of the relevant steps of eDSSb is completed, the processed data is rotated back to the original map space.

2.2 Modelling wind flow over terrain

Successful modelling of seed dispersal from upwind sources to various parts of the landscape is a crucial part of wilding spread modelling. Unfortunately, wind is complicated to model, and it is clear that it does not propagate in a simple geometric manner. For example, a predominant North-West wind, generally associated with wilding seed spread, generates orographic lift at the base of hills, which will carry seed further than from trees on flat or sheltered sites. Modelling orographic lift requires knowledge of the terrain and the nature of the spreading wind, and this is a difficult fluid mechanics problem.

Modelling wind flow in a local area using numerical methods from fluid mechanics is feasible (Reid 2006), and it is even possible to simulate the complex eddy flow around and over complex hill structures (Kim & Patel 2000). However, the modelling of arbitrary wind flow over all terrain in the South Island represents a considerable challenge, and the associated computing requirements are formidable. Even if it were possible to model the wind flow in detail using these methods, the results might not justify the computational effort required, since the precise wind seeding conditions for wilding spread are not generally known; they are assumed from expert knowledge.

3. Objectives

The objective is to map spread risk and control prioritisation in the Canterbury region. Under Objective 1 of the project, Milestone 3 requires the construction and validation of a Decision Support System (DSS) to assess the risk of wilding establishment. Milestone 4 requires this DSS to be implemented in map form. This report describes the computer-based method used for mapping the wilding risk DSS, and provides examples of its use in the Canterbury region.

4. Methods

4.1 Data sources

Information for topography is provided by a national Digital Elevation Model (DEM) of New Zealand, obtained by interpolation of 20-metre contours, spot heights, trig points, coastline, and lake level information sourced from Land Information New Zealand (LINZ). The DEM is provided with 25m postings in the New Zealand Map Grid projection, and is described in (Barringer *et al* 2002). This DEM has been assessed using Lidar and gives an unbiased estimate of terrain height with a standard deviation of 5.3m (Barringer *et al* 2002).

Information for land cover was provided by the Land Cover Database 2 (LCDB-2), which is a classification into 61 different land cover types derived from optical satellite imagery over the 2001/2002 period. The classes for LCDB-2 are given for reference in Appendix 2. LCDB-2 was provided as a vector coverage in the ArcInfo (ESRI, Redlands, California, USA) GIS system, but this database was converted to a raster dataset using nearest-neighbour interpolation with the same sampling interval as the DEM (25m) and with the same map extents.

Information for wilding sources was provided by an ArcInfo database gathered in 2006/2007 as part of Objective 1, Milestone 1 of this project, and documented in (North *et al* 2007). The wilding database contains a number of different attributes, such as area, species, originating source, as well as source-specific information (e.g. in some cases stand density is provided). Unfortunately, this information is variable in quality due to the wide range of data sources and the different forms in which the data were supplied (from hand-written notes and sketches to GIS shape files).

As with the LCDB-2, this database was converted to a raster dataset with the same sampling interval as the DEM (25m) and with the same map extents, with the raster dataset using nearest-neighbour interpolation. The raster version of the database was generated using the wilding polygon identification number for each raster cell, or a value of zero where no wildings were found. The ArcInfo database tables were converted to an Excel spreadsheet, indexed by a wilding polygon identification number.

Processing of the various raster datasets to produce a risk map was done in the Matlab computational environment (version 2007b, The MathWorks, Natick, Massachusetts, USA). This processing environment was used since Matlab provides built-in procedures for processing large raster datasets in a single step, can conveniently handle Excel reference information, rapid changes can be made to the computational source code, and the code can run on a number of operating systems.

Finally, the Matlab script that produces the risk is controlled by a small text file that defines the map extent of the calculation, the location of the various datasets, as well as some of the values of parameters used in the modelling, and referred to in later sections of this report. Using a small text file in this way allows the text files to document the processing undertaken, and prevents less experienced users from having to understand the complicated Matlab code that runs the modelling.

4.2 Modelling wind flow over terrain

In order to reduce the computational requirements of wind flow modelling to a tractable form in this research, a heuristic approach was adopted to predict which points on the landscape are exposed, fully-, or partially-sheltered from the spreading wind. In particular, it was assumed that:

- wind flows in a single vector direction, with no cross-wind effects,
- interactions with the terrain are defined by the location of simple topographic features, such as ridge points and positional slope estimates,

The above assumptions effectively reduce the modelling of wind exposure and shelter to a straight-forward geometric problem, which is very easily implemented in a computer model. Although topographic features define points susceptible to seed spread, the complicated interactions between the wind and terrain were not modelled.

4.3 Geometric modelling of wind exposure and shelter

Wind flow is modelled in eDSSb by geometric modelling from a single vector direction. The basis of the geometric modelling is that an obstruction to the wind provides shelter from the wind for a certain distance behind the obstruction, partial shelter from the wind for some distance beyond that, and is fully exposed to the wind thereafter. There are a number of rules-of-thumb in use for the distance downwind from an obstruction that is considered fully-sheltered that are available; none of these rules is definitive.

In this modelling work, the rule for wind shelter that is used is that an obstruction of a given height has a fully-sheltered region of ten times that height behind the obstruction, and a further distance of ten times that height beyond that is considered partially sheltered. The figure of ten used here (called a shelter protection ratio) is common in the design of farm shelters. In eDSSb, the topography is classified according to this rule, consistent with a given wilding seeding wind, into one of three mutually-exclusive classes: fully sheltered from the wind, partially sheltered (or, equivalently, partially exposed to the wind), and fully wind exposed. The effect of this rule can be seen in Figure 1, where the method is applied to an 80km terrain profile. Shaded regions in each part of Figure 1 indicate the fully-sheltered, partially-sheltered, or fully-exposed regions of the profile.

Note that an assessment of vegetation risk, as opposed to an assessment of risk relative to specific wilding source as shown in section 5.2 later, only requires consideration of DSSb rules 5 and 6. Thus, in the assessment of vegetation risk, consideration of fully- or partially-sheltered sites is not relevant.

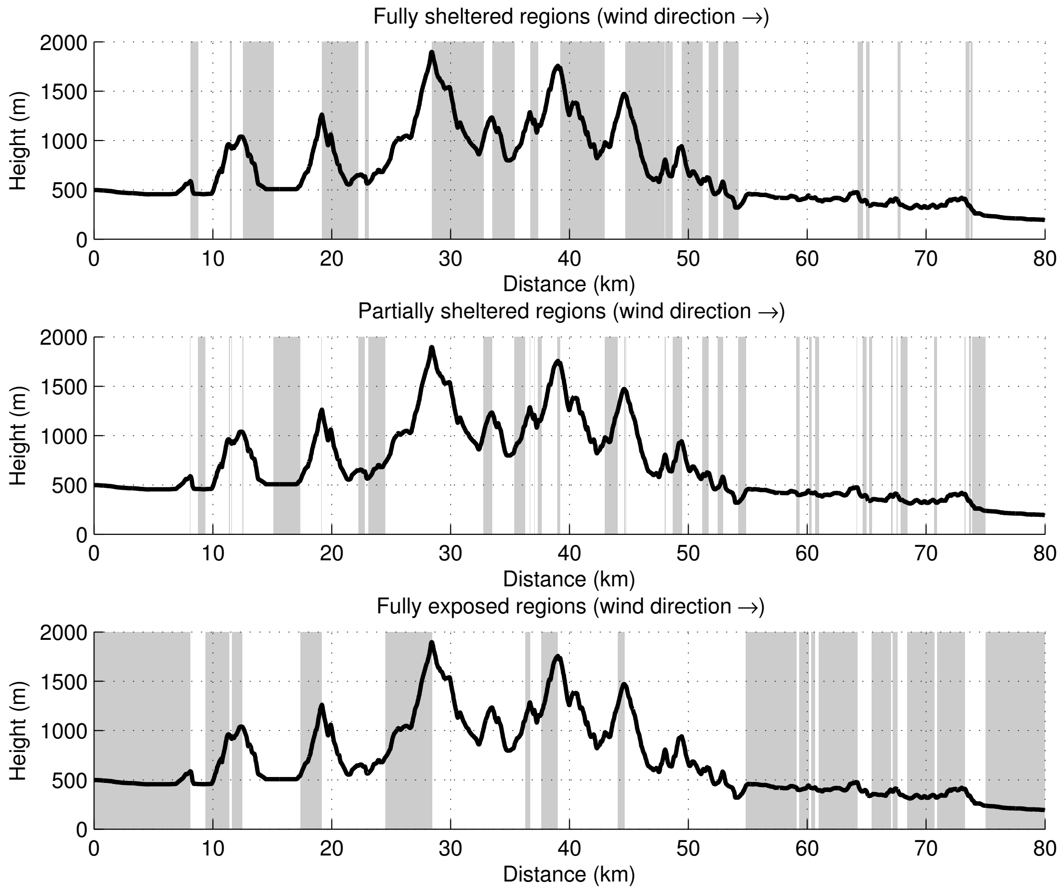

Figure 1. Fully sheltered (top, shaded), partially-sheltered (middle) and fully-exposed regions of a profile.

4.4 Calculation of risk associated with conifer species providing seed source

The seed source risk factor is the first of six risk factors required in DSSb. In eDSSb, it is provided from the rasterised version of the wilding database. However, the wilding sites need to be propagated in the downwind direction to provide a link between the seed source and other points on the landscape. This calculation is carried out in the rotated-map domain referred to in section 2.1.

The wilding species for a given location is determined using a lookup table procedure from the wilding polygon identification number. The species information is in the form of a text string (e.g. *pinus radiata*),

4.5 Calculation of risk associated with siting of source trees

The source tree siting risk factor (DSSb risk factor 2) is calculated from the 25m DEM. However, since the topographic analysis requires information from the wind direction, this calculation is carried out in the rotated-map domain referred to in section 2.1.

Classification of the degree of exposure or sheltering from the seeding wind is carried out by the simple wind-modelling procedure in section 4.3. Terrain slope is measured using a moving window estimate of point slope, since point-by-point processing yields slope estimates with too much point-to-point uncertainty. The scale for this moving window is determined by a simulation parameter defined in the simulation text parameter file, as described in section 4.1. Lee slopes are determined using the classification of the downwind topography, as noted in section 4.3. Ridges are determined using morphological operators to find local terrain maxima (Anonymous 2001).

An important consideration for the siting of source trees risk factor is to find those locations at the base of exposed slopes with a slope greater than 10 degrees, as well as exposed slopes and exposed ridge-tops. Wildings located at these points are subject to orographic lift, which can spread seed to the lee side of the hill. In eDSSb, the base of these hills is determined using a second-derivative estimate of the downwind topographic slope; this provides the location of the point where the greatest rate-of-change of slope is occurring. Then, this information is combined with the exposure classification of the terrain and the smoothed-estimate of the slope. Although the second derivative is usually considered numerically-sensitive, this calculation is quite robust, since it combines second derivative estimates with a slope threshold and an exposure mask. Once terrain points subject to orographic lift are estimated, they can be used as one component in DSSb risk factor 2.

4.6 Calculation of risk associated with siting of sample site relative to source trees

The source tree siting risk factor (risk factor 3 in DSSb) is calculated from the 25m DEM. However, since the topographic analysis requires information from the wind direction, this calculation is carried out in the rotated-map domain referred to in section 2.1.

This DSSb risk factor codifies the sample site with respect to the seed-dispersing winds, requiring a classification of the sample site as upwind, within an eddy or cross-wind zone, or downwind. In eDSSb by contrast, since winds are modelled using the simple procedure as described in section 4.3, it is not possible to classify the sample site as subject to cross winds. This is a limitation of eDSSb compared with DSSb, as discussed in section 6.1.

4.7 Calculation of risk associated with distance of sample site from source trees

The risk factor that is calculated from the distance of the sample site from the source trees (risk factor 4 in DSSb) is calculated from topographic analysis of the 25m DEM, as well as the rasterised wilding dataset. Again, since this analysis requires information from the wind direction, this calculation is carried out in the rotated-map domain referred to in section 2.1. The distance to source trees is calculated using the morphological distance from wilding trees, a calculation that is very fast in Matlab. This morphological-distance-to-feature is then converted to downwind distance using morphological operators. As noted later in section 4.10, the risk score is only valid when the distance from the source trees is no larger than 5 km.

4.8 Calculation of risk associated with vegetation of sample site

The risk factor associated with the vegetation at the sample site (risk factor 5 in DSSb) is calculated from the LCDB-2, calculated in the original map domain. The various land cover classes defined in DSSb for this risk assessment are mapped to their equivalent classes in LCDB-2 (see Table 1), along with the LCDB-2 definitions from Appendix 2.

Note that the LCDB-2 classes used in the assessment of this risk factor do not map perfectly on to the corresponding definitions in DSSb; the LCDB-2 class combinations have been chosen as a "best fit" to the definition, and after inspection of the results of classifications using this scheme.

Table 1. The LCDB-2 classes used to amalgamate into DSSb classes *

DSSb classes(s)	LCDB-2 classes(s)
Developed pasture, rank grass, closed canopy forest/scrub, tussock grassland with a continuous, vigorous, permanent vegetation cover	SHORTROTATION_CROPLAND) ... VINEYARD ORCHARD_AND_OTHER_PERENNIAL_CROPS HERBACEOUS_FRESHWATER_VEGETATION HERBACEOUS_SALINE_VEGETATION HIGH_PRODUCING_EXOTIC_GRASSLAND PINE_FOREST_OPEN_CANOPY PINE_FOREST_CLOSED_CANOPY AFFORESTATION_NOT_IMAGED AFFORESTATION_IMAGED FOREST_HARVESTED MINOR_SHELTERBELTS MAJOR_SHELTERBELTS OTHER_EXOTIC_FOREST DECIDUOUS_HARDWOODS INDIGENOUS_FOREST MANGROVE MIXED_EXOTIC_SHRUBLAND
Open forest, Shrub, tussock, grassland with mostly dense vegetation cover	GORSE_AND_OR_BROOM MANUKA_AND_OR_KANUKA MATAGOURI BROADLEAVED_INDIGENOUS_HARDWOODS
Shrubland, tussock, grassland with a moderate vegetation cover	FLAXLAND FERNLAND LOW_PRODUCING_GRASSLAND GREY_SCRUB TALL_TUSSOCK_GRASSLAND
Open slips/rockland, Shrubland/tussock/grassland with a light vegetation cover	ALPINE_GRASS_HERBFIELD DEPLETED_GRASSLAND SUB_ALPINE_SHRUBLAND

4.9 Calculation of risk associated with grazing within sample area

The risk factor associated with grazing within sample area (risk factor 6 in DSSb) is calculated from the LCDB-2, calculated in the original map domain. Land use information of the type required by this risk factor in DSSb is difficult to provide, and grazing cannot generally be obtained with any reliability from the LCDB-2 classes alone.

In the end, grazing pressure was calculated using a combination of LCDB-2 classes and a grazing pressure index for the grassland classes calculated from the Enhanced LCDB-2 (sourced from AsureQuality). Specifically, the grazing pressure for known farm types was provided as a single numeric index 0–3 (as used in risk factor 6 in DSSb) by Thomas Paul (Scion Research). For unknown farm types, or LCDB-2 classes for which a grazing risk might be assumed, a set of simple rules were used to find a "best fit" correspondence between LCDB-2 class and grazing pressure. The final grazing pressure classification used in the model was combined with LCDB-2 classes as shown in Table 2.

Table 2. The LCDB-2 classes used within DSSb grazing levels 0-3

Grazing level classification	LCDB-2 classes(s)
0	Grassland grazing level 0 or one of the following LCDB-2 classes: HIGH_PRODUCING_EXOTIC_GRASSLAND
1	Grassland grazing level 1 or one of the following LCDB-2 classes: GORSE_AND_OR_BROOM MANUKA_AND_OR_KANUKA MATAGOURI
2	Grassland grazing level 2 or one of the following LCDB-2 classes: FLAXLAND FERNLAND GREY_SCRUB
3	Grassland grazing level 3 or one of the following LCDB-2 classes: ALPINE_GRASS_HERBFIELD SUB_ALPINE_SHRUBLAND

4.10 Collation of risk factors

Collation of all the risk factors described in sections 4.4 to 4.9 above is simply a matter of adding the values of the ordinal risk values calculated for each factor, with a maximum possible ordinal risk value of 21. As required by DSSb, the total risk score is reset to zero if any of the individual risk scores is equal to zero.

As with DSSb, the total risk is assessed with reference to a specified threshold value of 14; ordinal risk values equal to or larger than this value indicate a high risk of invasion into the sample area.

4.11 Additional risk calculations

A number of additional calculations must be made in the total risk calculation in addition to those outlined in sections 4.4 to 4.9 above.

First, in addition to the zero score resulting from covers given under factor 5 in DSSb, wildings are also assigned a zero total risk weighting for other land cover classes where they could not establish, such as lakes, ponds, rivers, and estuarine open water LCDB-2 classes. Also given a zero total risk weighting are the built-up area, urban parkland/open space, surface mine, dump, and transport infrastructure LCDB-2 artificial cover classes. These LCDB-2 classes are defined in Appendix 2.

Second, it is reasonable to expect that wildings will not establish above a certain maximum elevation. This maximum elevation is likely to be above the known tree line, and will vary with wilding species, and latitude. As the interaction between these factors is not known precisely at this stage, a single maximum establishment altitude of 1400m was adopted. This figure could be changed in later versions of the simulation modelling.

4.12 Post processing

Although the modelling of the wilding risk is done in Matlab, some post processing is performed in Leica Imagine version 9.1. Imagine is used to combine risk maps with existing topographic maps, and convert these maps to printable form.

5. Results

The maps resulting from modelling with eDSSb are illustrated in this report by way of a test area in the Canterbury region covering the InfoMap 260-series 1:50 000 map sheet K34. This area covers NZMG eastings from 2370000 to 2410000 (40km wide) and northings from 5770000 to 5800000 (30km high), as shown in Figure 2.

5.1 Vegetation risk map

The vegetation risk map (Figure 2) shows the risk of wilding establishment as a result of the land cover and land use information, independent of seeding wind or potential sources of conifer seed. This map only utilises DSSb risk codes 5 and 6 to show the likely risk of wilding establishment. Hence the map can be used to indicate areas where wilding establishment is most likely to be a threat, as well as those that ought to be avoided when planting new areas of spread-prone conifers.

Rather than provide a numeric code for the vegetation risk map, the elevated risk is provided as a three-level code (moderate, high or extreme risk). The three-level code provides a risk boundary that is less harsh, and more able to be interpreted by visual inspection, and it is coded from DSSb risk codes 5 and 6 as shown in Table 3 below, where the output vegetation risk is coded as either low, moderate (M), high (H) or extreme (E). Low risk areas are those in Figure 2 where the background topographic map is uncoloured, while moderate, high or extreme risk areas are those in the figure where the background topographic map is coloured as in the figure key.

Table 3. Mapping between eDSSb risk scores and the overall vegetation risk.

Risk score 6 \ Risk score 5	1	2	3
1	M	M	H
2	H	H	E
3	H	E	E

Figure 2 shows the vegetation risk map for the InfoMap 260-series K34 map sheet. In this representation, the risk levels from moderate to extreme correspond to progressively darker red colours. The risk classification is blended in with the topographic map of K34.

5.2 Map showing spread risk from specific conifer seed sources

The risk map incorporating specific conifer seed sources (Figure 3) shows the risk of wilding establishment, using all the DSSb risk codes 1 to 6. A combined total risk score of 14 or greater, calculated as described in section 4.10, indicates a high risk of invasion by the assessed species onto the sample area. In eDSSb, two risk levels are indicated. First, a total risk score of 14 or higher (out of a maximum possible value of 21) indicates high risk. Second, a total risk score of 10–13 (inclusive) indicates a moderate risk. The additional risk level ("moderate") has been included to provide a softer risk boundary than would be the case from a strict interpretation of DSSb. Given the uncertainties in each of the risk scores, the use of a two-level risk score is easier to interpret visually.

Figure 3 shows the risk map from specific wilding sources for the InfoMap 260-series K34 map sheet. In this representation, the risk levels of moderate and high correspond to light and dark red. The risk classification is blended in with the topographic map of K34. In this map, the wilding seed wind is assumed to come from the North West direction or from an azimuth angle of 315 degrees clockwise from North, with a 15 degree possible spread. That is, the seeding wind could come from plus-or-minus 7.5 degrees from the nominal angle of 135 degrees.

Needless to say, this risk map is very dependent on the correctness of the information contained in the wilding pine inventory, and as indicated later in section 6.2 the information in the inventory is variable due to the wide range of sources and the different forms in which it was supplied.

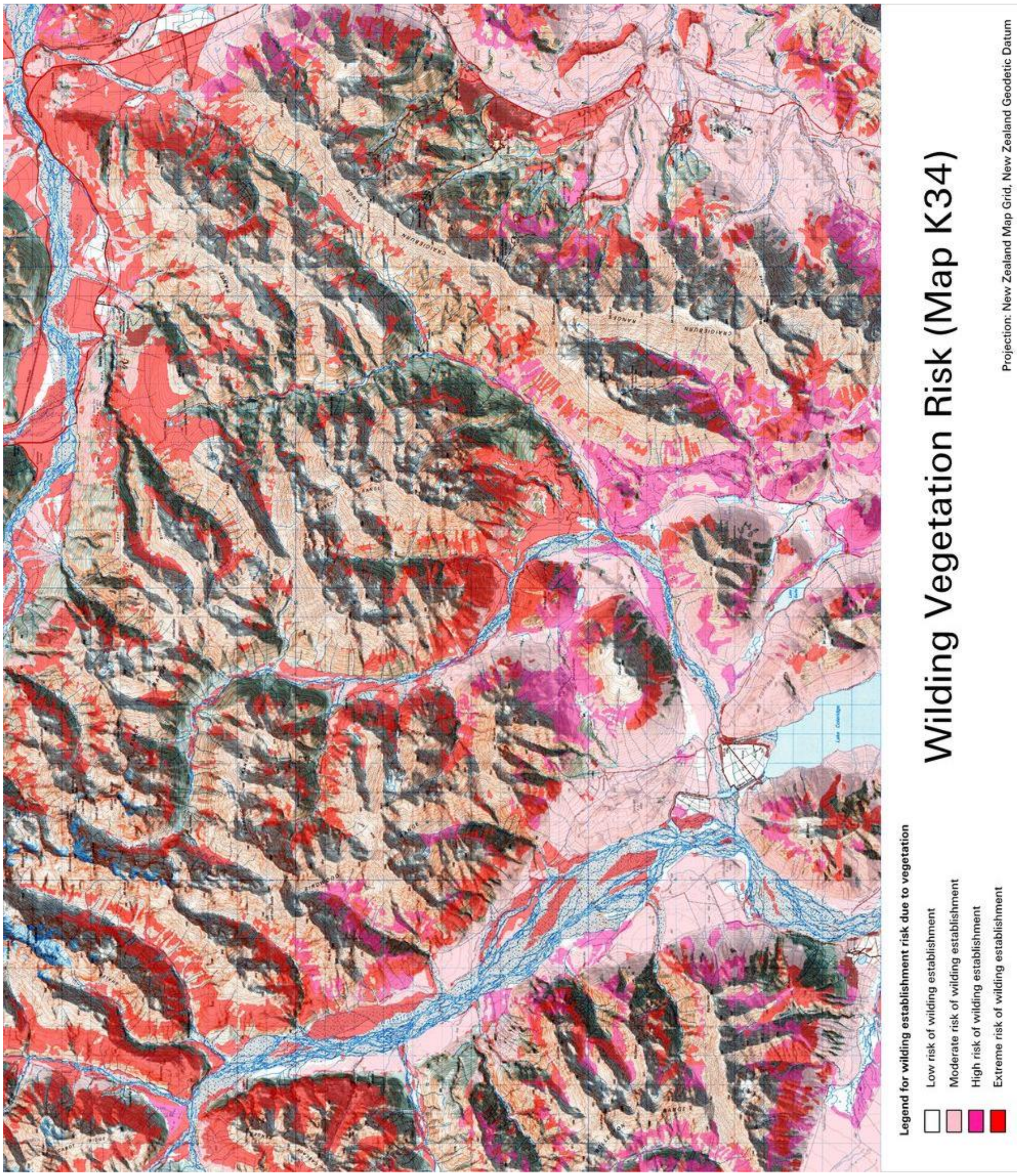

Figure 2: Example of the vegetation risk map, using the InfoMap 260-series K34 map sheet (covering 40 x 30 km). This image has been rotated to match the page format of this report. In this representation, the risk levels from moderate to extreme correspond to progressively darker red colours over the underlying topographic map, while low risk levels are represented are uncoloured over the underlying topographic map. Note that the image shown in this figure is of much lower resolution than that generated by the modelling procedure, in order to keep the size of the electronic version of this report to a manageable level.

Figure 3: Example of the risk map incorporating known conifer seed sources using the InfoMap 260-series K34 map sheet (covering 40 x 30 km). This image has been rotated to match the page format of this report. In this representation, the risk levels of moderate and high correspond to light and dark red. Note that the image shown in this figure is of much lower resolution than that generated by the modelling procedure, in order to keep the size of the electronic version of this report to a manageable level.

6. Discussion

6.1 Adequacy of wind modelling

Although it is possible, in principle, to model the flow of wind in a technically-detailed manner, as noted in section 2.2, it is very difficult to model the wilding seed wind in practise over a large area. Such a task is too computationally difficult given the resources available in this project. In any case, the conditions of the seeding wind are not sufficiently well-known, so that detailed wind modelling might not be justified.

The approach taken in eDSSb has been to reduce the three-dimensional wind flow modelling to a single-dimensional topographic modelling problem, using heuristic rules to model the relationship between the terrain and the seed dissemination process. This model assumes wind runs in a single direction, with no cross wind effects. This is clearly a very simple model, perhaps too simplistic, but it is adequate to represent the basic details of DSSb. Furthermore, although the model is simple, it is a useful starting point from which more complex modelling might be considered in the future, if warranted.

Since the precise wilding seeding wind is not known, the specification of a single wind direction (such as from the North-West) is not realistic. This uncertainty is taken into account in the wind modelling by allowing the wind to occupy a range of values. In the examples shown in this report, the nominal seeding wind is assumed to come from the North West direction or from an azimuth angle of 315 degrees clockwise from North, with a 15 degree possible spread. That is, the seeding wind could come from plus-or-minus 7.5 degrees from the nominal angle of 135 degrees.

It is difficult to test the appropriateness of the simple model of wind exposure modelling. However, the general areas of exposure correspond to those expected. In addition, it is straightforward to modify the method to give shelter protection distance factors more conservative or liberal than the factor of ten used here.

6.2 Accuracy of species information

The wilding database was assembled from a variety of different sources (North *et al* 2007) with considerable variation in original data quality. There is some ambiguity in the definition of some species, and some species are unmarked, or marked as “unknown”, “mixed”, or “others”. The approach taken in eDSSb is to set unknown or ambiguous species definitions to have the same species risk as radiata and ponderosa pine, although no changes have been made to the wilding database itself. Clearly, some effort will be required to locate, and hopefully correct these ambiguous wilding sources, but at present it is possible that some wilding sources have an under-estimated risk. Lowering the risk level of unknown species to that of cypresses, spruces or cedars would effectively remove these ambiguous wilding sources from view, which would further under-estimate the true risk.

In addition, although the majority of species are well-defined, there are some polygons that have spelling mistakes. For example *P.laricio* may be specified instead of *P.nigra*, and there are also some variations on standard naming schemes, such as *muricata* and *P.mca*. All the variations in species names have been enumerated by inspection of the wilding database, and the alternative spellings of species are corrected at the point where risk calculations are made. No changes have been made to the spelling of incorrect species names in the wilding database, but variations in spelling have been accommodated and corrected within eDSSb.

It is reasonable to expect that later, updated, versions of the wilding database will correct spelling mistakes and remove ambiguities in species identifications, so the problems due to naming will be less likely over time, and will eventually be eliminated.

6.3 Interpretation of DSSb

DSSb requires an interpretation of relationship between terrain, wind and site. For example, DSSb has a statement that requires interpretation of whether the sample site is "subject to cross-winds and/or wind-eddies relative to prevalent or strong winds" (DSSb risk factor 3). It is difficult to codify the logic of this kind of relationship, even though the statement appears to be quite well-defined.

One advantage of the eDSSb approach is that there is quite a close coupling between the statements in DSSb and their coding in Matlab. As mistakes in the interpretation of DSSb are found, it should be relatively simple to make changes in the corresponding Matlab scripts to correct the interpretation.

6.4 Land use grazing information

As noted in section 4.9, eDSSb requires an assessment of grazing as a land use pressure for use as risk factor 6. In practise, land use and grazing is difficult or in some cases impossible to obtain. The approach taken in eDSSb is to estimate grazing from a combination of land cover from LCDB-2 and the classification of a farm type layer. The reliability of the grazing assessment is dependent on the accuracies of the LCDB-2 and the farm type layer (Enhanced LCDB-2), and the rules used to transform this layer information into the ordinal grazing pressure score used in eDSSb. Errors are known to exist in LCDB-2 and Enhanced LCDB-2 is derived from aspatial information (in part, from a questionnaire), so the grazing pressure is likely to contain some uncertainty.

Grazing is arguably the most important factor relative to wilding risk and spread, but is ever changing. This dynamic nature means that the maps produced in this report from eDSSb can only represent present day circumstances — and these can rapidly change over short periods of time.

6.5 Shortcomings of fundamental data

The modelling process uses information from a DEM obtained by interpolating contouring and topographic spots, as well as a rasterised version of a classified satellite image (LCDB-2), and a wilding GIS coverage. None of these fundamental data sources is error free, and some of the sources have unknown, but potentially very large, errors.

The LCDB-2 was generated from 2001/2002 satellite imagery and the currency of this land cover classification is degrading over time. This is particularly true in some regions of New Zealand where considerable land use conversion has taken place, such as from forestry to dairy farming. In principle, land use information can be updated using new satellite imagery, and an updated version of the LCDB would improve the currency of the wilding spread risk scores. At the time of writing, there are no firm dates for a successor to LCDB-2.

LCDB-2 will have some error associated with the incorrect classification of a point on the landscape into one of the pre-defined classes. This confusion is inevitable in any classification procedure, and the spatial error processes involved can be very complicated. There are no comprehensive measures of LCDB-2 accuracy, and the few measures that are described in the literature either quote total area error estimates (MfE 2008) or are based on opportunistic spatial sampling (Coomes *et al* 2002) and are not strictly valid spatial sampling estimates. Nevertheless, the available evidence suggests that the class accuracies of LCDB-1 and LCDB-2 can be poor, particularly near polygon boundaries, and between classes that are similar in optical spectral signature. The effect of poor LCDB-2 classification accuracy on the total risk score for wilding establishment is thus difficult to determine.

7. Conclusions

The implementation of eDSSb attempts to reproduce the logic in DSSb, as described by (Ledgard 2008). The resulting maps do give a good ‘first order’ representation of the risk of wilding invasion, but there are a number of areas where the output from eDSSb will differ from that of an expert assessment using DSSb. The major reason is that the spatial data bases used, particularly relative to land use, are not of sufficient accuracy. In addition, the wilding information gathered (Objective 1, Milestone 1) is variable in quality due to the wide range of data sources, and wind has been modelled in a single flow direction, for simplicity reasons. Finally, while the logic of DSSb is followed closely in eDSSb, there may be some differences of interpretation to that used by an expert.

Hence, the eDSSb wilding risk maps should be carefully communicated to end users, since the quality of land use information, and that involving the potential conifer seed sources, has considerable impact on the overall risk result. Given time, the variable seed source data can be corrected, but the poor quality of the land use information will not be easy to overcome in the near future.

8. Acknowledgements

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Appendix 1: (DSSb) Calculating risk of wilding tree spread into/within new sites

1). SPECIES PROVIDING SEED SOURCE *(choose one species only)*

Spreading vigour varies with species:

➢ Cypresses, spruces and cedars	0
➢ Radiata (*P. radiata*) and ponderosa (*P. ponderosa*)	1
➢ Muricata (P. *muricata*) and maritime (*P. pinaster*) pine and larches (*Larix* spp)	2
➢ Corsican (*P. nigra*) and mountain/dwarf mountain (*P. uncinata/mugo*) pine	3
➢ Douglas-fir (*Ps. menziesii*), Scots (*P. sylvestris*) and Lodgepole/contorta (*P. contorta*) pine	4

Enter score (0, 1, 2, 3 or 4) here ☐

2). SITING OF SOURCE TREES *

Source trees are on….

➢ Sites well sheltered from prevalent and strong winds	0
➢ Flat sites (<10^0), partially exposed to strong/prevalent winds	1
➢ Lea slopes where strong eddy gusts are likely	2
➢ Flat sites (<10^0), fully exposed to strong/prevalent winds	3
➢ *Either* elevated 'take-off' sites, (ridge-tops, or base of exposed slopes >10^0) *or* undulating land, fully exposed to strong/prevalent winds	4

Enter score (0, 1, 2 or 3) here ☐

3). SITING OF SAMPLE SITE RELATIVE TO SOURCE TREES

Location relative to seed-dispersing winds

➢ Up-wind relative to prevalent or strong winds (If upwind and >1km distant - score 0)	1 (0)
➢ Subject to cross-winds and/or wind-eddies relative to prevalent or strong winds	2
➢ Down-wind relative to prevalent and strong winds (often from N and W)	3

Enter score (0, 1, or 3) here ☐

4). DISTANCE OF SAMPLE SITE FROM SOURCE TREES

➢ Greater than 5km	0
➢ 1-5km	1
➢ 200m – 1km	3
➢ 0-200m	4

Enter score (0, 1, 2 or 4) here ☐

5). VEGETATION OF SAMPLE SITE *(if Douglas-fir involved see ** below)*

➢ *Either* developed pasture, *or* rank grass; closed canopy forest/scrub; *or* tussock/grassland with a continuous, vigorous, permanent vegetation cover	0
➢ *Either* open forest *or* shrub/tussock/grassland with mostly dense vegetation cover	1
➢ Shrubland/tussock/grassland with a moderate vegetation cover	2
➢ *Either* open slips/rockland *or* shrubland/tussock/grassland with a light vegetation cover	3

Enter score (0, 1, 2 or 3) here ☐

6). GRAZING WITHIN SAMPLE AREA

➢ Developed pasture and / or regular mob stocking with sheep ***	0
➢ Semi-improved grazing (sheep/cattle)/ occasional mob stocking with sheep	1
➢ Extensive grazing only ****	2
➢ No grazing	3

Enter score (0, 1, 2 or 3) here ☐

TOTAL SCORE (SUM):* ☐

NOTES:

* Altitude. The coning ability of some species drops off quickly with increasing altitude. Contorta and mountain pine will establish and cone above native treeline. Scots pine and Douglas-fir will establish at tree line. Corsican pine and Douglas-fir coning drops off quickly above 800 and 1100 m respectively – the limit for Scots pine coning is unknown. Radiata pine is a reluctant spreader above 6-700 m, except on the warmer sites. The altitudinal establishment and coning limits for muricata pine and larch are unknown.

* * Douglas-fir. This species is more shade tolerant than the other common conifers. For this species score 2 for open forest *or* shrub/tussock/grassland with mostly dense vegetation cover, or 3 for shrubland/tussock/grassland with a moderate vegetation cover.

** * Regular mob stocking. If the pasture is only semi-improved and the seed rain is heavy, such as alongside mature conifers (particularly Corsican pine – the least palatable conifer), regular mob stocking may not prevent wilding establishment over the long term.

**** Light grazing. This will reduce wilding establishment, but given enough time, some wildings will eventually grow to above browse height. Palatability of introduced conifers is (in decreasing order): radiata > ponderosa > contorta > larch > Scots pine > Douglas fir > Corsican pine.

Larger sources of seed are likely to lead to a greater density of seedlings.

ASSESSMENT

A score of **14** or more indicates a high risk of invasion by the assessed species onto the sample area. But a high risk is unlikely where any one category scores a '0' , especially in 1), 5) or 6)

A high risk does not necessarily mean that the area will inevitably succumb to wilding trees. A commitment to wilding removal can be made, possibly involving the owner of the source trees. Providing it is timely (before wildings cone and produce seed), this commitment need not necessarily be onerous.

Note: this appendix documenting DSSb is reproduced from the following reference:

Ledgard NJ. 2008. Assessing risk of wilding spread. Accepted for: *New Zealand Plant Protection Society Conference*, August, Paihia, New Zealand, 8 pp.

Appendix 2: LCDB-2 Class Descriptions

First-order class	Class	Class description
Artificial surfaces	1	Built-up Area
	2	Urban Parkland/Open Space
	3	Surface Mine
	4	Dump
	5	Transport Infrastructure
Bare or lightly vegetated surfaces	10	Coastal Sand and Gravel
	11	River and Lakeshore Gravel and Rock
	12	Landslide
	13	Alpine Gravel and Rock
	14	Permanent Snow and ice
	15	Alpine Grass-/Herbfield
Water bodies	20	Lake and Pond
	21	River
	22	Estuarine Open Water
Cropland	30	Short-rotation Cropland
	31	Vineyard
	32	Orchard and Other Perennial Crops
Grassland	40	High Producing Exotic Grassland
	41	Low Producing Grassland
	43	Tall Tussock Grassland
	44	Depleted Grassland
	45	Herbaceous Freshwater Vegetation
Sedgeland saltmarsh	46	Herbaceous Saline Vegetation
	47	Flaxland
Scrub and shrubland	50	Fernland
	51	Gorse and or Broom
	52	Manuka and or Kanuka
	53	Matagouri
	54	Broadleaved Indigenous Hardwoods
	55	Sub Alpine Shrubland
	56	Mixed Exotic Shrubland
	57	Grey Scrub
Forest	60	Minor Shelterbelts
	61	Major Shelterbelts
	62	Afforestation (not imaged)
	63	Afforestation (imaged, post LCDB 1)
	64	Forest - Harvested
	65	Pine Forest - Open Canopy
	66	Pine Forest - Closed Canopy
	67	Other Exotic Forest
	68	Deciduous Hardwoods
	69	Indigenous Forest
	70	Mangrove