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Technical Report

TR-07-2008 R

Development of a GIS model for predicting outdoor marijuana cultivation in Southern British Columbia

Executive Summary

March 2008

Project Manager:

Sgt. Rick Parent PhD
Justice Institute of British Columbia

For the
Canadian Police Research Centre

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Final Report: Development of a GIS model for predicting outdoor marijuana cultivation in Southern British Columbia

Report: 1515-07-JU/456

Project Manager:
Sgt. Rick Parent PhD
Justice Institute of British Columbia

Executive summary

There are numerous undetected outdoor marijuana growing sites in Southern British Columbia. Traditionally airborne surveillance has been used to detect sites on an *ad hoc* basis. Airborne surveillance whilst very effective when executed by trained spotters is expensive. Moreover, it requires dedicated helicopters and is constrained logistically by the vast territory involved. A recent study conducted by Titan Analysis strongly suggests that three sites are undetected for every site positively identified. The estimated value of known outdoor marijuana sites ranges from M$ 138.5 – 296.7 (wholesale) for the Vancouver Island-Gulf Islands-Coastal region; M$ 17.9 (11.4 – 24.4) (wholesale)for the Harrison-Chilliwack-Abbotsford region; M$ 86.8 – 186.0 (wholesale) for the Okanagan region. Potentially undetected sites are estimated at three times those amounts. The purpose of the present study was to develop a new methodology that predicts possible growing sites based on complex criteria developed from known sites. It uses a methodology called Multi-criteria Evaluation that models multiple factors and constraints in a geographic information systems (GIS) environment. In addition, we have run a Bayesian analysis as a validation technique. Bayesian analysis is a sophisticated form of artificial intelligence that is increasingly used in fields as diverse as medical diagnostics, epidemiology, ecology, and forestry.

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1. Summary of previously completed work

Data integration summary

A major portion of this study consisted of data preparation – details of which were presented in reports #1515-07-JU/456 and #633348b delivered on March 31st. To summarize, there is no existing digital geographical dataset describing British Columbia. This project integrated multiple segments of BC TRIM data in order to create a contiguous map with several different layers (variables) across the three areas of analysis.

Hours of sunshine summary

This project developed this variable (hours of sunshine) as an extra deliverable when research (see report #633348a) revealed its importance in detecting areas of possible cultivation. We investigated a number of methodologies and ultimately developed a unique algorithm taking into account various elements of the methodologies we examined to determine hours of sunshine in British Columbia on August 15th. The details and background for this exercise are contained in the preliminary reports #1515-07-JU/456, #633348a and #633348b.

2. Objectives

The main objectives of study were 1) to develop a predictive model for marijuana cultivation in Southern British Columbia that can potentially be used for selecting remotely sensed imagery and choice of flight paths for surveillance purposes and 2) estimate the associated potential crop value in the province. The three regions considered were the Harrison-Chilliwack-Abbotsford region (7,716 km^2), Vancouver Island-Gulf Islands-Coastal region (39,205 km^2) and the Okanagan region (36,601 km^2).

3. Multi-criteria evaluation: identifying suitable sites

Multi-Criteria Evaluation (MCE) is a decision framework that employs multiple synergestic qualitative and quantitative factors in order to locate spatial phenomena. It incorporates multiple criteria in order to derive a *suitability index* for location of a spatial entity (e.g. marijuana grow-op). The first step in MCE is to define the problem and relevant factors and criteria. Then, each criterion is scored depending on its relevance to the spatial solution. The scoring remains a subjective process; its strength is in the ability to use scoring criteria commensurate with the goals of the analysis and changing conditions. This enables analysts to tweak the model when, for instance, growers change their patterns or preferences in order to conceal the locations of the plants (e.g. start to use new vegetative sites at higher elevations or in more remote locations).

Factors are those influences that affect the location but do not determine it. A constraint is a stricter criterion. For instance, a site that did not have any water supply would be eliminated as a candidate. After the weighting is determined, a *composite index of suitability* is developed and used to locate the possible growing sites. The factors and constraints for this project were selected based on known geographical influences on crop viability (see report #633348b) as well as a study of characteristics of known sites.

The performance of the model was evaluated by examining its performance with known sites. We also validated the results of MCE independently with a Bayesian Network. A Bayesian Network is a model that merges graph and probability theory to characterize suspected relations between variables. The networks provide a means of modeling complex problems because they combine the robustness of probabilistic methods with the expressiveness of graphs to encode relationships between variables and offer a framework for handling uncertainty and complexity in decision-support systems within a single model. By comparing the Bayesian Network with the MCE, the deliverable is a more robust prediction model – that supersedes the thoroughness of previous studies.

This predication model described below will enable rationalization of flight-time surveillance and imagery purchase. Moreover, it will enable policy makers to recognize potential growing sites and to understand the extent of viable cropland in the province – with associated potential crop value.

Development of the MCE model

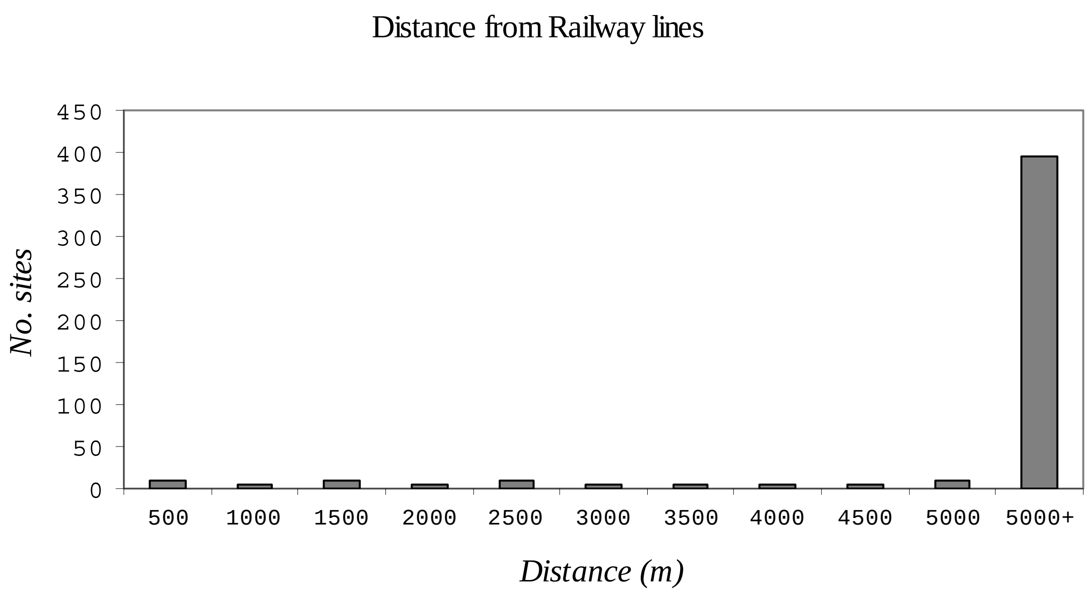
The potential criteria considered for the model were:

- Distance from railway lines
- Distance from roads

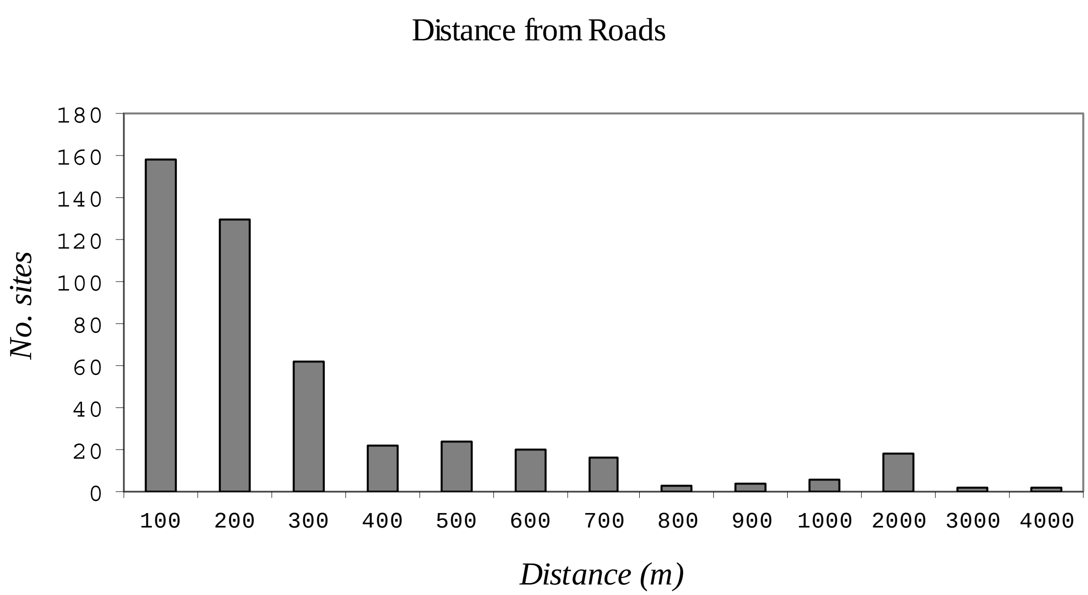
- Distance from salt water (i.e. Pacific Ocean, inlets, straights, etc.)
- Elevation
- Slope
- Aspect
- Sunlight hours for August 15th
- Distance from minor water source (e.g. smaller lakes, rivers, creeks)
- Distance from major fresh water (e.g. major lakes or rivers)
- Landuse (e.g. Forest, recently cleared, urban, glacier/snow, etc.)

Histograms (i.e. graphs showing frequency) of the approximately 450 known sites (from previous years) were produced to determine the variation of these values at known sites from the Vancouver Island-Gulf Island-Coastal and Harrison/Chilliwack/Abbotsford regions (Figure 1a-l).

a)

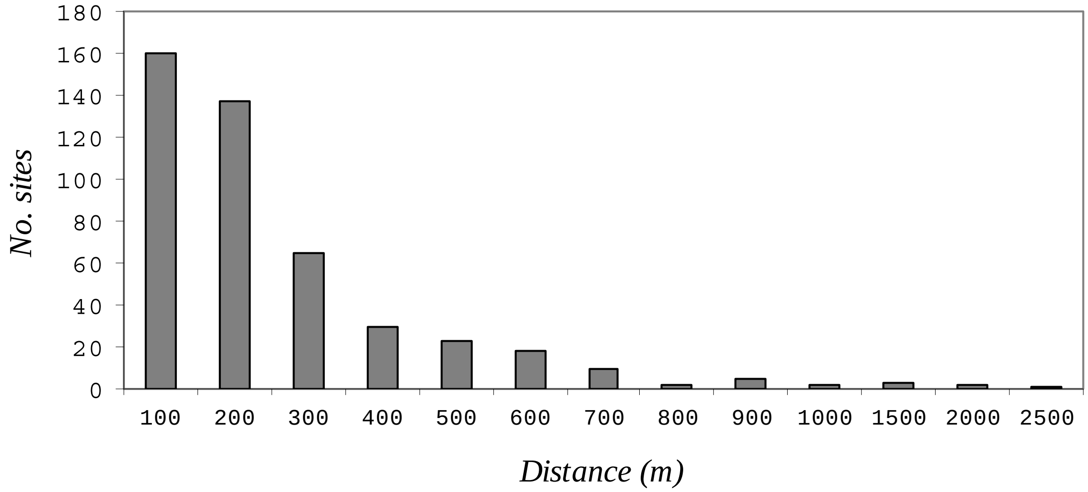


b)



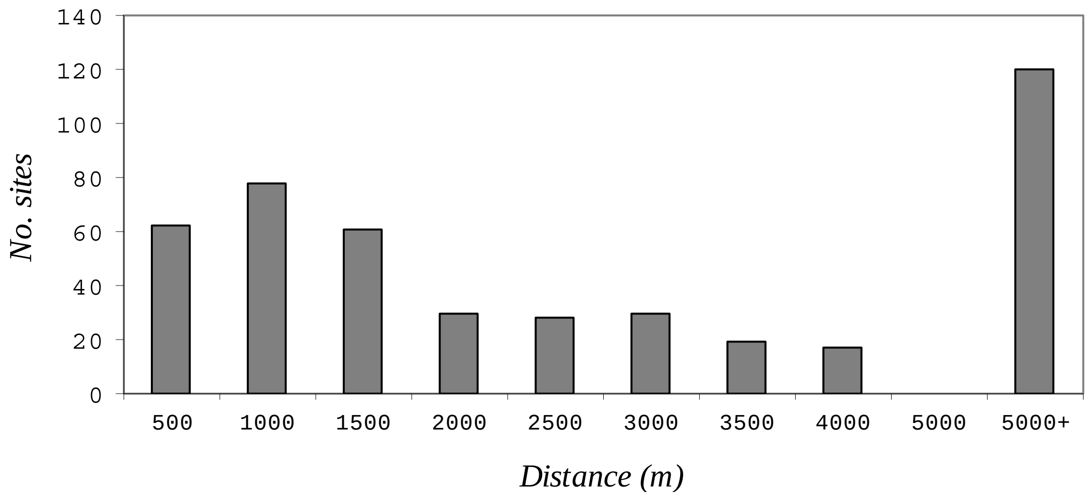
Distance from Salt Water or Roads

c)



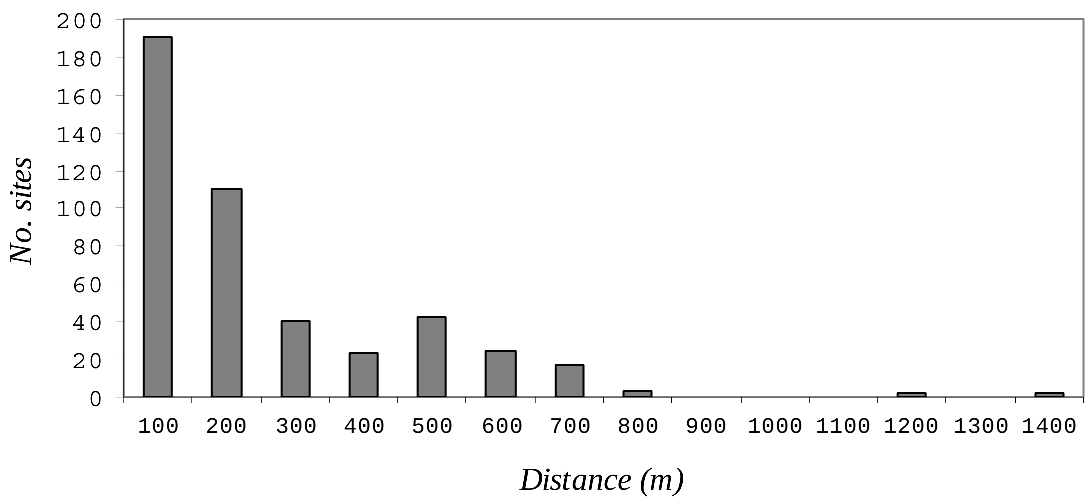
Distance from Salt Water

d)



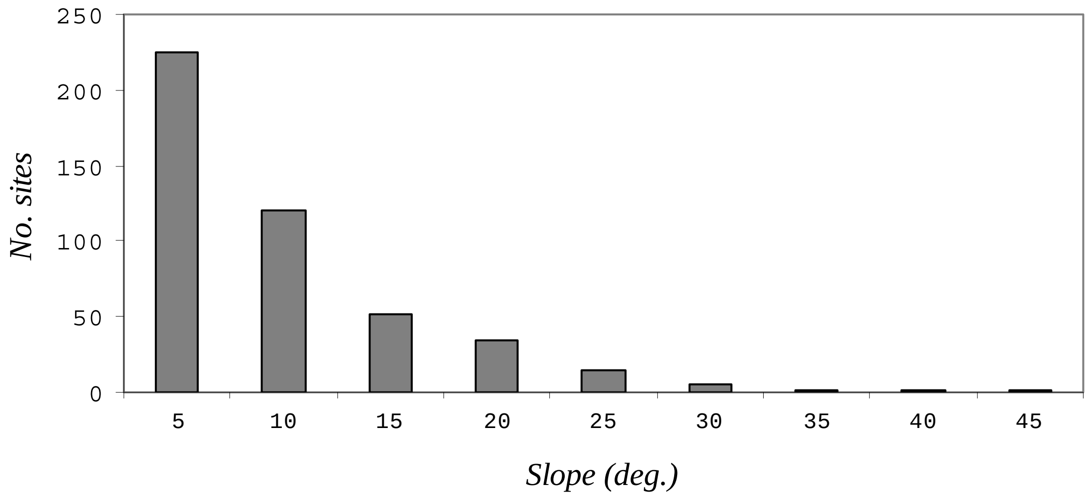
Elevation

e)



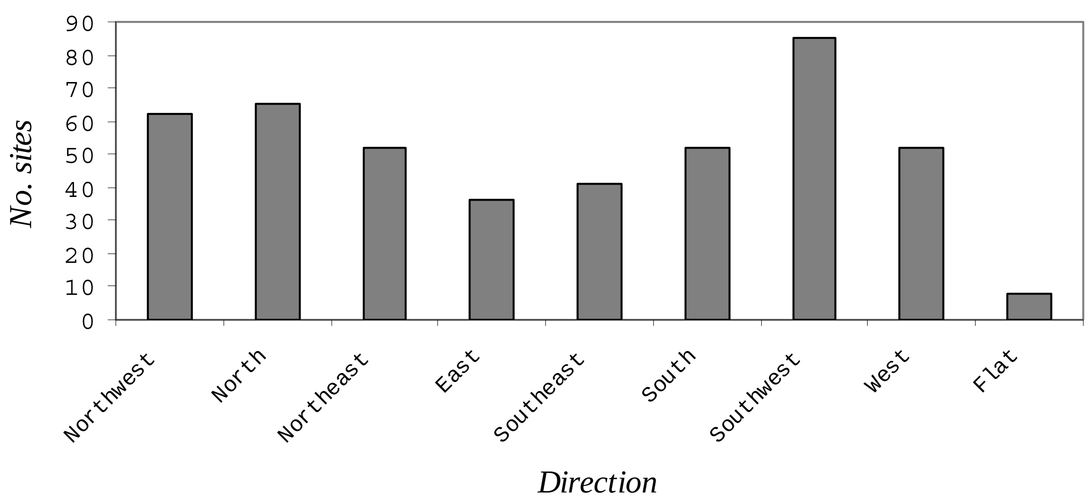
Slope

f)



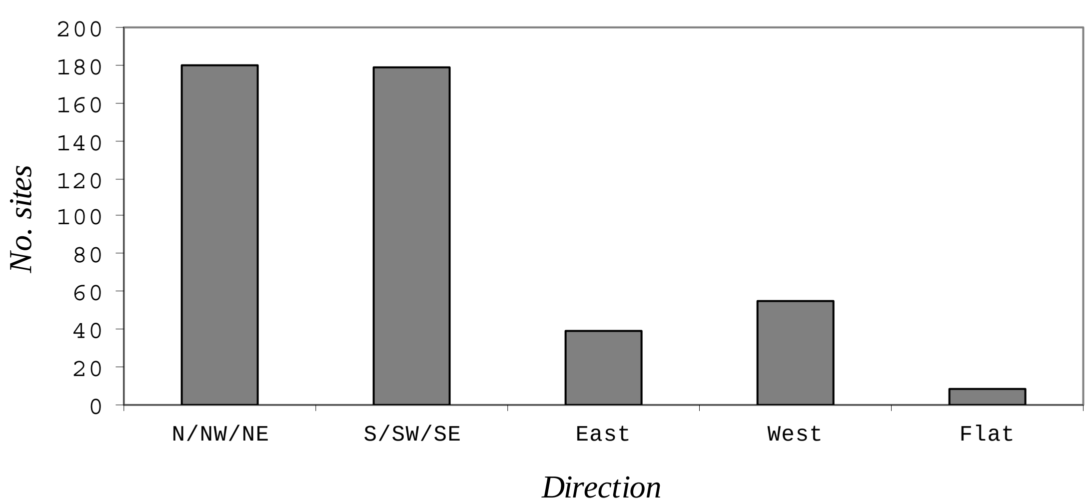
Aspect

g)



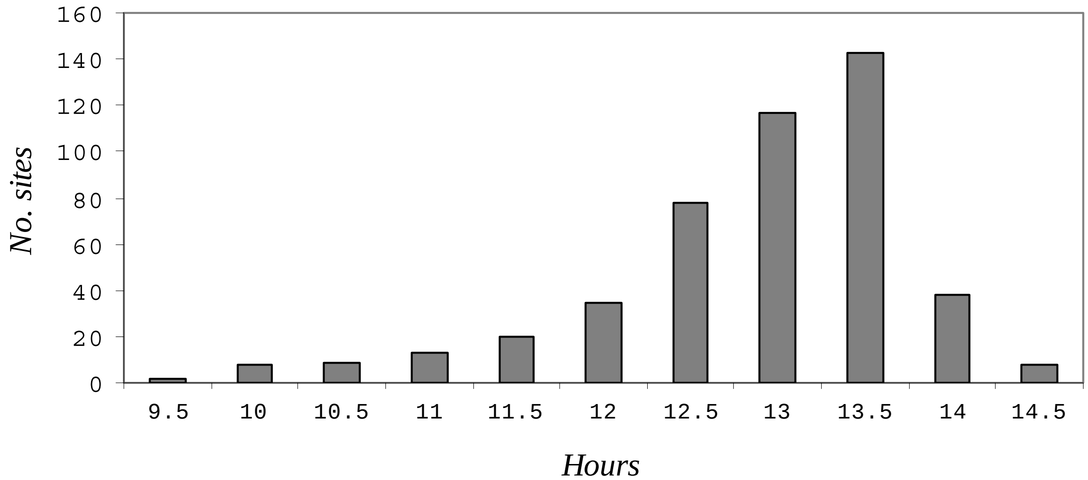
Generalized Aspect

h)



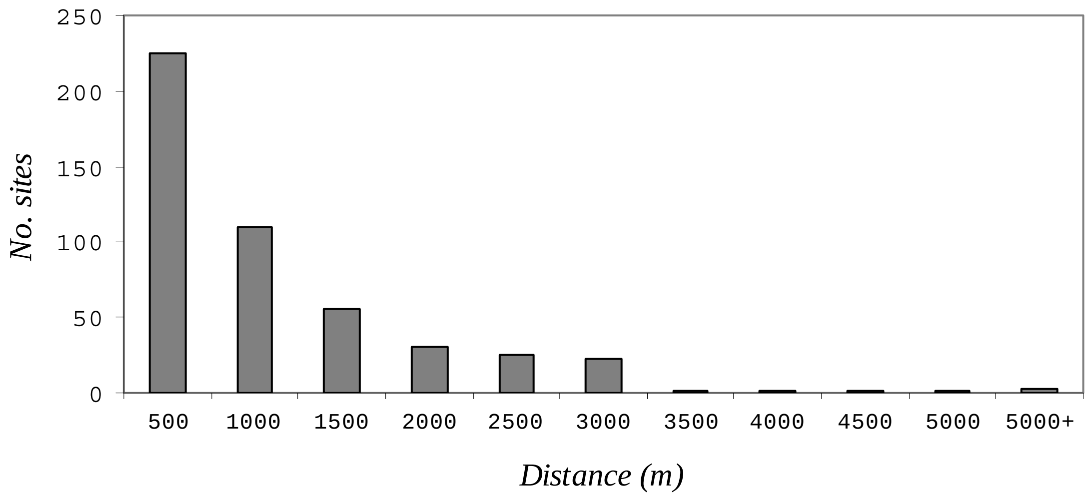
Sunlight Hours (Aug. 15th)

i)



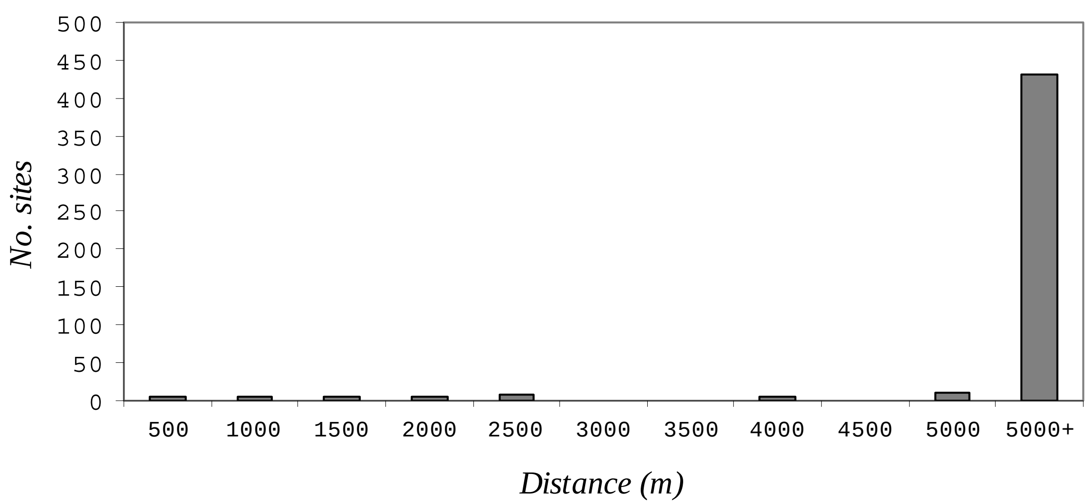
Distance from Minor Water Source

j)



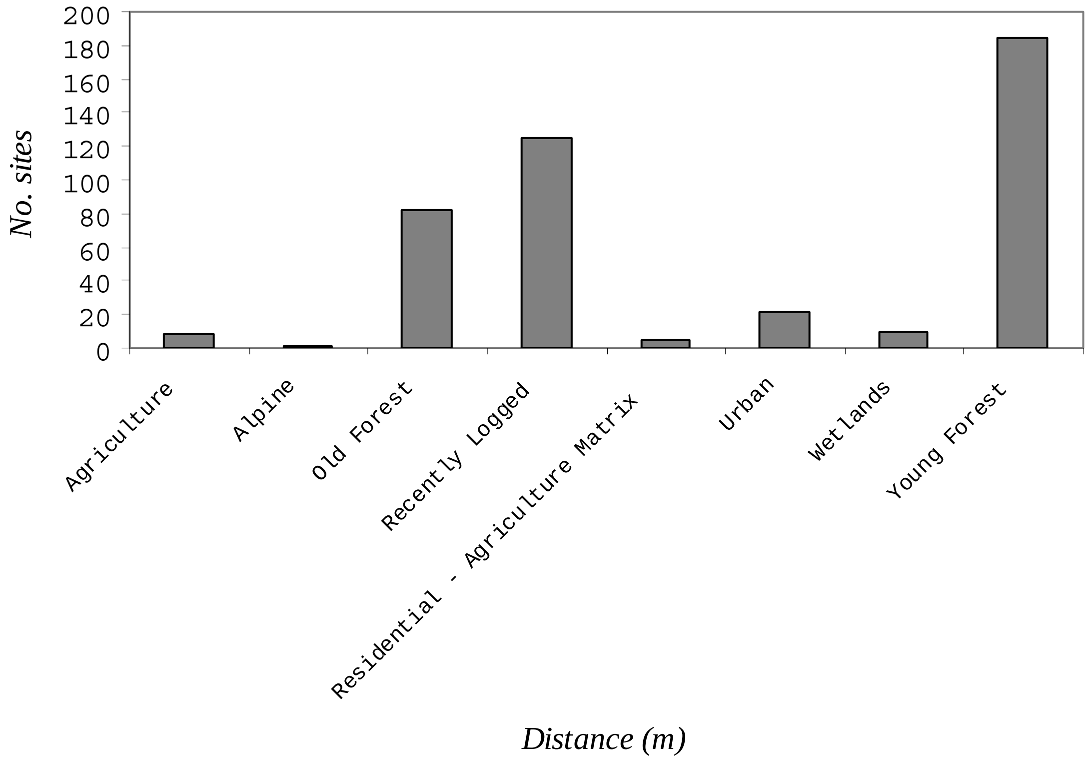
Distance from Major Lakes/Rivers

k)



Landuse

l)



Trends in locations of known sites

From the histograms (Figure 1), and their general scarcity in overall landscape it was inferred that railways do not affect suitability (Figure 1a). Known sites seem to be located preferentially farther from major fresh water sources such as large lakes and rivers (Figure 1k) but close to large salt water bodies (e.g. inlets, bays, etc.) (Figure 1d), therefore, it was assumed that these large salt water bodies may be used as a method of transport. Thus, it was decided to combine road and salt water distance together to describe the ease of transport criterion (Figure 1c).

Lower elevations seemed to be preferred with no known sites found above 1400 meters (Figure 1e). This could be due to ease of access, warmer temperatures and gentler slopes at lower elevations. All sites were located on slopes of 0 to 45 degrees with most sites between 0 and 5 degrees; site frequency decreases with increases in slope (Figure 1f).

Aspect varied among sites; east appears to be the least popular choice (Figure 1g). If northeast, north and northwest frequencies are summed the total is 180. Doing likewise for southeast, south and southwest, yields a sum of 178. So, the average value for these 6 octants is about 60. Since west has a frequency of 53 and east has one of 37, it was inferred that northeast, north, northwest, southeast, south and southwest are considered most suitable, followed by west and then east (Figures 1g,h).

Most sites were found to receive 13.5 hours of sunlight on August 15th. The amount of sites decreased as the hours decreased to 9.5. No site had less than 9.5 hours of sunlight. Few sites were found to receive 14 or more hours of sunlight (Figure 1i). This may be because areas with over 14 hours are infrequent due to BC's undulating terrain and/or because exposing the plants to excessive sunlight can cause the plants to enter a vegetative state in which they do not flower.

Most sites were near a minor water source (e.g. smaller lakes, rivers, creeks) (Figure 1j) but tended to shy away from major water sources (Figure 1k). Site frequency decreased with distance from a minor water source (Figure 1j). The favored landuse was Young Forest, followed by Recently Logged and Old Forest. A few sites were found in other landuse areas (Figure 1l).

Standardizing the criteria

Raster maps were created for each criterion which showed the variation in each criterion over the areas of interest. For each raster, the values were reclassified to values between 10 and 0, where 10 represents the highest level of suitability and 0 represents no suitability. Suitability values for each criterion were derived from the trends seen in the histograms.

4. The Criteria

Criterion 1: Distance from roads or salt water

Surfaces representing the distance from roads were created for the three regions. A straight line distance function was used with a maximum search radius of 2,500 m. For the Vancouver Island area only, a surface representing the distance to salt water features was also created using the same method. The final distance surface consisted of the maximum value (i.e. either to road or salt water) reclassified according to the scheme in Table 1.

Table 1. Suitability scores for the ease of access criterion

Distance from road or salt water (meters)	Suitability value
0 – 200	10
200 – 300	8
300 – 500	6
500 – 600	5
600 – 700	4
700 – 2500	2
> 2500	0

Criterion 2: Elevation

To create the standardized elevation rasters, the digital elevation surface for each area was reclassified according to Table 2.

Table 2. Suitability scores for elevation

Elevation (meters)	Suitability value
0 – 100	10
100 – 200	8
200 – 500	6
500 – 700	4
700 – 1400	2
> 1400	0

Criterion 3: Slope

Slope was derived from the digital elevation surface and reclassified according to Table 3.

Table 3. Suitability scores for slope

Slope (degrees)	**Suitability value**
0 – 5	10
5 - 10	8
10 - 15	6
15 - 20	4
20 - 45	2
> 45	0

Criterion 4: Aspect

Aspect was derived from the digital elevation surface and reclassified according to Table 4.

Table 4. Suitability scores for aspect

Aspect (degrees)	**Suitability value**
- 1 (flat)	8
0 – 67.5 (north)	10
292.5 – 360 (north)	10
112.5 – 247.5 (south)	10
247.5 – 292.5 (west)	8
67.5 – 112.5 (east)	6

Criterion 5: Hours of Sunshine

The hours of sunshine surfaces were created by summing half hour incremental hillshade rasters produced from the digital elevation surfaces (see report #1515-07-JU/456). The reclassification of the standardized hours of sunshine rasters were done according to Table 5.

Table 5. Suitability scores for hours of sunshine

Sun hours August 15	Suitability value
< 9.5	0
9.5	2
10	4
10.5	6
11 - 12	8
12.5 – 13.5	10
14 – 14.5	8

Criterion 6: Distance to minor water features

The distance to minor water features (e.g. small rivers and creeks) distance was created using a straight line distance function. The reclassification scheme of this criterion is according to Table 6.

Table 6. Suitability scores for the distance to minor water features criterion

Distance from minor water (meters)	Suitability value
0 – 500	10
500 – 1000	8
1000 - 1500	6
1500 – 3000	4
> 3000	2

Criterion 7: Distance to major fresh water features

As for the other distance surfaces, a straight line function was used to calculate this surface. The resultant rasters were reclassified according to the scheme in Table 7.

Table 7. Suitability scores for the distance to major fresh water features criterion

Distance from major fresh water (meters)	Suitability value
0 - 5000	4
> 5000	10

Criterion 8: Landuse

The landuse polygon shapefile was converted to a raster and reclassified according to the scheme in Table 8.

Table 8. Suitability scores for various types of land use

Landuse	Suitability value
Young Forest	10
Recently Logged	9
Old Forest	8
Urban	6
Wetland	4
Agriculture	4
Residential Agriculture Mixtures	4
Alpine	2
All other types	0

Weights

The following weights were assigned to each criterion:

Very important criteria:
- Distance to roads or salt water features
- Hours of sunshine

Important criteria:
- Slope
- Distance to minor water features
- Landuse

Somewhat important criteria:
- Elevation

Small importance criteria:
- Aspect

Very small importance criteria:
- Distance to major fresh water features

Constraint surfaces

Two rasters for each area (i.e. one for minor and major water features respectively) were created to specify that water is not a suitable area for growth (i.e. a constraint).

5. Results and discussion

We generated three suitability maps for outdoor marijuana cultivation covering the three regions of interest. Three additional maps were generated (one for each region) representing the most suitable areas where growers could achieve a second harvest. The methodology was successful in that we were able to identify precise locations where optimal growing conditions exist. Table 9 illustrates the total area of each region per suitability class.

Table 9. Total suitable area for outdoor marijuana cultivation for each region

Area	**Area of optimally suitable land (%)**	**Area of suitable land (%)**	**Area of marginally suitable land (%)**	**Total (%)**
Harrison-Chilliwack – Abbotsford	9	28	34	81
Vancouver Island and surroundings	26	38	25	89
Okanagan	19	52	24	95

Harrison-Chilliwack-Abbotsford

This area is proximate to the metropolis of Vancouver and spans the cities of Abbotsford and Chilliwack as well as the US border. The map below (Figure 2) illustrates its main features and road networks.

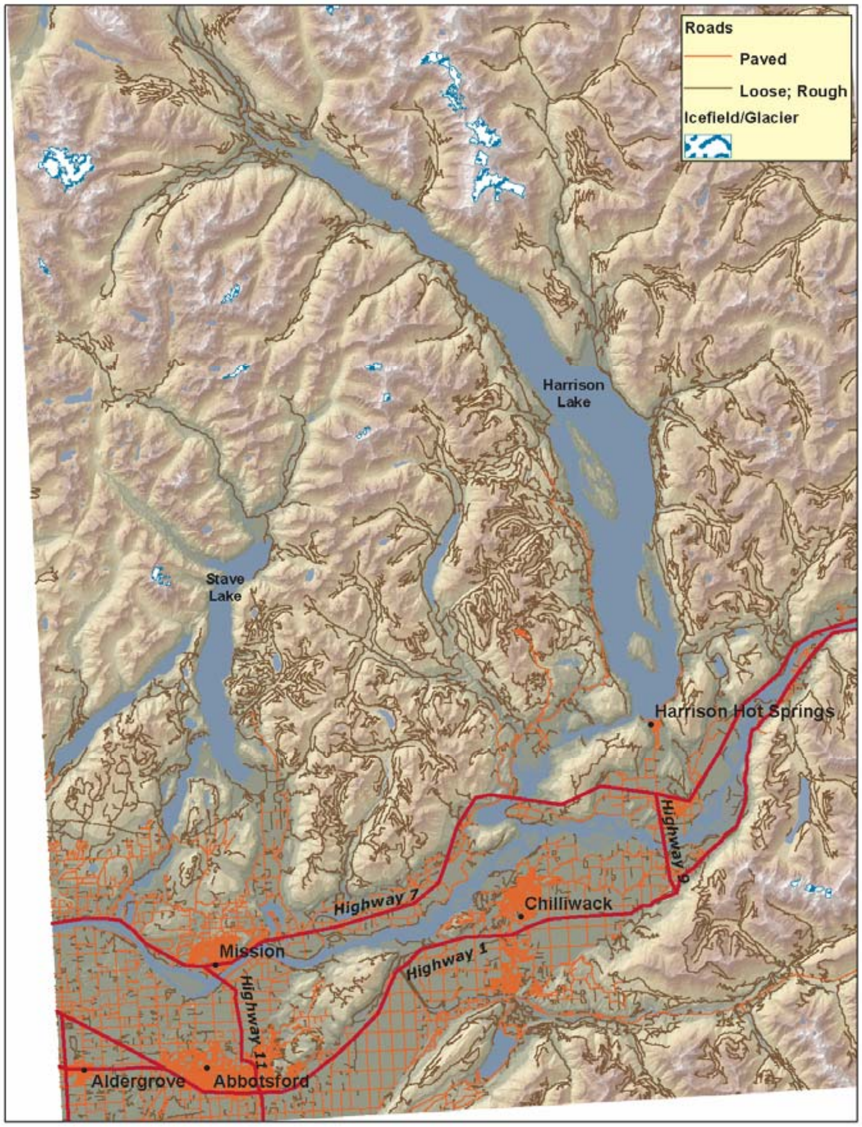


Figure 2. Main features of the Harrison-Chilliwack-Abbotsford region.

Areas of optimal suitability include the southwestern quadrant of the region, along the Fraser River and in discrete pockets throughout the landscape as shown in Figure 3.

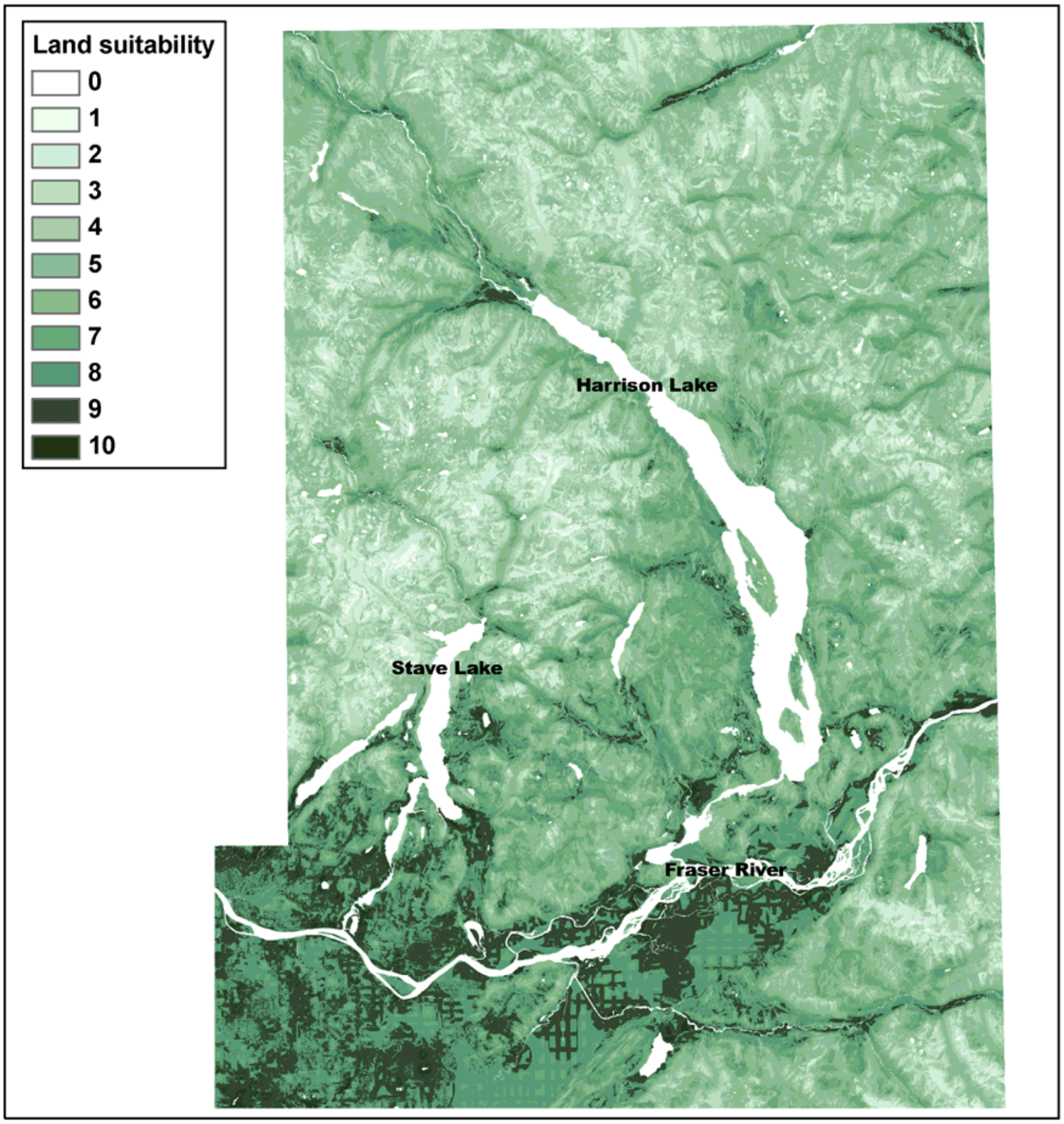


Figure 3. Suitability map for the Harrison-Chilliwack-Abbotsford region based on the eight criteria described above. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

Vancouver Island and surrounding Gulf Islands

Vancouver Island comprises a large relatively isolated land mass and is surrounded by a number of smaller Gulf Islands. Vast tracts of land are undeveloped and thus represent relatively isolated potential growing sites.

Areas of suitability are depicted below in Figure 4. It is clear that the eastern coast and smaller Gulf Islands are potentially the most suitable sites though pockets of high suitability exist in the southwestern coastal region.

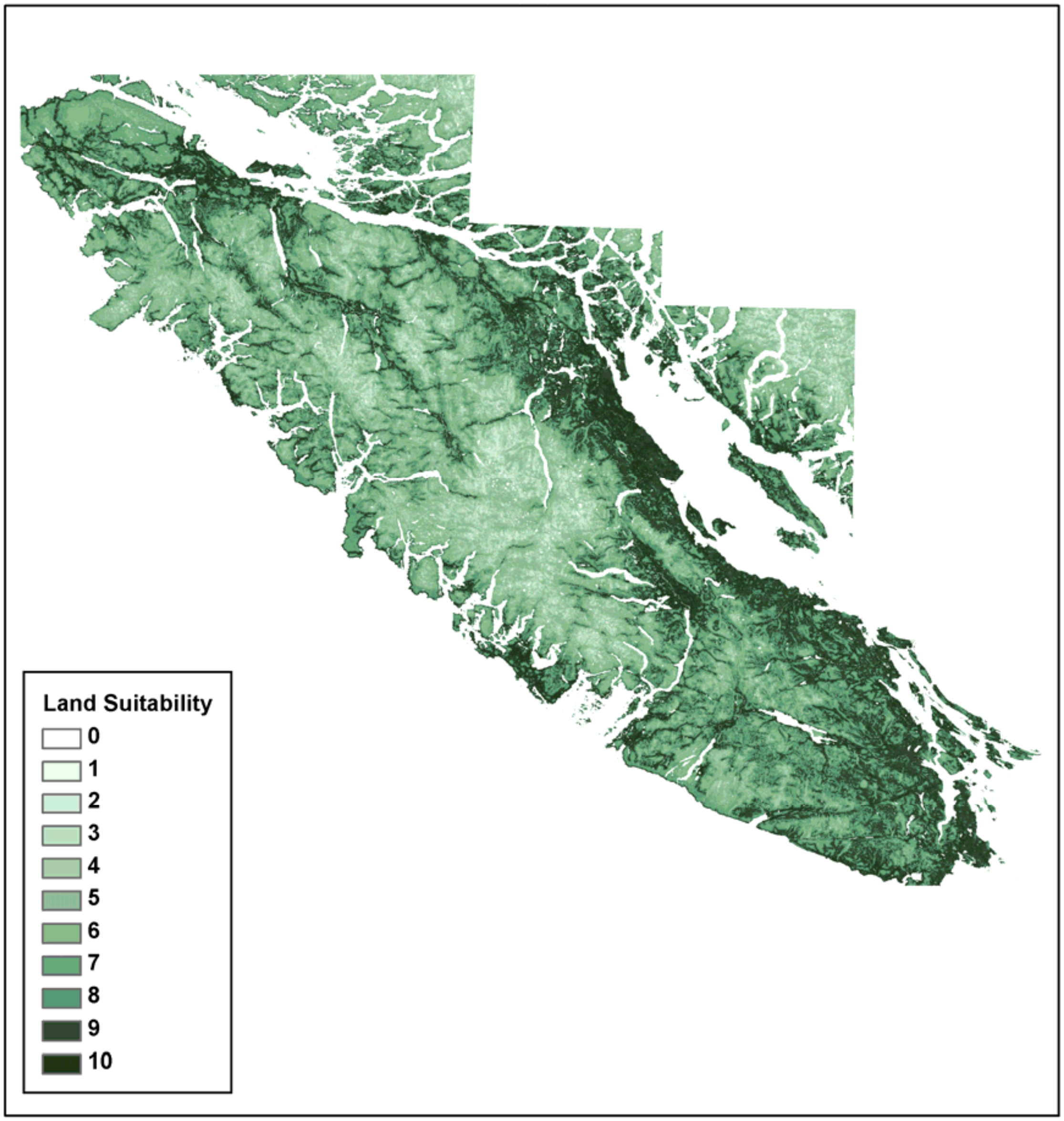


Figure 4. Suitability map for Vancouver Island, the Gulf Islands and the west coast based on the eight criteria described above. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

Interior region (Okanagan)

The Okanagan Valley is one of the most fertile agricultural areas in Canada. Its long growing season and many hours of sunlight make it attractive to farmers of all types.

Farming in the region is hindered, however, by relative drought conditions and accessibility to water is a key factor in this area. Figure 5 illustrates the most suitable areas for cultivation.

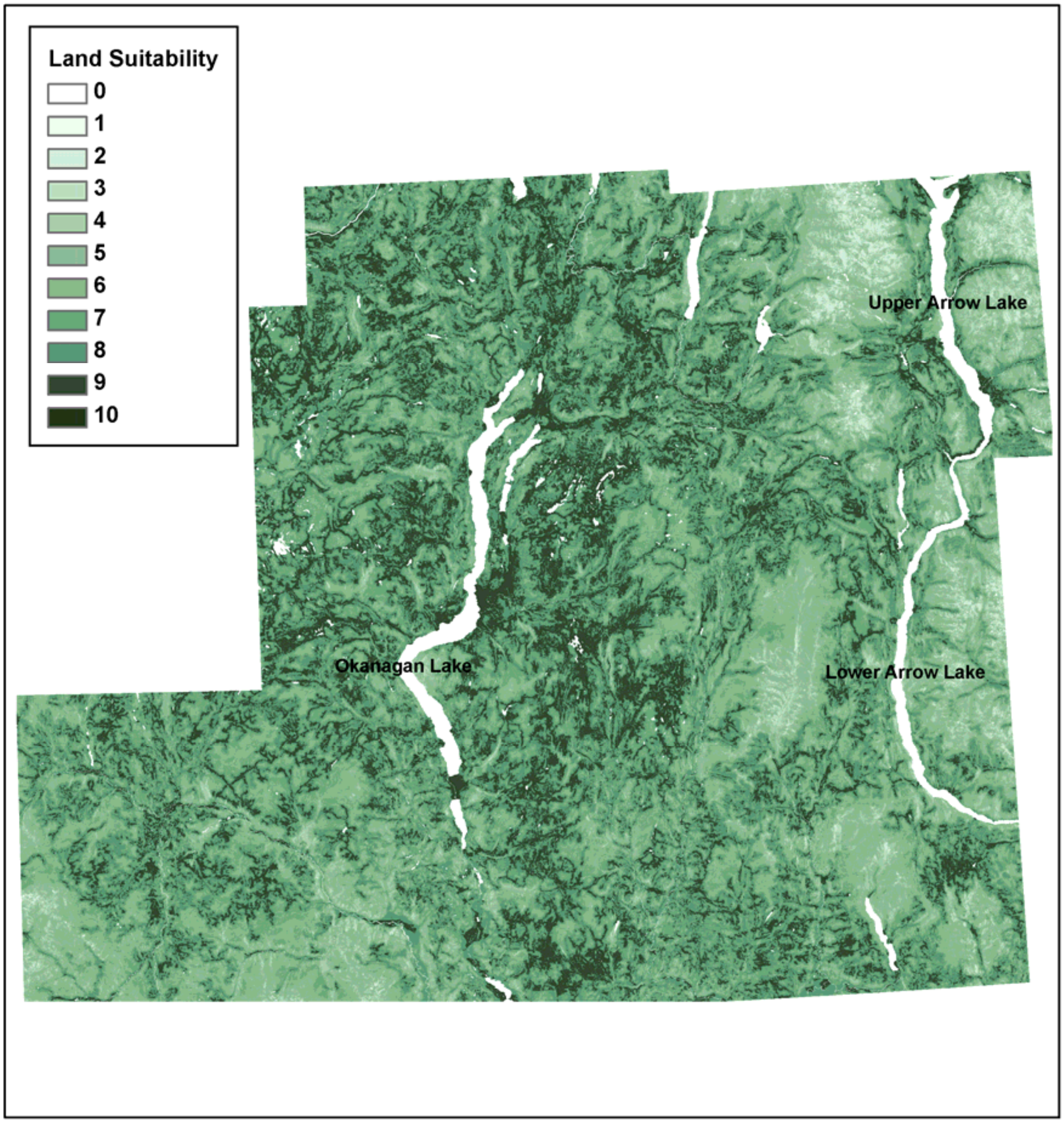


Figure 5. Suitability map for the Okanagan region based on the eight criteria described above. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

The suitability map above (Figure 5) illustrates the importance of access to water. Indeed the optimal growing areas are strewn throughout the region following the hydrological features. Whilst major lakes (e.g. Okanagan Lake) might be considered optimal cultivation sites, they are excluded in many cases because of their proximity to urban centres and tourist attractions.

Areas suitable for a second harvest

When the criteria were constrained based on the illumination conditions necessary to achieve a second harvest the suitable areas decreased substantially for each area (Table 10). Half of the known sites located in optimal areas would be able to sustain a second harvest (Table 11). Similarly, 57-77% of the known sites are located in suitable and 50-100% of known sites from marginally suitable areas would be able to sustain a second harvest (Table 11). Figures 6-8 illustrate the second harvest suitability maps for the three regions.

Table 10. Area suitable for a second harvest.

Area	Area optimally suited for second harvest (%)	Area suited for second harvest (%)	Area marginally suited for second harvest (%)	Total (%)
Harrison-Chilliwack-Abbotsford	5	33	26	64
Vancouver Island and surroundings	16	30	19	65
Okanagan	13	40	19	72

Table 11. Percentage of known sites capable of sustaining a second harvest for each suitability class.

Suitability	Suitability class	No. of known sites	Percentage of total known sites
Optimal	10	28	50
	9	139	56
Suitable	8	58	57
	7	20	77
Marginal	6	5	100
	5	1	50
Unsuitable	0-4	0	0

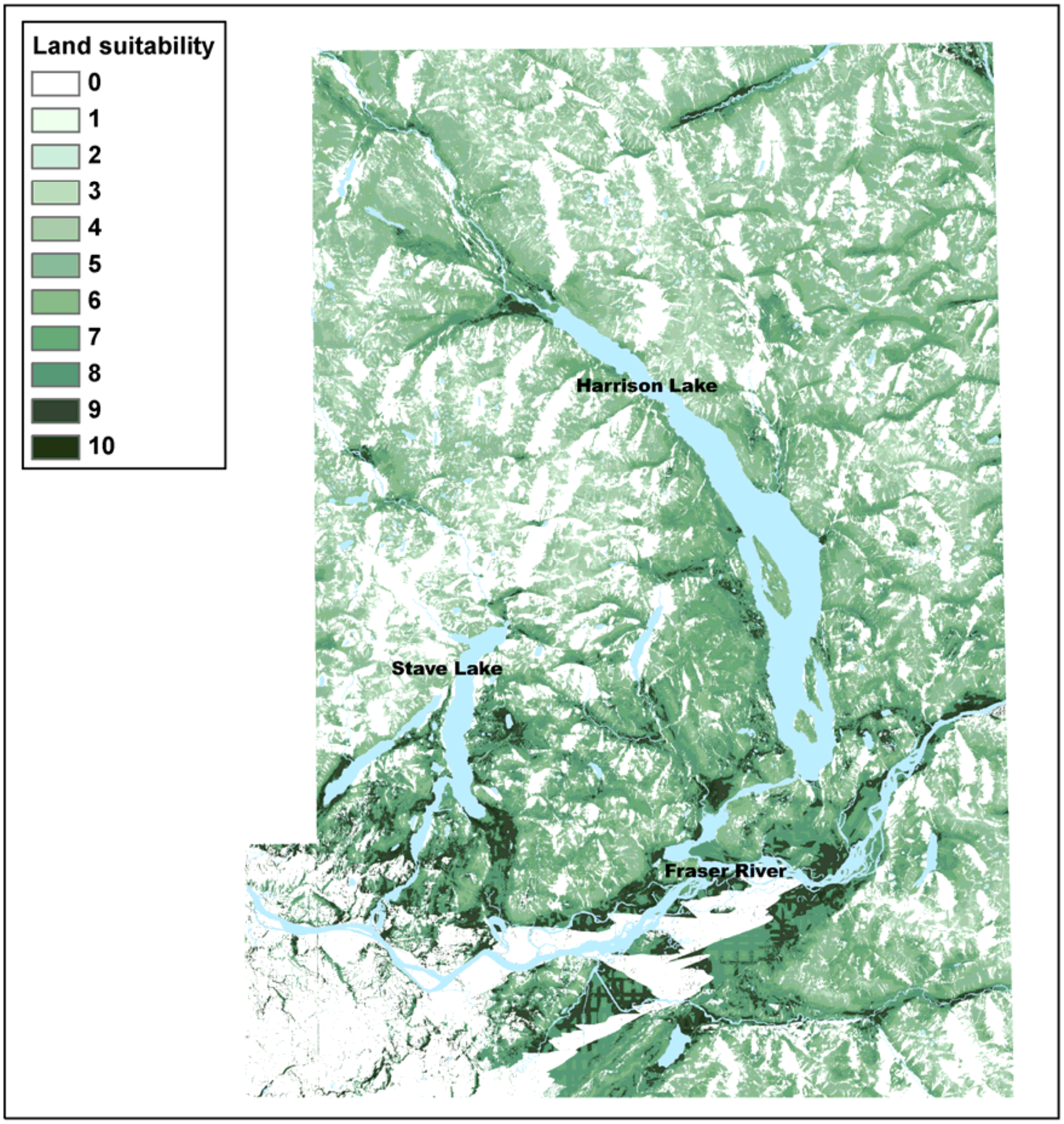


Figure 6. Suitability map for a second harvest in the Harrison-Chilliwack-Abbotsford region. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

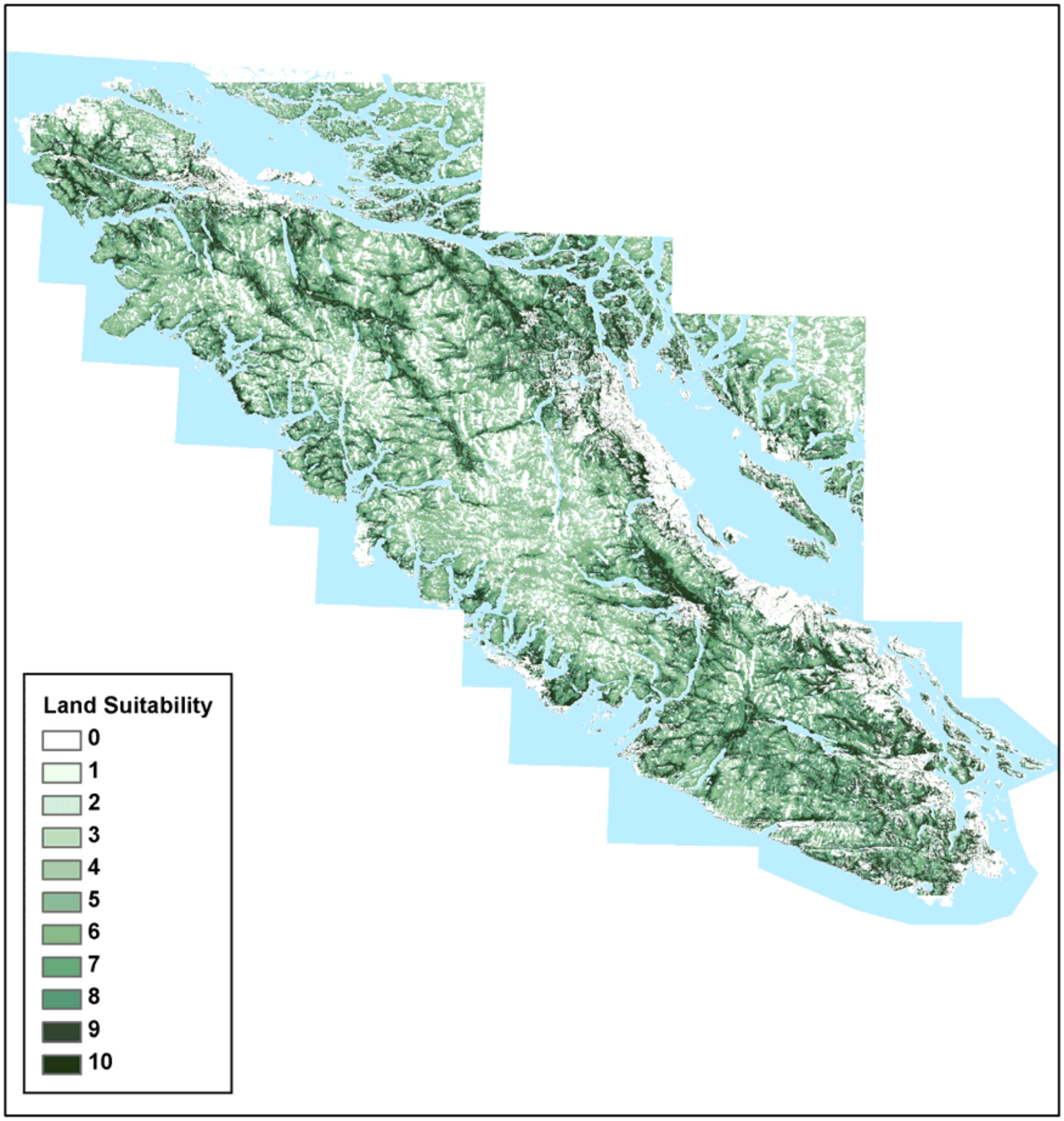


Figure 7. Suitability map for a second harvest in the Vancouver Island, Gulf Islands and coastal region. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

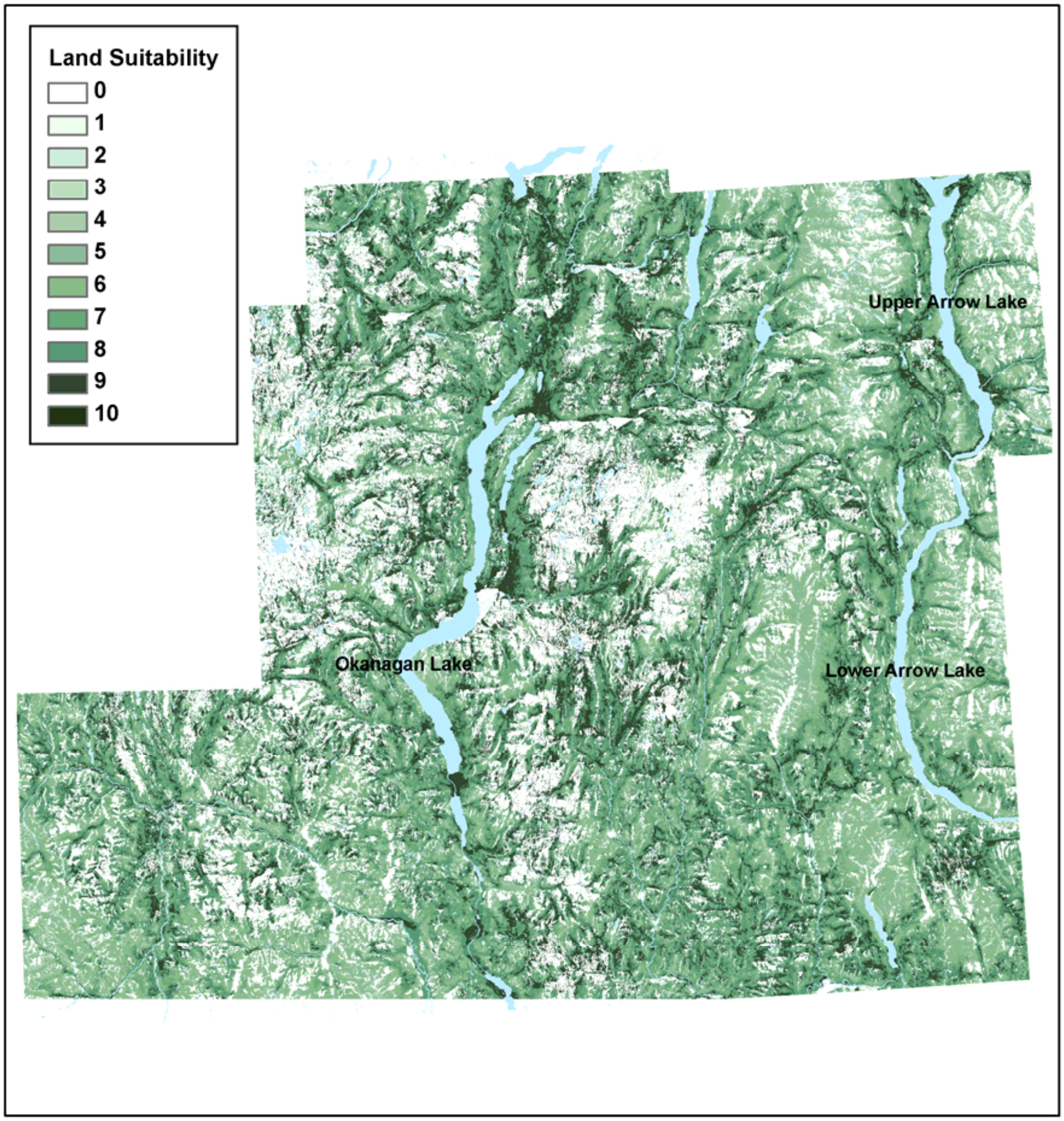


Figure 8. Suitability map for a second harvest in the Okanagan region. Values of 9 and 10 represent optimal regions, 7 and 8 represent suitable regions, 5 and 6 represent marginally suitable regions. Values of 0-4 are not suitable for outdoor marijuana cultivation.

Validation

Because the database of historically known sites is predominantly from the Vancouver Island-Gulf Islands-Coastal region, validation was performed for that region. When the known sites were overlain on the suitability map, 69% were located in the optimal areas and 29% were located in suitable areas for a combined total of 98% (Table 12). The remaining 2% of the historically known sites were located in the marginally suitable class. No known historical points were located in unsuitable areas (Table 12).

Table 12. Distribution of known site per suitability class

Suitability	Suitability class	No. of known sites	Percentage of known sites
Optimal	10	56	13
	9	249	57
Suitable	8	102	23
	7	26	6
Marginal	6	5	1.5
	5	2	0.5
Unsuitable	0-4	0	0

As a second independent analysis of the suitability model with the known historical sites we examined the patterns of the outdoor cultivation with a Bayesian Network (Figure 9).

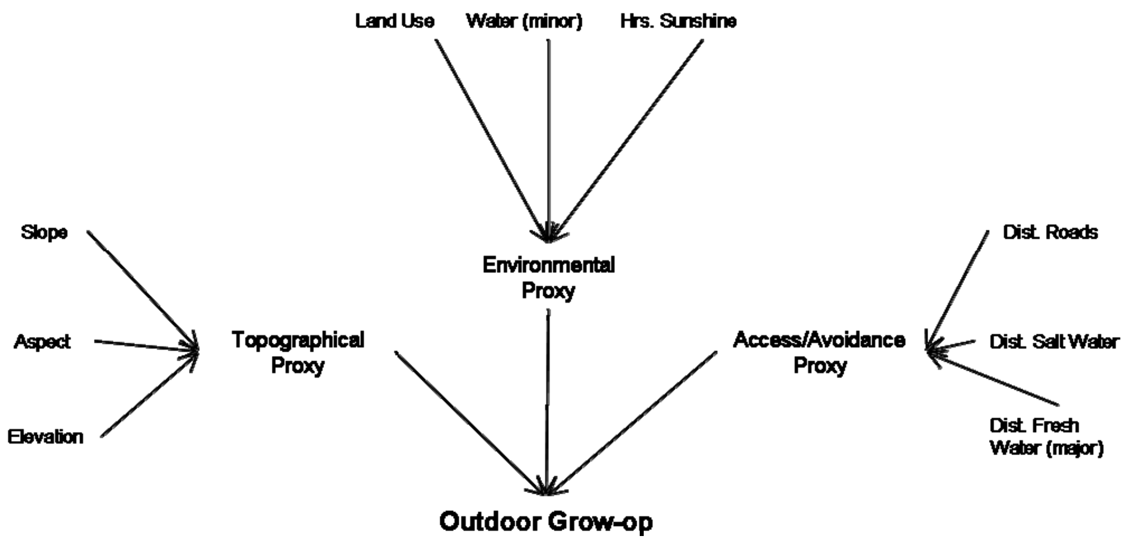


Figure 9. Topology of the Bayesian Network constructed to verify the results from the MCE analysis for the Vancouver Island region.

The nine base variables constitute the observed nodes and are the parents of three unobserved (latent) proxy nodes (topographical, environmental and access/avoidance). The three proxy nodes in turn are the parental nodes of the variable/node of interest: the presence/absence of an outdoor grow-op. The results for the Vancouver Island region indicate a 1.18% overestimation of suitable areas.

Total street values

Tables 13-15 illustrate the estimated value of the outdoor marijuana for each suitability class. Values were calculated with the assumptions of a planting density of 0.625 plants/m^2 and a total amount of useable product of 400g/plant (see report #633348b). For the Harrison- Chilliwack -Abbotsford and the Okanagan regions, we extrapolated the value from the historical sites from (i.e. No. sites/km^2) under the assumption that the distribution of the sites in the landscape and the distribution of the number of plants per site are similar to the Vancouver Island-Gulf Islands-Coasta region. For all regions, the estimated value represents 3x the calculated value based on the number of sites estimated to be missed by aerial census (#TR-01-2007-E). Values are in millions of dollars (Canadian).

Table 13. Value of *Cannabis* products from outdoor cultivations in the Harrison-Chilliwack-Abbotsford region per suitability class.

Suitability Class	Value ($)	Estimated value ($)
Optimal	9.0 (5.7-12.3) (M)	27.0 (17.2-36.9) (M)
Suitable	7.9 (5.0 – 10.7) (M)	23.7 (15.1 – 32.4) (M)
Marginal	989K (629.5K – 1.3) (M)	2.9M (1.9M – 4) (M)
Total	**17.9 (11.4 – 24.4) (M)**	**53.7 (34.2 – 73.3) (M)**

Table 14. Value of *Cannabis* products from outdoor cultivations in the Vancouver Island-Gulf Islands-Coastal region per suitability class.

Suitability Class	Value (M$)	Estimated value (M$)
Optimal	150.8 (96.0-205.7)	452.4 (288.0 – 617.1)
Suitable	63.3 (40.3 – 86.3)	189.9 (120.9 – 258.9)
Marginal	3.5 (2.2 – 4.7)	10.5 (6.6 – 14.1)
Total	**217.6 (138.5 – 296.7)**	**652.8 (415.5 – 890.1)**

Table 15. Value of *Cannabis* products from outdoor cultivations in the Okanagan region per suitability class.

Suitability Class	Value (M$)	Estimated value (M$)
Optimal	86.2 (54.9-117.6)	258.8 (164.7-352.9)
Suitable	48.1 (30.6 – 65.6)	144.4 (91.8 – 196.9)
Marginal	2.0 (1.3 – 2.8)	6.1 (3.9 – 8.3)
Total	**136.4 (86.8 – 186.0)**	**409.3 (260.4 – 558.2)**

6. Final comments and conclusions

This methodology has shown to be valuable in predicting areas of potential marijuana cultivation. The results can be used to guide surveillance efforts and assist in creating drug control policies. The following general observations were seen from the results:

- Growers generally concentrate their efforts in areas that are climatically, topographically, and logistically favourable. A handful of cases however, do appear in marginal conditions. Growers are risk averse; thus minimize their risk of being detected while still providing the minimum conditions for the plants. These areas comprise the smallest number of sites.
- Surveillance concentrated in the most optimal areas of growth would maximize the number of sites and plants detected. These areas, prioritized for aerial surveillance/ collection of remote imagery, would greatly increase the chance of detection of the growing sites.
- Due to the logistical and environmental constraints, it is not feasible for growers to concentrate their efforts in marginally suitable areas.
- Substantial areas in all three regions can optimally support a second harvest, beyond the date where most eradication campaigns would have finished. These harvests, though weather dependent, could be achieved by knowledgeable growers who have a collection of plants grown indoors in a vegetative phase (i.e. no flowering). Once moved outside after the largest risk of detection has passed, the plants exposed to a specific range of sunshine will rapidly flower, producing a second crop.
- Both the values of the known sites and the overall estimated values of the *Cannabis* products are substantial, and only represent a portion of one province in Canada.

7. Acknowledgements

This project was jointly supported by the Canadian Police Research Centre and Public Safety and Emergency Preparedness Canada. Data and logistical assistance was provided by the Chilliwack RCMP Detachment, Abbotsford Police Department, Vancouver Island RCMP Detachment and E Division RCMP Air Services.

8. Appendix 1

The following three pages illustrate the maps for the hours of sunshine for each of the three regions.