

**Development of Regeneration Imputation Models for
the IDF dk1, dk2, and dk3 Subzone Variants of
the Kamloops and Cariboo Forest Regions**

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EXECUTIVE SUMMARY

Many models have been developed that attempt to predict future forest resource conditions based on information from current stand characteristics. In order to do so, all aspects of forest succession must be included in the model, including the regeneration component, which is often overlooked in simulation modelling. Estimations of post-harvest conditions and regeneration require a substantial amount of data be collected over vast forested landscapes. Because of this, stand level information that is available over the forested landscape is often supplemented with more detailed information on sampled areas. Imputation modelling objectively links detailed ground samples to the stand level information available for a larger portion of the entire landscape.

Accuracy of prediction of regeneration for Interior Douglas-fir dry cool subvariants (IDFdk1, dk2, and dk3) in the Kamloops and Cariboo Forest Regions was tested using two imputation methods: tabular and Most Similar Neighbour (MSN). For the tabular imputation, tables of average number of seedlings per ha were calculated using sample data by species and height class for a specified time since disturbance, site series class, and overstory basal area. MSN used reference plots containing complete information about stand overstory and site characteristics and regeneration variables to estimate the regeneration values for target plots that only contained information about stand overstory and site characteristics.

Data from 335 plots were collected in the summer of 1999. The sampling and measurement protocols employed were based on methods developed for the small tree and regeneration components of Prognosis, a single tree growth and yield model developed in Idaho. More than 70% of the plots were disturbed in the previous 12 years. More regenerated trees were found in open sites ($\leq 30.0 \text{ m}^2/\text{hectare}$ residual basal area) than in dense sites ($> 30.0 \text{ m}^2/\text{hectare}$ residual basal area). The most common regenerating species found was Douglas-fir. The majority of regeneration in dense stands occurred in wet areas, and in mesic sites in open stands. In dense stands, regeneration was highest within 6-10 years-since-disturbance, and in open stands, 1-5 years-since-disturbance.

Both the tabular and the MSN methods performed well. Each had relatively low bias and RMSE; however, the tabular method had slightly lower error than MSN. Many of the plots contained a large number of zeros, representing no regeneration of a particular species, which may explain the low bias and RMSE found in the tabular method. For MSN, a large percentage of the overall plots (80%) were used for the reference plots. Such high sampling intensity may explain the low bias and RMSE found for this method. The tabular results can be used to estimate regeneration in non-sampled areas, by selecting a table based on stand and site variables, and substituting the average regeneration values.

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INTRODUCTION

Many models have been developed that attempt to predict future forest resource conditions based on information from current stand characteristics. In order to do so, all aspects of forest succession must be included in the model, including the regeneration component, an area that is often overlooked in simulation modelling (Ek *et al.* 1997). Ek *et al.* suggested that this limited development of regeneration models might be due to the imprecision in estimating post-harvest conditions. Estimations of post-harvest conditions and regeneration require a substantial amount of data be collected over vast forested landscapes, a task that is virtually impossible. Because of this, information that is available over the forested landscape as a whole is often supplemented with more detailed information on sampled areas. Imputation modelling may be one way to make up for deficiencies in data coverage for large areas by objectively linking small intensity detailed sample data to larger intensity coverage or census with less detail (Moeur *et al.* 1995).

The interior Douglas-fir zone (IDF) dominates the low- to mid-elevation landscape of south-central interior British Columbia (Hope *et al.* 1991). Table 1 lists the local and scientific names of the common softwood species found in this zone. Pure Douglas-fir climax stands are common throughout the IDF; however, on drier sites ponderosa pine may be present as a climax species. Western red cedar may also occur in mature forests on wetter sites, and lodgepole pine may commonly be found at higher elevations (Hope *et al.* 1991).

Table 1: Local and scientific names, and species codes for common softwood species found in IDFdk subzone.

Local Name	Scientific Name	Code*
Douglas-fir	<i>Pseudotsuga menziesii</i> var. <i>glauca</i> (Beissn.) Franco	Fd
hybrid spruce	<i>Picea engelmannii</i> Parry x <i>glauca</i> (Moench) Voss	Sx
lodgepole pine	<i>Pinus contorta</i> Dougl. Var. <i>latifolia</i> Dougl	Pl
ponderosa pine	<i>Pinus ponderosa</i> Dougl. ex Laws.	Py
subalpine fir	<i>Abies lasiocarpa</i> (Hook.) Nutt.	Bl
western redcedar	<i>Thuja plicata</i> Donn	Cw

* tree species codes follow the British Columbia Ministry of Forests, Inventory Branch Standards

The Dry Cool IDF subzone (IDFdk) occupies the low- to mid-elevations of the southern Interior Plateau. Typical site associations found in this subzone are:

- 1) Douglas-fir – Lodgepole pine – Pinegrass – Fethermoss, found in drier sites;
- 2) Douglas-fir – Snowberry – Bluebunch wheatgrass, dry, nutrient-poor sites;
- 3) Douglas-fir – Pinegrass – Yarrow, moderately dry sites; and
- 4) Hybrid spruce – Douglas-fir – Gooseberry – Feathermoss, very moist, nutrient-medium to rich sites (Hope *et al.* 1991).

Imputation involves replacing non-sampled or missing measurements from a particular unit of a population with sampled measurements from another unit that has similar characteristics (Ek *et al.* 1997). Moeur and Stage (1995) suggested that imputation modelling could be utilised to model ecosystem functioning and response to intervention, as well as retain the complex interaction between multivariate attributes. Other modelling strategies typically use regression or stratified random sampling for estimation or means (e.g. Ferguson *et al.* 1986). Ek *et al.* (1997) suggested that imputation modelling might be a better tool over estimation by means because the covariance matrix for the population will be reflected by the sample.

Ek *et al.* (1997) used tabular imputation to estimate post-harvest stand characteristics. Simple tabular analysis was used to show average stand basal area and stems per hectare for different cover types and times since harvest. The outputs of these models were designed to facilitate their use as input data for existing growth and yield models. This approach was also used to generate tree-lists from aerial inventory data, along with an MSN approach (LeMay and Temesgen 2001).

The MSN method uses auxiliary information to refine the selection of a replacement unit for non-sampled/missing units. Selection of the replacement unit is done using a minimum Euclidean distance formulation that is weighted by correlation coefficients calculated between all auxiliary variables and the inventoried variables (Moeur 2000). Moeur (2000) used MSN to classify percent canopy cover and basal area with auxiliary geo- and topographical data. She found that cover type was correctly classified in 76 percent of the cases.

The purpose of this study is to test two imputation techniques, tabular imputation and most similar neighbour (MSN), for predicting regeneration in the IDFdk 1, 2 and 3 subzones and to present average regeneration tables.

METHODS

Data Description

Sampling Frame

Field sampling was carried out in the summer of 1999 (Lencar and Marshall 2000). The percentage of area reported with single tree selection represents 44% of the total area in the Cariboo Forest Region and 31% in the Kamloops Forest Region (J.S. Thrower and Associates 1995). Sampling included a high proportion of sites harvested with partial cutting systems to represent future types of harvesting.

For IDF dk1 and dk2, the BC Ministry of Forests (BCMof) provided the sampling frame for Kamloops Forest Region, consisting of all polygons located in the IDFdk1 and dk2, irrespective of ownership, that were disturbed in the last 20 years. Stratified random sampling was conducted by having the polygons separated by year since disturbance (2 - 20) and intensity of disturbance (0 - 100%). Stands were randomly selected to ensure an unbiased choice among all candidate stands. Available time did not allow sampling a large number of plots for each combination of factors. Stratification of the area into several smaller geographic areas was not done, since the geography and climate are very alike across the extent of IDF dk1 and dk2 in the Kamloops region.

For IDF dk3, Ministry of Forests and Inland Timber Management Ltd. constructed the sampling frame. Stratified random sampling was conducted by having polygons separated by year since disturbance into three strata: 1995 - present, 1990 - 1994 and pre - 1990. The attempt was to establish an equal number of plots in these three strata.

Sampling Procedures

Site Selection

For IDF dk1 and dk2, approximately 80 percent of the sampling effort was from partially cut stands. The remaining 20 percent of the sample sites were split between undisturbed and clearcut areas. These areas were selected purposively based on similarities in site characteristics to those in the partially cut stands. For IDF dk3, 90 percent of the sampled units were located in partially cut stands, and the remaining 10 percent were located in clearcut stands.

The number of sites sampled was solely a function of time and budget. For IDF dk1, 40 sites were selected, for IDF dk2, 21 sites, and for IDF dk3, 50 sites were selected.

Sampling and data collection

For IDF dk1 and dk2, plots within sites were selected using a systematic sample with a random start. For each site selected, the length of the road that crossed that site or went beside that site was measured. A random number between one and the measured length of the road minus 100 was selected. This was done to avoid locating the plots closer than 50 m to the boundaries of the site. Once the starting point was selected, a bearing of 90 degrees from the road azimuth leading into the site was chosen for the first plot. Plots had to be located at least 40 m from the road and the spacing chosen to reduce the influence of the road opening (Landbeck 1965; Van Laar *et al.* 1990) The direction used after the location of the first plot varied accordingly to site area and shape.

Each plot had to be homogeneous from a stand structure perspective. If, by chance, a plot ended up in a heterogeneous area, for example, a partially cut and uncut stand, it was offset with 20 m in a randomly chosen direction. The year of cutting, geographic location, elevation, and sometimes intensity of disturbance were stand variables that did not differ among plots within a stand. The number of plots located at each site was based

on the variability of that site in terms of stratification criteria; the more variable the site, the more plots established. At least two plots were selected at each site. The most plots on any site were nine.

The trees on each plot were separated into two sub-populations: (1) large and small trees and (2) regeneration. These sub-populations describe the stand as a whole when combined. Regeneration was defined as being represented by all trees above 15 cm in height and below 7.5 cm dbh (diameter outside bark at 1.3m above ground) (Ferguson *et al.* 1986). Small trees were defined as all trees with dbh between 2.0 cm and 7.5 cm. Large trees were defined as trees above 7.5 cm dbh. For regeneration, the minimum size that was used in order to differentiate between seedlings and regeneration trees was different than the minimum size adopted by Ferguson and Carlson (1993) for Douglas-fir and lodgepole pine. The minimum height adopted by them was 50 cm; however, after consultation with professionals working in the IDF dk1 and dk2, the requirement for viable regeneration was established at a 15 cm height.

The regeneration sub-population was sampled with fixed area, circular plots of 1/300 acre (0.00135 ha) equivalent to a radius of 2.07 m. Four satellite plots were located at the cardinal directions, 11.28 m from the plot centre. These plots served to establish stocking probability. Small trees and large trees were sampled with a fixed area plot of 0.04 ha (11.28 m radius), following the BC Ministry of Forests recommendations. Plot layout is illustrated in Figure 1.

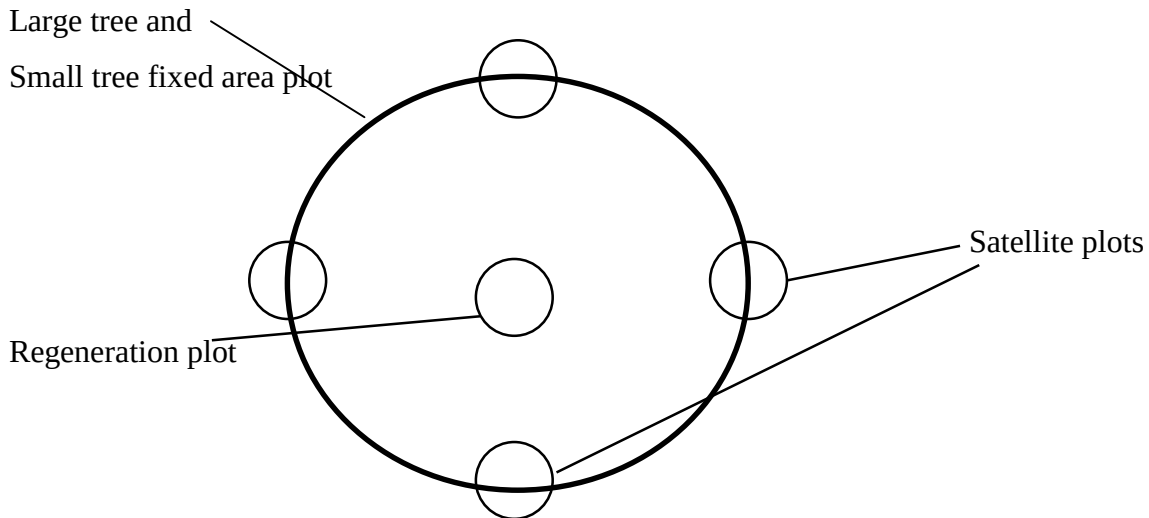


Figure 1. Plot layout for sampling large tree, small tree and regeneration sub-populations.

For each plot, the Biogeoclimatic Ecological Classification (BEC) site series, aspect, elevation, slope percent, slope position stratified plots, years since last disturbance, the number of residuals by species, and site preparation were measured. To provide a record of the plots, each site was assigned a number, as well as each plot within the site. Site information was collected using BCMoF ecosystem field forms.

In IDF dk1 and dk2, measurements started with the regeneration plots. Species were counted, recorded and divided into four categories based on height: (i) under 50 cm, (ii) between 50 and 100 cm, (iii) between 100 and 130 cm and (iv) over 130 cm. A subsample of height and ground age for the ‘best trees’ was taken. Best trees were chosen by:

1. Selecting the two tallest trees on each central regeneration plot regardless of species;
2. Selecting the one tallest tree of each additional species present on the plot; and
3. If the first two rules did not result in four trees, selecting in order of descending height from any remaining trees until at least four trees, if present, were chosen (Ferguson and Carlson 1993).

Tree heights were measured up to the end of the previous (1998) growing season to ensure that all trees sampled during the field season were comparable. In the satellite plots, the number of regeneration trees was counted by height class and species; no subsample for the best trees was taken. A plot that had at least one regeneration tree was considered stocked. If no regeneration was found in the centre plot, a satellite plot was randomly selected to provide the measurements for best regeneration trees as considered above.

All small and large trees were measured for dbh, and at least five small trees for each species were measured for five years height growth and total height as well. At least two large trees from each species were measured for height.

For the IDF dk3 subzone, a cluster of five Prognosis^{BC} plots was established in connection with the multi-layer silvicultural survey plots (Figure 2). The locations of the clusters within each block coincided with one or more of the multi-layer survey points. The field crew was not required to select which multi-layer plot centre to be used as the Prognosis^{BC} plot centre. The multi-layer plot centres that also served as Prognosis^{BC} plot cluster centres were chosen randomly.

If the pre-determined plot (centre) location fell within 2 (upper canopy) tree lengths of a landing, permanent road, clearcut or permanent natural opening, the plot was moved to the next multi-layer plot location, or if that one was not suitable, the preceding multi-layer plot location.

The numbers of clusters per selected block depended on the size of the block. The objective was to insure adequate sampling of the microsites within each selected block. A grand total of 150 clusters across the range of site factors present and stand densities in the survey area was deemed sufficient.

Each cluster consisted of an enhanced regeneration plot, a small tree plot and a prism sweep all on the same point surrounded by four satellite plots located 11.28 m from the centre in cardinal directions (Figure 3).

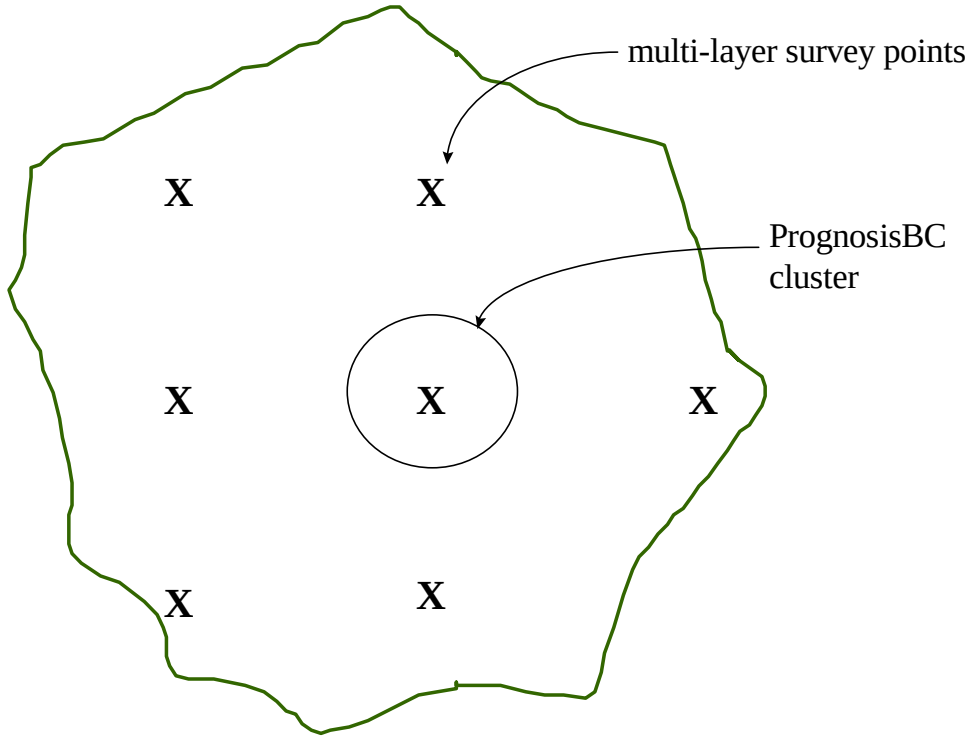


Figure 2. Prognosis^{BC} – plot cluster (superimposed over the multi-layer survey).

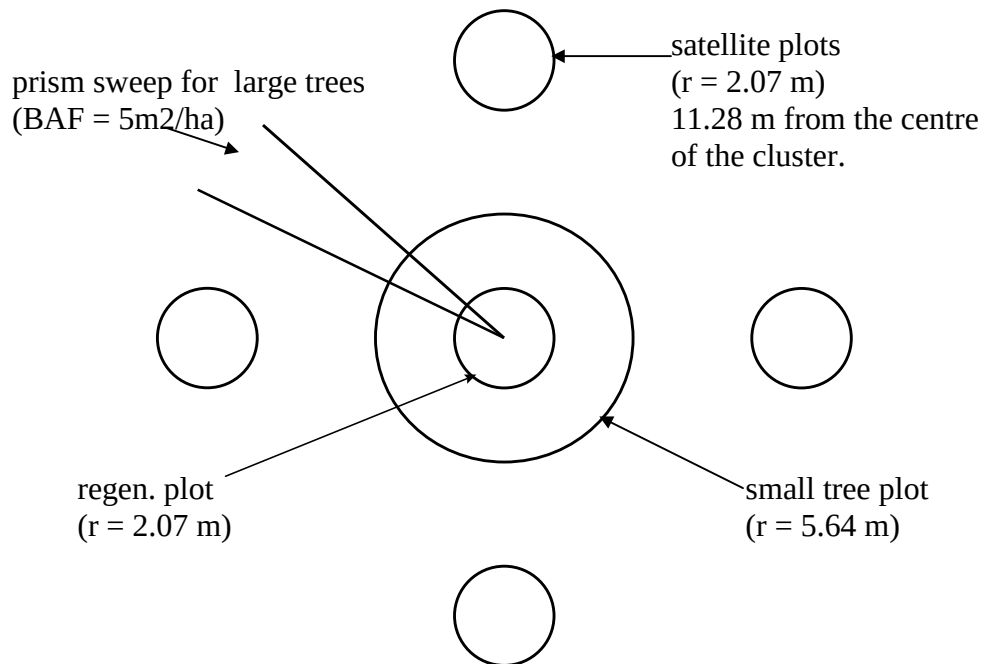


Figure 3. Prognosis^{BC} – plot layout.

The regeneration sub-plot was 2.07 m in radius. Regeneration (trees > 15cm in height and < 7.5cm dbh) were tallied into height classes and a sub-sample was aged. A 15 cm height cut-off was used to ensure that the regeneration measured is likely to survive the current growing season. This information was used to estimate the amount and height of regeneration and advance growth “X” years after partial cutting. The small tree sub-plot (5.64 m radius) was used to sample trees 2 - 7.5 cm dbh. Sub-samples of these trees were measured to determine small tree height growth. The prism sweep was used to estimate the overstory retention level and its resultant impact on regeneration establishment and growth. Finally, the four satellite plots (2.07 m radius) were used to assess the presence or absence of regeneration by species.

In IDF dk3, BEC classification was obtained for half of the plots in 1999 and the remaining half in 2000.

Analysis Procedures

Data preparation and summary

All data collected were entered into Excel spreadsheets, separated into plot information, large tree, small tree, and regeneration components. Data were grouped together to generate summaries in Excel. Further analyses and summaries were performed in SAS, Version 8.0.

Plots were identified by site, years-since-disturbance, and basal area classes. Five site classes were categorised based on site series (dry, slightly dry, mesic, slightly wet, and wet). The six years-since-disturbance intervals include 0 (0 years since harvest), 1 (1 – 5), 2 (6-10), 3 (11-15), 4 (16-20), and 5 (21-25). The two basal area classes were Open (≤ 30.0 m²/ha) and Dense (> 30.0 m²/ha). Regenerating trees were stratified into four height classes (15 - 49.9 cm; 50 - 99.9 cm; 100 - 129.9 cm; ≥ 130 cm), and for some analyses, also by shade tolerance (intolerant – Py, Pl; semi-tolerant – Fd, tolerant – Cw, Bl, Sx).

Tabular Imputation Models

Tables were generated to indicate average stems per hectare of regenerating trees for each plot level category, where plot level categories are described by each of the five site classes for each years-since-disturbance interval and basal area class. For example, one plot level category could include an open, dry site that was disturbed 15 years ago. Three sets of tables were generated in total for each plot level category:

- 1) average stems per hectare of all regenerating trees combined;
 - 2) average stems per hectare of regenerating trees for each species separately;
- and,

- 3) average stems per hectare of regenerating trees for each species at each height class.

Validation of tabular imputation models was done through comparison of observed and predicted stems per hectare values. Plots were subdivided for validation purposes; data from eighty percent of the plots were used to generate tables of predicted values to be compared with the true observations of the remaining twenty percent of plots. This subdivision was repeated five times, so that each plot had a predicted set of values and an observed set of values associated with it. From this, the model could be evaluated by comparing the observed and predicted values for each plot, where very different values of observed vs. predicted would result in a large amount of bias and squared error. To calculate bias, an overall average of mean deviations was calculated, along with an average of absolute deviations (Equations 1 and 2). For precision, the root mean squared error (RMSE) was calculated (Equation 3).

$$bias = \sum_{i=1}^n \frac{observed_i - predicted_i}{n} \quad (1)$$

$$average\ absolute\ deviation = \sum_{i=1}^n \frac{|observed_i - predicted_i|}{n} \quad (2)$$

$$RMSE = \sum_{i=1}^n \sqrt{\frac{(observed_i - predicted_i)^2}{n}} \quad (3)$$

where n is equal to the number of plots per run.

MSN Modelling

Data for this method were analysed using MSN 2.0 developed by Moeur (2000).

Plots were split randomly into reference and target plots. For each of five runs, approximately 80% of the plots were used for reference and 20% for target plots. Reference plots included all regeneration (Y) and stand overstory and site information (X). Target plots contained only stand overstory and site information.

The regeneration variables were the amount of regenerating trees per hectare of each species classed by shade tolerance for each of the four height classes. The stand overstory and site variables included: BEC zone; site class; years-since-disturbance; aspect class (cardinal directions); elevation (m); slope (degrees); residual basal area per hectare; crown competition factor (CCF); and number of residual trees per hectare.

For the MSN analysis, canonical correlation analysis between the dependent and the independent variables was used to calculate weights for the neighbour similarity measure. From this, the most similar reference plot was selected and its regeneration values were used to predict target plot regeneration.

As with tabular modelling, the results of the MSN technique were validated by calculating bias, average absolute deviation, and RMSE using the observed and predicted values of the regeneration variables (Equations 1, 2 and 3). Also, model validation statistics were computed by comparing the observed values of the stand overstory and site variables with those in the reference plot selected. Validation on these variables included calculation of bias and RMSE, as well as calculation of the coefficient of determination (R-SQ). This value provides information on how strongly associated predicted and observed values are by indicating the amount of variation in the predicted values that can be explained by the relationship between the observed and predicted values (Moeur 2000).

RESULTS AND DISCUSSION

Data Summary

Data were collected in 335 plots. Table 2 provides ranges of data for eight variables. Of the three subzones, IDF dk2 contained the fewest plots. More than 70% of the plots were disturbed in the previous 12 years. At least half of the plots were found in site series 01. A wide range of elevations, aspects, and slopes was represented in the plots. Eighty percent of plots consisted of residual basal areas ranging from 0.1-24.9 m²/ha, and 55% of plots had a crown competition factor between 50 and 149.9.

Tabular Imputation

Table 3 shows the regeneration per hectare by years-since-disturbance, site and basal area classes. There were a total of 75 plots that were classed as dense, and 257 plots that were considered open.

For the dense sites, no regenerating trees were found in years-since-disturbance class 0 in slightly dry sites, in years-since-disturbance class 3 in dry and wet sites. No plots were found in 1) dense, wet sites in years-since-disturbance classes 0, 4, and 5; 2) dense, dry sites in years-since-disturbance classes 1 and 2; and 3) dense, slightly dry sites in years-since-disturbance class 5. For wet sites, no plots were located in dry, slightly wet and wet sites for years-since-disturbance class 0, nor in wet sites for years-since-disturbance class 5.

Table 2: Number of plots summarised by variable classes.

Class	No. Plots	Class	No. Plots	Class	No. Plots
BEC subzone		Site Series		Slope Percent	
IDF dk1	120	01	169	0-5	94
IDF dk2	62	02	3	6-15	98
IDF dk3	153	03	25	16-25	68
		04	52	26-35	43
Years Since Last Disturbance		05	68	≥36	30
0	18	06	5	NR*	2
1	2	07	7		
2	6	08	4	Residual Basal Area (m²/ha)	
3	19	NR*	2	0	5
4	41	Elevation (m)		0.1-9.9	118
5	33	700-899	5	10-24.9	149
6	4	800-899	30	≥25	63
7	11	900-999	60		
8	19	1000-1099	41	Crown Competition Factor	
9	21	1100-1199	73	0-49.9	68
10	8	1200-1299	71	50-99.9	94
11	27	1300-1399	26	100-149.9	91
12	33	≥ 1400	22	150-199.9	46
13	9	NR*	7	200-249.9	21
14	16	Aspect		250-299.9	9
15	12	E	35	≥300	6
16	5	F	62		
17	15	N	52		
18	11	NE	42		
19	8	NW	33		
20	5	S	24		
21	12	SE	22		
		SW	27		
		W	35		
		NR*	3		

*not recorded

Table 3: Average regeneration per ha by years-since-disturbance class interval and site class for basal area classes “Dense” and “Open” (335 plots).

Dense (75 plots)	Years Since Disturbance Class	Site Class				
		Dry	Slightly Dry	Mesic	Slightly Wet	Wet
	0	149	0	559	2866	-
	1 (1-5)	-	1391	3306	1937	5944
	2 (6-10)	-	1937	7430	708	11175
	3 (11-15)	0	3278	1651	794	0
	4 (16-20)	299	373	1562	695	-
	5 (21-25)	447	-	596	1639	-
Open (257 plots)	0	-	224	7604	-	-
	1 (1-5)	15975	3278	5696	2519	1524
	2 (6-10)	1341	1356	6490	1907	5214
	3 (11-15)	2086	2970	4788	3959	7244
	4 (16-20)	708	1490	2628	2399	3127
	5 (21-25)	795	1291	745	2682	-

For the dense sites, the most regeneration was found in wet sites, even though only two years-since-disturbance classes contained regenerating trees. The majority of regeneration occurred within 10 years-since-disturbance for all site classes combined. In the open sites, mesic site classes contained the most regeneration, and for all site classes combined, the years-since-disturbance class 1 had the most regeneration.

Tables 4 and 5 show the regeneration per hectare by years-since-disturbance for basal area categories dense and open for all site classes. Overall, six species were found within plot locations, with Douglas-fir representing the most regeneration, and ponderosa pine the least. The open and mesic site had the most regeneration overall, and the dense and dry sites had the least.

In dense and dry sites, only Douglas-fir was present, and only in years-since-disturbance classes 0, 4 and 5. In dense and slightly dry sites, only Douglas-fir and subalpine fir were found, neither of which were found in years-since-disturbance-class 0, and only Douglas-fir was found in classes 2-5. The most regeneration overall in the dense and slightly dry sites occurred in years-since-disturbance class 3. In dense, mesic and dense, slightly wet sites, only Douglas-fir, lodgepole pine and hybrid spruce were found. The most regeneration occurred in the years-since-disturbance class 2 for mesic sites and class 0 for slightly wet sites. In the dense and wet sites, Douglas-fir was found only in the years-since-disturbance classes 1 and 2, and western red cedar was only in class 2. No other regenerating trees were found.

Table 4: Average regeneration per ha by years-since-disturbance class interval for basal area category “Dense” for all five site classes.

Dry	Years Since Disturbance	Species						Total
	Class	Bl	Cw	Fd	Pl	Py	Sx	
Dry	0	0	0	149	0	0	0	149
	1 (1-5)	0	0	0	0	0	0	0
	2 (6-10)	0	0	0	0	0	0	0
	3 (11-15)	0	0	0	0	0	0	0
	4 (16-20)	0	0	298	0	0	0	298
	5 (21-25)	0	0	447	0	0	0	447
Slightly Dry	0	0	0	0	0	0	0	0
	1 (1-5)	50	0	1341	0	0	0	1391
	2 (6-10)	0	0	1937	0	0	0	1937
	3 (11-15)	0	0	3278	0	0	0	3278
	4 (16-20)	0	0	373	0	0	0	373
	5 (21-25)	0	0	0	0	0	0	0
Mesic	0	0	0	484	75	0	0	559
	1 (1-5)	0	0	3195	37	0	74	3306
	2 (6-10)	0	0	7306	124	0	0	7430
	3 (11-15)	0	0	1321	83	0	248	1652
	4 (16-20)	0	0	1562	0	0	0	1562
	5 (21-25)	0	0	596	0	0	0	596
Slightly Wet	0	0	0	1489	744	0	633	2866
	1 (1-5)	0	0	0	0	0	1937	1937
	2 (6-10)	0	0	410	0	0	298	708
	3 (11-15)	0	0	397	248	0	149	794
	4 (16-20)	0	0	298	0	0	397	695
	5 (21-25)	0	0	1490	149	0	0	1639
Wet	0	0	0	0	0	0	0	0
	1 (1-5)	0	0	5944	0	0	0	5944
	2 (6-10)	0	10430	745	0	0	0	11175
	3 (11-15)	0	0	0	0	0	0	0
	4 (16-20)	0	0	0	0	0	0	0
	5 (21-25)	0	0	0	0	0	0	0

Table 5: Average regeneration per ha by years-since-disturbance class interval for basal area category “Open” for all five site classes.

Dry	Years Since Disturbance	Species						Total
	Class	Bl	Cw	Fd	Pl	Py	Sx	
Dry	0	0	0	0	0	0	0	0
	1 (1-5)	0	0	13003	2972	0	0	15975
	2 (6-10)	0	0	1341	0	0	0	1341
	3 (11-15)	0	0	1937	149	0	0	2086
	4 (16-20)	0	0	708	0	0	0	708
	5 (21-25)	0	0	745	50	0	0	795
Slightly Dry	0	0	0	224	0	0	0	224
	1 (1-5)	19	0	2645	559	0	56	3279
	2 (6-10)	0	0	1207	60	89	0	1356
	3 (11-15)	30	0	2066	735	0	139	2970
	4 (16-20)	0	0	1167	174	0	149	1490
	5 (21-25)	0	0	1142	149	0	0	1291
Mesic	0	0	0	5003	1981	0	619	7603
	1 (1-5)	0	0	5172	220	0	304	5696
	2 (6-10)	0	0	6300	66	0	124	6490
	3 (11-15)	0	0	2041	2525	0	221	4787
	4 (16-20)	0	0	1504	799	0	325	2628
	5 (21-25)	0	0	745	0	0	0	745
Slightly Wet	0	0	0	0	0	0	0	0
	1 (1-5)	128	0	1849	160	0	383	2520
	2 (6-10)	0	9	1069	214	0	615	1907
	3 (11-15)	15	15	2737	745	0	447	3959
	4 (16-20)	0	0	894	626	0	879	2399
	5 (21-25)	0	0	2533	0	0	149	2682
Wet	0	0	0	0	0	0	0	0
	1 (1-5)	0	0	1300	0	0	224	1524
	2 (6-10)	0	3576	1390	0	0	248	5214
	3 (11-15)	0	0	3715	0	0	3529	7244
	4 (16-20)	0	0	2904	0	0	224	3128
	5 (21-25)	0	0	0	0	0	0	0

In open and dry sites, only Douglas-fir and lodgepole pine were found. Neither species were found in years-since-disturbance class 0, and lodgepole pine was found only in classes 1, 3 and 5. All species except western red cedar were found in the open, slightly dry sites, with Douglas-fir and lodgepole pine dominating regeneration for all years-since-disturbance classes except 0, in which only Douglas-fir was present. The most regeneration across years-since-disturbance classes for open, slightly dry sites occurred in class 1. In open, mesic sites, only Douglas-fir, lodgepole pine and hybrid spruce were found, with years-since-disturbance class 0 having the most regeneration. In slightly wet, open sites, all species were present except ponderosa pine. No species were present in the years-since disturbance class 0, and the most regeneration occurred in class 3. For the open and wet sites, Douglas-fir and hybrid spruce were found only in years-since-disturbance classes 1-4, and western red cedar was found only in class 2. No other species were found. The years-since-disturbance class with the most regeneration was class 3.

Regeneration tables were further broken down by height class for each species in each years-since-disturbance class interval for basal area categories and site classes. A total of 45 tables were created, and examples of these are shown in Tables 6 and 7, with the remaining tables included in Appendix A (dense sites) and B (open sites). These tables can be used to provide base-line information for any growth and yield model requiring regeneration input for particular site characteristics (Ferguson *et al.* 1986).

Table 6: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	4	Fd	37	37	0	410	484
		Pl	0	0	0	75	75
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	37	37	0	485	559

Table 7: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	6	Fd	2229	1610	495	669	5003
		Pl	124	372	372	1115	1983
		Sx	124	0	0	495	619
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	2477	1982	867	2279	7605

How To Use Tabular Imputation Results to Estimate Regeneration

Regeneration predictions for a particular stand of interest can be obtained through the tables provided in this report if knowledge of site, basal area, and years-since-disturbance classes is available. For example, if information on regeneration is of interest for a dry, open site that was logged 15 years ago, Table 3 will provide information on overall species regeneration (2086 regenerating trees per ha), Table 5 will provide information on regeneration for particular species (e.g. Fd = 1937 regenerating trees per ha), and Table B13 will provide information on a particular species at a particular height class (e.g. Fd height class 1 = 428 regenerating trees per ha). For regeneration information on sites that were not represented by this data set (*i.e.* dry, dense sites in years-since-disturbance class 1), the best alternative is to use values from sites with the most similar site class (e.g. use mesic sites to replace slightly dry sites).

MSN Method

Table 8 shows correlations between the stand overstory and site variables and the regeneration variables. Douglas-fir regeneration within all height classes was positively correlated with BEC zone and aspect, and negatively correlated with years-since-disturbance. For height classes ≥ 50 cm, Douglas-fir regeneration was positively correlated with residual trees per hectare, and for < 130 cm there was a negative correlation with elevation. Residual basal area and crown competition factor were positively correlated with Douglas-fir regeneration in height class 4 only.

Lodgepole pine regeneration was negatively correlated with residual basal area and crown competition factor for all four height classes. A positive correlation was found between aspect and lodgepole pine regeneration for height classes 1, 2, and 4, and weakly correlated for height class 3. Very few trends were found in the data between hybrid spruce regeneration and stand overstory and site variables.

Table 8: Correlations between stand overstory and site variables (X) and regeneration variables (Y). X variables include BEC, year-since-disturbance (Yrsince), residual basal area (BAHA), crown competition factor (CCF), residual trees per hectare (TPH), elevation, and slope. Y variables include the three main tree species, Douglas-fir, lodgepole pine and hybrid spruce for each height class. Shown are Pearson's correlation coefficients and p-values. Significant correlations are shown in bold.

	BEC	Yrsince	BAHA	CCF	TPH	Aspect	Elevation	Slope
FD1	0.2537 <.0001	-0.1284 0.0187	-0.0136 0.8038	-0.0486 0.3750	-0.0019 0.9722	0.2197 <.0001	-0.1946 0.0003	-0.0107 0.8454
FD2	0.1816 0.0008	-0.1281 0.0190	0.0092 0.8664	-0.0156 0.7763	0.1331 0.0147	0.2044 0.0003	-0.2527 <.0001	0.0099 0.8569
FD3	0.1728 0.0015	-0.1275 0.0196	0.0310 0.5722	0.0494 0.3678	0.3797 <.0001	0.1360 0.0161	-0.1465 0.0072	0.0112 0.8389
FD4	0.2367 <.0001	-0.1280 0.0191	0.1278 0.0193	0.2237 <.0001	0.6669 <.0001	0.1206 0.0329	-0.0939 0.0863	0.0240 0.6616
PL1	0.0269 0.6243	0.0423 0.4407	-0.2315 <.0001	-0.2196 <.0001	-0.0539 0.3253	0.1911 0.0007	0.0029 0.9585	-0.0106 0.8465
PL2	-0.0238 0.6649	0.1182 0.0306	-0.2594 <.0001	-0.2607 <.0001	0.0119 0.8284	0.2321 <.0001	0.0155 0.7779	-0.0123 0.8226
PL3	-0.0183 0.7381	0.0186 0.7339	-0.2219 <.0001	-0.2138 <.0001	-0.0481 0.3803	0.0941 0.0967	0.0024 0.9646	-0.0034 0.9500
PL4	0.0774 0.1574	0.0553 0.3132	-0.2098 0.0001	-0.1840 0.0007	0.2319 <.0001	0.1836 0.0011	-0.0337 0.5386	-0.0078 0.8865
SX1	-0.0240 0.6613	0.0324 0.5546	0.0045 0.9345	-0.0202 0.7128	-0.0479 0.3824	-0.0506 0.3725	0.0960 0.0792	0.0152 0.7811
SX2	-0.0785 0.1519	0.0351 0.5223	-0.1196 0.0286	-0.1552 0.0044	-0.1082 0.0478	-0.0973 0.0858	0.1263 0.0207	0.0064 0.9077
SX3	-0.1641 0.0026	0.0645 0.2394	-0.0866 0.1138	-0.0973 0.0753	-0.0655 0.2319	-0.0955 0.0916	0.0930 0.0894	-0.0016 0.9768
SX4	0.0149 0.7862	-0.0172 0.7545	-0.0506 0.3555	-0.0832 0.1286	0.0081 0.8827	-0.0227 0.6890	0.1060 0.0526	0.0219 0.6893

How To Use MSN to Estimate Regeneration

Unlike the tabular imputation results, the MSN program and a set of sample data (reference plots) are needed to obtain regeneration estimates for a stand of interest (target stand). The reference plots contain information on both the independent (e.g. stand overstory and site) variables and the dependent (e.g. regeneration) variables. The data used for this project will be available for use as reference plots. For the target stand, the stand overstory and site variables would need to be available. The MSN program would then take the information for the target stand, and find a suitable match from the

reference list. The regeneration from the selected reference plot would then be used as the estimate for the target stand. The MSN program can be downloaded from:

<http://forest.moscowfsl.wsu.edu/4155/msn.html>.

The MSN program will generate a “for/use” file indicating the reference plot to use in providing information about regeneration in the target stand. The MSN program will also provide validation statistics indicating how close the match was between the target plot and the reference plot chosen based on a comparison of the stand overstory and site variables from both plots.

Validation of Tabular and MSN

Table 9 shows the validation results using the tabular and MSN methods based on the observed and predicted values of regeneration values. Statistics are based on all regeneration variables over all target plots.

Table 9: Bias, mean absolute deviation (MAD), and root mean squared error (RMSE) for each run for tabular and most similar neighbour analyses.

Tabular/ Run No.	No. of Target Plots	Bias	MAD	RMSE
1	59	-17	188	513
2	69	79	270	759
3	65	-19	242	637
4	67	-40	198	507
5	75	-31	206	533
Means	67	-6	221	590
MSN/ Run No.	No. of Target Plots	Bias	MAD	RMSE
1	59	5	172	495
2	69	40	281	847
3	65	-31	249	692
4	67	-2	177	523
5	75	-17	197	586
Means	67	-1	215	629

The RMSE was quite low for both tabular and MSN, an average that represents less than one regenerating tree per plot difference. Both the mean deviation and the absolute

deviation of the MSN analysis were lower than for tabular imputation, however the overall RMSE was lower for tabular imputation.

Table 10 shows the MSN validation results for the target observations for Run 1. For all the variables, the mean of the residual is not significantly different from zero ($p > 0.05$), suggesting that, on average, there is agreement between observed and predicted values for each variable listed. The residual means from the other four runs were not significantly different from zero for all variables, with the exception of residual basal area per hectare for Runs 4 and 5 ($p = 0.002$ and 0.017 , respectively), and crown competition factor for Run 4 ($p = 0.004$). A large proportion of the total variation in the predicted values for the residual basal area per hectare, the crown competition factor and the residual trees per hectare could be explained by the relationship between the observed and imputed values for these variables ($R\text{-}SQ \geq 0.70$), with $R\text{-}SQ$ values remaining fairly high for these three variables in the remainder of the runs. The $R\text{-}SQ$ for slope was consistently low for all five runs ($R\text{-}SQ < 0.08$).

Table 10: MSN validation results for 59 target observations for Run 1.

Variable	Standard Difference		Residuals				
	Mean	SD	Mean	t-Ratio	P> t	RMSE	R-SQ
Years-since-disturbance class	0.04	0.32	0.70	0.89	0.38	6.07	0.23
Elevation	0.17	0.81	94.20	1.60	0.11	461.18	0.23
Slope	0.73	3.62	37.95	1.55	0.13	191.83	0.02
Residual basal area per hectare	0.01	0.12	-0.33	-0.30	0.77	8.56	0.70
Crown competition factor	0.00	0.12	-0.52	-0.09	0.93	44.56	0.73
Residual tress per hectare	0.02	0.15	107.75	1.12	0.27	746.89	0.71

Both imputation techniques resulted in relatively low bias and low RMSE values. For the tabular method, low bias and RMSE could be because of the number of zeros present in the entire data set. If a larger range of species were found within each height class category, bias and RMSE might have been much higher due to increased variation. Low bias and RMSE in the MSN method could be due in part to the high sampling intensity used for the reference plots. In a typical inventory, a detailed ground sample might consist of less than 20% sampling intensity. LeMay and Temesgen (2001) varied the sampling intensities used for imputation modelling, and found that the mean of the mean squared error for estimating Douglas-fir stems per hectare decreased with increasing sampling intensity, when sample size was increased from 20 to 50%, but there was little further gain when sample size was further increased to 80%.

SUMMARY

This report describes the procedures used to estimate regeneration in the IDFd1, 2, and 3 subzones in the Kamloops and Cariboo Forest regions. The regeneration data collected in the summer of 1999 were summarised by variable classes for stand site and overstory variables. Tabular imputation models were developed that describe the average regeneration by site, residual density, years-since-disturbance, and height classes for each species. Most similar neighbour models were tested as an alternative to tabular imputation using averages, as this preserves the variance of regeneration over the plots.

Validation of both modelling techniques was done, and relatively low biases and root mean squared errors were found for both techniques. For the tabular method, low bias and root mean squared error could be due to the high number of zeros found within each plot for some species and height class categories. For the MSN method, low root mean squared error could be due to the high sampling intensity for reference plots.

Further work will be done in examining the effectiveness of these methods with lower sampling intensities, pending funding. If funding is provided, tabular results will be prepared for presentation on-line, and a manual will be developed outlining how to use MSN in combination with the data collected on this project.

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APPENDIX A – BASAL AREA CLASS “DENSE”

Disturbance class 0

Table A1: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Dense” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	1	Fd	0	0	0	149	149
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	0	0	0	149	149

Table A2: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	4	Fd	37	37	0	410	484
		Pl	0	0	0	75	75
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	37	37	0	485	559

Table A3: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	4	Fd	223	224	224	819	1490
		Pl	186	186	0	372	744
		Sx	75	0	37	522	634
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	484	410	261	1713	2868

Disturbance class 1

Table A4: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	20	Fd	929	557	260	1449	3195
		Pl	0	0	0	37	37
		Sx	0	0	0	74	74
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	929	557	260	1560	3306

Table A5: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Dense” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	3	Fd	0	149	50	1142	1341
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	50	0	50
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	0	149	100	1142	1391

Table A6: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	1	Fd	0	0	0	0	0
		Pl	0	0	0	0	0
		Sx	1341	298	149	149	1937
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	1341	298	149	149	1937

Table A7: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Dense” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	3	Fd	991	1238	248	3467	5944
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	991	1238	248	3467	5944

Disturbance Class 2

Table A8: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	6	Fd	1981	1734	619	2972	7306
		Pl	0	0	0	124	124
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	1981	1734	619	3096	7430

Table A9: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Dense” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	1	Fd	1043	745	0	149	1937
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	1043	745	0	149	1937

Table A10: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	4	Fd	186	0	37	186	409
		Pl	0	0	0	0	0
		Sx	149	37	37	75	299
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	335	37	74	261	708

Table A11: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Dense” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	1	Fd	149	0	0	596	745
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	2235	3427	2086	2682	10430
		Total	2384	3427	2086	3278	11175

Disturbance Class 3

Table A12: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	9	Fd	495	83	0	743	1321
		Pl	83	0	0	0	83
		Sx	248	0	0	0	248
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	826	83	0	743	1652

Table A13: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Dense” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	1	Fd	298	298	298	2384	3278
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
	Total	298	298	298	2384	3278	

Table A14: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	3	Fd	297	0	0	99	396
		Pl	149	50	0	50	249
		Sx	149	0	0	0	149
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	595	50	0	149	794

Disturbance Class 4

Table A15: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Dense” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	3	Fd	0	0	0	298	298
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	0	0	0	298	298

Table A16: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	2	Fd	75	224	0	1264	1563
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	75	224	0	1264	1563

Table A17: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Dense” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	2	Fd	0	0	0	373	373
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	0	0	0	373	373

Table A18: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	3	Fd	149	0	0	149	298
		Pl	0	0	0	0	0
		Sx	199	50	0	149	398
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	348	50	0	298	696

Disturbance Class 5

Table A19: Average regeneration per ha by height class and species for the years-since-disturbance class 5, basal area class “Dense” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	2	Fd	0	75	0	373	448
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	0	75	0	373	448

Table A20: Average regeneration per ha by height class and species for the years-since-disturbance class 5, basal area class “Dense” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	1	Fd	298	149	0	149	596
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	298	149	0	149	596

Table A21: Average regeneration per ha by height class and species for the years-since-disturbance class 5, basal area class “Dense” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	1	Fd	447	0	149	894	1490
		Pl	149	0	0	0	149
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	596	0	149	894	1639

APPENDIX B - BASAL AREA CLASS “OPEN”

Disturbance Class 0

Table B1: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	2	Fd	75	0	0	149	224
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	75	0	0	149	224

Table B2: Average regeneration per ha by height class and species for the years-since-disturbance class 0, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	6	Fd	2229	1610	495	669	5003
		Pl	124	372	372	1115	1983
		Sx	124	0	0	495	619
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	2477	1982	867	2279	7605

Disturbance Class 1

Table B3: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Open” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	2	Fd	0	1115	2229	9659	13003
		Pl	0	0	0	2972	2972
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
Total			0	1115	2229	12631	15975

Table B4: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	46	Fd	2413	827	262	1670	5172
		Pl	139	16	13	52	220
		Sx	97	84	0	123	304
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	2649	927	275	1845	5696

Table B5: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	8	Fd	1304	335	168	838	2645
		Pl	540	19	0	0	559
		Sx	37	19	0	0	56
		Bl	0	0	0	19	19
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	1881	373	168	857	3279

Table B6: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Open” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	14	Fd	840	149	106	754	1849
		Pl	96	21	11	32	160
		Sx	266	43	0	45	354
		Bl	85	43	0	0	128
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	1287	256	117	831	2491

Table B7: Average regeneration per ha by height class and species for the years-since-disturbance class 1, basal area class “Open” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	4	Fd	743	0	186	372	1301
		Pl	0	0	0	0	0
		Sx	75	75	0	75	225
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	818	75	186	447	1526

Disturbance Class 2

Table B8: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Open” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	4	Fd	75	224	224	820	1343
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	75	224	224	820	1343

Table B9: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	18	Fd	2923	834	297	2246	6300
		Pl	41	8	8	8	65
		Sx	66	25	8	25	124
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	3030	867	313	2279	6489

Table B10: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	10	Fd	164	134	89	820	1207
		Pl	15	15	15	15	60
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	75	0	0	15	90
		Cw	0	0	0	0	0
		Total	254	149	104	850	1357

Table B11: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Open” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	16	Fd	158	168	121	623	1070
		Pl	28	84	37	65	214
		Sx	102	158	102	251	613
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	9	0	0	0	9
		Total	297	410	260	939	1906

Table B12: Average regeneration per ha by height class and species for the years-since-disturbance class 2, basal area class “Open” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	3	Fd	397	248	149	596	1390
		Pl	0	0	0	0	0
		Sx	99	0	0	149	248
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	1142	993	947	944	4026
		Total	1638	1241	1096	1689	5664

Disturbance Class 3

Table B13: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Open” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	8	Fd	428	577	149	782	1936
		Pl	56	37	37	19	149
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	484	614	186	801	2085

Table B14: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	45	Fd	1090	340	122	489	2041
		Pl	1087	463	139	836	2525
		Sx	76	30	26	89	221
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	2253	833	287	1414	4787

Table B15: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	15	Fd	437	358	189	1083	2067
		Pl	89	219	30	397	735
		Sx	30	79	0	30	139
		Bl	20	0	0	10	30
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	576	656	219	1520	2971

Table B16: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Open” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	10	Fd	1279	521	60	878	2738
		Pl	209	313	45	179	746
		Sx	313	75	0	60	448
		Bl	0	15	0	0	15
		Py	0	0	0	0	0
		Cw	15	0	0	0	15
		Total	1816	924	105	1117	3962

Table B17: Average regeneration per ha by height class and species for the years-since-disturbance class 3, basal area class “Open” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	4	Fd	2601	372	186	557	3716
		Pl	0	0	0	0	0
		Sx	1300	186	0	2043	3529
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
	Total	3901	558	186	2600	7245	

Disturbance Class 4

Table B18: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Open” and “Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Dry	4	Fd	0	149	37	522	708
		Pl	0	0	0	0	0
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
	Total	0	149	37	522	708	

Table B19: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Open” and “Mesic” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Mesic	11	Fd	571	124	174	968	708
		Pl	348	124	25	646	0
		Sx	223	99	25	174	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	348	50	0	298	708

Table B20: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	6	Fd	596	298	50	224	1168
		Pl	50	0	25	99	174
		Sx	25	75	0	50	150
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	671	373	75	373	1492

Table B21: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Open” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	11	Fd	402	179	75	238	894
		Pl	89	209	30	298	626
		Sx	313	194	45	328	880
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	804	582	150	864	2400

Table B22: Average regeneration per ha by height class and species for the years-since-disturbance class 4, basal area class “Open” and “Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Wet	2	Fd	149	521	149	2085	2904
		Pl	0	0	0	0	0
		Sx	75	75	75	0	225
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	224	596	224	2085	3129

Disturbance Class 5

Table B23: Average regeneration per ha by height class and species for the years-since-disturbance class 5, basal area class “Open” and “Slightly Dry” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Dry	3	Fd	646	199	50	248	1143
		Pl	0	50	0	99	149
		Sx	0	0	0	0	0
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	646	249	50	347	1292

Table B24: Average regeneration per ha by height class and species for the years-since-disturbance class 5, basal area class “Open” and “Slightly Wet” sites.

Site	Number Of Plots	Species	Height Class				Total
			1	2	3	4	
Slightly Wet	1	Fd	894	745	298	596	2533
		Pl	0	0	0	0	0
		Sx	0	149	0	0	149
		Bl	0	0	0	0	0
		Py	0	0	0	0	0
		Cw	0	0	0	0	0
		Total	894	894	298	596	2682