Alberta Forest Biodiversity Monitoring Program
Technical Report #4:

Ecological Land Class and Benchmark Representation For Different Sampling Networks

Alberta Forest Biodiversity Monitoring Program Technical Report #4: Ecological Land Class and Benchmark Representation For Different Sampling Networks

Philip Lee[1] and Marion Herbut

Alberta Research Council

Vegreville, Alberta

Developed in Conjunction with the Alberta Forest Biodiversity Monitoring Program Technical Committee

Project Scientist[1]

Philip Lee

Alberta Research Council

P.O. Bag 4000

Vegreville, AB

T9C 1T4

Phone: 1-780-632-8348

Fax: 1-780-632-8379

Mobile 1-780-632-8871

Email: phil@arc.ab.ca

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This document examined the representation of ecological land classes and benchmarks, i.e. protected areas, attained by different sampling networks. In keeping with the Alberta Forest Biodiversity Monitoring Programs primary objective of monitoring at regional scales, we examined the logistic and financial feasibility of monitoring over ecoregion, subregion, and ecodistrict land classifications. Furthermore, we crossed this scheme with the network of provincial and federal protected areas to determine potential benchmark representation within land classes. Analysis focused on the number of sampling points in each land class obtained by using different densities of weighted (based on land class area), balanced, and mixed network designs. Evaluations of sample design suitability were based on generally acceptable numbers of replicates ($n \geq 15$), logistic, and financial constraints. The underlying large-scale spatial temporal variation for indicators were not part of this analysis. These were examined in a separate analysis and will be integrated with these results later.

All other sources of variation being equal, sample point density depended upon the desired degree of landbase resolution. A spatially weighted network with a 40 km grid of sample points provided representation at the ecoregion level. To resolve subregions, the maximum spacing allowable was 20 km while ecodistricts required a spacing of no more than 10 km. Balanced designs had the same number of sample points across all classes within a hierarchial level. Despite the attractiveness of potentially lower overall sample sizes, the design suffers from a number of drawbacks including; future changes to land class boundaries, poor representation of spatial variation in larger land classes, scaling between hierarchial levels of classification, and limitations on spatial analysis. A reasonable compromise was the mixed or partially weighted model. With this model, a weighted design would be used as the basic network with supplemental sites placed in land classes with lower than a minimum number of sites. This network had more sample points in larger land classes while maintaining a minimum number of sample points for smaller land classes. A review of monitoring programs in other jurisdictions suggests this is a common solution. For subregion and ecodistrict levels, a 20 km grid with supplemental sample points for small land classes was a reasonable balance between overall sample size and representation.

Protected areas formed a subset of the land classes within the land classification scheme. A 20 km grid provided 144 sample points within protected areas, and an overall ratio of 1:7.7 protected area to non-protected area sample points. However, the ratio varied greatly among subregions. Rocky Mountain and some Boreal subregions were the most equitable because of large national parks, while subregions in the Foothills and Canadian Shield ecoregions were extremely biased towards non-protected sample points. Like the previous analysis, one possible solution was to use a mixed design involving a base overlay of points derived from a 20 km grid with supplemental sample points within both protected and non-protected areas for subregions not attaining at least 15 or 25 sample points. Such a network would result in an overall sample sizes of 1,323 to 1,984 sample points and protected:non-protected ratios ranging from 1:4.5 to 1:5.0.

ACKNOWLEDGEMENTS

This report was sponsored and funded by the Sustainable Ecosystem Fund, Alberta Environment (AENV), Alberta Research Council, Foothills Model Forest, and Alberta Science and Research Authority. We are particularly indebted to AENV's Sustainable Ecosystem Research Users Group. GIS overlays were provided by Michael Gartrelle at Canadian Forest Service, Duke Hunter at Alberta Environment, and Daniel Farr at the Foothills Model Forest. Document production and editing support were provided by Patricia Soldan and Stephan Hanus.

INTRODUCTION

The primary goal of the Alberta Forest Biodiversity Monitoring Program (AFBMP) is the assessment of biodiversity indicators at a regional scale. Until now, the question of what regional scale has remained unanswered. A number of factors play into this decision. Biological factors include the scale of disturbances we wish to track, spatial and size distributions of ecological land classes, types of indicators, and their underlying spatial and temporal variation. Non-biological factors include administrative boundaries, financial and logistic considerations, and integration with other monitoring programs. To date the AFBMP has used a regular grid of points over the forested region of Alberta as a "straw-man" network of sample sites (Schneider 1997). This design provided a predictable, unbiased, and consistent sampling design for purposes of discussion. Through informal discussion with the technical committee, its merits and shortcomings have been examined. As the program moves from identification of indicators to development of logistic and financial models, the process of finalizing the sampling network needs to proceed.

The use of a regular grid network of sample sites has a number of important implications for ecological representation. Aside from logistic advantages of having a predictable pattern to sampling sites, the primary statistical advantage is that the systematic grid automatically weights sample sites according to area of land classes, i.e., a weighted distribution based on land area. All other sources of variation being equal, larger areas have a greater degree of spatial variation. This strength is also its greatest weakness. A high degree of variation among land classes leads to large land classes having many sites while small land classes having fewer sites. If grid spacing is too large or the variation between land classes is too great, then smaller land classes may have an insufficient number of samples to carry out comparisons within the land class or sufficiently represent the variation within the land class. To adequately represent smaller land classes, the grid spacing must be reduced, however, this leads to an increase in overall sampling intensity. At some point, further reductions of grid spacing with increasing sample size will overwhelm the financial and logistic capabilities and a grid design will no longer be practical.

In comparison, a balanced system places the same number of samples in each land class within a classification scheme. If the design is skewed towards a minimum sample within the small- or mid-sized land classes, then a lower total sample size may be required. Lower sample sizes make the program more attractive from a logistic and financial stand-point. However, it assumes that the underlying spatial variation in land classes is not related to area. This is unlikely to be true. One potential compromise is to weigh sample size according to land area, but to also have a higher density of samples within smaller land classes. This can be accomplished by either supplementing sample points within smaller land classes to a set minimum or using a smaller grid spacing within smaller land classes.

Protected areas represent a special subset of land classes. In developing most monitoring programs, protected areas are used as benchmarks where some types of land use are absent. However, protected areas vary in their degree of human disturbance. In all likelihood, protected areas will form the smallest land classes, hence, their size and distribution across land classes is likely to be a driving factor in network resolution and design.

The primary task in network design lies in ensuring adequate representation of the smallest land class while keeping the program logistically and financially tenable. This report explored the implications to ecological and benchmark representation of using weighted, balanced, or mixed networks. We evaluated each design to determine the coverage of ecoregion, subregion, and ecodistrict land classes. Furthermore, we examined the distribution and ratio of protected to non-protected area sample points for each design.

METHODS

Alberta's ecoregion, subregion, and ecodistrict land classification system were used in the analysis of ecological representation (Alberta Environmental Protection 1994; Strong and Thompson 1995). Its' hierarchial nature allows nested scaling between different regional scales. Also, it is well supported by available background data and GIS products. For these reasons, we chose to use this classification scheme for our analysis.

Ecoregions represent the coarsest scale of natural land classification and are delineated by their unique regional climate producing distinctive vegetation and site conditions (Fig. 1). These distinctive vegetation and site conditions are repeated throughout the ecoregion. Alberta has six ecoregions, of which the Boreal Forest, Foothills, Canadian Shield, and Rocky Mountain (except Alpine subregion) ecoregions form the forested landbase to be sampled by the AFBMP (Appendix 1).

Natural subregions represent a second, finer level of ecological classifications (Fig. 2). Subregions are subdivisions of ecoregions delineated by a combination of landforms, superficial materials, drainage, dominant soils, and vegetation. There are twenty subregions in Alberta with 12 subregions under consideration for monitoring (Appendix 1). Selection was based on the presence of closed forest over the majority of the subregion. This eliminated most Grassland and Parkland subregions, and the Alpine subregion from the Rocky Mountain ecoregion. The Foothills Parkland subregion is a potential candidate, however, much of the landbase has already been cleared with open forests dominating the remaining undisturbed landbase.

The finest level of landscape classification were ecodistricts (Fig. 3). Ecodistricts follow a similar but more detailed classification than subregions. This land class is regional and based primarily on local physiographic and/or geological patterns than subregion, e.g. flood plains, ridge complexes. There are 106 different types of ecodistricts in the AFBMP sample area. These vary greatly in size from the 59 to 22, 902 km^2 for the sub-Alpine of the Waterton Mountains and the Hay River Plains, respectively (Appendix 1).

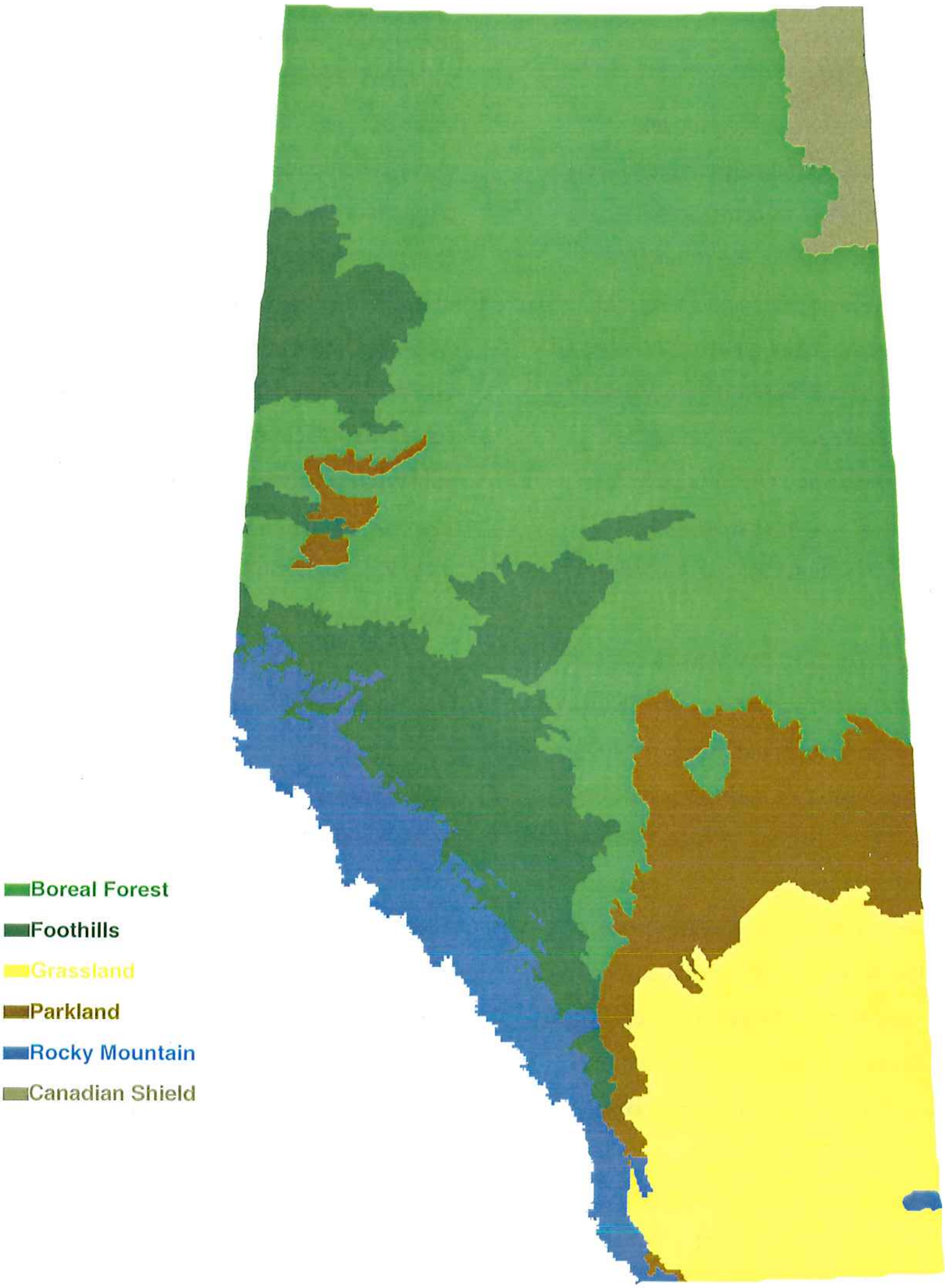

Figure 1 Ecoregions of Alberta.

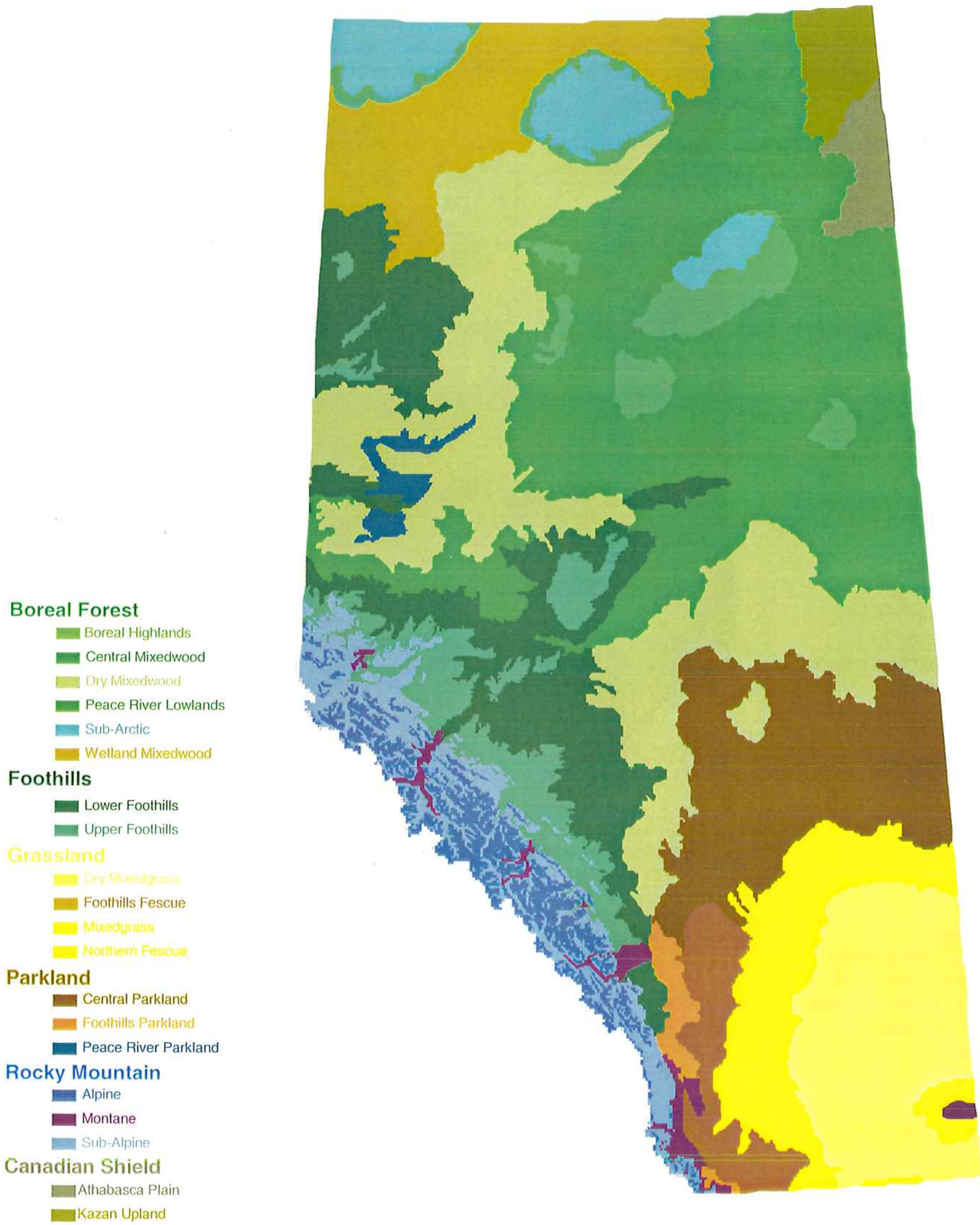

Figure 2 Subregions of Alberta.

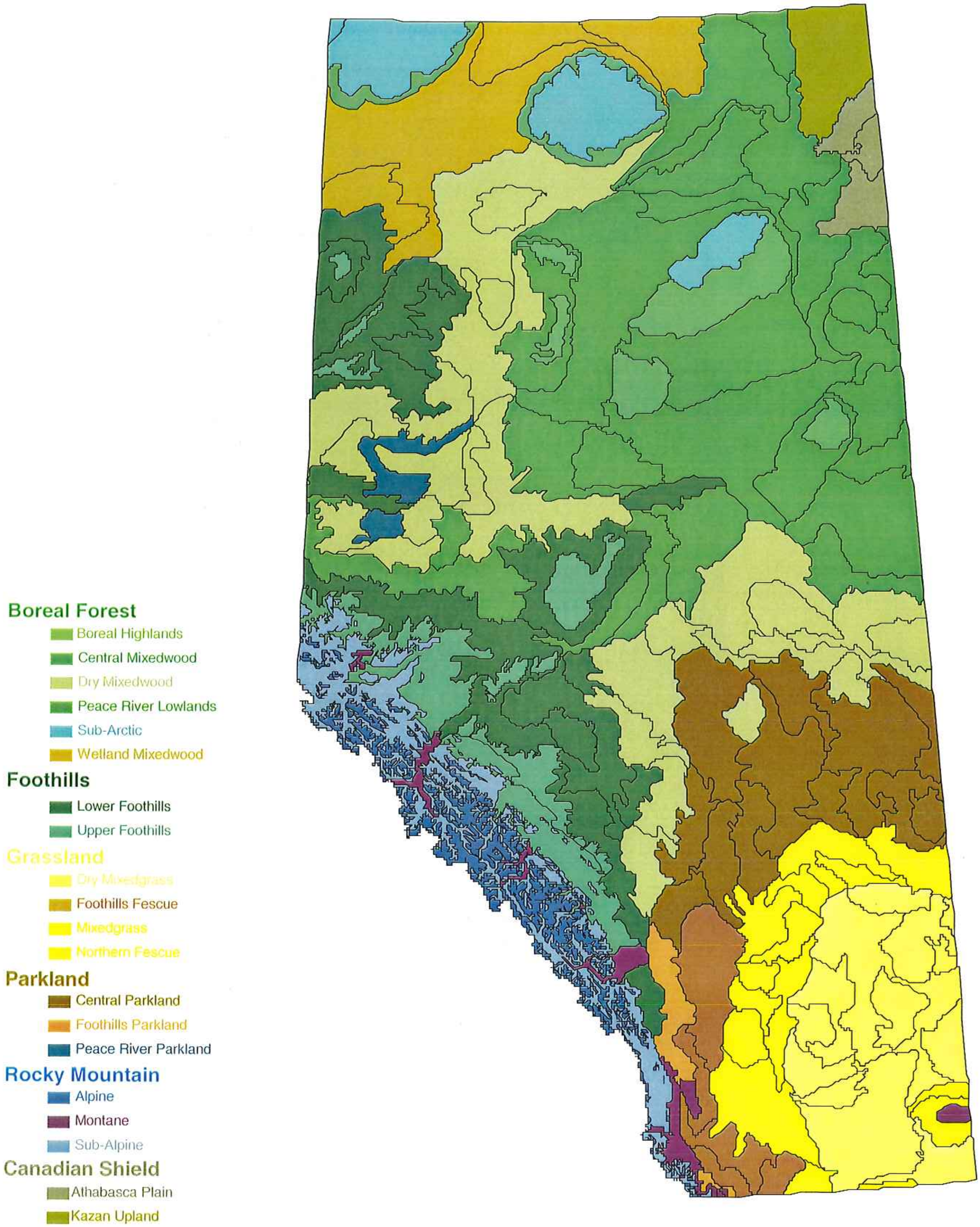

Figure 3 Ecodistricts of Alberta.

Boreal Forest

- Boreal Highlands
  - Birch Upland
  - Cameron Slope
  - Caribou Slope
  - Crow Lake Plain
  - Peerless Upland
  - Russell Upland
  - Wadlin Upland
- Central Mixedwood
  - Birch Fans
  - Buffalo Head Upland
  - Christina Plain
  - Cross Lake Upland
  - Embarras Plain
  - Firebag Hills
  - Fox Lake Plain
  - Freeman Upland
  - Garson Lake Plain
  - Hart Lake Plain
  - Heart River Upland
  - Hondo Plain
  - Iosegun Plain
  - Knight Creek Plain
  - Loon Lake Plain
  - Mackay Plain
  - Mostoos Upland
  - Muskeg Upland
  - Pinehurst Upland
  - Puskwaska Upland
  - Steepbank Plain
  - Stony Mountain Upland
  - Utikuma Plain
  - Wabasca Plain
- Dry Mixedwood
  - Athabasca Plain
  - Beaver River Plain
  - Beaverlodge Plain
  - Blueberry Upland
  - Boyer Plain
  - Breton Upland
  - Cache Plain
  - Caroline Plain
  - Cooking Lake Upland
  - Debolt Plain
  - Dunvegan Plain
  - Falher Plain
  - Frog Lake Upland
  - Grimshaw Plain
  - High Level Plain
  - Lac Ste Anne Upland
  - Manning Plain
  - McLennan Plain
  - Myrnam Upland
  - Onion Lake Plain
  - Redwater Plain
  - Rimbey Upland
  - Smoky Plain
  - Westlock Plain
  - Whitefish Upland
  - Worsley Plain
- Peace River Lowlands
  - Athabasca Delta
  - Salt River Plain
- Sub-Arctic
  - Cameron Hills Upland
  - Caribou Upland
  - North Birch Upland
- Wetland Mixedwood
  - Buffalo River Plain
  - Hay River Plain
  - Rainbow Lake Plain
  - Yates River Plain

Foothills

- Lower Foothills
  - Blueridge Upland
  - Bragg Creek Foothills
  - Chinchaga Plain
  - Clear Hills Upland
  - Cutbank Upland
  - Cynthia Upland
  - Driftpile Upland
  - Edson Plain
  - Milligan Upland
  - Notikewin Plain
  - Obed Upland
  - O'Chiese Upland
  - Pelican Upland
  - Saddle Upland
  - Winfield Upland
- Upper Foothills
  - Berland Upland
  - Clear Hills Upland
  - Mayberne Upland
  - Milligan Upland
  - Ram River Foothills
  - Swan Hills
  - Wolf Lake Upland

Grassland

- Dry Mixedgrass
  - Acadia Valley Plain
  - Berry Creek Plain
  - Bindloss Plain
  - Bow City Plain
  - Brooks Plain
  - Foremost Plain
  - Oyen Upland
  - Purple Springs Plain
  - Rainy Hills Upland
  - Schuler Plain
  - Sibbald Plain
  - Sounding Creek Plain
  - Vauxhall Plain
  - Wild Horse Plain
- Foothills Fescue
  - Cardston Plain
  - Del Bonita Plateau
  - Delacour Plain
  - Twin Butte Foothills
  - Willow Creek Upland
- Mixedgrass
  - Blackfoot Plain
  - Cypress Hills
  - Cypress Slope
  - Lethbridge Plain
  - Majorville Upland
  - Milk River Upland
  - Standard Plain
  - Sweetgrass Upland
  - Vulcan Plain
- Northern Fescue
  - Castor Plain
  - Drumheller Plain
  - Endiang Upland
  - Neutral Hills
  - Sullivan Lake Plain
  - Wintering Hills

Parkland

- Central Parkland
  - Andrew Plain
  - Bashaw Upland
  - Daysland Plain
  - Leduc Plain
  - Lloydminster Plain
  - Olds Plain
  - Pine Lake Upland
  - Provost Plain
  - Red Deer Plain
  - Ribstone Plain
  - Sedgewick Plain
  - Vermilion Upland
- Foothills Parkland
  - Black Diamond Upland
  - Blairmore Foothills
- Peace River Parkland
  - Grande Prairie Plain
  - Rycroft Plain

Rocky Mountain

- Alpine
  - Banff Mountains
  - Crowsnest Mountains
  - Icefield Mountains
  - Jasper Mountains
  - Luscar Foothills
  - Waterton Mountains
  - Willmore Foothills
- Montane
  - Banff Mountains
  - Blairmore Foothills
  - Cypress Hills
  - Jasper Mountains
  - Morley Foothills
  - Willmore Foothills
- Sub-Alpine
  - Banff Mountains
  - Berland Upland
  - Crowsnest Mountains
  - Jasper Mountains
  - Luscar Foothills
  - Ram River Foothills
  - Waterton Mountains
  - Willmore Foothills

Canadian Shield

- Athabasca Plain
  - Athabasca Dunes
  - Carswell Plain
  - Lake Athabasca
- Kazan Upland
  - Uranium City Upland

Figure 3….continued

A base 10 km grid was provided by Canadian Forest Service and was derived from the 20 km grid proposed for the National Forest Inventory (J.S. Thrower and Associates 1998). Larger grid spacings, e.g. 40 km, were produced by selectively eliminating appropriately spaced points from the 10 km grid while the 5 km grid was produced by adding points.

To determine the number of sample points in a land class, classification maps were overlaid with the grid of sample points. The identity of the land class was recorded for each sample point. Overlaying maps and sampling grids was accomplished using ARC/INFO (Version 7.1, Environmental Systems Research Institute, Inc. 1997). In overlaying some of the maps, boundaries frequently did not match. These inconsistencies resulted in very small (<0.05%) changes to the areas being examined. Furthermore, boundaries tended to intertwine, hence, differences tended to "average out" over the whole polygon. Due to their relatively small size, these boundary discrepancies were ignored in further analysis.

To compare the overall sample sizes obtained by weighted and balanced networks, we applied different grid spacings to each level of the land classification and compared those results to different sample sizes for each land class. At the subregion level, we stratified all land classes with 50 and 100 sites each while sampling intensities of 15, 25, and 35 sites were applied to ecodistricts.

We examined two types of mixed systems. In one system, land classes had a minimum number of sites, otherwise the number of sites would be determined by the area of the land class. At the subregion level, we applied a minimum of 100 samples under a 20 km spacing and a minimum of 25 samples under a 40 km spacing. At the ecodistrict level, we applied a minimum of 100 samples to a 20 km spacing and a minimum of 25 samples to a 40 km spacing. The other mixed system utilized a decreased grid spacing in smaller land classes. Combinations of 10 and 20 km spacing was used for subregions having fewer than 100 and 25 sample points under 20 and 40 km spacing, respectively.

Our GIS database for protected areas was obtained from Alberta Environment (provided October 1999). It does not contain the proposed Special Places 2000 sites for Alberta. Due to the relatively small area, spatially weighted analysis was based on 10 and 20 km grids. We also applied a balanced model with 25 sites in protected areas and 100 sites in non-protected areas. Mixed networks with 10 km grid with 50 and 25 site minimums and 20 km grid with 25 and 15 site minimums were applied at the subregion level. An alternative mixed network using a base 10 km grid with a 5 km grid over protected areas with fewer than 25 sites was also examined.

RESULTS

Ecological Representation

Using a grid network of sites, the total number of samples for the forested subregions of Alberta ranged from 4,885 to 137 sites for spacings of 10 km and 60 km, respectively (Figs. 4-6; Table 1). The number of sites increased exponentially with decreasing grid spacing. The smallest ecoregion, the Canadian Shield, supported 39, 10, and 4 sites at spacings of 20, 40, and 60 km, respectively. Conversely, the Boreal Forest, the largest ecoregion, supported 867, 217, and 97 sites at grid spacings of 20, 40, and 60 km respectively. If a minimum of 15 sample points were required for reporting at the ecoregion level, a maximum grid spacing between 20 and 40 km could be tolerated.

To resolve trends at the finer subregion level, we required a greater density of points due to the relatively smaller size of these land classes. Only six of twelve subregions had greater than 15 sample points with a spacing of 40 km. A smaller grid spacing of 20 km was required to produce sample sizes of 15 and 17 in the smallest subregions, the Montane and Athabasca Plain, respectively. The 20 km spacing produced a total of 1,222 sites over the forested subregions of Alberta (Fig. 5).

At the level of ecodistricts, a grid spacing of 20 km resulted in 43.4% (n=46) of ecodistricts having less than 15 sample points. Only three subregions, Sub-Arctic, Wetland Mixedwood, and Kazan Upland, had 15 or more sample points in all their ecodistricts (Table 2). This number increased to 89.6% (n=95) with a grid spacing of 10 km (Fig. 6). As with all other analyses, the smallest land classes had the least sites. In general, mountainous ecodistricts had the fewest sample points. Cypress Hills, Waterton Mountains, Ram River Foothills, Banff Mountains, and the Willmore Foothills had less than 15 sites. These areas were smaller and more dissected than other ecodistricts. Not surprisingly, larger grid spacings or a requirement for more sample points reduced the percentage of ecodistricts meeting a minimum number of sample points (Table 2). As an example, only 21.2% of ecodistricts had a minimum sample size of 20 or more points with a 20 km grid. To achieve a sample size of at least 15 sites in all ecodistricts, we would require a spacing of 5 km. Such a grid spacing would, in all likelihood, be

Table 1 Number of sample points for varying densities of different sampling networks applied over the forested ecoregions and subregions of Alberta. Numbers of samples in the weighted design were based on grids varying from 10 to 60 km. The balanced design placed 100 and 25 sites per subregion. The mixed 20 and 40 km designs were grid networks with sites added to smaller land classes to produce a minimum of 100 and 25 sites per subregion, respectively. The 10-20 and 20-40 km mixed networks were smaller grids embedded into larger grids. A 10 km network was embedded into 20 km grid for subregions with fewer than a 100 sites under the larger network. A 20 km network was embedded into a 40 km network for subregions with fewer than 25 sites.

Ecoregion	Subregion	Weighted 10 km	Weighted 20 km	Weighted 40 km	Weighted 60 km	Balanced N=100	Balanced N=25	Mixed 20 km	Mixed 40 km	Mixed 10-20 km	Mixed 20-40 km
Boreal Forest	Boreal Highlands	209	53	13	6	100	25	100	25	209	53
Boreal Forest	Central Mixedwood	1,539	387	97	43	100	25	387	97	387	97
Boreal Forest	Dry Mixedwood	1,003	251	63	28	100	25	251	63	251	63
Boreal Forest	Peace River Lowlands	102	25	6	3	100	25	100	25	102	25
Boreal Forest	Sub-Arctic	228	55	14	6	100	25	100	25	228	55
Boreal Forest	Wetland Mixedwood	385	96	24	11	100	25	100	25	385	96
Subtotal		**3,466**	**867**	**217**	**97**	**600**	**150**	**1,038**	**260**	**1,562**	**379**
Canadian Shield	Athabasca Plain	67	17	4	2	100	25	100	25	67	17
Canadian Shield	Kazan Upland	92	22	6	2	100	25	100	25	92	22
Subtotal		**159**	**39**	**10**	**4**	**200**	**50**	**200**	**50**	**159**	**39**
Foothills	Lower Foothills	681	168	42	19	100	25	168	42	168	42
Foothills	Upper Foothills	265	69	17	8	100	25	100	25	265	69
Subtotal		**946**	**237**	**59**	**27**	**200**	**50**	**268**	**67**	**433**	**101**
Rocky Mountain	Montane	63	15	4	2	100	25	100	25	63	15
Rocky Mountain	Sub-Alpine	251	64	16	7	100	25	100	25	251	64
Subtotal		**314**	**79**	**20**	**9**	**200**	**50**	**200**	**50**	**314**	**79**
Grand Total		**4,885**	**1,222**	**306**	**137**	**1,200**	**300**	**1,706**	**427**	**2,468**	**599**
Mean plots per subregion		**407**	**102**	**26**	**11**	**100**	**25**	**142**	**36**	**206**	**50**
Coefficient of Variation		**111**	**112**	**112**	**111**	**0**	**0**	**59**	**63**	**54**	**55**

Table 2 Percentage of ecodistricts having at least 15 and 25 sites using spatially weighted grids.

Ecoregions	Subregions	No. of Ecodistricts	10 km 15 sites	20 km 15 sites	40 km 15 sites	60 km 15 sites	10 km 25 sites	20 km 25 sites	40 km 25 sites
									0
Boreal Forest	Boreal Highlands	7	100	14	0	0	57	14	0
Boreal Forest	Central Mixedwood	24	100	71	8	0	88	25	0
Boreal Forest	Dry Mixedwood	26	100	27	0	0	77	12	0
Boreal Forest	Peace River Lowlands	2	100	50	0	0	100	50	0
Boreal Forest	Sub-Arctic	3	100	100	0	0	100	67	0
Boreal Forest	Wetland Mixedwood	4	100	100	25	0	100	25	0
% Ecodistricts		**66**	**100.0**	**50.0**	**4.5**	**0.0**	**81.8**	**21.2**	**0.0**
Canadian Shield	Athabasca Plain	3	100	0	0	0	67	0	0
Canadian Shield	Kazan Upland	1	100	100	0	0	100	100	0
%Ecodistricts		**4**	**100.0**	**25.0**	**0.0**	**0.0**	**75.0**	**25.0**	**0.0**
Foothills	Lower Foothills	15	100	53	0	0	80	27	0
Foothills	Upper Foothills	7	86	29	0	0	57	14	0
% Ecodistricts		**22**	**95.5**	**45.5**	**0.0**	**0.0**	**72.7**	**22.7**	**0.0**
Rocky Mountain	Montane	6	33	0	0	0	17	0	0
Rocky Mountain	Sub-Alpine	8	25	25	0	0	25	25	0
% Ecodistricts		**14**	**28.6**	**14.3**	**0.0**	**0.0**	**21.4**	**14.3**	**0.0**
% Overall Ecodistricts		**106**	**89.6**	**43.4**	**2.8**	**0.0**	**71.7**	**20.8**	**0.0**

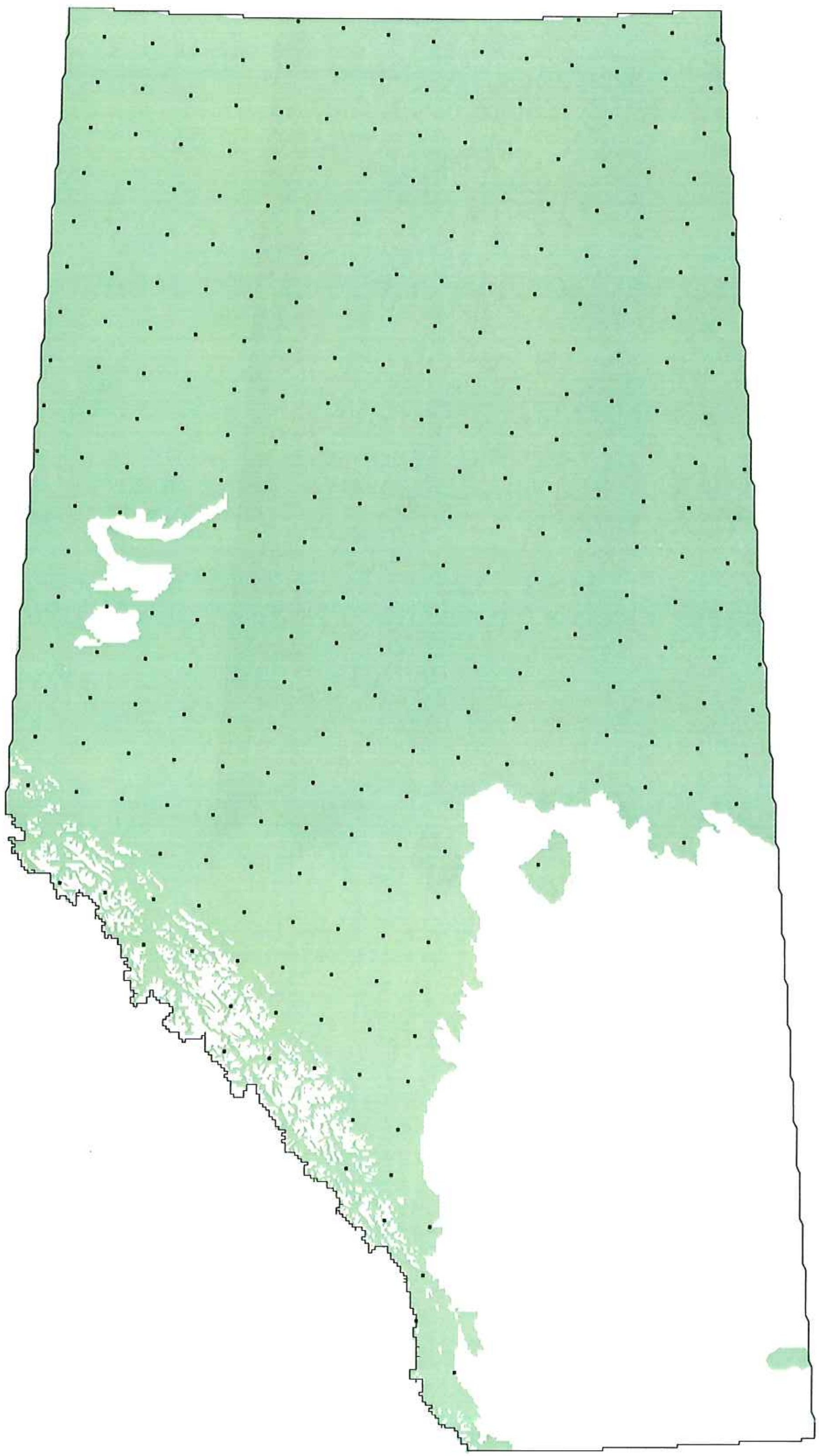

Figure 4 Forested subregions of Alberta overlaid with a 40 km sampling grid.

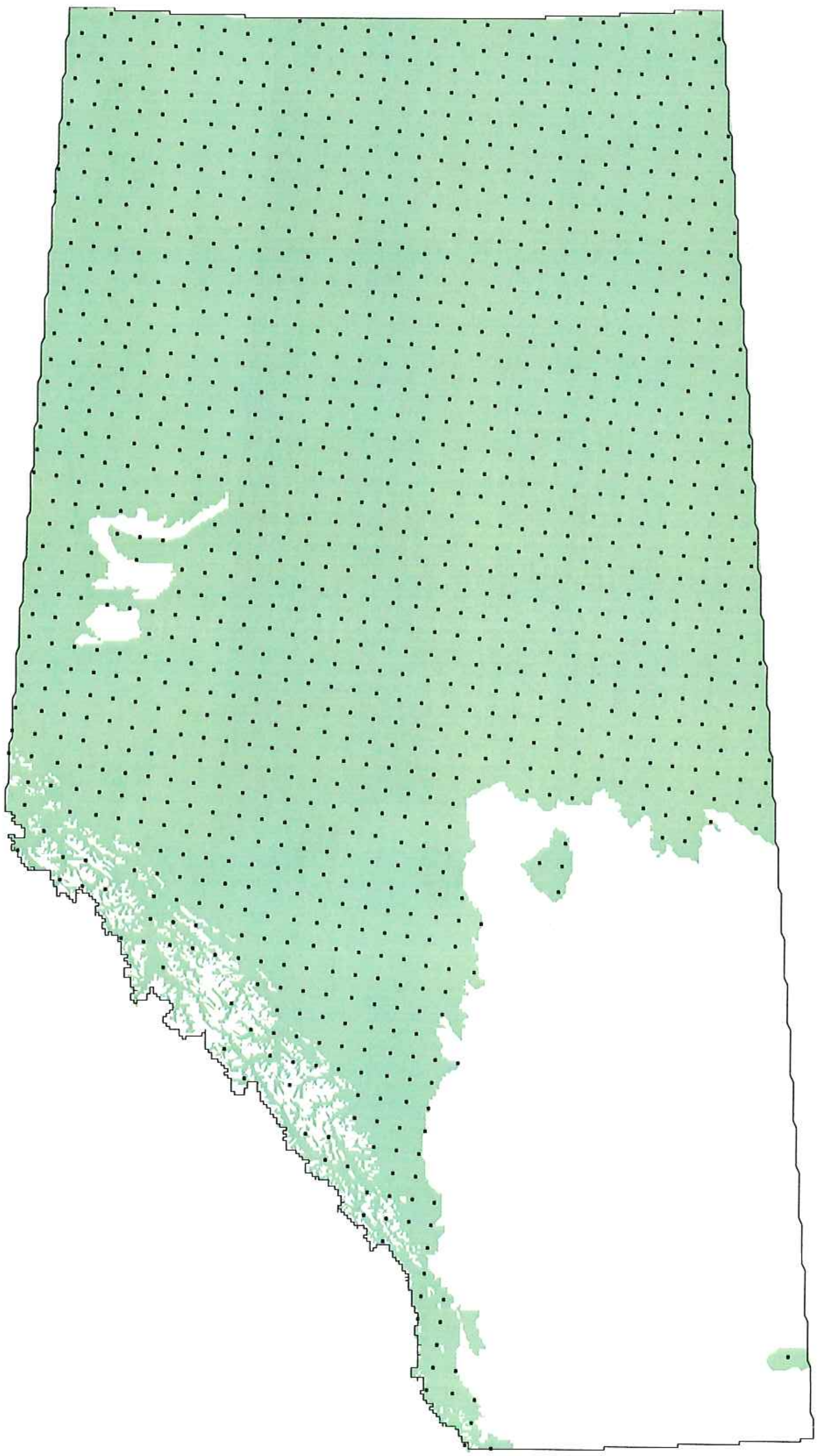

Figure 5 Forested subregions of Alberta overlaid with a 20 km sampling grid.

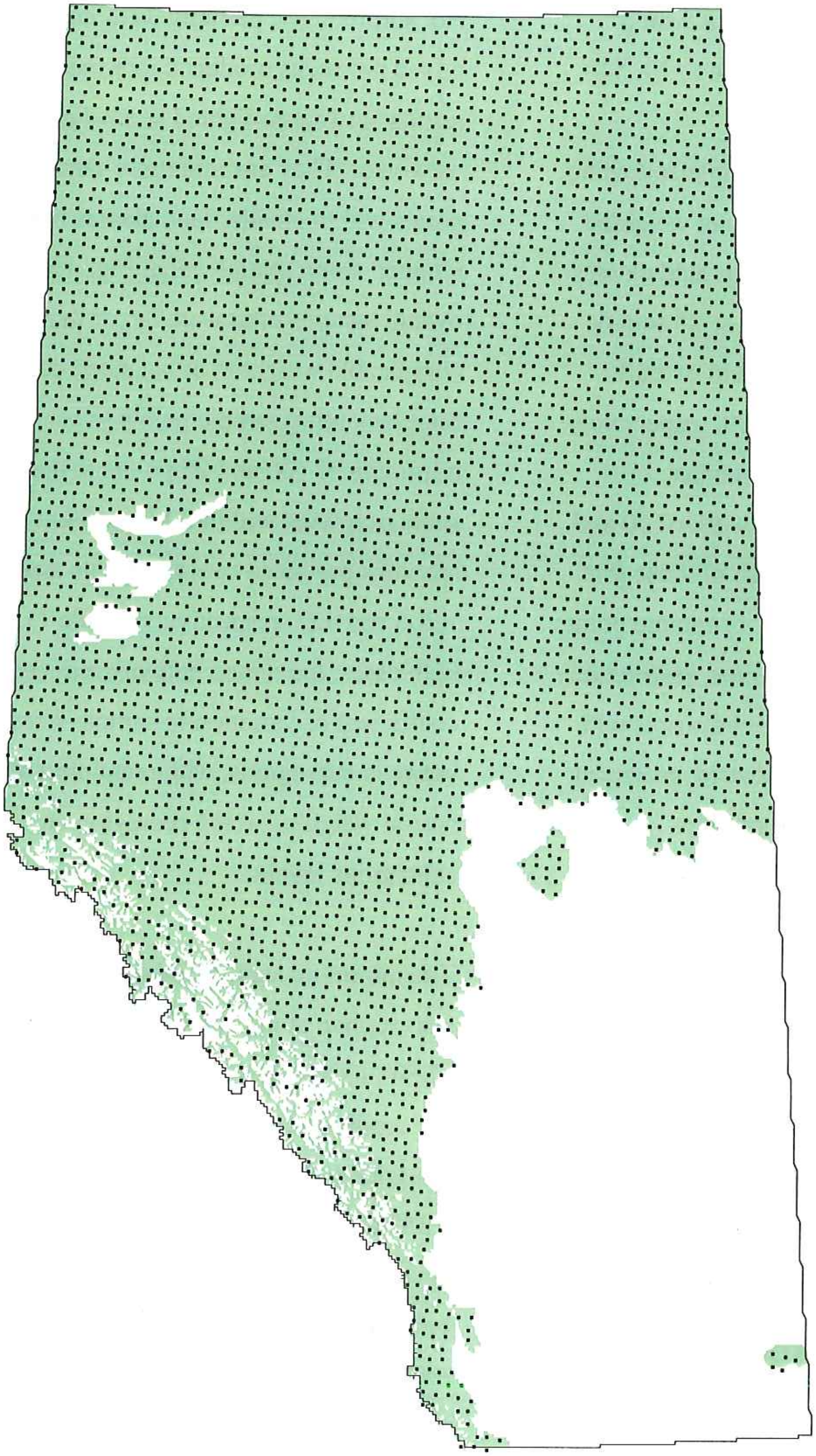

Figure 6 Forested subregions of Alberta overlaid with a 10 km sampling grid.

logistically unacceptable since it would increase the overall sample size to 19, 540.

In general, the overall sampling effort using balanced networks was less than weighted networks spread across similar land classes (Table 1). Placement of 100 or 25 sample points per subregion resulted in overall sample sizes of 1,200 and 300, respectively. This overall density was somewhat comparable to weighted network of 40 and 20 km, respectively. At each of these grid spacings, the mean number of sample points were 26 and 102 sample points, respectively. A balanced design within ecodistricts with 15, 25, or 35 sites per ecodistrict produced 1,590, 2,650, and 3,710 total sites, respectively (Table 3).

It is important to note that balancing sample sizes at one level of ecological classification does not create a balanced design at other levels. As an example, 100 sites placed in each subregion produced 600 sites in the Boreal ecoregion, but only produced 200 sites in other ecoregions (Table 3). At a finer resolution, 100 sites per subregion placed four sites per ecodistrict within the Dry Mixedwood subregion, but 33 sites per ecodistrict across the Athabasca Plain.

Not surprisingly, partially weighted or mixed networks produced intermediate results between weighted and balanced networks. They ensured more sampling points within smaller land classes but retained some spatial weighting. However, overall sample sizes were larger than comparable weighted or balanced designs. Supplementing sample points to achieve a minimum of 100 and 25 points at the subregion level within 20 and 40 km grid spacings produced overall sample sizes of 1,706 and 427, respectively (Table 1). In both cases, the mixed network reduced the coefficient of variation in sample sizes between subregions, while retaining the spatial weighing at the ecoregion and subregions levels.

The minimum sample, mixed design was also applied at the ecodistrict level. Minimum sample sizes of 25 and 15 sites per ecodistrict supplementing the 10 and 20 km grids produced overall sample sizes of 5,352 and 1,893, respectively (Table 3). Of the designs presented, the use of a mixed 20 km grid with a minimum of 15 sites per ecodistrict was probably the most reasonable method of sampling to the ecodistrict level.

Table 3 Number of sites within ecoregions, and subregions using balanced and mixed sampling designs. Balanced designs placed 15, 25, and 35 samples in each ecodistrict. Mixed 10 or 20 km networks placed a minimum of 25 and 15 sites per ecodistrict, respectively. Mixed grids placed a smaller grid (5 or 10 km) into a larger grid (10 or 20 km) for ecodistricts with fewer than 15 and 25 sites, respectively.

Ecoregion	Subregion	# of Ecodistricts	Balanced n=15	Balanced n=25	Balanced n=35	Mixed 10 km	Mixed 20 km	Mixed 5-10 km	Mixed 10-20 km
Boreal Forest	Boreal Highlands	7	105	175	245	253	111	387	149
Boreal Forest	Central Mixedwood	24	360	600	840	1,571	478	1,696	790
Boreal Forest	Dry Mixedwood	26	390	650	910	1,077	430	1,673	660
Boreal Forest	Peace River Lowlands	2	30	50	70	105	35	165	41
Boreal Forest	Sub-Arctic	3	45	75	105	219	61	219	84
Boreal Forest	Wetland Mixedwood	4	60	100	140	384	102	38	166
Subtotal		**66**	**990**	**1,650**	**2,310**	**3,609**	**1,217**	**4,524**	**1,890**
Canadian Shield	Athabasca Plain	3	45	75	105	82	45	177	68
Canadian Shield	Kazan Upland	1	15	25	35	90	22	90	22
Subtotal		**4**	**60**	**100**	**140**	**172**	**67**	**267**	**90**
Foothills	Lower Foothills	15	225	375	525	716	253	992	366
Foothills	Upper Foothills	7	105	175	245	321	118	361	147
Subtotal		**22**	**330**	**550**	**770**	**1,037**	**371**	**1,353**	**513**
Rocky Mountain	Montane	6	90	150	210	151	90	136	60
Rocky Mountain	Sub-Alpine	8	120	200	280	383	148	335	85
Subtotal		**14**	**210**	**350**	**490**	**534**	**238**	**98**	**15**
Grand Total		**106**	**1,590**	**2,650**	**3,710**	**5,352**	**1,893**	**6,642**	**2,638**

The alternative mixed design using 10-20 and 20-40 km grids produced overall sample sizes of 2,468 and 599 sites, respectively (Table 3). With both mixed grids, the density of sample points in smaller land classes was increased by a factor of four. Mixed grid systems were very sensitive to the threshold value used to implement the smaller grid spacing. As an example, the use of a 100 site per subregion threshold with the 10-20 km design reduced the overall weighting given to larger land classes with many smaller land classes having a similar number of points. Wetland Mixedwoods had 385 sample points, while a much larger subregion, such as the Central Mixedwoods, had 387. Whereas, a criteria of 50 sites would have produced only 96 sites in the Wetland Mixedwoods. Ideally, the threshold should be set at a value less than ¼ of the number of points in the largest land class.

Protected Areas

Protected areas formed a subset of the ecological representation at larger land classes. Using a 10 km grid, 560 sites were placed within protected areas while a 20 km grid placed 144 sites (Tables 4 and 5). Using 10 or 20 km grids, the overall ratios of protected to non-protected sites were 1:7.7 or 1:7.5, respectively. However, there was a great deal of variation among ecoregions and subregions. The presence of large national parks increased protected areas representation in the Rocky Mountain and some subregions of the boreal ecoregion. Indeed, Jasper, Banff, and Wood Buffalo national parks accounted for ~80% of protected area sites (Fig. 7). Subregions associated with these parks had the lowest ratios ranging from 0.3:1.0 to 1:2.3 (Table 4). The low ratio of the Boreal ecoregion was due largely to sample points from the Wetland Mixedwoods and Peace River Lowlands subregions. These subregions have large areas within Wood Buffalo National Park. Much higher ratios (range 1:12.8 to 1:124.5) were noted in the

Table 4 Ratio of sites within protected areas (PA) to non-protected areas (NPA) for a 10 km grid overlaid on ecoregions and subregions of Alberta. A weighted mean (by subregion area) is given for each ecoregion. The mixed 25 design was based on a 10 km grid with protected and non-protected areas supplemented to minimum of 25 sites per subregion. The mixed 5-10 km design applied a 5 km grid to supplement sites onto a 10 km network in subregions with fewer than 25 sites.

Ecoregion	Subregion	10 km PA Sites	10 km NPA Sites	10 km Ratio	Mixed 25 PA Sites	Mixed 25 NPA Sites	Mixed 25 Ratio	Mixed 5-10 PA Sites	Mixed 5-10 NPA Sites	Mixed 5-10 Ratio
Boreal Forest	Boreal Highlands	9	200	22.2	25	200	8.0	37	200	5.4
Boreal Forest	Central Mixedwood	205	1,334	6.5	205	1334	6.5	205	1334	6.5
Boreal Forest	Dry Mixedwood	10	993	99.3	25	993	39.7	39	993	25.5
Boreal Forest	Peace River Lowlands	76	26	0.3	76	26	0.3	76	26	0.3
Boreal Forest	Sub-Arctic	13	215	16.5	25	215	8.6	52	215	4.1
Boreal Forest	Wetland Mixedwood	84	301	3.6	84	301	3.6	84	301	3.6
Subtotals/Ratios		**397**	**3,069** **3,466**	**7.7**	**440**	**3,069** **3,509**	**7.0**	**493**	**3,069** **3,562**	**6.2**
Canadian Shield	Athabasca Plain	1	66	66.0	25	66	2.6	4	66	16.5
Canadian Shield	Kazan Upland	10	82	8.2	25	82	3.3	41	82	2.0
Subtotals/Ratios		**11**	**148** **159**	**13.5**	**50**	**148** **198**	**3.0**	**46**	**148** **198**	**3.2**
Foothills	Lower Foothills	6	675	112.5	25	675	27.0	24	675	28.1
Foothills	Upper Foothills	2	263	131.5	25	263	10.5	8	263	32.9
Subtotals/Ratios		**8**	**938** **946**	**117.3**	**50**	**938** **988**	**18.8**	**32**	**938** **970**	**29.3**
Rocky Mountain	Montane	19	44	2.3	25	44	1.8	73	44	0.6
Rocky Mountain	Sub-Alpine	125	126	1.0	125	126	1.0	125	126	1.0
Subtotals/Ratios		**144**	**170** **314**	**1.2**	**150**	**170** **320**	**1.1**	**198**	**170** **368**	**0.9**
Grand Totals /Ratios		**560**	**4,325** **4,885**	**7.7**	**690**	**4,325** **5,015**	**6.3**	**719**	**4,325** **5,044**	**6.0**

Table 5 Ratio of sites within protected areas (PA) to non-protected areas (NPA) for a 20 km grid overlaid on ecoregions and subregions of Alberta. A weighted mean (by subregion area) is given for each ecoregion. The mixed 25 design was based on a 20 km grid with protected areas supplemented to a minimum of 25 sites and non-protected areas supplemented to minimum of 100 sites per subregion. The mixed 5-10 km design applied a 10 km grid to supplement a 20 km over subregions that had fewer than 25 sites.

Ecoregion	Subregion	20 km PA	20 km NPA	20 km Ratio	Mixed 25 PA	Mixed 25 NPA	Mixed 25 Ratio	Mixed 10-20 PA Sites	Mixed 10-20 NPA Sites	Mixed 10-20 Ratio
Boreal Forest	Boreal Highlands	2	51	25.5	25	100	4.0	9	51	5.7
Boreal Forest	Central Mixedwood	50	337	6.7	50	337	6.7	50	337	6.7
Boreal Forest	Dry Mixedwood	2	249	124.5	25	249	10.0	10	249	24.9
Boreal Forest	Peace River Lowlands	19	6	0.3	25	100	4.0	76	26	0.3
Boreal Forest	Sub-Arctic	4	51	12.8	25	100	4.0	13	51	3.9
Boreal Forest	Wetland Mixedwood	21	75	3.6	25	100	4.0	84	75	0.9
Subtotals/Ratios		**98**	**769**	**7.8**	**175**	**986**	**5.6**	**242**	**789**	**3.2**
			867			**1,161**			**1,031**	
Canadian Shield	Athabasca Plain	1	16	16.0	25	100	4.0	1	66	66.0
Canadian Shield	Kazan Upland	3	19	6.3	25	100	4.0	10	82	8.2
Subtotals/Ratios		**4**	**35**	**8.8**	**50**	**200**	**4.0**	**11**	**128**	**11.6**
			39			**250**			**139**	
Foothills	Lower Foothills	1	167	167.0	25	167	6.7	6	167	27.8
Foothills	Upper Foothills	1	68	68.0	25	100	4.0	2	68	34.0
Subtotals/Ratios		**2**	**235**	**1,17.5**	**50**	**267**	**5.3**	**8**	**235**	**29.3**
			237			**317**			**243**	
Rocky Mountain	Montane	5	10	2.0	25	100	4.0	19	44	2.3
Rocky Mountain	Sub-Alpine	31	33	1.1	31	100	3.2	31	33	1.1
Subtotals/Ratios		**36**	**43**	**1.2**	**56**	**200**	**3.6**	**50**	**77**	**1.5**
			79			**256**			**127**	
Grand Totals /Ratios		**144**	**1,082**	**7.5**	**331**	**1,653**	**5.0**	**311**	**1,229**	**4.0**
			1,222			**1,984**			**1,540**	

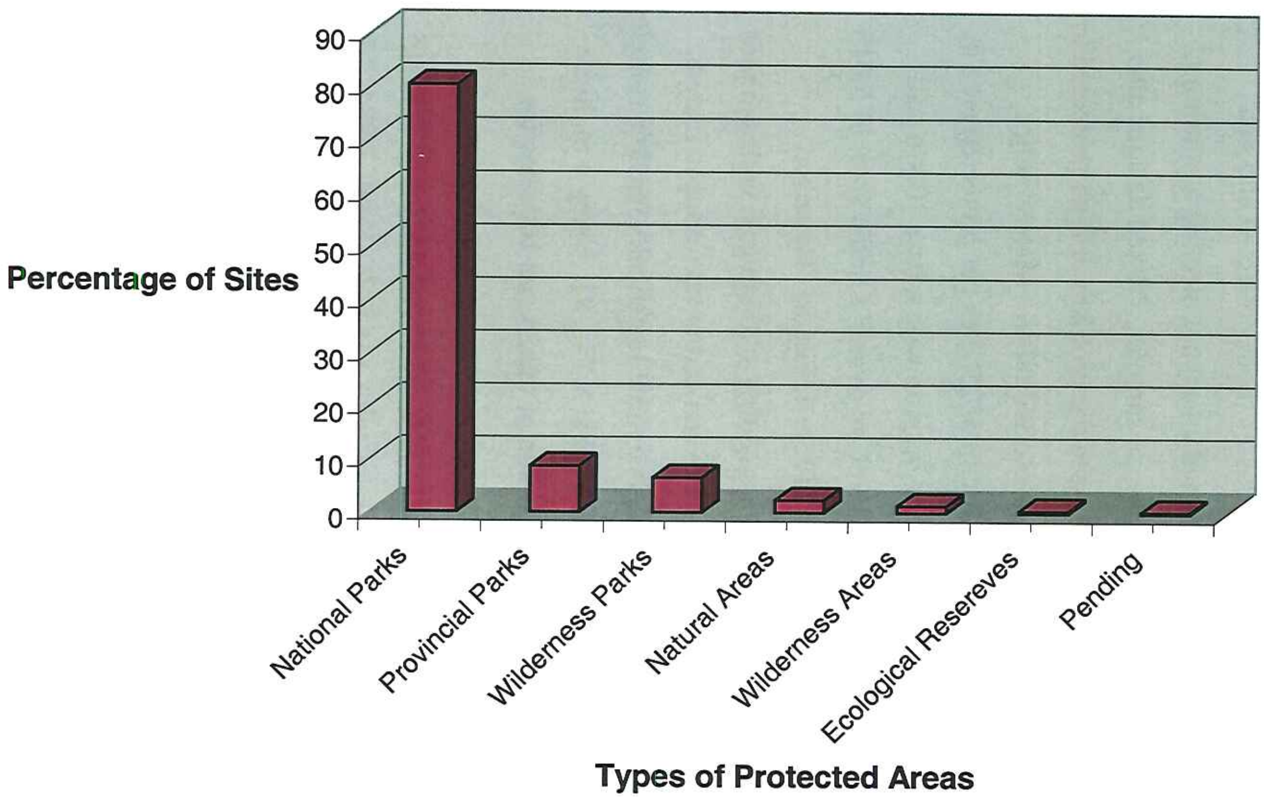

Figure 7 Percentage of protected areas sample points across with a 20 km spatially weighted network.

remaining boreal subregions, such as Sub-Arctic, Boreal Highlands, and Dry Mixedwoods. The highest overall ratios were found in the Foothills ecoregion. Lower and Upper Foothills subregions had protected areas:non-protected areas ratios of 1:167 and 1:68, respectively, using a 20 km grid spacing.

As with the previous analysis, spatially weighted networks allocated sites in proportion to the size of protected areas within a land class. In general, weighted designs did not lead to sufficient sample sizes for analysis. Ten and twenty kilometer spacing produced fewer than 15 sample points within protected areas for 50% and 67% of forested subregions, respectively.

A balanced design produced, by definition, an equal number of sample points across all sites. Furthermore, the design could be balanced to provide a constant ratio of protected to non-protected sample points. The overall sample size depended upon the desired ratio of protected to non-protected sites. For example to achieve a ratio 1:4 with a baseline of 100 non-protected sites within each subregion, we would require an additional 25 protected sites for each subregion. The overall sample size would be 1,500.

A possible solution for the uneven representation of protected areas is to again use partially weighted or mixed designs. Sample points were supplemented to those land classes (both protected and non-protected areas) not meeting a minimum number of samples. Mixed designs also addressed the problem of high protected to non-protected ratios. Maintaining a minimum of 25 sites per protected area in each subregion with a base 10 km grid produced an overall sample sizes of 5,015 sites (Table 4, Fig. 8). However, supplementing a 20 km grid with samples for protected and/or non-protected areas produced more logistically feasible sample sizes (Table 5, Fig. 9). Using a multiple minimum of the 25 and 100 sites for protected and non-protected areas, respectively, an overall ratio of 1:5.0 was achieved with a sample size of 1,984. More importantly, the variation in the ratios among subregions was reduced.

Using mixed grids of 5-10 km and 10-20 km produced results intermediate between the weighted and balanced designs. In general,

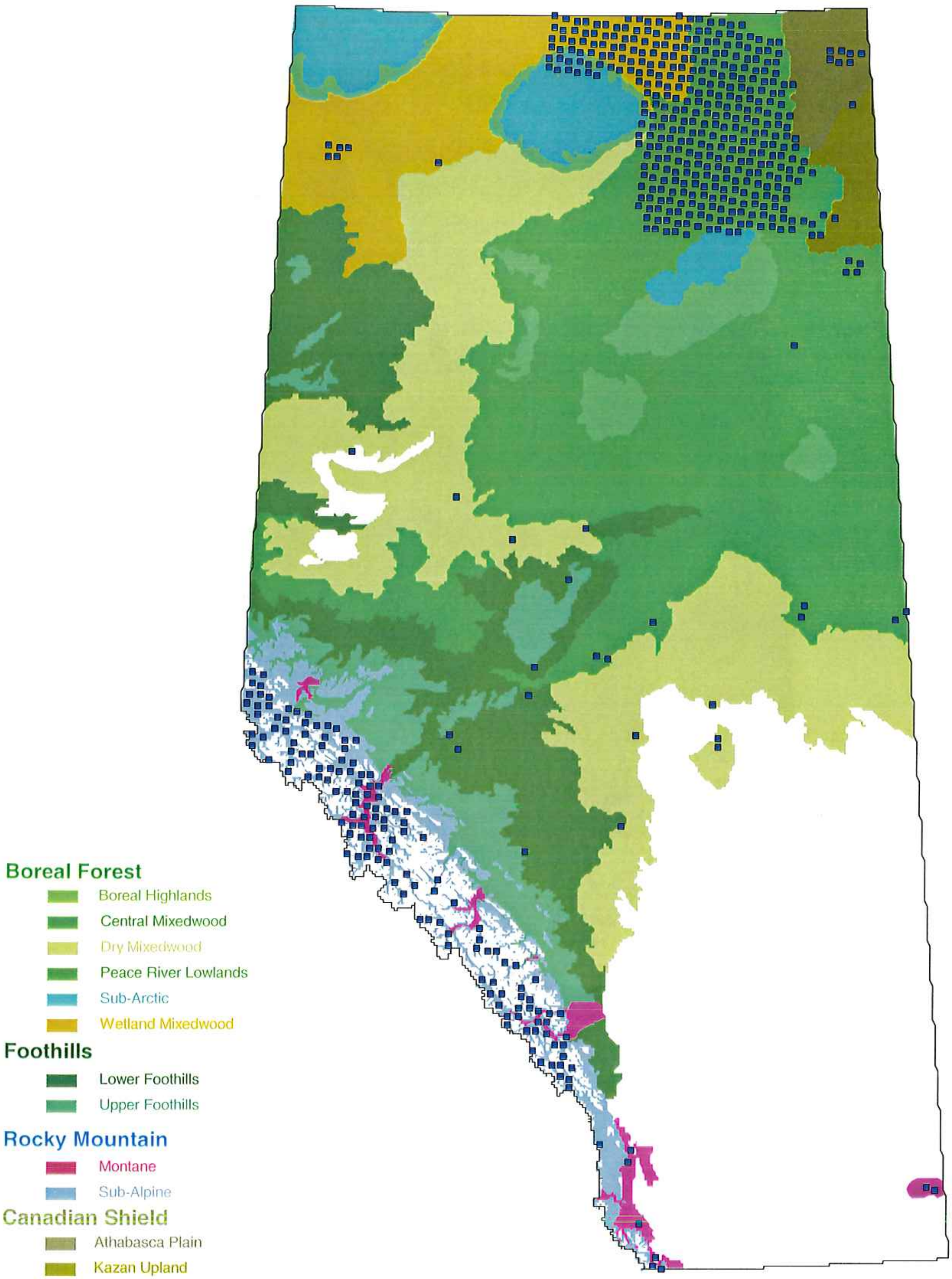

Figure 8 A 10 km grid overlaid on the protected areas within the forested subregions of Alberta.

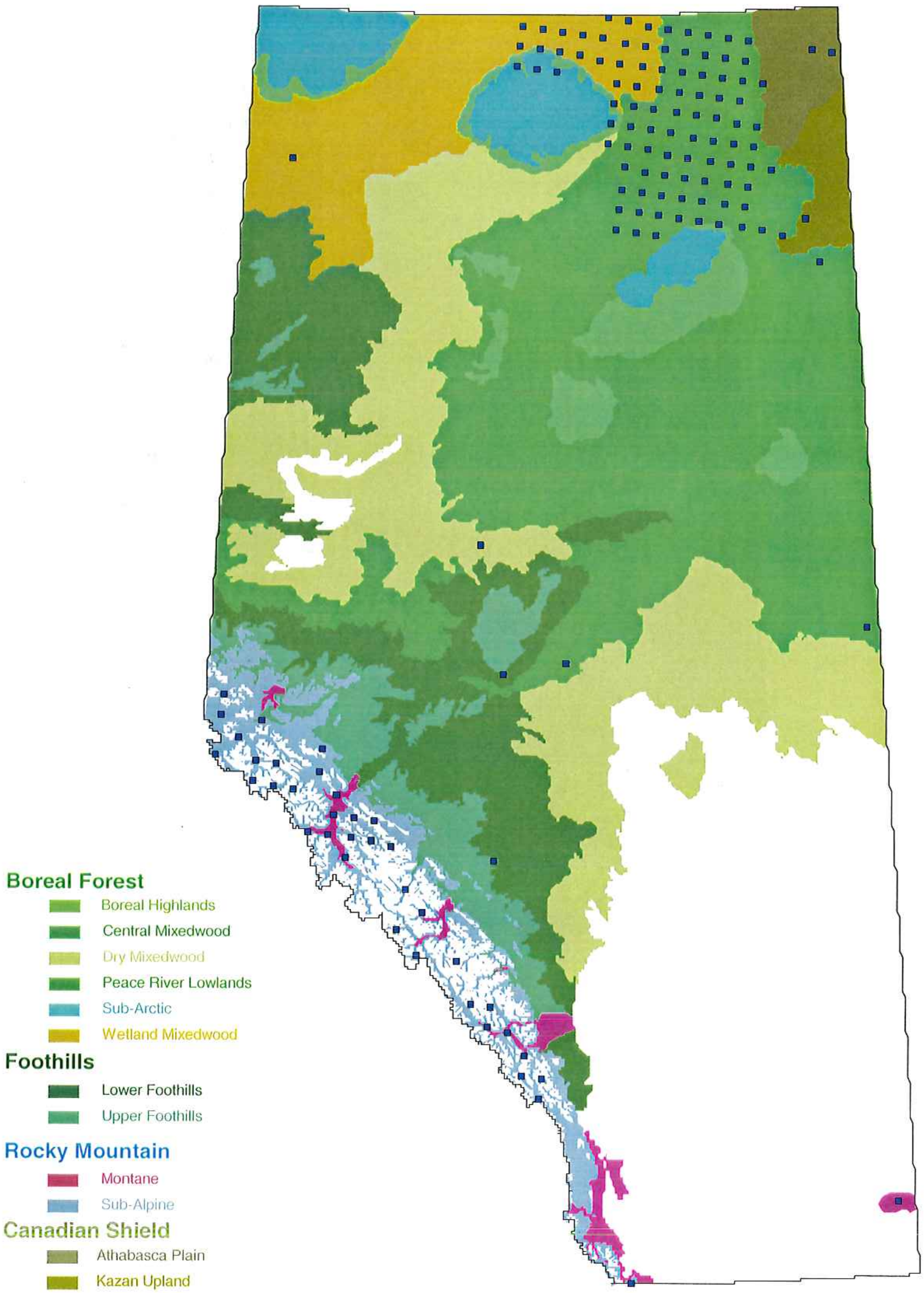

Figure 9 A 20 km grid overlaid on the protected areas within the forested subregions of Alberta.

ratios were lower than weighted networks, while not as consistent as with balanced or mixed designs with minimum samples per subregion designs (Tables 4 and 5). Slightly larger sample sizes were incurred using mixed grids.

At the ecodistrict level, the inclusion of protected areas as a fundamental part of the sampling network would prove difficult. Many ecodistricts do not have protected areas of sufficient size to support even a single sample point (800 x 800 m). Of the 106 ecodistricts, 36 were not represented by a single point (Lee et al. 2000) (Table 6). As the minimum number of sites increased, the percentage of ecodistricts meeting these requirements declined. Only 48.1% (n=51) of ecodistricts had large enough areas to support 15 or more points. At 50 or more points, the percentage of ecodistricts dropped to 33%.

The percentage of ecodistricts with protected areas within the Boreal and Canadian Shield were greater than Foothills and Rocky Mountain ecoregions (Table 6). In particular, percentages of Foothills ecodistricts declined rapidly with increasing minimum sample size. This was largely due to smaller and fewer protected areas within Lower Foothills. In comparison, Rocky Mountain subregions maintained relatively even percentages of protected areas representation due to the presence of large national parks. However, outside these large parks, Rocky Mountain ecodistricts had relatively low representation in protected areas. In both the Foothills and Rocky Mountains, ecodistricts are relatively small and associated with specific topographical features.

Table 6 Percentage of ecodistricts within each subregion having at least one or more 800 x 800 m^2 sampling plot. Means for each ecoregion were weighted by the area of each subregion.

Ecoregions	**Subregions**	**Total No. of Ecodistricts**	**Total No. of 800 m^2 units**	**≥1 sample points**	**≥10 sample points**	**≥15 sample points**	**≥25 sample points**	**≥50 sample points**
Boreal Forest	Boreal Highlands	7	1,490	28.6	28.6	28.6	28.6	28.6
Boreal Forest	Central Mixedwood	24	28,882	70.8	50.0	50.0	41.7	37.5
Boreal Forest	Dry Mixedwood	26	808	80.8	46.2	46.2	30.8	15.4
Boreal Forest	Peace River Lowlands	2	11,006	100.0	100.0	100.0	100.0	100.0
Boreal Forest	Sub-Arctic	3	1,531	66.7	66.7	66.7	66.7	66.7
Boreal Forest	Wetland Mixedwood	4	12,326	75.0	75.0	75.0	75.0	75.0
Mean		**66**		**72.2**	**52.8**	**52.8**	**44.7**	**38.4**
Canadian Shield	Athabasca Plain	3	123	66.7	66.7	66.7	33.3	33.3
Canadian Shield	Kazan Upland	1	1,469	100.0	100.0	100.0	100.0	100.0
Mean		**4**		**85.5**	**85.5**	**85.5**	**70.9**	**70.9**
Foothills	Lower Foothills	15	84	46.7	20.0	20.0	13.3	0.0
Foothills	Upper Foothills	7	230	57.1	42.9	42.9	42.9	42.9
Mean		**22**		**49.7**	**26.7**	**26.7**	**21.9**	**12.5**
Rocky Mountain	Montane	6	163,371	83.3	83.3	83.3	83.3	66.7
Rocky Mountain	Sub-Alpine	8	14,371	42.9	42.9	42.9	42.9	42.9
Mean		**14**		**50.5**	**50.5**	**50.5**	**50.5**	**47.4**
Grand Mean		**106**		**66.1**	**48.1**	**48.1**	**40.6**	**33.0**

DISCUSSION

The primary trade-offs in developing a sampling network are the underlying natural variation of indicators, ecological representation, and logistic and financial considerations. As mentioned from the outset, the spatial variation inherent within indicators was not part of this analysis. They are being dealt with in a separate analysis and report (Farr et al. 2000). Many of the indicators do not have baseline data at large spatial scales. Paradoxically, indicators that currently have data would already be part of a large scale monitoring effort, hence, may not require further monitoring. The recommendations on sample network from this report should be viewed as preliminary. As data is gathered, the network should be modified.

From a logistic and financial point of view, a regular grid of sample points would be appropriate for monitoring and reporting at relatively large spatial scales. The minimum resolution of the sampling network depends on the extent of land use activity and its intensity. As an example, an activity occurring over an area of 4,000 km^2 would be overlaid by 10 sample points with a 20 km grid, and 40 sample points with a 10 km grid. If larger sample sizes are required, then a smaller grid spacing or only larger management activities could be reported. Some apriori decisions need to be made about the types and spatial extent of particular activities. Using 15 sample points as a guideline, 10 km, 20 km, and 40 km networks would have a minimum resolution for activities covering 1,500 km^2, 6,000 km^2, and 24,000 km^2, respectively. Obviously, more intrusive activities would require fewer sample point, hence, could be detected over smaller areas.

In the case of ecological land classifications, 20 km spacing was appropriate for measurement of ecoregions and subregions, and 5 to 10 km grid spacing for ecodistricts when 15 sample points were used as a guideline. Given that spacings of less than 10 km are likely to be prohibitively expensive and logistically difficult to implement, it is unlikely that a fully weighted sampling network would provide a resolution sufficient for ecodistrict representation. This is not to say monitoring data cannot be used to resolve features at lower spatial scales. In particular, data collected at larger spatial scales can be used to provide a mechanism of "scaling up" finer resolution research and monitoring.

The greatest weakness of the weighted sampling technique is its ability to adequately represent small land classes. Alberta has huge differences in the sizes of the largest and smallest land classes at each of the hierarchial levels (Appendix 1). The Boreal ecoregion is 22x larger than the Canadian Shield, while the Central Mixedwoods subregion is 25x larger than the Montane. At the level of ecodistricts, the Loon Lake Plains were 358x larger than the subalpine of the Waterton Mountains. Hence, ecodistricts and perhaps subregions may require a break from a fully systematic grid to achieve reasonable sample sizes with practical logistic and financial considerations.

In comparing spatially weighted and balanced designs, it is tempting to utilize the latter because of the advantage of having similar sample sizes among land classes and potentially fewer overall sample points. It ensures sufficient sample points for small land classes that under spatially weighted networks may only receive a few sample points. There are, however, a number of disadvantages to balancing sample sizes according land classes. The current land classification scheme of ecoregions, subregions, and ecodistricts has been in use since 1995 (Strong and Leggat 1992; Alberta Environmental Protection 1994; Strong and Thompson 1995). It was the result of departmental amalgamations within Alberta Environmental in 1995. Previous to 1981, there was no ecoregion classification. Land classifications within Alberta, as they are in many other jurisdictions, are constantly evolving. Greater understanding of what similarities and dissimilarities exist within and between ecosystems, and changes in administrative boundaries will contribute to a changing land classification system. In all likelihood, a balanced network would only be equitable in the short-term eventually revision of land classes would unbalance the design.

A second problem with a balanced design is the potential under-representation of the spatial variation in large land classes. All other sources of variation being equal, larger land classes or management activities, will have greater amounts of spatial variation. By definition, a spatially weighted network has more samples in larger areas, thereby, capturing the underlying variation. Also, in comparing different-sized land classes, samples within balanced networks represent different areas of influences. As an example, 100 sites placed the Central

Mixedwood and Kazan Upland subregions would represent areas of 1,547 and 90 km^2 per site, respectively. There is a 17x size discrepancy. Conversely, if 10 sites were required to resolve the patterns of Central Mixedwoods that pattern would have to occur over 15,470 km^2, whereas the 10 sites within Kazan Upland would resolve patterns at 900 km^2. Interpretation of data from these subregions would be potentially confounded because of different factors operating at different scales. Varying grid spacing among land classes is likely to produce different levels of detection for different factors among land classes. Lastly, a balanced design at a particular land classification does not ensure a balanced design at lower or higher land classifications.

In recognizing the need for larger areas having more samples and smaller areas having a minimum number of samples, mixed designs seem to offer a possible solution. Mixed designs reduced the variation amongst land classes while retaining some of the weighting with land class size. The minimum sample network was the most direct method of supplementing points to smaller land classes. At completion, spacing of grid points would be different within each of the subregions receiving points. Again, this could lead to problems with detection and spatial scale. However, the variance would be less than a balanced design.

The alternative mixed design uses two grid spacings. This has been the solution in many Nordic countries, which use regular grids for forest monitoring (see later section). This reduces the interpretation problems caused by having multiple scales across different subregions. Furthermore, if the two grids are multiples, larger scale factors may be investigated by analyzing a lower density of points from the smaller grid spacing. The drawback with the two grid network is that it is more difficult to maintain relationships between land class size and total sample size, because samples per subregion are a function of relative sizes of the two grids.

As land development proceeds on non-protected areas in Alberta, the benchmark value of protected areas will increase. These are amongst the most stable administrative boundaries on the landscape. Boundaries of protected areas are not likely to change through time. To capture protected areas as benchmarks, we may be able to make an argument for breaking from the spatially weighted design and increasing the sample density within protected areas. The distribution of protected areas was strongly biased towards Rocky Mountain and Boreal ecoregions because of three large national parks. In the Boreal, sample points within protected areas are not dispersed throughout the ecoregion but are concentrated in the northeast corner because of the Wood Buffalo National Park. To a degree, this clustering of points is true for all protected areas.

National parks in Alberta are ecodistrict size entities and represent some regional areas very well. However, they poorly represent subregions and are totally missing in some ecodistricts. Barring the creation of new and relatively large protected areas dispersed amongst under represented subregions and ecodistricts, it is unlikely that a sampling network will be able to explicitly incorporate protected areas at the ecodistrict level. This decision to explicitly incorporate protected areas even at the subregion level needs to be discussed and acted upon. If protected areas are included, then the current network of protected areas in Upper and Lower Foothills, Boreal Highlands, Dry Mixedwoods, Sub-Arctic, and Athabasca Plains subregions needs to be "saturated" with monitoring plots to achieve equitable ratios.

OTHER MONITORING SYSTEMS

A number of other jurisdictions utilize a regular grid in monitoring forest resources. In Canada, the National Forest Inventory has proposed a network of regularly spaced 20 km sample points (Magnussen and Bonnor 1998). A combination of remote and ground plot attributes will be measured at each point. This project is a good match for the AFBMP because the potential similarities in broad sample network and ground plots (J.S. Thrower and Associates 1998).

Systematic grids for sampling forest resources are the norm in Nordic countries (Table 7). Grid spacings range from 3 x 3 km in Norway (Nellmann and Sletnes 1995) to 32 x 32 km in northern Sweden (Wulff 1995). Many jurisdictions utilize multiple

Table 7 Examples of systematic grid networks from other jurisdictions.

Jurisdiction	Grid Spacing	References
Canada	20 x 20 km	Thrower and Associates 1998 Magnussen and Bonnor 1998
Denmark	7 x 7 km 16 x 16 km	Hansen and Rasmussen 1995 UN-ECE 1989
Finland	16 x 16 km 32 x 32 km	Lindgren and Salemaa 1995
Norway	3 x 3 km 9 x 9 km 18 x 18 km	Nelleman and Sletnes 1995
Sweden	16 x 16 km 32 x 16 km 32 x 32 km	Walff 1995

grid patterns with different scales. Denmark has a national network of grid points based on a 7 x 7 km grid of points. It also participates in the International Cooperative Programme (ICP) on forest monitoring utilizing a 16 x 16 km grid of sample points (UN-ECE 1989; Hansen and Rasmussen 1996). Norway uses a hierarchial system of 3 x 3 km, 9 x 9 km, and 18 x 18 km grids. The smaller grids are assigned to more intensely developed areas (Nellmann and Sletnes 1996). Most of these are found in the southern forests, and as development expands northward the grid spacing will decrease.

Similar strategies exist in both Sweden and Finland (Wulff 1996; Lindgren and Salemaa 1996). In Sweden, grid spacing in the southern region is 16 x 16 km, the central region has a spacing of 16 x 32 km, while the northern region has a grid spacing of 32 x 32 km. Finland uses a grid spacing of 16 x 16 km in the south and a 32 x 32 km grid in the north. In both of these cases, the networks are scaled such that the more intensive grid can be easily incorporated into the more extensive grid. This will be done as development proceeds northward.

These programs suggest the overall utility of a grid network in a forested landscape similar to Alberta's. They suggest a network be laid out in stages with a low density grid being laid over the whole forested landscape followed by a more intensive grid over more developed areas. Based on this experience, it may be worthwhile to schedule overlaying of a dispersed grid over the entire province, e.g. 40 km, then apply smaller grid spacing, e.g. 10 and 20 km, to more developed or benchmark areas.

FINDINGS AND RECOMMENDATIONS

Based on the scope of this report, the following findings and recommendations are made:

1. A regular, systematic grid of sample points was adequate for subregion and ecoregion land classes. For smaller land classes including ecodistricts and protected areas, a mixed network using a base grid network with supplemental sample points for smaller land classes is recommended.

2. Ecoregions require a grid spacing of 40 km or less for representation of at least 15 sites in the smallest land class.
3. Subregions require a grid spacing of 20 km or less for representation of at least 15 sites in the smallest land class.
4. Ecodistricts require a grid spacing less than 10 km to achieve representation of each ecodistrict. This would likely not be logistically or financially feasible. A 10 km grid with either a 5 km grid or set number of minimum points in smaller ecodistricts is a more logistically and financially reasonable design.
5. Due to large disparities in the size and distribution of protected areas, a grid network of sample points will not capture equitable ratios of protected to non-protected areas sample points. If protected areas are to be used as benchmarks, then sample points need to be added into existing protected areas. Like ecodistricts, protected areas could be represented by using a 10 km grid with either a 5 km grid or set number of minimum points in smaller protected areas.
6. In scheduling the monitoring network, we recommend applying a light grid over the entire province, e.g. 40 km. Afterwards, more a intensive sample grid should be placed over more developed or protected areas.
7. Further discussion and development of the sampling network should proceed after answering two questions;
   - What level of regional resolution is desirable for reporting?
   - Are protected areas to be explicitly included in the sampling design as benchmarks?

REFERENCES

Alberta Environmental Protection. 1994. Natural regions and subregions of Alberta: summary. Alberta Environmental Protection. Publ.No. I/531. 18 pp.

Environmental Systems Research Institute, Inc. 1997. ARC/INFO Version 7.1. Environmental Systems Research Institute, Inc., Redlands, CA, USA.

Farr, D., M. Hiltz, and M. Carlson. 2000. The Alberta Forest Biodiversity Monitoring Program: Cost-effectiveness of alternative monitoring designs. Foothills Model Forest, Publication, Hinton, AB. In prep.

Hansen, K. and L. Rasmussen. 1996. The Danish forest condition survey 1994 - level I and level II networks. In Monitoring Forest Damage in the Nordic Countries. Selected proceedings from meeting in the SNS-ad hoc group on Monitoring forest damage, 9-10 May 1995, Umea, Sweden. Edited by U. Soderberg and S. Wulff. Department of Forest Resource Managment and Geomatics, Swedish University of Agricultural Sciences, Umea, Sweden, Report No. 4. 1-12 pp.

J.S. Thrower and Associates. 1998. Provincial forest growth monitoring and national forest inventory implementation in Alberta. Report prepared for M. Gillis, Manager, National Forest Inventory, Canadian Forest Service, Victoria, B.C. Project: CFS-501-003. 16 pp.

Lee, P., S. Hanus, K. Sturgess, L. Tomyn, and J. Joy. 2000. The Alberta Froest Biodiversity Monitoring Program: Test of Field Procedures for Terrestrial Ground Plots. Alberta Research Council Publication, Vegreville, AB. In prep.

Lindgren, M. and M. Salemaa. 1996. Forest tree condition in Finland 1994. In Monitoring Forest Damage in the Nordic Countries. Selected proceedings from meeting in the SNS-ad hoc group on Monitoring forest damage, 9-10 May 1995, Umea, Sweden. Edited by U. Soderberg and S. Wulff. Department of Forest Resource Managment and Geomatics, Swedish University of Agricultural Sciences, Umea, Sweden, Report No. 4. 13-23 pp.

Magnussen, S. and G.M. Bonnnor. 1998. A plot-based national forest inventory design for Canada. Version 1.1. Canadian Forest Service, Victoria, British Columbia. 57 pp.

Nellemann, C. and A.I. Sletnes. 1996. Spatial and temporal patterns of forest vitality in Norway. In Monitoring Forest Damage in the Nordic Countries. Selected proceedings from meeting in the SNS-ad hoc group on Monitoring forest damage, 9-10 May 1995, Umea, Sweden. Edited by U. Soderberg and S. Wulff. Department of Forest Resource Managment and Geomatics, Swedish University of Agricultural Sciences, Umea, Sweden, Report No. 4. 25-35 pp.

Strong, W. and K.R. Leggat. 1992. Ecoregions of Alberta. Prepared for Alberta Forestry, Lands and Wildlife, Land Information Services Division, Resource Information Branch. Publication Number T:245. 60 pp.

Strong, W.L. and J.M. Thompson. 1995. Ecodistricts of Alberta: Summary of Biophysical Attributes. Alberta Environmental Protection, Edmonton, Alberta. Publication No. T/319. ISBN 0-7732-1437-2. 92 pp.

Wulff, S. 1996. Forest condition in Sweden 1994. In Monitoring Forest Damage in the Nordic Countries. Selected proceedings from meeting in the SNS-ad hoc group on Monitoring forest damage, 9-10 May 1995, Umea, Sweden. Edited by U. Soderberg and S. Wulff. Department of Forest Resource Managment and Geomatics, Swedish University of Agricultural Sciences, Umea, Sweden, Report No. 4. 37-45 pp.

UN-ECE. 1989. Manual on methodologies and criteria for harmonized sampling, assessment, monitoring, and analysis of the effects of air pollution on forests. Global Environment Monitoring System. 90 pp.

Appendix 1 Sizes of forested ecoregions, subregions and ecodistricts within Alberta.

Ecoregion	Subregion	Ecodistrict	Area (km^2)
Boreal Forest	Boreal Highlands	Birch Upland	8,430
Boreal Forest	Boreal Highlands	Cameron Slope	2,158
Boreal Forest	Boreal Highlands	Caribou Slope	3,626
Boreal Forest	Boreal Highlands	Crow Lake Plain	1,641
Boreal Forest	Boreal Highlands	Peerless Upland	3,315
Boreal Forest	Boreal Highlands	Russell Upland	1,086
Boreal Forest	Boreal Highlands	Wadlin Upland	963
Subtotal			**21,218**
Boreal Forest	Central Mixedwood	Birch Fans	3,830
Boreal Forest	Central Mixedwood	Buffalo Head Upland	6,272
Boreal Forest	Central Mixedwood	Christina Plain	2,627
Boreal Forest	Central Mixedwood	Cross Lake Upland	6,792
Boreal Forest	Central Mixedwood	Embarras Plain	5,725
Boreal Forest	Central Mixedwood	Firebag Hills	1,703
Boreal Forest	Central Mixedwood	Fox Lake Plain	5,583
Boreal Forest	Central Mixedwood	Freeman Upland	2,481
Boreal Forest	Central Mixedwood	Garson Lake Plain	4,303
Boreal Forest	Central Mixedwood	Hart Lake Plain	4,253
Boreal Forest	Central Mixedwood	Heart River Upland	6,740
Boreal Forest	Central Mixedwood	Hondo Plain	3,513
Boreal Forest	Central Mixedwood	Knight Creek Plain	9,667
Boreal Forest	Central Mixedwood	Loon Lake Plain	21,135
Boreal Forest	Central Mixedwood	Losegun Plain	9,547
Boreal Forest	Central Mixedwood	Mackay Plain	12,875
Boreal Forest	Central Mixedwood	Mostoos Upland	10,336
Boreal Forest	Central Mixedwood	Muskeg Upland	1,602
Boreal Forest	Central Mixedwood	Pinehurst Upland	4,030
Boreal Forest	Central Mixedwood	Puskwaska Upland	1,708
Boreal Forest	Central Mixedwood	Steepbank Plain	2,794
Boreal Forest	Central Mixedwood	Stony Mountain Upland	5,469
Boreal Forest	Central Mixedwood	Utikuma Plain	4,120
Boreal Forest	Central Mixedwood	Wabasca Plain	17,567
Subtotal			**154,671**
Boreal Forest	Dry Mixedwood	Athabasca Plain	9,357
Boreal Forest	Dry Mixedwood	Beaver River Plain	4,411
Boreal Forest	Dry Mixedwood	Beaverlodge Plain	2,125
Boreal Forest	Dry Mixedwood	Blueberry Upland	1,981
Boreal Forest	Dry Mixedwood	Boyer Plain	2,402
Boreal Forest	Dry Mixedwood	Breton Upland	3,075
Boreal Forest	Dry Mixedwood	Cache Plain	1,511
Boreal Forest	Dry Mixedwood	Caroline Plain	3,147
Boreal Forest	Dry Mixedwood	Cooking Lake Upland	1,578
Boreal Forest	Dry Mixedwood	Debolt Plain	1,545
Boreal Forest	Dry Mixedwood	Dunvegan Plain	3,488
Boreal Forest	Dry Mixedwood	Falher Plain	1,823
Boreal Forest	Dry Mixedwood	Frog Lake Upland	2,398
Boreal Forest	Dry Mixedwood	Grimshaw Plain	3,256
Boreal Forest	Dry Mixedwood	High Level Plain	13,809

Ecoregion	**Subregion**	**Ecodistrict**	**Area (km²)**
Boreal Forest	Dry Mixedwood	Lac Ste Anne Upland	6,191
Boreal Forest	Dry Mixedwood	Manning Plain	7,442
Boreal Forest	Dry Mixedwood	McLennan Plain	9,273
Boreal Forest	Dry Mixedwood	Myrnam Upland	1,625
Boreal Forest	Dry Mixedwood	Onion Lake Plain	3,638
Boreal Forest	Dry Mixedwood	Redwater Plain	963
Boreal Forest	Dry Mixedwood	Rimbey Upland	3,086
Boreal Forest	Dry Mixedwood	Smoky Plain	2,033
Boreal Forest	Dry Mixedwood	Westlock Plain	2,257
Boreal Forest	Dry Mixedwood	Whitefish Upland	3,459
Boreal Forest	Dry Mixedwood	Worsley Plain	4,702
Subtotal			**100,578**
Boreal Forest	Peace River Lowlands	Athabasca Delta	7,994
Boreal Forest	Peace River Lowlands	Salt River Plain	2,117
Subtotal			**10,111**
Boreal Forest	Sub-Arctic	Cameron Hills Upland	8,734
Boreal Forest	Sub-Arctic	Caribou Upland	9,450
Boreal Forest	Sub-Arctic	North Birch Upland	3,804
Subtotal			**21,987**
Boreal Forest	Wetland Mixedwood	Buffalo River Plain	6,142
Boreal Forest	Wetland Mixedwood	Hay River Plain	22,903
Boreal Forest	Wetland Mixedwood	Rainbow Lake Plain	4,486
Boreal Forest	Wetland Mixedwood	Yates River Plain	4,852
Subtotal			**38,382**
Total Boreal Forest			**346,947**
Canadian Shield	Athabasca Plain	Athabasca Dunes	1,415
Canadian Shield	Athabasca Plain	Carswell Plain	3,177
Canadian Shield	Athabasca Plain	Lake Athabasca	2,210
Subtotal			**6,802**
Canadian Shield	Kazan Upland	Uranium City Upland	**8,988**
Subtotal			**8,988**
Total Canadian Shield			**15,790**
Foothills	Lower Foothills	Blueridge Upland	1,284
Foothills	Lower Foothills	Bragg Creek Foothills	1,721
Foothills	Lower Foothills	Chinchaga Plain	6,315
Foothills	Lower Foothills	Clear Hills Upland	9,120
Foothills	Lower Foothills	Cutbank Upland	9,733
Foothills	Lower Foothills	Cynthia Upland	2,011
Foothills	Lower Foothills	Driftpile Upland	8,043
Foothills	Lower Foothills	Edson Plain	7,855
Foothills	Lower Foothills	Milligan Upland	2,075
Foothills	Lower Foothills	Notikewin Plain	4,083
Foothills	Lower Foothills	Obed Upland	4,035
Foothills	Lower Foothills	O'Chiese Upland	4,993
Foothills	Lower Foothills	Pelican Upland	2,022
Foothills	Lower Foothills	Saddle Upland	2,471
Foothills	Lower Foothills	Winfield Upland	1,561
Subtotal			**67,324**
Foothills	Upper Foothills	Berland Upland	9,419
Foothills	Upper Foothills	Clear Hills Upland	1,274

Ecoregion	Subregion	Ecodistrict	Area (km^2)
Foothills	Upper Foothills	Mayberne Upland	1,190
Foothills	Upper Foothills	Milligan Upland	411
Foothills	Upper Foothills	Ram River Foothills	7,731
Foothills	Upper Foothills	Swan Hills	3,736
Foothills	Upper Foothills	Wolf Lake Upland	3,789
Subtotal			**27,550**
Total Foothills			**94,874**
Rocky Mountain	Montane	Banff Mountains	401
Rocky Mountain	Montane	Blairmore Foothills	2,558
Rocky Mountain	Montane	Cypress Hills	598
Rocky Mountain	Montane	Jasper Mountains	936
Rocky Mountain	Montane	Morley Foothills	1,266
Rocky Mountain	Montane	Willmore Foothills	225
Subtotal			**5,984**
Rocky Mountain	Sub-Alpine	Banff Mountains	13,863
Rocky Mountain	Sub-Alpine	Berland Upland	289
Rocky Mountain	Sub-Alpine	Crowsnest Mountains	893
Rocky Mountain	Sub-Alpine	Jasper Mountains	9,357
Rocky Mountain	Sub-Alpine	Luscar Foothills	277
Rocky Mountain	Sub-Alpine	Ram River Foothills	155
Rocky Mountain	Sub-Alpine	Waterton Mountains	59
Rocky Mountain	Sub-Alpine	Willmore Foothills	870
Subtotal			**25,763**
Total Rocky Mountain			**31,748**
Grand Total			**489,359**