Final Report of the Joint Fire Science Program Project
Characterizing Historic and Contemporary Fire Regimes in the Lake States

November 2005

Principal Investigators: David Cleland[1], Thomas Crow[1], Sari Saunders[2] Ann Maclean[2], and Donald Dickmann[3]

1. USDA Forest Service; 2 Michigan Technological University; 3 Michigan State University

Summary of Project: The overall goal of this project was to contribute to our knowledge of historical and modern fire regimes within northern Michigan, Minnesota, and Wisconsin. Specific goals were to: (1) synthesize available information on historic fire regimes; (2) map landscape ecosystems of varying susceptibility to disturbance across sixty million acres of forestlands; and (3) document how fire regimes have changed since European settlement.

Achievements: Each of these deliverables was produced and distributed to the research and land management communities through publications, posting of results on the Great Lakes Ecological Assessment (GLA) web page (http://www.ncrs.fs.fed.us/gla/), and actual application in state and federal fire and land management activities. These activities included assistance with National Forest land management and fire management plans, fire regime condition class mapping within National Forests, interagency fire risk assessments, development of LANDFIRE reference models used in the Rapid Assessment, and implementation of the Healthy Forest Restoration Act through identification of fire-prone landscapes. A synthesis of the literature was completed, and an annotated bibliography of 500 manuscripts and a brief summary of the literature were posted on the Great Lakes Ecological Assessment web page.

Brief Lessons Learned:

(1) historical rotations of catastrophic forest fires ranged from periods of a few decades within the most fire-prone ecosystems to more than a millennium within fire-resistant ecosystems;
(2) ecosystems that were historically highly fire-prone forest ecosystems comprised 26% of the study area, whereas 60% consisted of fire-resistant “asbestos” forests;
(3) modern forest fire rotations are an order of magnitude longer than historical rotations;
(4) modern fire regimes are far more associated with human ignition, detection, and suppression than ecological factors governing historical fire regimes;
(5) modern ignitions are almost exclusively due to humans;
(6) extended fire rotations are due to modern fire suppression and conversion of extensive areas of upland conifers to deciduous forests, which effectively reduced crown fire potential;

Introduction

A number of approaches have been used to characterize historical fire regimes. These include use of dendrochronological techniques to date fire scars (Clements 1910, Heinselman 1973, Arno and Sneck 1977, Simard and Blank 1982, Loope 1991, Brown et al. 2001), use of current age class data fit to a negative exponential curve to calculate fire rotations (Van Wagner 1978), and use of stratigraphic charcoal analysis on petrographic thin sections (Clark 1988a, 1988b). Each of these methods has advantages and disadvantages related to assessing adequately fire regimes at relevant spatial and temporal scales (Agee 1993). However, none of these methods could be applied practically across the expansive study area of this research due to data availability requirements.

The many challenges associated with characterizing fire regimes include accommodating area effects on estimates of fire return intervals or fire rotations (Arno and Petersen 1983, Johnson and Gutsell 1994), assumptions regarding flammability of fuels and fire behavior across heterogeneous landscapes (Baker 1989, Turner et al. 1989, Gosz 1992, Turner and Romme 1994, Brown et al. 2001), and adequacy of approaches for understanding long term patterns (Clark 1988a, 1988b, 1990). An important initial facet of our research was to reconstruct historical forest fires across the entire study area, and map categories of landscape ecosystems based on associations of ecological factors known to affect fire regimes and the biogeography of forest communities. Area effects on estimates of fire occurrence were addressed by studying fire regimes across a very large study area. Landscape heterogeneity was reduced by networking landscape ecosystems into similar vegetative and edaphic classes, and determining fire rotations within relatively homogeneous units. Long-term patterns were partially addressed by studying fires occurring in the early 1800s, prior to fire suppression, as well as modern fires.

Study Area

The study was conducted across a 60 million acre area in northern Michigan, Wisconsin, and Minnesota. Delineated as the Laurentian Mixed Forest within the National Hierarchy of Ecological Units (Cleland et al. 1997), Province 212 separates the northern deciduous-coniferous forest biome from the southern oak-hickory-prairie biome, primarily due to broad-scale gradients as well as Pleistocene glaciation. Section-level divisions within Province 212 reflect orographic, latitudinal, and lake effects on climate, differences in bedrock ages and types, and subregional patterning of glacial deposits and associated soil properties.

Climate varies considerably across the Province. Mean annual precipitation increases from 20 to 38 inches along a west to east axis; this gradient reverses direction in northern lower Michigan due to the effects of Lake Michigan and prevailing westerly winds. Mean annual frost free days range from 63 to 150. Mean annual snowfall ranges from 35 inches on the western and southern border of the Province to more than 200 inches in areas strongly affected by Lake Superior.

Province 212 is a glaciated ecoregion of generally low relief. Glacial deposits and associated landforms and soils strongly influenced the distribution of species and communities, and the nature and frequency of natural disturbance regimes. Landforms range from well sorted high-energy glaciofluvial, ice-contact and disintegration relief composed of relatively homogeneous sandy and gravelling soils, to low-energy silty glacial lakebeds, to heterogeneous sandy to loamy moraines. Nutrient and moisture regimes across these deposits vary from extremely xeric to very mesic conditions.

Historical forest types ranged from fire-dependent upland pine and spruce-fir ecosystems to fire-resistant northern hardwood ecosystems. Forest fire regimes associated with these communities ranged from frequent catastrophic stand replacing crown fires to a near non-fire regime. The latter old growth “asbestos” forests (Grimm 1981) were disturbed principally by fine-scale gap phase dynamics following blowdown of individual and small groups of trees.

Methods

Spatially explicit information on historical fires and vegetation was obtained or developed from General Land Office (GLO) survey data for the entire study area by project staff in Michigan, and cost-share or cooperative agreements in Wisconsin (Dr. David Mladenoff, UW-Madison) and Minnesota (Dr. John Almendinger, MN DNR). GLO surveyors marked township and section boundaries, and noted a number of ecological conditions every half-mile and along transects of section lines, providing a grid of ecological data at a relatively fine scale (Manies et al. 2001). Observations included areas that were burned or blown down, as well as other indications of recent disturbance such as “pine thickets”, pine and oak barrens, prairies, and so forth. Microfilmed GLO notes were converted to ArcInfo point coverages.

Historical fire boundaries were determined using ordinary kriging for the interpolation of the fire occurrence data points, with output in the form of a probability map (Maclean and Cleland 2003). A modern fire database for the 1985-2000 period was obtained from federal and state agencies, from which two fire databases were created: one containing all reported fires, and the other containing only fires occurring within predominantly forested survey sections. Because locational accuracy of these records was only at a one square mile resolution, fires were placed at the center of the survey section, and relationships of fuels to modern fire occurrence were studied by assuming ignitions occurred within the dominant vegetative type.

The synthesis of the literature was used as an initial step in identifying categories of ecosystems of varying susceptibility to disturbance. Forest-replacement fire rotations for biophysical unit landscape ecosystem categories derived from the literature ranged from very short (<100 years) to very long (>1,000 years). Literature used to formulate landscape ecosystem categories based on historical forest replacement fire rotations and associated community composition and physical environment is summarized in Appendix A.

Landscape ecosystems were mapped by examining relationships among physical and biological ecosystem components. Spatial data included General Land Office survey notes on tree species and diameter, fine-scale SSURGO certified Natural Resource Conservation Service (NRCS) digital soil surveys, US Forest Service ecological landtype maps, digital elevation models, hydrography, surficial geology, landform, and current vegetation from USGS GAP and Department of Natural Resources landcover data. Landscape ecosystem boundaries coincide with NRCS soil mapping units or US Forest Service ecological landtypes where these coverages were available. In areas lacking this fine scale information, boundaries were derived from relationships between historical vegetation and topography.

These landscape-level ecosystem units were nested within broader-scale ecological units (Sections of the National Hierarchy of Ecological Units) to accommodate variations in macroclimate and physiography and determine if differences occurred in fire rotations within communities of similar composition or in community composition within analogous landform – soil complexes. Comparisons of historical and modern fire rotations were made within landscape ecosystem categories at a state-wide and eco-subregion scale.

The national LANDFIRE effort has coined the term "Biophysical Units" to describe ecosystems mapped based upon multiple biotic and abiotic factors. The 2005 Fire Regime Condition Class guidebook states "Biophysical settings (BpS) are the primary landscape delineations for determination of the natural fire regime and fire regime condition class (FRCC)." "Physical characteristics include climate, geology, geomorphology, and soils. Vegetation includes native species and successional stages found under our best understanding of the historic range of variation, including disturbances." To accommodate the national system, landscape ecosystems mapped in this research are now called biophysical units (BPUs).

Changes in fire regimes since European settlement were documented by comparing historical fire rotations in different landscape ecosystem or biophysical unit categories to modern fire rotations based on fire information from 1985 through 2000. Fire rotations usually are determined by calculating the average stand age of a forest whose age distribution fits a negative exponential or a Weibull function (Van Wagner 1978). For our study, historical fire rotations were determined by calculating the area burned for each fire rotation category, dividing the area burned by the area of forestland within each unit, and dividing this area by 15 to estimate area burned per annum while assuming this to be a conservative burned area recognition window (Canham and Loucks 1984). Modern (1985-2000) fire rotations were determined by dividing the area burned for each fire rotation category by the number of years of records (16) to estimate area burned per annum.

Social and ecological factors affecting modern fire occurrence were analyzed using classification tree and logistic regression techniques. Classification tree analyses were applied to binary (fire/nonfire) section observations using the RPART extension to SPlus 2000. Forest fire observations were analyzed in comparison with all fire observations in each of three minimum size classes. Classification trees were pruned using the cross-validation procedures of Atkinson and Therneau (2000), and 50% of observations were withheld for validation. The spatial variability of the modern fire regime, and differences in logistic regression models for predicting fire probability across administrative, climatic, and ecological units were examined.

Results

Mapping landscape ecosystems of varying susceptibility to fire

A map of biophysical units was completed across the study area (Figure 1). A comprehensive report describing ecological conditions and changes within biophysical units is in progress. Appendix B displays graphs comparing historical versus current tree species proportions within biophysical units nested within broader-scale ecological units based on GLO observations and Forest Inventory and Analysis (FIA) plot-level data. Generalized descriptions of biophysical units are:

BPU1 - landscape ecosystems historically experiencing frequent, large catastrophic stand-replacing fires. These ecosystems typically occur within high energy glacial fluvial deposits underlain by coarse-textured sandy soils, or shallow bedrock controlled soils of comparable low moisture availability. The dominant forest types were short-lived jack pine and mixed pine forests throughout the study area, and jack pine- black spruce in northeastern Minnesota. Average fire return intervals reported in the literature ranged from 26 to 69 years, and fire rotations ranged from 50 to 170 years.

BPU 2 **–** landscape ecosystems historically experiencing large, catastrophic stand-replacing fires at lower frequencies, hence longer fire rotations than the BPU 1 category. These ecosystems typically occur within dry outwash plains and ice-contact landforms underlain by sandy and loamy sand soils. The dominant forest types were mixed red-white-jack pine forests. Average fire return intervals reported in the literature ranged from 83 to 250 years, with fire rotations of 150 to 350 years.

BPU 3W **–** landscape ecosystems historically experiencing relatively infrequent stand-replacing fires. These wetland ecosystems occur within or adjacent to fire-prone landscapes, with fires often intruding from adjacent landscapes. The dominant forest types were wetland conifers including cedar, tamarack, white pine, and hemlock. Average fire rotations reported in the literature ranged from 100 to 190 years. Fire regimes and fuel formation were likely caused by interactions of insect and disease, blow-downs, as well as periods of drought exposing underlying desiccated organic soils.

BPU 3 **–** landscape ecosystems historically experiencing infrequent stand-replacing fires at much longer fire rotations than the BPU 1 or BPU 2 categories. These ecosystems typically occur within dry-mesic to mesic ice-contact and glacial lakebed landforms underlain by loamy sand to silt loam soils. The dominant forest type was long-lived mixed conifer forests with minor elements of northern hardwood forests; however, forest composition varied substantially by ecoregion. Average fire return interval reported in the literature for white pine-hemlock forests was 250 years.

BPU 4 – landscape ecosystems historically experiencing very infrequent stand-replacing fires. These ecosystems typically occur within mesic to moist-mesic moraines underlain by fine-textured sandy loam to heavy clay and silt loam soils. The dominant forest types were long-lived, fire-intolerant northern hardwood forests including sugar maple, beech, and hemlock within Wisconsin, Michigan, and southern Minnesota, whereas communities in northeastern Minnesota were dominated by late successional coniferous species. Average fire return intervals reported in the literature ranged from 400 to 700 years, with fire rotations ranging from 550 to 2800 years.

BPU 4W – landscape ecosystems historically experiencing very infrequent stand-replacing fires. These ecosystems occur within wetlands embedded within or adjacent to fire-resistant, hence fire protected landscape ecosystems (BPU 4). The dominant forest types were wetland conifer-hardwood forests. Average fire return intervals reported in the literature ranged from 400 to 1,700 years, and fire rotations averaged from 890 to 6,000 years.

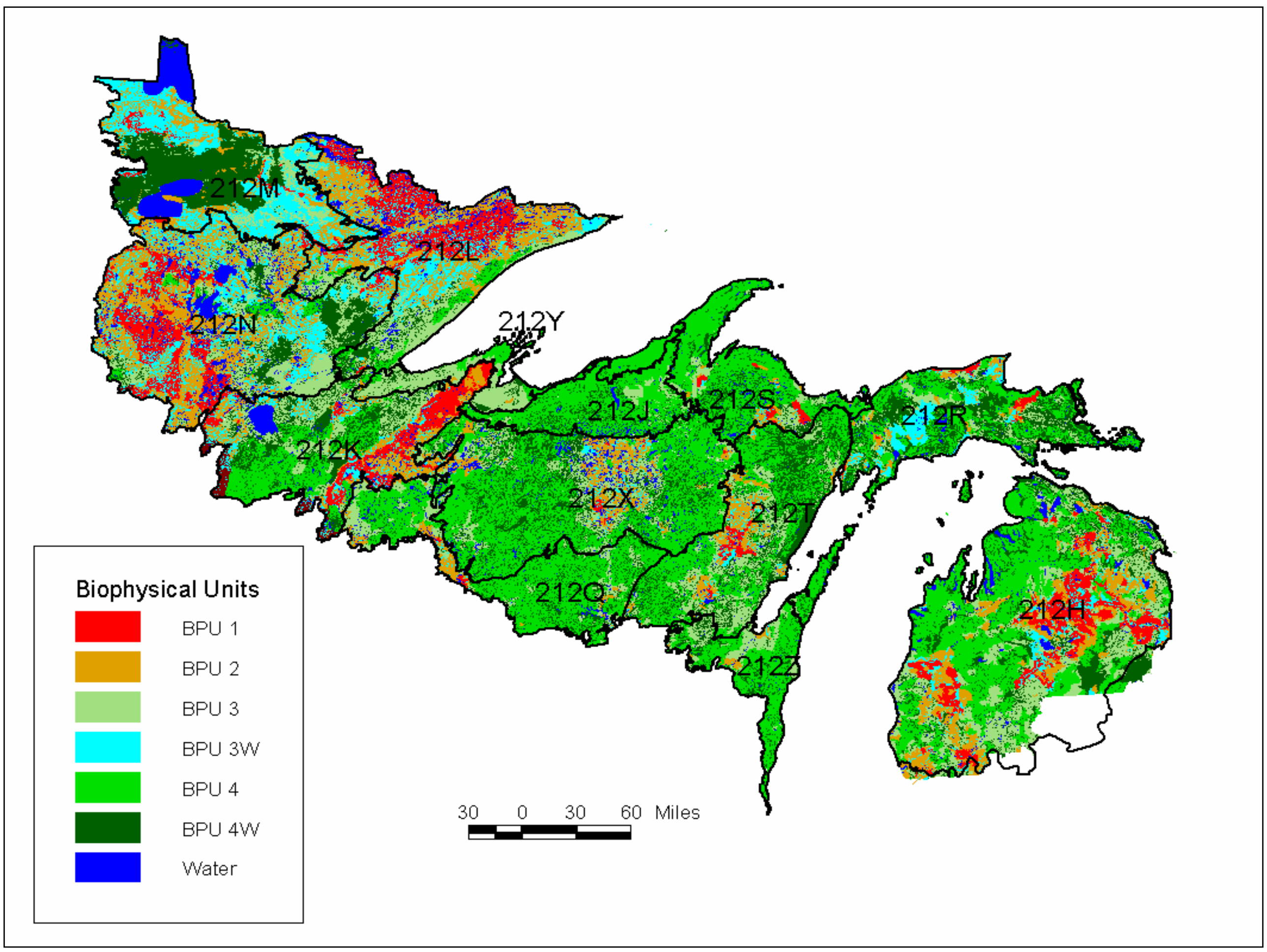

Figure 1. Biophysical Units nested within Ecological Subregions – Sections.

Characterizing historical and modern fire regimes

Table 1 arrays historical fire rotations by biophysical unit on a state-wide basis. Table 2 arrays comparisons of historical and modern forest fire rotations by biophysical unit nested within broader-scale ecological units. Several interesting findings can be reported.

- Historical forest fire rotations were an order of magnitude less than modern rotations.

- Historical forest fire rotations for respective biophysical units were similar across the study area when viewed from a state-wide basis, although units in Minnesota tended to burn within shorter rotations than analogous units in the other states.

- Historical forest fire rotations generally correspond with the life expectancy of dominant species within fire-prone ecosystems.

- Fire played a negligible role in the predominantly wind-driven natural disturbance regimes affecting mesic upland northern hardwood or associated wetland conifer communities, which collectively comprised 60% of the study area.

- Differences in fire rotations within biophysical units nested within ecoregions can be related to regional variations in landscape heterogeneity or macroclimate. For example, the long rotation for the red-white pine community occurring within BPU 2 in Section 212X of north-central Wisconsin is likely due to the high proportions of wetlands and lakes occurring within a sandy pitted outwash landform. This contrasts with the shorter rotations observed for this unit within other ecoregions, which typically consist of extensive upland landforms lacking natural fuel breaks. Rotations for units adjacent to the prairie in Minnesota may be shorter than units occurring farther east due to lower precipitation and higher fire season temperatures.

- Differences in fire rotations for wetland conifers can be related to landscape-level variations and local context. Wetland coniferous forests embedded within fire-prone landscapes tended to burn in rotations far shorter than comparable wetlands embedded within fire-resistant landscapes.

- Wetland coniferous forests embedded within fire-resistant landscapes burned more often than upland mesic deciduous species, probably due to concentrations of volatile foliar substances leading to higher crown-fire potential.

- In some cases, the small acreage of particular biophysical units within an ecoregion resulted in inconsistent estimates when compared to analogous units in other parts of the study area. This may be due to the inadequate size of the unit, as well as the random variation of fire occurring with the limited period of GLO surveyor observations.

Table 1. Historical Forest Fire Rotations of Biophysical Units Summarized by State

Biophysical Unit	Total Acres	Openland Acres	Forested Acres	Acres Burned	**Fire Rotation**
<u>Northern Lower Michigan</u>					
BPU1	1,067,862	209,279	858,583	209,279	**62**
BPU2	1,341,840	139,084	1,202,756	139,084	**130**
BPU3W	675,248	62,311	612,937	62,311	**148**
BPU3	1,684,495	47,256	1,637,239	47,256	**520**
BPU4	4,191,150	50,698	4,140,452	50,698	**1,225**
BPU4W	1,161,275	23,139	1,138,136	23,139	**738**
<u>Upper Peninsula Michigan</u>					
BPU1	164,558	14,353	150,205	33,886	**66**
BPU2	376,139	16,667	359,472	31,686	**170**
BPU3W	1,055,205	18,897	420,474	56,900	**111**
BPU3	433,383	12,908	1,055,205	47,291	**329**
BPU4	5,639,130	40,904	5,598,226	44,871	**1,871**
BPU4W	2,728,259	29,831	2,698,428	58,696	**690**
<u>Wisconsin</u>					
BPU1	769,834	462,285	307,548	74,521	**62**
BPU2	1,699,962	323,013	1,376,948	135,320	**153**
BPU3W	506,629	112,174	394,455	24,050	**246**
BPU3	3,186,414	78,332	3,108,081	97,849	**476**
BPU4	8,410,321	25,922	8,384,399	54,614	**2,303**
BPU4W	3,276,750	26,858	3,249,892	25,619	**1,903**
<u>Minnesota</u>					
BPU1	2,605,155	1,072,612	1,532,543	525,413	**44**
BPU2	5,242,110	307,035	4,935,075	831,818	**89**
BPU3W	4,782,397	402,420	4,379,977	598,054	**110**
BPU3	2,934,727	11,936	2,922,791	162,225	**270**
BPU4	1,600,491	700	1,599,791	18,621	**1,289**
BPU4W	3,618,449	10,878	3,607,571	144,219	**375**

Table 2. Historical and Modern Forest Fire Rotations of Biophysical Units Summarized by Ecological Subregions – Sections

Section	Biophysical Unit	Unit Size (Acres)	Acres of Historical Barrens	Net Historical Forested Acres	1985-2000 Forested Acres Burned	Historical Forest Acres Burned	**1985-2000 Forest Fire Rotation**	**Historical Forest Fire Rotation**
212H	BPU1	1,067,862	209,279	858,583	16,387	209,279	**1,043**	**62**
212H	BPU2	1,341,840	139,084	1,202,756	13,133	139,084	**1,635**	**130**
212H	BPU3W	675,248	62,311	612,937	1,792	62,311	**6,029**	**148**
212H	BPU3	1,684,495	47,256	1,637,239	6,461	47,256	**4,171**	**520**
212H	BPU4	4,191,150	50,698	4,140,452	3,435	50,698	**19,522**	**1,225**
212H	BPU4W	1,161,275	23,139	1,138,136	2,489	23,139	**7,465**	**738**
212R	BPU1	89,096	13,855	75,241	36	17,643	**15,149**	**64**
212R	BPU2	202,930	14,494	188,436	113	26,680	**6,960**	**106**
212R	BPU3W	386,281	12,787	373,493	4,519	54,607	**4,695**	**103**
212R	BPU3	455,306	13,829	441,477	166	22,170	**4,695**	**299**
212R	BPU4	1,327,187	16,474	1,310,713	1,469	18,665	**10,640**	**1,053**
212R	BPU4W	1,211,370	21,115	1,190,255	683	28,665	**6,079**	**623**
212S,J,Y	BPU1	74,724	500	74,225	11	16,243	**113,878**	**69**
212S,J,Y	BPU2	112,544	3,209	109,335	54	2,249	**36,420**	**729**
212S,J,Y	BPU3	953,616	10,107	943,509	860	22,765	**18,871**	**622**
212S,J,Y	BPU3W	34,474	121	34,353	4	2,033	**140,101**	**253**
212S,J,Y	BPU4	3,741,710	20,210	3,721,500	2,578	6,227	**23,339**	**8,965**
212S,J,Y	BPU4W	883,888	6,841	877,047	1,172	1,191	**12,287**	**11,048**
212T	BPU1	105,151	15,307	89,844	17	29,218	**6,313**	**49**
212T	BPU2	409,884	26,958	382,926	43	56,800	**9,580**	**108**
212T	BPU3	895,641	30,224	865,417	38	38,638	**23,417**	**358**
212T	BPU3W	133,116	7,475	125,642	11	14,384	**12,369**	**140**
212T	BPU4	1,997,046	5,853	1,991,192	80	24,663	**24,957**	**1,292**
212T	BPU4W	1,397,335	13,778	1,383,558	42	33,925	**33,287**	**653**
212X	BPU1	25,721	11,183	14,538	1	4,203	**46,713**	**55**
212X	BPU2	620,065	57,522	562,542	46	16,826	**13,498**	**535**
212X	BPU3	879,853	15,220	864,633	48	10,210	**18,161**	**1,355**
212X	BPU3W	162,149	16,361	145,789	10	4,166	**16,874**	**560**
212X	BPU4	3,707,063	13,945	3,693,118	175	14,593	**21,237**	**4,049**
212X	BPU4W	1,539,252	7,022	1,532,231	140	5,995	**11,023**	**4,089**

Table 2. Historical and Modern Forest Fire Rotations of Biophysical Units Summarized by Ecological Subregions – Sections (continued)

Section	Biophysical Unit	Unit Size (Acres)	Acres of Historical Barrens	Net Historical Forested Acres	1985-2000 Forested Acres Burned	Historical Forest Acres Burned	**1985-2000 Forest Fire Rotation**	**Historical Forest Fire Rotation**
212Q	BPU2	226,841	64,472	162,369	146	37,817	**24,851**	**64**
212Q	BPU3	495,195	9,861	485,334	715	47,350	**11,076**	**154**
212Q	BPU3W	31,920	8,091	23,828	20	4,607	**25,925**	**78**
212Q	BPU4	2,210,441	3,159	2,207,282	2,605	35,175	**13,575**	**941**
212Q	BPU4W	537,777	2,436	535,341	769	10,117	**11,187**	**794**
212Z	BPU2	55,091	9,468	45,623	0	0	∞	∞
212Z	BPU3	335,688	15,006	320,681	2	1,945	**172,313**	**2,474**
212Z	BPU3W	6,621	979	5,642	0	0	∞	∞
212Z	BPU4	1,022,766	4,541	1,018,225	0	0	∞	∞
212Z	BPU4W	307,233	4,821	302,413	1	780	**279,145**	**5,819**
212K	BPU1	710,232	455,023	255,210	2,586	43,529	**4,394**	**88**
212K	BPU2	739,658	169,794	569,865	1,876	30,786	**6,307**	**278**
212K	BPU3	740,003	4,032	735,971	4,119	12,291	**2,874**	**898**
212K	BPU3W	464,783	85,799	378,984	1,003	4,785	**7,418**	**1,188**
212K	BPU4	1,096,753	2,644	1,094,109	4,858	3,315	**3,612**	**4,951**
212K	BPU4W	900,284	1,399	898,885	3,985	5,886	**3,615**	**2,291**
212L	BPU1	1,202,293	427,795	774,498	11,961	291,136	**1,608**	**40**
212L	BPU2	1,651,042	83,590	1,567,452	5,379	299,400	**4,911**	**79**
212L	BPU3	823,157	2,404	820,753	2,385	24,579	**5,521**	**501**
212L	BPU3W	1,097,121	143,483	953,637	6,059	167,304	**2,897**	**86**
212L	BPU4	300,045	308	299,737	964	6,231	**4,980**	**722**
212L	BPU4W	314,399	1,749	312,651	1,158	17,818	**4,343**	**263**
212M	BPU1	143,677	50,783	92,894	558	34,744	**4,119**	**40**
212M	BPU2	781,122	49,683	731,439	1,845	153,738	**6,775**	**71**
212M	BPU3	424,215	1,894	422,321	831	22,363	**8,165**	**283**
212M	BPU3W	1,630,969	83,989	1,546,980	22,853	190,908	**1,142**	**122**
212M	BPU4W	1,639,656	6,066	1,633,590	1,285	42,988	**20,418**	**570**

Table 2. Historical and Modern Forest Fire Rotations of Biophysical Units Summarized by Ecological Subregions – Sections (continued)

Section	Biophysical Unit	Unit Size (Acres)	Acres of Historical Barrens	Net Historical Forested Acres	1985-2000 Forested Acres Burned	Historical Forest Acres Burned	**1985-2000 Forest Fire Rotation**	**Historical Forest Fire Rotation**
212N	BPU1	1,132,306	566,309	565,997	2,779	187,151	**6,519**	**45**
212N	BPU2	2,542,784	166,247	2,376,537	4,703	362,537	**8,650**	**98**
212N	BPU3	1,114,289	6,196	1,108,093	4,122	104,211	**4,325**	**159**
212N	BPU3W	1,769,306	168,140	1,601,166	6,122	225,930	**4,624**	**106**
212N	BPU4	194,778	393	194,385	659	8,309	**4,732**	**351**
212N	BPU4W	870,852	1,777	869,075	4,032	87,342	**3,456**	**149**

There were nearly 3.5 million acres of historical forest fires occurring across the Lake States in the mid-1800s, compared to 156,000 acres of modern forest fires occurring over a comparable recognition window (16 year period). The enormous extension in fire rotations, or reduction in acres burned by wildfires across this area, can be attributed to two primary causes: a highly effective fire fighting capacity by federal, state, and local fire management organizations; and the wholesale conversion of extensive areas of upland conifers that formerly experienced fast moving crown fires to deciduous species subject to surface fires but resistant to crown fires (Figures 2 and 3). The latter condition has resulted in less severe fires that can be contained more easily.

Historical vegetation classes displayed in Figure 2 were created by generalizing cover types from individual data sets (Comer et al. 1995; Marshner 1974; Finley 1976). Current vegetation displayed in Figure 3 was classified through the Upper Midwest GAP project, USGS-Biological Research Division, in cooperation with the Michigan, Minnesota, and Wisconsin DNRs.

The extent of historical forest fires varied by state according to the proportions of fire-prone versus fire-resistant forest ecosystems (biophysical units), as well as subregional physiographic and macroclimatic influences (Figures 4, 6, 8, and 11). In all states, large fires were rare based on number of fires, but had an overwhelming effect on the landscape due to their extensiveness.

Fire size distributions followed a power or negative exponential curve function in Minnesota and Michigan, but not in Wisconsin (Figures 5, 7, 9, 12). The low frequency of small fires in northern Wisconsin was probably due to the nature of the GLO data for that area. GLO surveyors first surveyed township boundaries, then survey-section boundaries. Fires observed at section corners and quarters, as well as along section lines were recorded. However, observations along section lines, which would have accounted for many small fires, are missing for most of northern Wisconsin. The survey was disrupted by the Civil War, with townships inventoried before and sections inventoried after the war occurred.

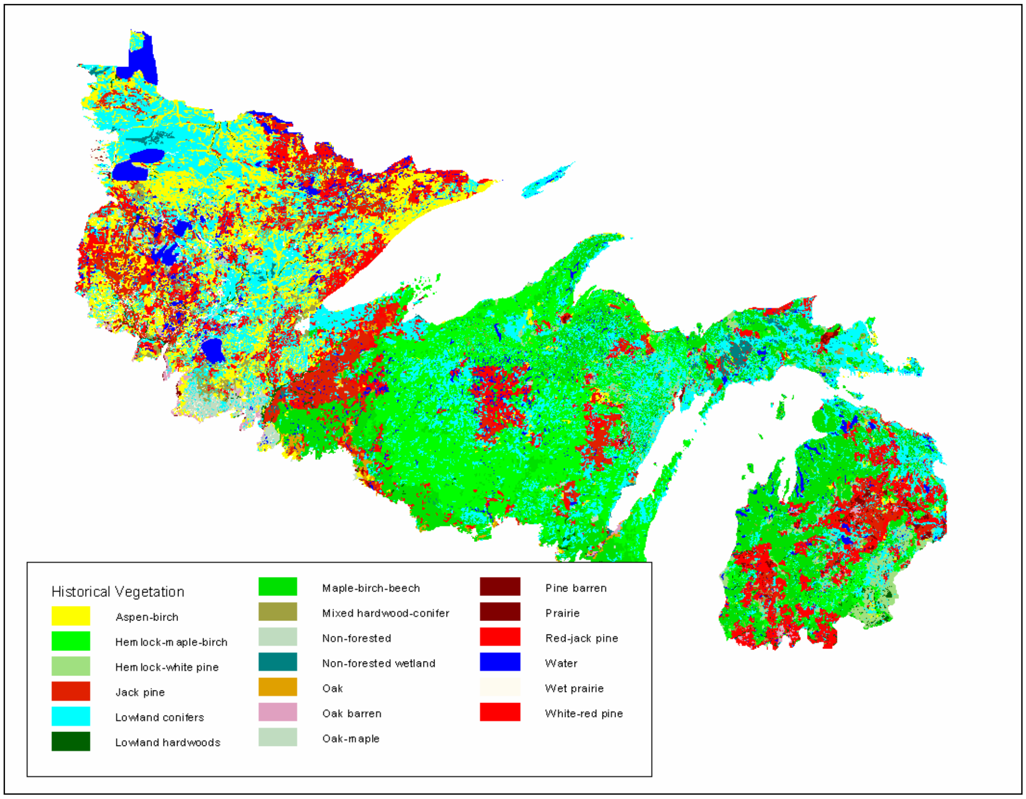

Figure 2. Historical vegetation of the study area.

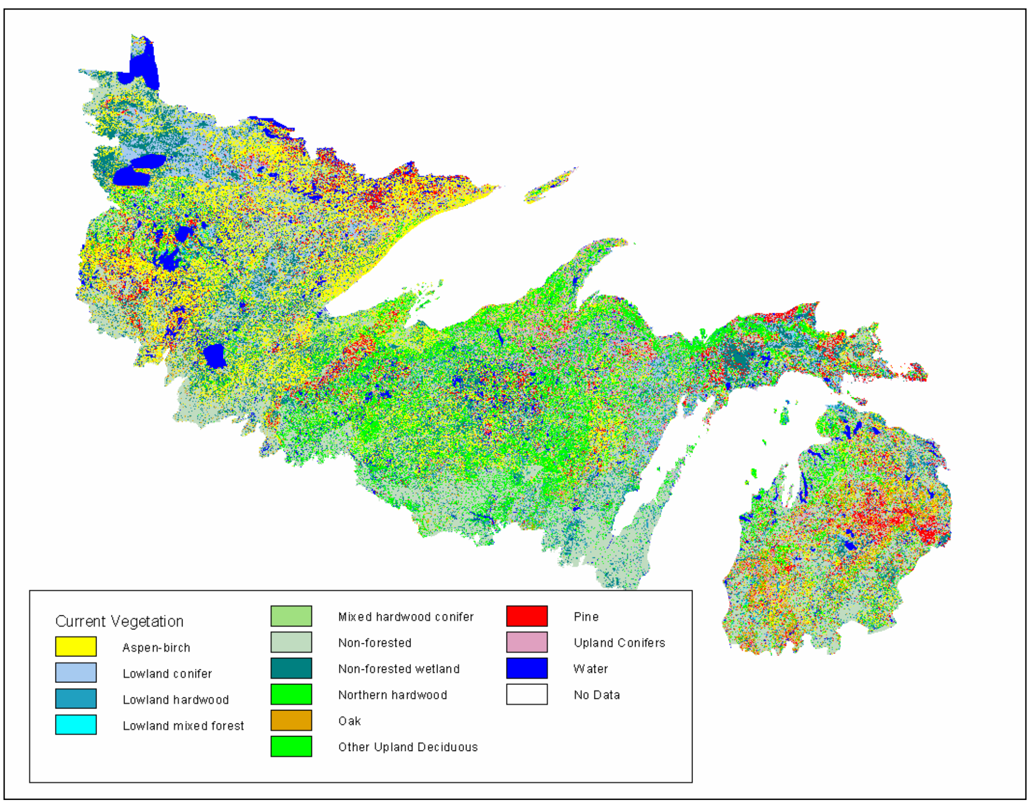

Figure 3. Current vegetation of the study area.

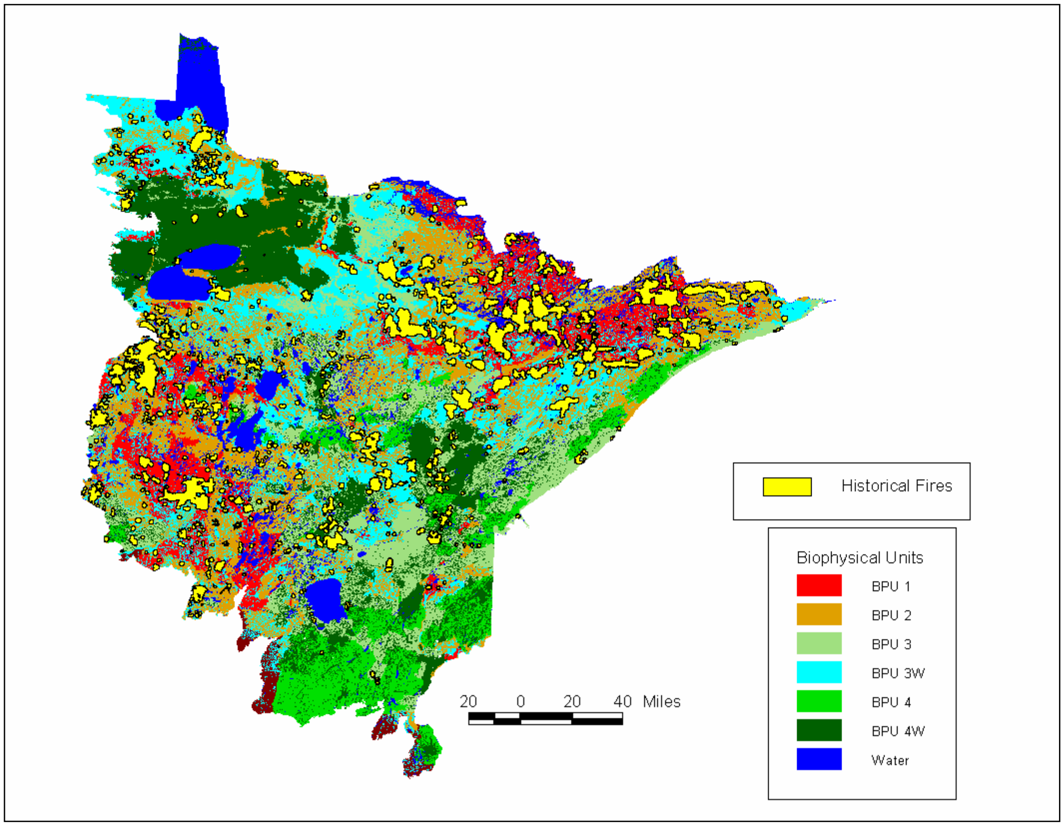

Figure 4. Historical forest fires within biophysical units of Minnesota.

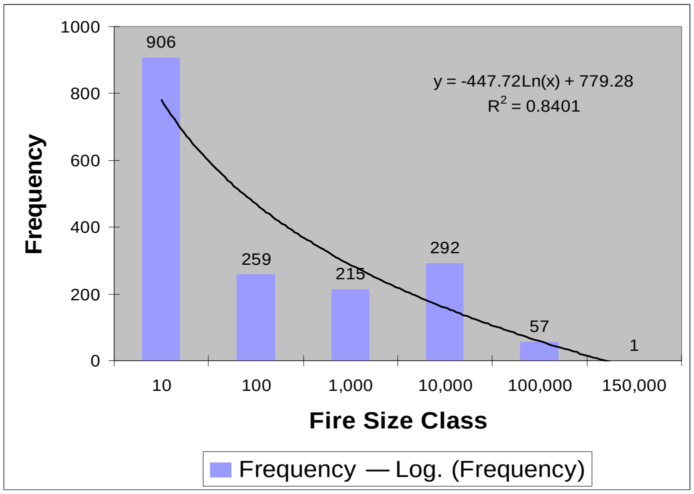

Figure 5. Historical forest fire frequency – size relationships in Minnesota.

In northern Minnesota, 1,730 historical forest fires burned 2,486,000 acres across the 20.8 million acre study area (Figures 4, 5). Fires were larger than in adjacent states, with 3.5% of all fires larger than 10,000 acres accounting for 64% of the total area burned. The largest 10% accounted for 83% of the total area burned. Fires smaller than 10 acres represented 52% of all fires, and accounted for less than 1% of the total area burned.

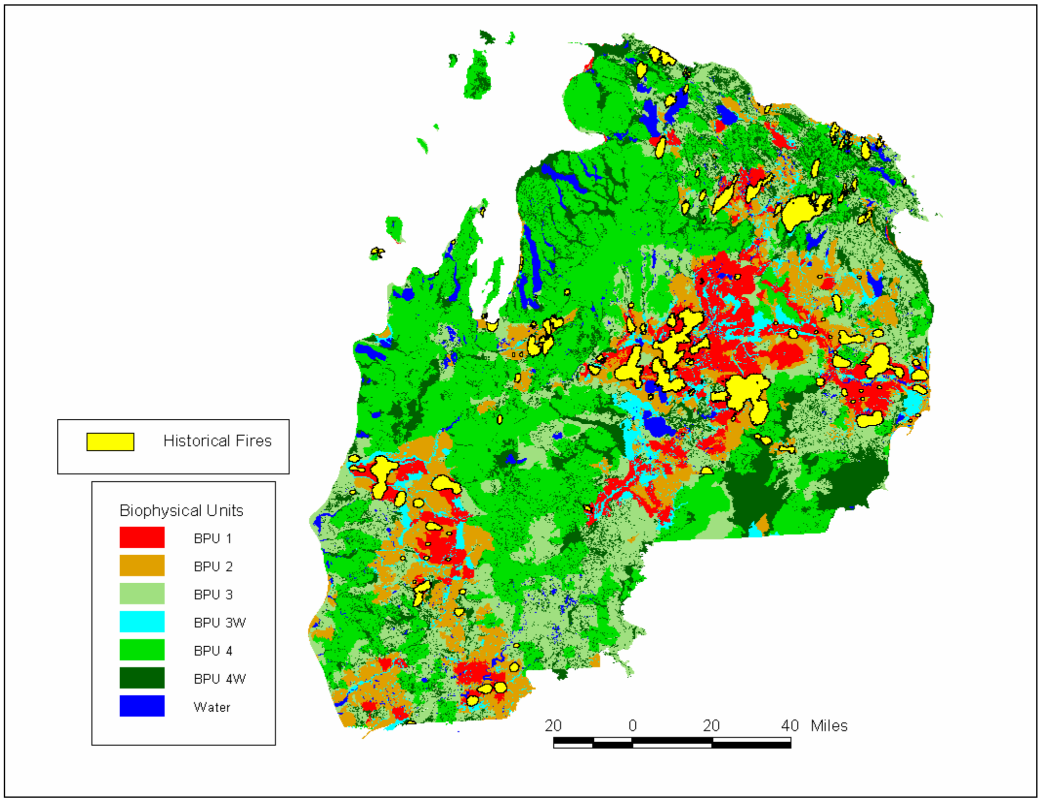

Figure 6. Historical forest fires within biophysical units of northern lower Michigan.

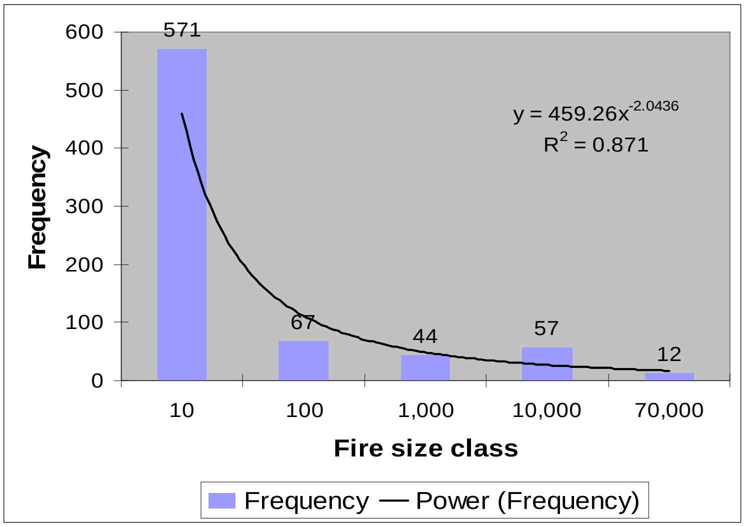

Figure 7. Historical fire frequency – size relationships in northern lower Michigan.

In northern Lower Michigan, 751 historical forest fires burned a total of 544,000 acres within 10.2 million acre study area (Figures 6, 7). The largest 12 fires (1.6%) accounted for 61% of the total area burned, and the largest 10% accounted for 96% of the total area burned. Fires smaller than 10 acres represented 76% of the total number of fires, but accounted for less than 1% of the total area burned.

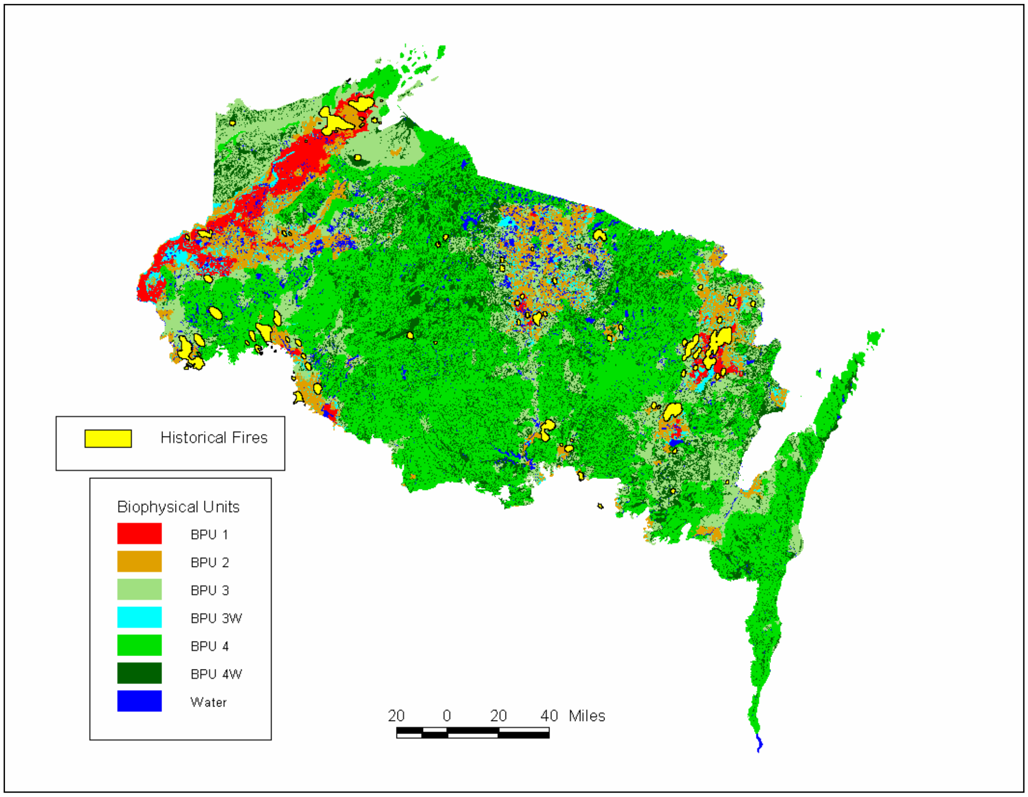

Figure 8. Historical forest fires within biophysical units of northern Wisconsin.

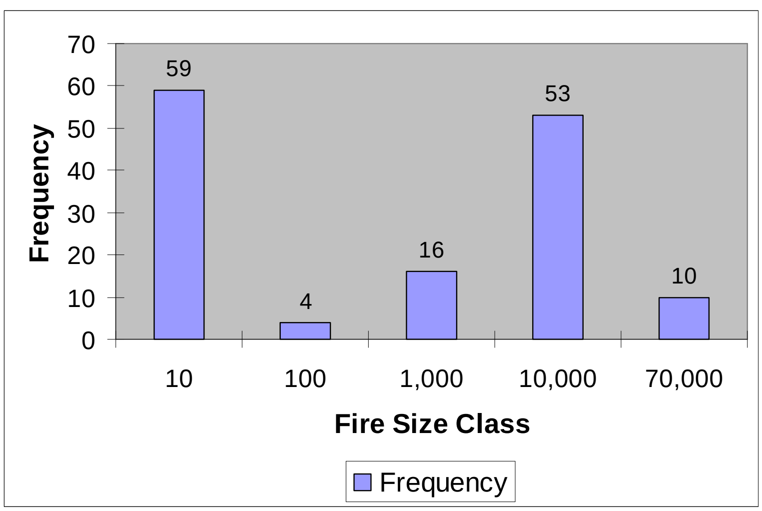

Figure 9. Historical fire frequency – size relationships in northern Wisconsin.

In northern Wisconsin, 142 historical forest fires burned a total of 426,430 acres within the 17.8 million acre study area (Figures 8, 9). Fires larger than 10,000 acres represented 7% of the total number of fires and accounted for 59% of the total area burned. The largest 10% of all fires accounted for 67% of the total area burned. Fires smaller than 10 acres represented 40% of the total number of fires, but accounted for less than 1% of the total area burned.

Northern Wisconsin's historical fire regime for xeric BPU 1 was unique due to the abundance of openlands, which occupied 60% of the unit state-wide and nearly all of the sand plains in northwest Wisconsin (Figure 10). Rotations estimated in this report are for forest replacement fires that occurred within the forested portion of respective biophysical units. Surface fires were not estimated because of the very short recognition window assumed for GLO surveyor observations; evidence of surface fires was not persistent. Rotations within the barren or openland components of BPU 1 in Wisconsin likely occurred within periods of a few years to a decade, in a time frame too short for jack pine to produce sufficient quantities of viable seed for self-replacement. The area-wide rotation of surface and forest fires within this biophysical unit was probably less than half of forest replacement estimates, or less than 30 years.

Interpretations of interpolated fire boundaries in northern Wisconsin are also affected by the absence of line note observations of disturbance within the study area. The relatively low proportion of fires smaller than 100 acres in these estimates compared to those in Michigan or Minnesota may be due to the lack of supplementary line note observations where fires would have been noted, the lag of corner-quarter notes (0.5 mile), or surveyor bias in selecting a healthy tree for monumenting section corners and quarter-corners.

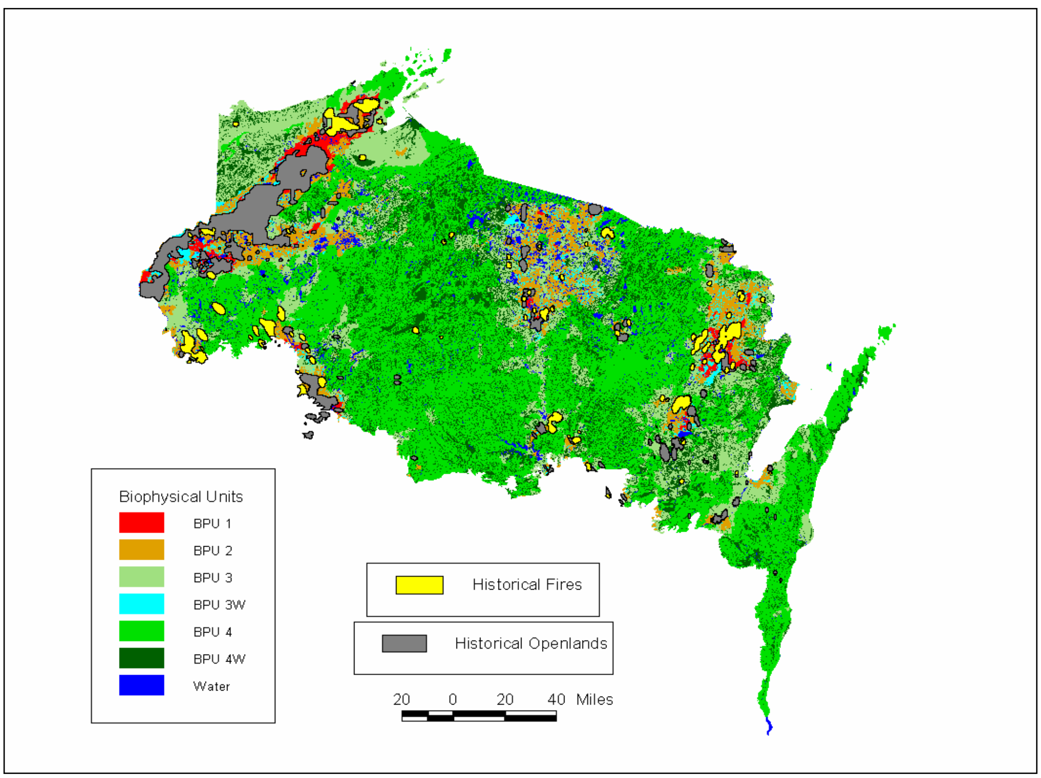

Figure 10. Historical forest fires and openlands within biophysical units of northern Wisconsin.

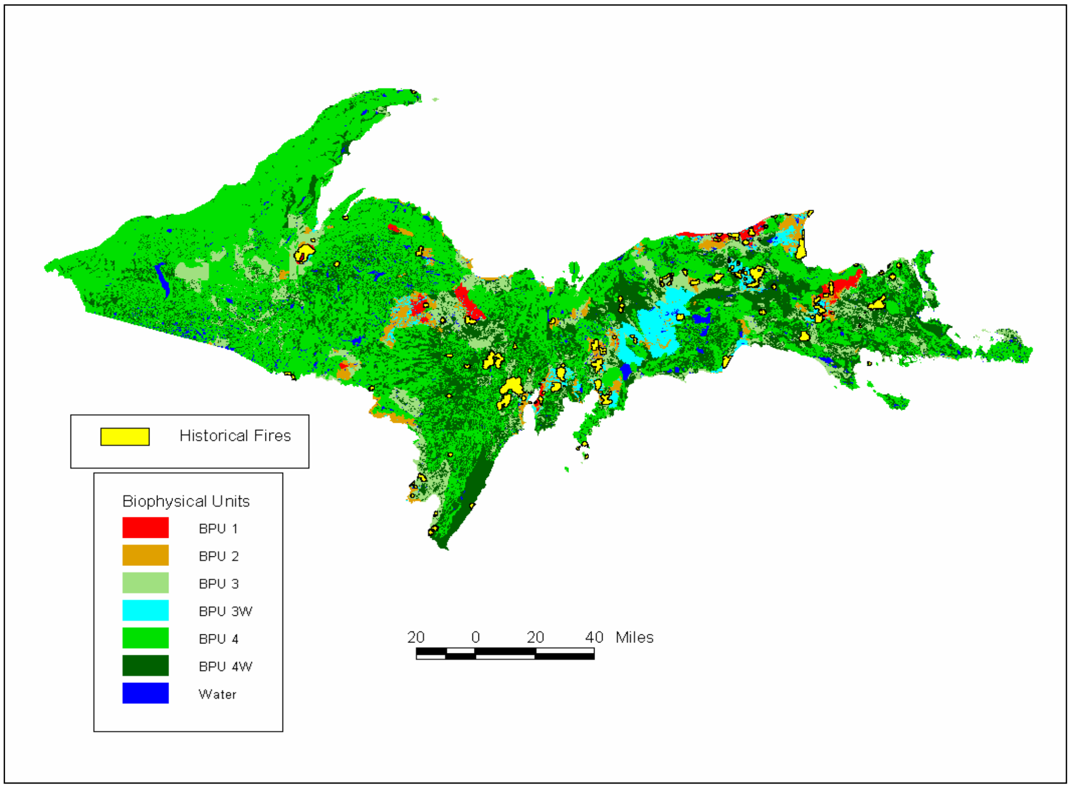

Figure 11. Historical forest fires within biophysical units of the Upper Peninsula of Michigan.

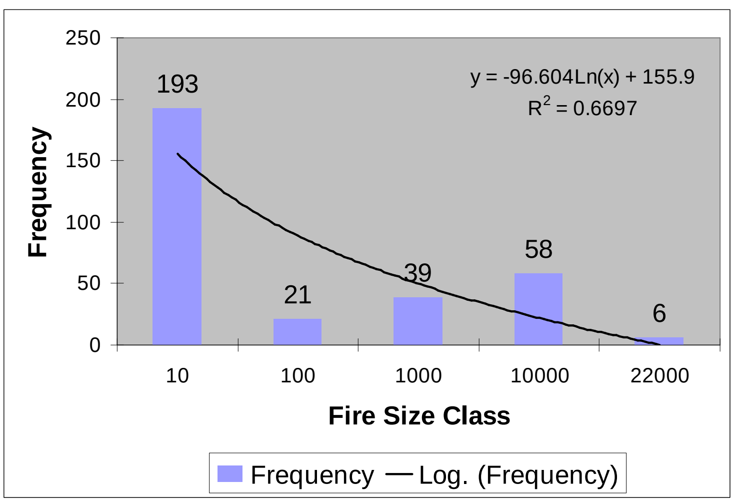

Figure 12. Historical fire frequency – size relationships in the Upper Peninsula of Michigan.

In the Upper Peninsula of Michigan, 317 historical forest fires burned 278,000 acres across the 10.4 million acre study area (Figures 11, 12). Fires were smaller than in adjacent states, with only 6 fires larger than 10,000 acres accounting for 33% of the total area burned. The largest 10% accounted for 75% of the total area burned. Fires smaller than 10 acres represented 60% of all fires, but accounted for less than 1% of the total area burned.

Modern Fire Regimes

Interactions among social and ecological factors govern the modern fire regimes of the Lake States. Cardille et al. (2001) reported that 98% of all fires in the study area are human-caused, with 58% of all fires larger than 100 acres due to arson. Classification tree analyses and logistic regression analyses show ignition density is largely associated with human population density and access variables, and fire spread is associated with both the flammability and connectivity of fuels and fire suppression activities. Collectively our results indicate that while human factors dominate the probability of fire ignitions, ecological factors constrain the ability for those fires to spread.

There were 46,439 reported fires (hereafter "all fires") from 1985 through 2000 in the northern Great Lakes Region. 20,536 (44.2%) of those fires occurred on forested land (hereafter "forest fires"). The distribution of fires among years was similar for both datasets (i.e., for all fires and for forest fires only). The highest percentage of fires over the time period occurred in 1988 (11.2%, N = 1899 all fires; 11.2%, N = 769 forest fires; Fig. 13). The lowest percentage occurred in 1993 (4.1%, N = 5196 all fires; 3.7%, N=2300 forest fires). Numbers in 1987 were also relatively high (N = 4488 all fires; N = 1943 forest fires). Other years with relatively few fires were 1985 (N=1981 all fires; N = 907 forest fires) and 1986 (N=1939; N = 887 forest fires).

A total of 434, 921 acres burned in the study region over the 16-year period. Forest fires burned 156,337 acres (35.9%), representing 0.4% of the forested landscape. The largest percentage of area burned over the study period was in 1987 (17.3%, 75, 042 acres all fires; 16.5%, 25, 813 acres forest fires). The least amount of area burned by year was in 1993 (2.6%, 11381 acres, all fires; 1.5%, 2358, acres forest fires).

The majority of fires on both forested land (forest fires) and non-forested land (non forest fires) during this period were ≤0.5 acres (51.9% and 50.7% respectively; Figure 14). Median sizes of fires differed between forests and nonforests when all fires were included (Wilcoxon Rank Sum Z=-4.73, p<0.0001) and when only those fires ≥0.5 acre were compared (Z=-2.43, p<0.015). The overall distribution of fires sizes also differed between these two groups ($K\text{-}S_{asymptotic}$=2.566, p<0.0001). The main differences in the distribution of fire sizes appears to be for fires >20 acres, which constitute 6.4% fires on nonforested land, but only 2.0% forest fires.

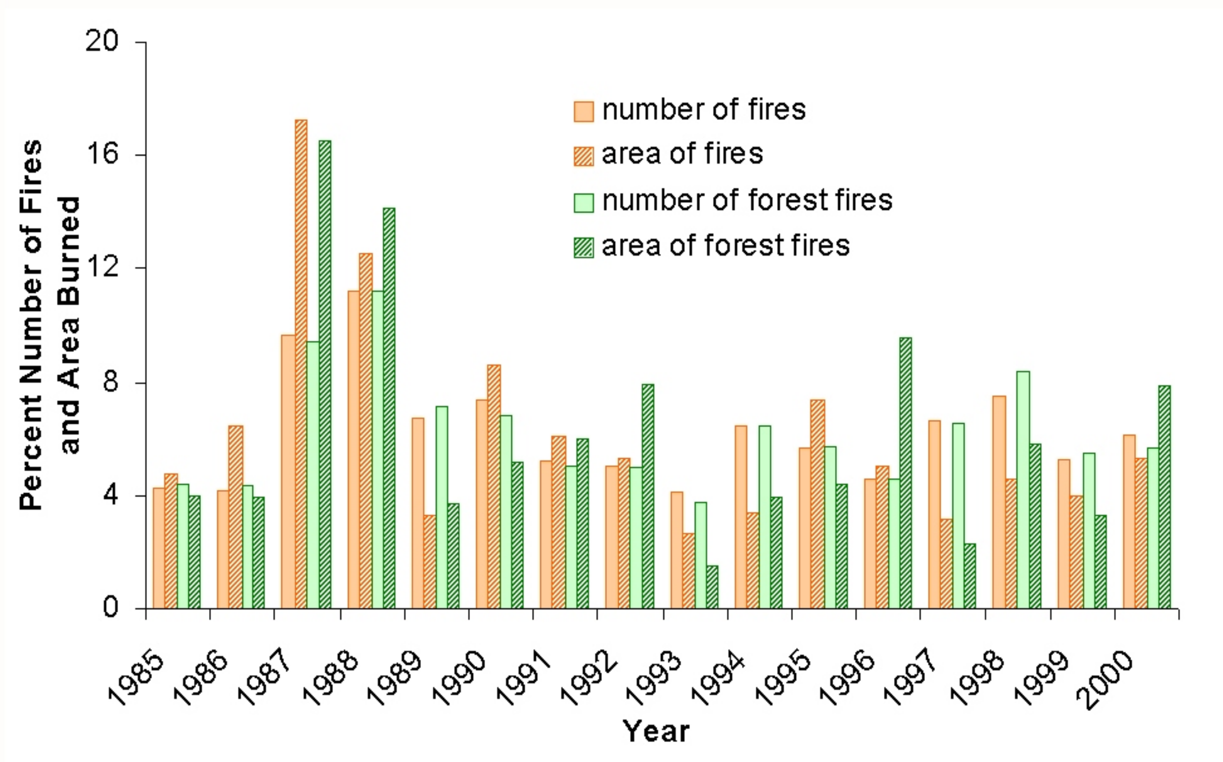

Figure 13. Percent of the number and area of all fires (*N* = 46,439, 434,921 acres) and of forest fires (*N*=, 20,536, 156,337 acres) occurring each year from 1985-2000.

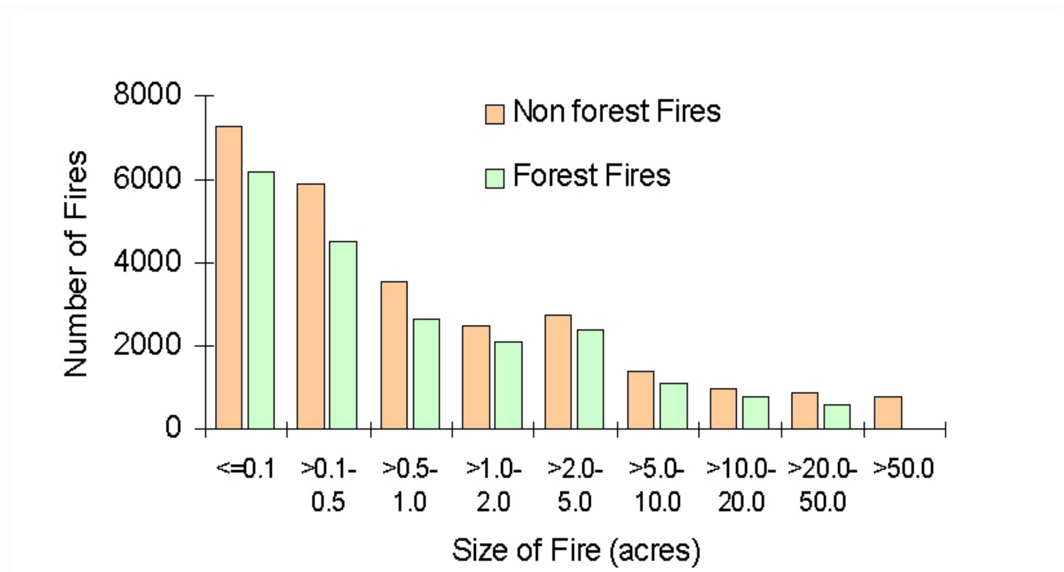

Figure 14. Frequency of fires in different size categories on forested land (*N* =20, 536) and on non forested land (*N* =25, 903).

Average size of forest fires ranged from a low of 2.7 acres in 1997 to 16.0 acres in 1996 (Fig. 15). Maximum fire size was lowest in 1993 (106 acres) and highest in 1988 (7100 acres).

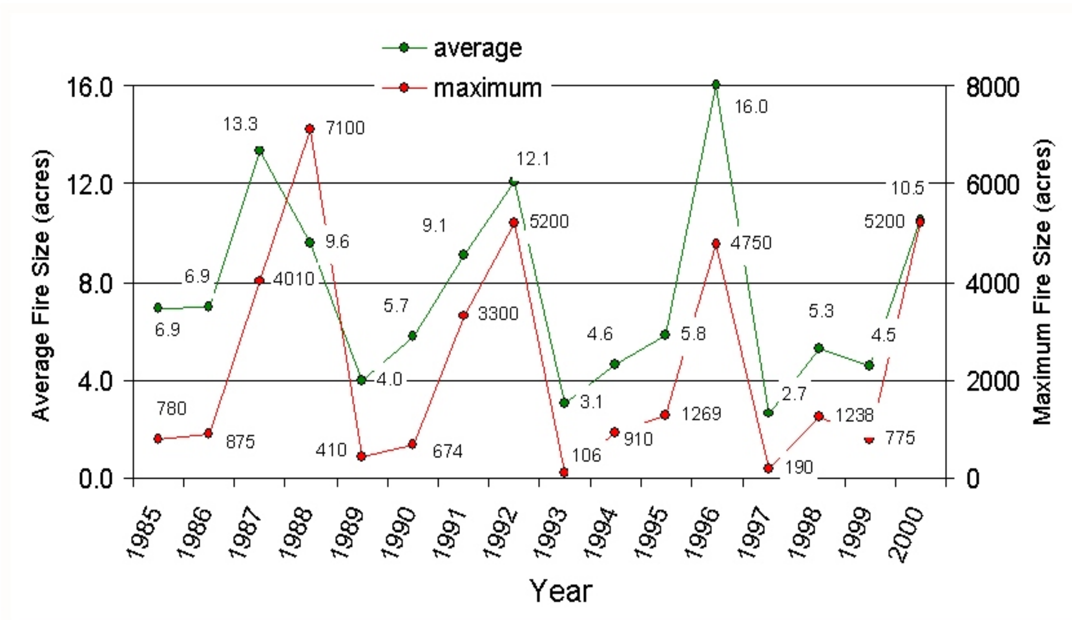

Figure 15. Average and maximum sizes of forest fires by year, 1985-2000.

Months with the highest maximum forest fire sizes were recorded in April (7100 acres) and May (5200 acres, Fig. 16 These were the same months as had the highest total number and highest total area burned by forest fires (see Fig. 19). However, months with highest average fires sizes were June (10.6 acres) and October (10.0 acres).

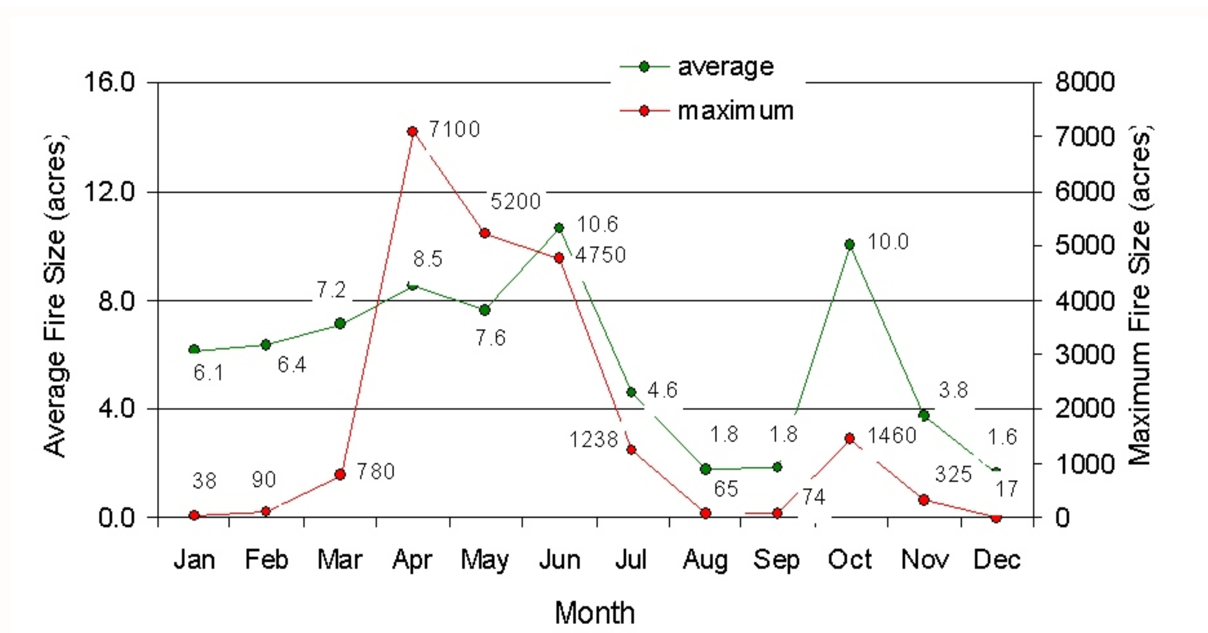

Figure 16. Average and maximum sizes of forest fires by month from 1985-2000.

Classification Tree Analysis of Social and Ecological Factors Affecting Modern Fire Regimes

Classification tree analyses of binary (fire/nonfire) section observations were conducted in northern Wisconsin to evaluate the relative importance of human versus ecosystem variables influencing the likelihood of a fire of a given size or type (Sturtevant and Cleland 2004). The primary variable affecting the likelihood of a fire of any type was population density, which explained roughly 40% of the variation in the data. Proximity to roads and railroads also increased the likelihood of a fire ignition, but explained far less variation in the data. Similarly, forest fire ignitions were predicted primarily by housing density, a strong correlate of population density. Ecological variables were less common in the classification trees for fire ignitions.

For forest fires greater than 1 acre, landscape ecosystem category (biophysical unit) explained the most variation (Figure 17). The ecosystem fire resistance variable (EFR) was an assigned value between 1 and 5 corresponding with the ordinal rank in historic fire rotation length for each respective biophysical unit class. Forest fires greater than 10 acres were most likely to occur in BPU 1, relatively flammable vegetation, or close to railroads. This suggests that ecosystems historically subject to frequent fires and composed of flammable fuels still are more subject to burning despite an aggressive fire fighting capacity within the region.

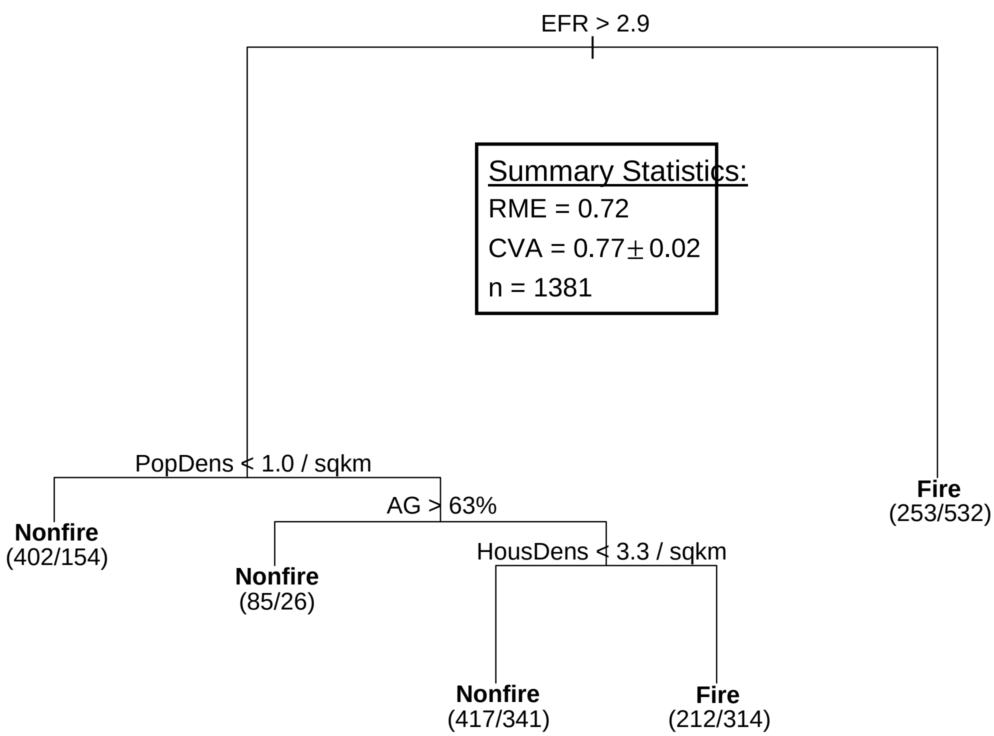

Figure 17. Classification tree of modern forest fires > 1 acre in northern Wisconsin. Splitting criteria are shown, with true statements flowing to the left. RME = relative misclassification error; CVA = cross-validation error; n = number of fire observations in the modeled database.

For all fire occurrences greater than 1 acre, the presence of agriculture or grassland cover types was the most important predictor following population density (Figure 18).

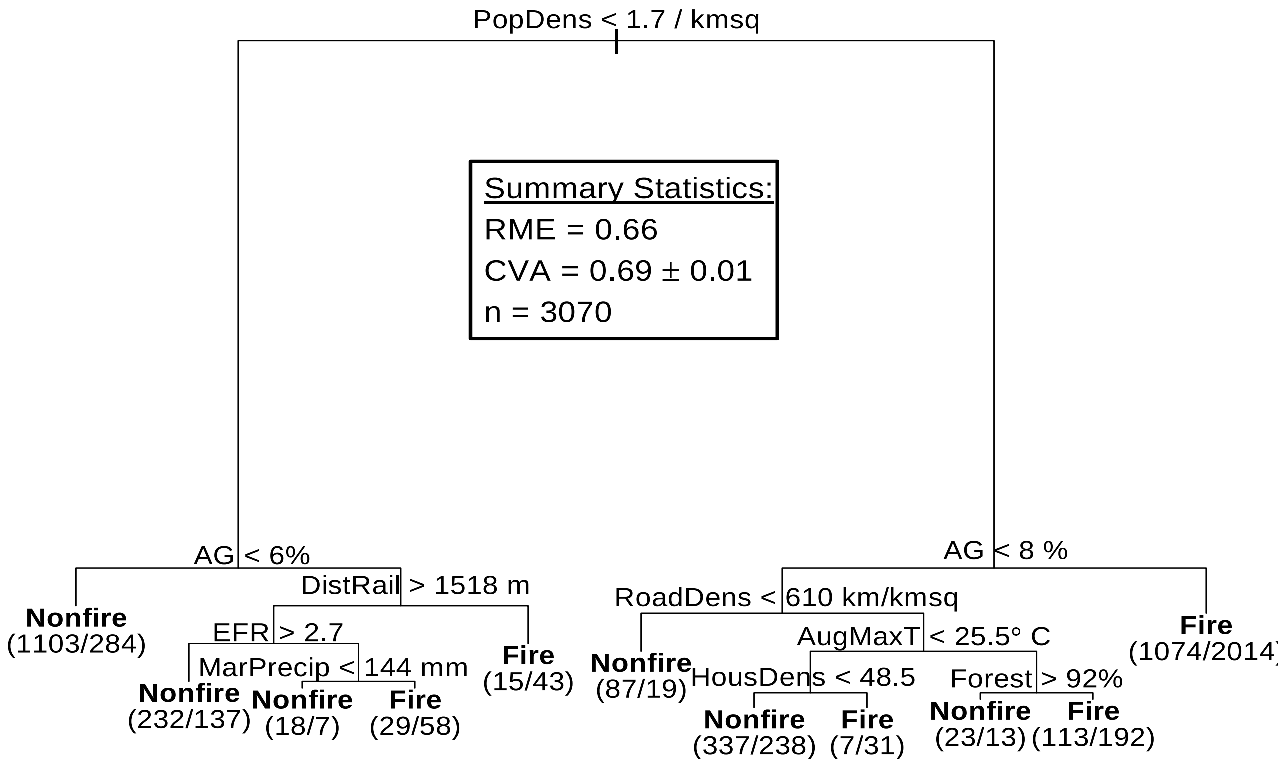

Figure 18. Classification tree of all modern fires > 1 acre in northern Wisconsin. Splitting criteria are shown, with true statements flowing to the left. RME = relative misclassification error; CVA = cross-validation error; n = number of fire observations in the modeled database.

Our results are consistent with previous research in the Lake States that show that both human and environmental factors influence the likelihood of fires in the region (Cardille et al. 2001, Saunders et al. in review). Unlike previous analyses, we found that the relative importance of human versus environmental factors changed with the minimum fire size thresholds. Cover type information recorded within the Wisconsin fire database provided additional insights into causal factors underlying land cover-specific fires, and we found that the historical fire rotation classification provided by Cleland et al. (2004) provided an important spatial context for understanding modern forest fire risk within the region.

Ignition patterns were overwhelmingly affected by human population density, for which housing density was a close surrogate. While Cardille et al. (2001) did not observe such a strong relationship between fire occurrence and human population in the same region, they restricted their analyses to fires greater than 1 acre in size. Our analyses indicated that the 1 acre fire size threshold corresponded with a transition in the relative importance of human versus environmental factors underlying fire likelihood. Nonetheless, the dramatic increase in fire ignitions with population and housing development has critical implications for fire risk within the wildland urban interface (WUI) in this region.

The application of classification tree analyses to the Wisconsin wildfire database provided some unique advantages over more traditional parametric techniques. We were able to include variables that were highly correlated without violating the assumptions of the technique. At times strongly correlated variables were virtually interchangeable, as indicated by examination of model improvement for alternative and surrogate splits, but the degree to which correlated variables were interchangeable varied across models. For example, housing density could have been easily substituted for population density in the general fire ignition model, but population density did not perform nearly as well as housing density in predicting forest fire ignitions. Similarly, the EFR variable was a much better predictor of forest fires 1 ac (0.4 ha) or greater in size than was vegetation fire resistance variable (VFR), while VFR predicted forest fires 40 ac (25 ha) or greater in size only marginally greater than EFR. These results indicate that the correlated variables can in fact provide different information. Since model improvement due to any one split is independent from the rest of the model, the degree to which correlated factors contribute to model improvement can be evaluated without interactions from other variables.

Tristate Logistic Analysis

We expanded our analysis of modern fire regimes to include fires throughout the tristate northern Great Lakes region. Although the majority of modern fires are human-caused (Cardille and Ventura 2001), results of Cardille et al. (2001) also suggested subregional, long-term influences of climate. We therefore considered that direct incorporation of a regional effect on fire regimes and the use of finer-scale climatic information might: (1) clarify the relative importance of climate, fuel, and human influence on fire regimes of the Region; and (2) improve the ability to predict fire occurrence in this human-dominated landscape.

We hoped to build upon the previous research of Cardille et al. (2001) by developing and comparing predictive models of fire occurrence using two subregional classification and mapping systems: networked subsections (hereafter subsections; Cleland et al. 1997, Cleland et al. 2005), and aggregated mesoclimatic climate zones (climate zones; Host et al. 1995). We expected the influences on fire probability of land cover, ground moisture, and climate would be relatively consistent within subsections (see Nowacki et al. 2001). In contrast to subsections, we expected climate zones to delineate areas within which fire was similarly influenced by climate over the time scale of our study, removing the need for utilizing broad-scale climate information when predicting fire probability within a zone. Our specific objectives were to: (1) assess the utility of using a single, regional model versus multiple, subregional models of forest fire causality within the Region; (2) determine, at the subregional level, whether, subsection or climatic units provided the best framework within which to predict forest fires in the Region; and (3) assess spatial variation in the parameters driving forest fire occurrence across the Region. We confined our study to the forested lands within Province 212 (Laurentian Mixed Forest; McNab and Avers, 1984), which comprised 72% of the area that has similar fire management protocols (Cardille, 1998). Twenty-three subsections, and 18 climate zones are represented in whole or in part within the ecoregion.

The subsections used as ecological units of analysis are conglomerations of subsections defined for the Region within the Forest Service National Hierarchical Framework of Ecological Units (Cleland et al. 2005, McNab and Avers 1994). The climatic zones used were developed by Host et al. (1995) to aid in interagency, regional planning and ecological classification and inventory on national forests. They correspond roughly in extent to the subsections of the National Hierarchical Classification. The zones incorporate monthly average values of precipitation and maximum and minimum temperature from a 30-year period (1961-1990), interpolated to a resolution of 1 km^2 (ZedX, Inc. Boalsburg, Pennsylvania 1995).

We developed a database including dates and locations of fires and associated land cover, climate, topography, and social data. We compiled the same information for center points of public land survey (PLS) sections that did not have fires in each month-year combination during our study period.

We used logistic regression to model the probability of fire occurrence during fire season for each set of spatial units (region, subsections, climate zones). For this study, we used only fires ≥ 0.2 ha (hereafter burns) on forested land (see below), that occurred during the fire season (April, May, June and July; see Figure 15) and within 40 km of a climate station (N = 8,356 fires).The logistic model defines the probability (*P*) of an event (i.e., burn) as:

$$P = e^V \big/ 1 + e^V \tag{1}$$

where *V* is a linear combination of explanatory variables (X):

$$V = \beta_0 + \beta_1 X_1 + \beta_2 X_2 ... \beta_n X_n \tag{2}$$

The independent variables considered for the models were in four categories:

(1) topography, including (a) slope and aspect, (see Beers et al., 1966, and Stage, 1976); (b) elevation; and (c) topographic relative moisture index (TRMI);

(2) land cover, including (a) dominant forest cover type, entered as a series of dummy variables; (b) stream density; and (c) percent water in surrounding landscape;

(3) climate, including variables specific to month-year of burn, representing within-season variation: (a) maximum temperature; (b) minimum temperature; (c) mean

temperature; (d) precipitation; (e) PET; and variables specific to year only of burn, representing annual and among-season variation: (f) minimum temperature in March; (g) mean temperature in October; and (h) precipitation for July; and

(4) social factors, including (a) density of roads; (b) population density; (c) density of total housing units; (d) density of seasonal housing units; (e) percent of housing units that were seasonal; and (f) median house value. Interactions between road and population density were also considered.

We constructed models for the Region (*N* = 8356 fires; hereafter the regional model) and those climate zones (*N* = 14) and subsections (*N* = 18) with $N \geq 75$ burns over the 16-year period. We randomly chose two thirds of the burns and an equal number of unburned cells from each spatial unit for model development. The remaining third of the burns and a similar number of randomly chosen unburned points were used for independent assessment of the model.

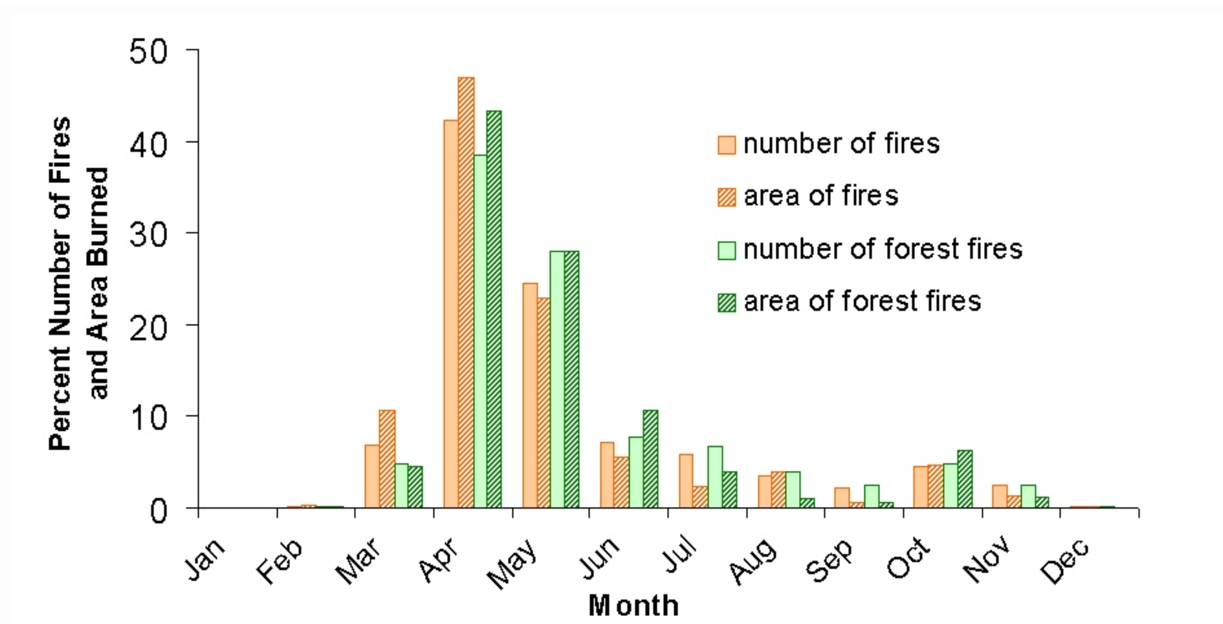

Figure 19. Percent of the number and area of all fires and of forest fires occurring each month during the years 1985-2000.

Based on the seasonal distribution of fire occurrence (Figure 19), we defined forest fire season as the months of April through July, incorporating 81% forest fires. A second peak of fires occurs in Oct (4.5% all fires and 4.8% forest fires); however, we expected these fires to be driven by different variables than those in the spring.

Prior to model development we examined Spearman rank correlations among all potential independent variables and excluded an initial subset based on correlations > 0.6 with other candidate variables. To further ensure minimal collinearity in the predictors, we calculated variance inflation factors (VIF); VIF were <3 for all variables (a strict criterion (McKenzie et al., 2003).

For each spatial unit, we derived an initial, "optimal" model using a forward selection logistic procedure in SAS, with a probability to enter or stay in the model ≤ 0.03. Criteria for finalizing the model included: (1) minimizing AIC (Akaike's information criterion; (2) Goodness of Fit (Hosmer and Lemshow chi-square test and p-value thereof) and; (3) are under the receiver operating characteristic (ROC) curve. From the initial model we sequentially exclude any variable that did not increase the model R^2 by at least 2% in the interest of model parsimony, with the requirement that AIC was not significantly increased by variable removal. We required that the area under the ROC curve (AROC) of a final model be ≥0.70 (a 'reasonable' discriminatory ability; Pearce and Ferrier, 2000). The ROC curve depicts the relationship between sensitivity, or the true positive fraction (fraction of fires predicted as such) relative to the false positive fraction (nonfire sites incorrectly predicted as fires). When these two fractions are plotted for a range of decision thresholds, the area under the curve corresponds to the ability of a model to discriminate between a fire and nonfire event (e.g., Venier et al. 2004).

We evaluated relative model performance by comparing the AROC curve of the model for the individual spatial unit applied to its validation set to the AROC for the tristate model applied to a spatial unit's validation data set. ROC curves were calculated using the Mann-Whitney statistic technique and differences between the ROC curves were evaluated by Chi-square statistics using the SAS ROC macro based on methods of Delong et al. (1988).

Results

The final regional logistic model for burns (fires ≥ 0.2 ha) during fire season was:

$$V = -0.778 + 2.967X_1 - 0.142X_2 - 0.009X_3 + 1.147X_4 + 0.829X_5 + 0.860X_6$$

where
X1 = road density
X2 = minimum temperature (during month of fire)
X3 = precipitation (during month of fire)
X4 = population density
X5 = jack pine (1 = jack pine, 0 = not jack pine)
X6 = aspen birch (1 = aspen birch, 0 = not aspen birch)

This model explained 38% of the variation in the data; AROC was 0.817.

Modeling by subsection improved model discriminatory ability in nine cases (two significant) but was less useful in eight cases (two significant). Unit-specific models were more useful than the tristate model for six climate zones (one significant) and less useful in eight (five significant; see Table 3).

Table 3. Comparisons of the discriminatory utility of logistic models developed to predict the probability of a burn (fire ≥ 0.2ha) within subsections and climate zones, relative to a tristate, regional model within the northern, Great Lakes Region. The area under the Receiver Operating Characteristic (ROC) curve, c, quantifies the ability of a model to discriminate between a burn and nonburn event; $0.700 < c < 0.900$ represents acceptable capability and $c \geq 0.900$ is considered excellent. Models were developed with a development data set and evaluated using an independent, assessment data set. We compared the effectiveness of the regional *versus* the subsection- or climate zone-specific model by applying both models to the assessment data set for a climate or subsection.

	Model Development		Model Assessment			Model comparison
Unit	Unit-specific		Unit-specific	Tristate		Unit *vs* tristate[a]
	C	N	C	C	N	χ^2, p-value
Subsection						
Hb	0.711	1435	0.723	0.735	707	1.293, 0.256
He	0.720	752	0.692	0.691	351	0.009, 0.923
Hh	0.761	559	0.732	0.695	256	5.288, 0.022
Ja	0.881	249	0.916	0.823	75	4.491, 0.034
Jb	0.735	121		0.753		[a]0.224, 0.636
Ka	0.797	327	0.727	0.752	110	0.387, 0.534
Kb	0.853	857	0.858	0.862	533	0.180, 0.671
La	0.829	645	0.806	0.791	303	0.701, 0.403
Lb	0.876	626	0.831	0.813	278	1.414, 0.234
Ma	0.867	528	0.840	0.834	213	0.188, 0.665
Na	0.851	1203	0.816	0.806	589	2.655, 0.103
Nb	0.872	923	0.851	0.851	421	0.002, 0.968
Qa	0.898	236	0.883	0.872	98	0.207, 0.642
Qb						
Ri						
Rk						
Sb	0.637	211	0.672	0.745	89	1.846, 0.174
Ta						
Tb	0.831	204	0.834	0.853	72	0.381, 0.537
Tc	0.845	382	0.880	0.862	178	0.756, 0.385
Xa	0.824	407	0.823	0.852		5.022, 0.025
Xb	0.792	262	0.825	0.882	91	3.877, 0.049
Za						

Table 3. (cont.).

Climate Zone						
1						
2	0.722	706	0.707	0.737	329	5.474, 0.019
3	0.707	271	0.725	0.833	110	5.593, 0.018
5	0.732	1149	0.755	0.781	533	4.098, 0.043
6						
7	0.907	163	0.744	0.773	69	5.558, 0.454
9	0.755	171		0.640	171	[a]6.126, 0.013
10	0.765	767	0.751	0.730	365	2.172, 0.141
11						
15						
16	0.788	205		0.729	205	[a]3.133, 0.077
17	0.803	220		0.764	220	[a]1.736, 0.188
18	0.833	968	0.771	0.820	482	12.267, 0.005[b]
19	0.801	1526	0.767	0.820	723	30.528, 0.001[b]
20	0.864	589	0.827	0.819	293	0.367, 0.544
21	0.825	2307	0.850	0.846	1112	0.345, 0.557
22	0.822	452	0.791	0.811	212	1.598, 0.206
23	0.855	562	0.873	0.884	230	0.816, 0.366

[a] compares the c values of the two models when applied to the assessment data set
[b] significant difference at Bonferroni corrected p = 0.05

Subsection models improved classification of burns (AROC) over the regional model primarily within the northwestern and eastern portions of the region (excepting subsection Hb; Figure 20A). In contrast, use of climate zones improved classification in the central and eastern areas relative to the regional model (excepting zones 3 and 5; Figure 20B).

Human and climate variables were most common categories in the logistic models (44 and 43 occurrences respectively; Table 4 and entered models a similar number of times within the two subregional groups (i.e., subsection and climate zone). Land cover variables were third in importance (six entries in models). Topographic variables were not included in any model.

The specific predictors of burns from the categories of human factors, climate, and land cover, differed among groups of models (Figure 21, Table 4). Both overall and for both subregional zonations, the most common variables in the models were road density (regional, 17 of 18 subsections, and 11 of 14 climate zones) and minimum temperature (regional, 12 of 18 subsections, and 9 of 14 climate zones). Precipitation, PET, and distance to nearest city of greater than 1000 people were also relatively common in models (Table 4). The regional model contained two forest cover variables (aspen-birch and jack pine). Models for three subsections and one climate zone incorporated forest cover; however, the cover types (LC6, lowland conifer and LC16, lowland hardwood-conifer) differed from those in the regional model.

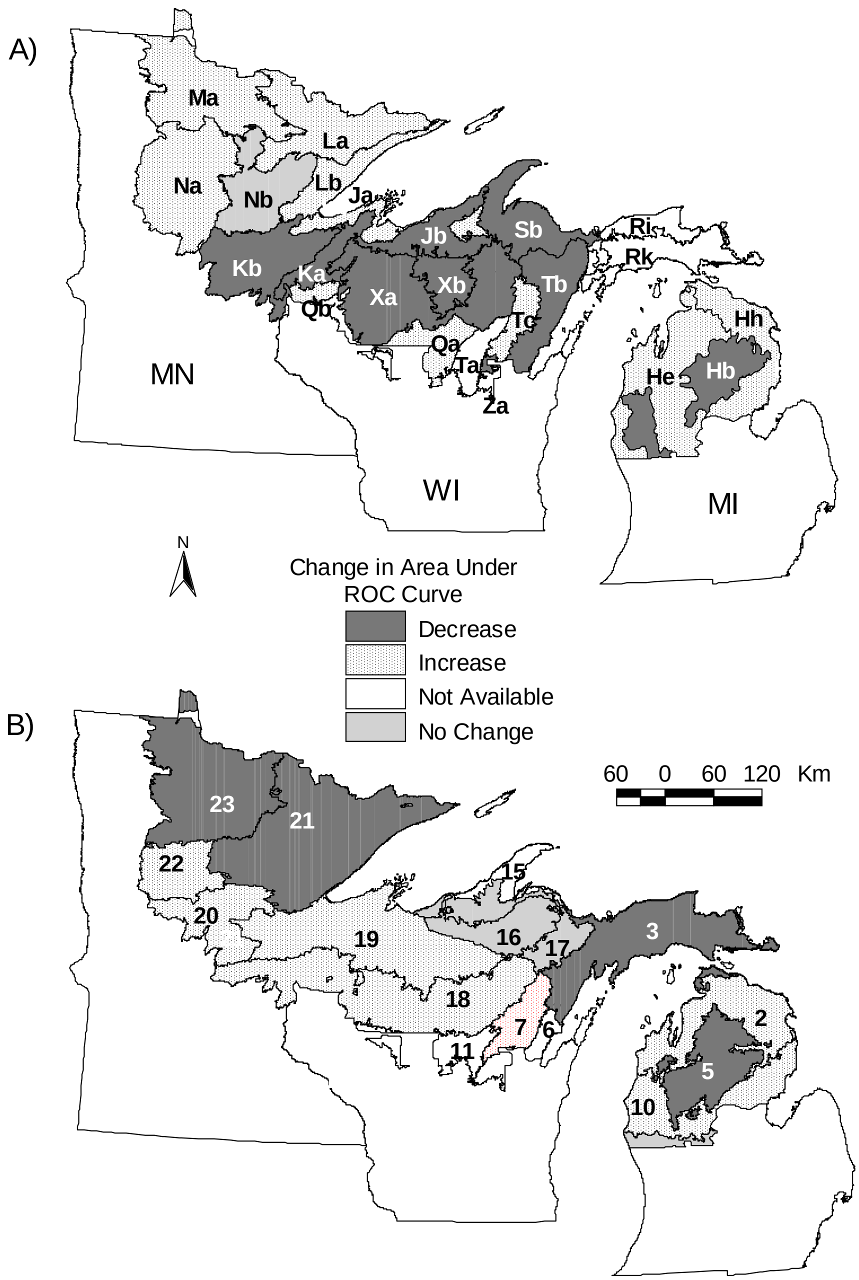

Figure 20. Change in area under the receiver operating characteristic curve (c) of logistic models predicting the probability of burns (fires ≥0.2 ha) within (A) subsections, and (B) climate zones relative to a regional model for the Northern Great Lakes Region. See Table 3 for statistical differences in c values for a section or climatic zone.

Table 4. Number of times variables entered significantly ($p \leq 0.03$) into logistic models predicting probability of a burn using three categories of spatial zonation for the northern Great Lakes Region.

Spatial Unit	N (models)	Category of Variables			
		Human	Climatic	Land Cover	Topographic
Regional	1	2	2	2	0
Subsection	18	26	23	3	0
Climate Zone	14	16	17	1	0
All Models	33	44	43	6	0

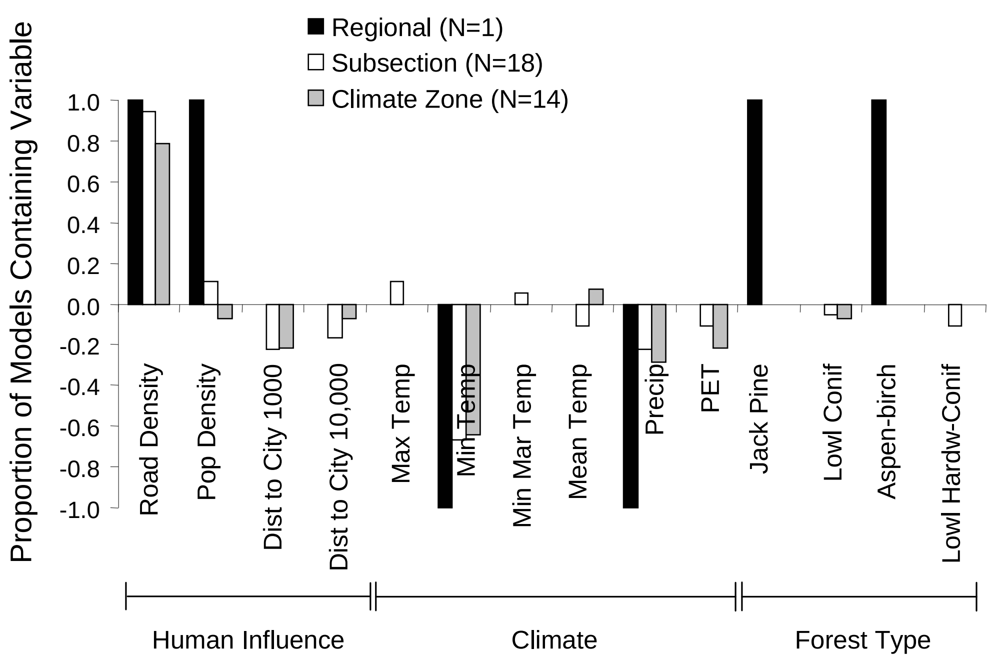

Figure 21. The proportion of logistic regression models developed for three spatial zonations (region, subsection, climate zone), that contained variables in the categories human influence, climate, and forest type. A negative proportion indicates that the variable had a negative influence on the probability of a burn.

Issues Regarding Use of the Modern Fire Data

Accuracy, precision, and standardization in reporting size and location of fires influenced our analytical procedures and results. Although we were able to acquire data on fire size and location for all fires, this information was not reported with the same accuracy or measured using consistent procedures across all agencies. In some cases, the location of a fire was recorded "exactly", with GPS (global positioning system) coordinates, in some cases it was given to the nearest quarter mi^2, in others to nearest mi^2 (a public land office survey section). There were also fire points for which both GPS coordinates and TRS (township/range/section) information were provided and for some of these (n>100) the two data did not coincide, i.e., the GPS location was not within the TRS listed. Using ancillary data, such as national forest boundaries and forest cover maps, we were able to determine which location data were correct in many cases.

Prior to any analysis of these data, it is also necessary to define a "fire". A huge proportion of the fires in the database covered ≤ 0.1 acres, really representing an ignition that did not burn any vegetation subsequently. Many of these occurred at the same place and time, indicating multiple ignition events resulting from the same activity. Though these can be verified as independent events in many cases, by contacting the appropriate reporting agency, other incidences cannot be clarified as true ignitions versus duplicate reporting. For our modeling purposes, we chose to eliminate this concern by focusing on the factors influencing burns, which we defined as those fire ≥ 0.5 acres. Use of a threshold like this eliminated concern regarding duplicate entries and restricted analysis to those fires that burned land cover rather than ignition events that were immediately suppressed. However, one could analyze the influence of cause, population density, road density, or other factors on ignition probability in an area. A study of ratio of ignitions to burns above a threshold size by causal agent may also provide useful information for fire management in the region.

Results Leading to Publications

Twelve manuscripts supported wholly or partially by this project have been published or posted on the GLA web site. These include:

Cleland, D.T., S.C. Saunders, T.R. Crow, D.I. Dickmann, A.L. Maclean, J.K. Jordan, R.L. Watson, A.M. Sloan, and K.D. Brosofske. 2004. Characterizing historical and modern fire regimes in Michigan: a landscape ecosystem approach. Landscape Ecology 19: 311–325.

Sturtevant, B.R., P.A. Zollner, E.J. Gustafson, and D.T. Cleland. 2004. Human influence on the abundance and connectivity of high-risk fuels in mixed forests of northern Wisconsin, USA. Landscape Ecology 19: 235–253.

Haight, R.G., D.T. Cleland, R.B. Hammer, V.C. Radeloff, and T.S. Rupp. 2004. Assessing fire risk in the wildland-urban interface. Journal of Forestry October/November : 41-48.

Schulte, L.A. and D.J. Mladenoff. 2005. Severe wind and fire regimes in northern forests: historical variability at the regional scale. Ecology 86: 431–445.

Ryu, S.R., J. Chen, T.R. Crow, and S.C. Saunders. 2004. Available fuel dynamics in nine contrasting forest ecosystems in North America. Environmental Management 33 (Suppl. 1): 87–107.

Maclean, A.L., and D.T. Cleland. 2003. Determining the spatial extent of historical fires with geostatistics in northern lower Michigan. Omi, P.N. and L.A. Joyce (tech. eds.), Fire, fuel treatments, and ecological restoration: Conference proceedings. April 16-18, 2002, Fort Collins, CO. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sturtevant, B.R. and D.T. Cleland. 2003. Human influence on fire disturbance in northern Wisconsin. Proceedings of the 2nd International Wildland Fire Ecology and Fire Management Congress, November 18-20, Orlando, Florida.

Anderson, P.J., D.T. Cleland, and J.C. Zasada. 2002. Annotated bibliography of natural disturbance in the Lake States. (http://www.ncrs.fs.fed.us/gla/)

Bresee, M., J. LeMoine, S. Mather, K. Brosofske, J. Chen, T. Crow, and J. Rademacher. 2004. Disturbance and landscape dynamics in the Chequamegon National Forest, Wisconsin, USA, from 1972 to 2001. Landscape Ecology 19:291-309.

Saunders, S.C., J. Chen, T.D. Drummer, T.R. Crow, K.D. Brosofske, and E.J. Gustafson. 2002. The patch mosaic and ecological decomposition across spatial scales in a managed landscape. Basic and Applied Ecology 3:49-64.

Cardille, J.A., S.J. Ventura, and M.G. Turner. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, USA. Ecological Applications 11: 111-127.
Cardille, J.A. and S.J. Ventura. 2001. Occurrence of wildfire in the northern Great Lakes Region: Effects of land cover and land ownership assessed at multiple scales. International Journal of Wildland Fire 10: 145–154.

Manuscripts in preparation include:

Saunders, S.C., M.R. Mislivets, D.T. Cleland, K.D. Brosofske, and J. Chen. Factors influencing fire distribution and prediction in ecological and climatic units of the northern Great Lakes Region, USA. Expected submission to International Journal of Wildland Fire, Dec. 2005.

Saunders, S.C., B.R. Sturtevant, K.D. Brosofske, and D.T. Cleland. An information theoretic approach to modeling fire risk in the northern Great Lakes Region, USA. Analysis partially complete, expected submission to Ecosystems, Feb. 2006.

Sturtevant, B.R. and D.T. Cleland. Relative influence of human versus ecosystem variables on modern fire disturbance in northern Wisconsin. Expected submission to International Journal of Wildland Fire, Dec. 2005.

Brosofske, K.D., D.T. Cleland, S.C. Saunders, and A.L. Maclean. Composition and diameter differences between line and corner trees in the General Land Office (GLO) Survey data for northern Michigan, USA. Draft complete; expected submission to Forest Science, Dec. 2005.

Conclusion

Characterizing historical "fire regimes" requires consideration of local ecological content and broader-scale context. As such, a fire regime is defined not only by the physical and biological properties of an ecosystem, but also by the surrounding landscapes that influence the spatial, temporal, and behavioral characteristics of the fires that burn in it. Meaningful characterization and comparison of fire frequencies and rotations will necessarily be restricted to spatially equivalent tracts, supporting one or several ecologically similar communities and associated physical substrates, and quantified over large areas. Understanding exogenous factors influencing these localized fire regimes, however, requires addressing broad-scale climatic gradients and landscape-level heterogeneity affecting the emergent properties of nested ecosystems, and local flammability of fuels.

Characterizing modern fire regimes and causal relationships among ecological and social factors is extremely complex within the highly developed and densely populated Lake States. Humans dominate modern fire regimes through ignitions as well as fire detection and suppression activities. All reported modern fires analyzed in this research were suppressed, and it is very likely not all fires that occurred were reported. There is a major distinction between modern fire potential or risk and modern fire occurrence. The former is largely determined by the flammability and connectivity of fuels, whereas the latter is more an expression of the effectiveness of fire fighting capacity.

Since the inception of the discipline, fire researchers have recognized the relationship of climate, soils, topography, and vegetation to fire regimes. Plummer (1912) cited wind, topography, inflammability of vegetation, and insect "depredations" as major "contributory causes" of fire. Mitchell and Sayre (1929) also noted the relationship of climate, soils, topography, vegetation, and land ownership patterns to fire occurrence. They asserted "From the standpoint of forest protection, the character of the soil is important since within a given climatic region it very largely determines the forest type prevailing. It also influences the moisture condition and hence the inflammability of the forest fire fuels overlaying it."

Applying the ecosystem concept defined by interactions among life forms and environment including disturbance regimes, and adopting a spatial hierarchy of ecological units provided a practical means of mapping and characterizing historical and current fire regimes in this research effort. The mapping of landscape ecosystems and the locations of modern and historical fires over large areas accommodated the random distribution of fires within smaller areas. This data development also enabled reasonable, spatially explicit estimates of historical fire regimes within ecologically similar spatial units. Coupling these maps with numerical analyses of historical and modern fire occurrence also demonstrated their utility.

Literature Cited

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Island Press: Washington, D.C., USA.

Arno, S.F. and T.D. Petersen. 1983. Variation in estimates of fire intervals: A closer look at fire history on the Bitterroot National Forest. USDA Forest Service Research Paper INT-301.

Arno, S.F. and K.M. Sneck. 1977. A method for determining fire history in coniferous forests of the mountain west. USDA Forest Service General Technical Report INT-42. Intermountain Forest And Range Experiment Station: Ogden, Utah, USA. 28 p.

Atkinson, E.J. and T.M. Therneau. 2000. An introduction to recursive partitioning using the RPART routinges. The Mayo Foundation.

Baker, W.L. 1989. Effect of scale and spatial heterogeneity on fire-interval distributions. Canadian Journal of Forest Research. 19(6):700-706.

Bergeron, Y. and J. Brisson. 1990. Fire regime in red pine stands at the northern limit of the species range. Ecology 71(4):1352-1364.

Bergeron, Y. and P. Dansereau. 1993. Predicting the composition of Canadian southern boreal forest in different fire cycles. Journal of Vegetation Science 4:827-832.

Bormann, F.H. and G.E. Likens. 1979. Catastrophic disturbance and the steady state in northern hardwood forests. American Scientist. 67:660-669.

Brown, P.M., M.W. Kaye, L.S. Huckaby, and C.H. Baisan. 2001. Fire history along environmental gradients in the Sacramento Mountains, New Mexico: influences of local and regional processes. Ecoscience 8(1): 115-126.

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65: 803-809.

Cardille, J.A., S.J. Ventura, and M.G. Turner. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, USA. Ecological Applications 11: 111-127.

Cardille, J.A. and S.J. Ventura. 2001. Occurrence of wildfire in the northern Great Lakes Region: Effects of land cover and land ownership assessed at multiple scales. International Journal of Wildland Fire 10: 145–154.

Chandler, C., P. Chene, P. Thomas, L. Trabaud, and D. Williams. 1983. Fire in forestry, vol. 1: forest fire behavior and effects. John Wiley & Sons: New York, NY, USA.

Clark, J.S. 1988a. Effect of climate change on fire regimes in northwestern Minnesota. Nature 334:233-235.

Clark, J.S. 1988b. Stratigraphic charcoal analysis on petrographic thin sections: applications to fire history in northwestern Minnesota. Quaternary Research 30:81-91.

Clark, J.S. 1990. Twentieth-century climate change, fire suppression, and forest production and decomposition in northwestern Minnesota. Canadian Journal of Forest Research 20:219-232.

Cleland, D.T., J.A. Feeouf, J.E. Keys, G.J. Nowacki, C. Carpenter, W.H. McNab. 2005. Ecological subregions: sections and subsections of the coterminous United States. Washington D.C.: U.S. Department of Agriculture, Forest Service. (A.M. Sloan technical editor).

Cleland, D.T., S.C. Saunders, T.R. Crow, D.I. Dickmann, A.L. Maclean, J.K. Jordan, R.L. Watson, A.M. Sloan, and K.D. Brosofske. 2004. Characterizing historical and modern fire regimes in Michigan: a landscape ecosystem approach. Landscape Ecology 19: 311–325.

Cleland, D.T., P.E. Avers, W.H. McNab, M.E. Jensen, R.G. Bailey, T. King, and W.E. Russell. National Hierarchical Framework of Ecological Units. 1997. Pp 181-200. In Boyce, M.S. and Haney, A. (eds.). Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources. Yale University Press, New Haven & London.

Clements, F.E. 1910. The life history of lodgepole pine forests. United States Forest Service Bulletin 79.

Comer, P.J., D.A. Albert, H.A. Wells, B.L. Hart, J.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Schuen. 1995. Michigan's native landscape, as interpreted from the General Land Office Surveys 1816-1856. Lansing, MI: Michigan Natural Features Inventory. 78 p. + digital map.

Cwynar, L.C. 1978. Recent history of fire and vegetation from laminated sediment of Greenleaf Lake, Algonquin Park, Ontario. Canadian Journal of Botany 56:10-21.

Dansereau, P. and Y. Bergeron. 1993. Fire history in the southern boreal forest of northwestern Quebec. Canadian Journal of Forest Research 23:25-32.

Davis, M.B., S. Sugita, R.R. Calcote, J.B. Ferrari, and L.E. Frelich. 1993. Historical development of alternate communities in a hemlock hardwood forest in northern Michigan, U.S.A. In Large Scale Ecology and Conservation Biology: The 35th Symposium of the British Ecological Society with the Society for Conservation Biology, pp. 19-39. Edited by P.J. Edwards, R.M. May and N.R. Webb. University of Southampton. Blackwell Scientific Publications: Boston, MA, USA.

Finley, R.W. 1976. Map. Original vegetation cover of Wisconsin, compiled from U.S. General Land Office notes. Madison, WI: University of Wisconsin Extension. map (1:500,000).

Frelich, L.E. and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock hardwood forests of the Upper Great Lakes Region. Ecological Monographs 61(2):159-162.

Frissell, S.S. Jr. 1973. The Importance of fire as a natural ecological factor in Itasca State Park, Minnesota. Quaternary Research 3:397:407.

Gosz, J.R. 1992. Gradient analysis of ecological change in space and time: implications for forest management. Ecological Applications 2(3):248-261.

Grimm, E.C. 1984. Fire and other factors controlling the Big Woods vegetation of Minnesota in the mid-nineteenth century. Ecological Monographs 54(3):291-311.

Heinselman, M.L. 1973. Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. Quaternary Research 3:329-382.

Heinselman, M.L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. In H.A. Mooney, T.M. Bonnicksen and N. Christensen.

Henry, J.D. and J.M.A. Swan. 1974. Reconstructing forest history from live and dead plant material—an approach to the study of forest succession in southwest New Hampshire. Ecology 55:772-783.

Host, G.E., Polzer, P.L. and Cleland, D.T. 1995. Regional Climatic analyses of the northern lake states– lake states national forests. NRRI Tech. Rep. NRRI/TR-95/32. Duluth, MN.

Johnson, E.A. and S.L. Gutsell. 1994. Fire frequency models, methods and interpretations. Advances in Ecological Research 25:239-287.

Larson, C.P.S. and G.M. MacDonald. 1998a. An 840-year record of fire and vegetation in a boreal white spruce forest. Ecology 79:106-118.

Larson, C.P.S. and G.M. MacDonald. 1998b. Fire and vegetation dynamics in a jack pine and black spruce forest reconstructed using fossil pollen and charcoal. Journal of Ecology 86:815-828.

Loope, W.L. 1991. Interrelationships of fire history, land use history, and landscape pattern within Pictured Rocks National Lakeshore, Michigan. Canadian Field-Naturalist 105(1):18-28.

Maclean, A.L., and D.T. Cleland. 2003. Determining the spatial extent of historical fires with geostatistics in northern lower Michigan. Omi, P.N. and L.A. Joyce (tech. eds.), Fire, fuel treatments, and ecological restoration: Conference proceedings. April 16-18, 2002, Fort Collins, CO. Proceedings RMRS-P-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Manies, K. L., D. J. Mladenoff, and E. V. Nordheim. 2001. Assessing large-scale surveyor variability in the historic forest data of the original U.S. Public Land Survey. Canadian Journal of Forest Research 31: 1719-1730.

Marschner, F.J. 1974. The Original Vegetation of Minnesota, a map compiled in 1930 by F.J. Marschner under the direction of M.L. Heinselman of the U.S. Forest Service. St. Paul, MN: Cartography Laboratory of the Department of Geography, University of Minnesota. Map (1:500,000).

McKenzie, D., Peterson, D.W., Peterson, D.L., and Thornton, P.E. 2003. Climatic and biophysical controls on conifer species distributions in mountain forests of Washington State, USA. Journal of Biogeography 30: 1093-1108.

McNab, W.H., Avers, P.E. 1994. Ecological subregions of the United States: Section Descriptions. WO-WSA-5, USDA Forest Service, Washington, DC.

Mitchell, J.A. and H.R. Sayre. 1929. Forest fires in Michigan. Michigan Conservation Department. 65 pp.

Nowacki, G., Shephard, M., Krosse, P., Pawuk, W., Fisher, G., Baichtal, J., Brew, D., Kissinger, E., Brock, T. 2001 Ecological Subsections of Southeast Alaska and Neighboring Areas of Canada. Technical Report R10-TP-75. USDA Forest Service, Alaska Region

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133: 225-245.

Plummer, F.G. 1912. Forest fires: their causes, extent and effects, with a summary of recorded destruction of loss. Government Printing Office, Washington D.C., Bulletin 117. 39 pp.

Simard, A.J. and R.W. Blank. 1982. Fire history of a Michigan jack pine forest. Michigan Academy 1982:59-71.

Stearns, F.W. 1949. Ninety years of change in a northern hardwood forest in Wisconsin. Ecology 30:350-358.

Sturtevant, B.R. and D.T. Cleland. 2003. Human influence on fire disturbance in northern Wisconsin. Proceedings of the 2nd International Wildland Fire Ecology and Fire Management Congress, November 18-20, Orlando, Florida.

Van Wagner, C.E. 1978. Age-class distribution and forest fire cycle. Canadian Journal of Forest Research 8: 220-227.

Venier, L.A., Pearce, J., McKee, J.E., McKenney, D.W., and Niemi, G.J. 2004. Climate and satellite-derived land cover for predicting breeding bird distribution in the Great Lakes Basin. Journal of Biogeography 31: 315-331

Swain, A.M. 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediments. Quaternary Research 3:383-396.

Swain, A.M. 1978. Environmental changes during the past 2000 years in north-central Wisconsin. Quaternary Research 10:55-68.

Swain, A.M. 1980. Landscape patterns and forest history in the Boundary Waters Canoe Area, Minnesota: A pollen study from Hug Lake. Ecology 61(4):747:754.

Turner, M.G., R.H. Gardner, V.H. Dale, and R.V. O'Neill. 1989. Predicting the spread of disturbance across heterogeneous landscapes. Oikos 55:121-129.

Turner, M.G. and W.H. Romme. 1994. Landscape dynamics in crown fire systems. Landscape Ecology 9:59-77.

Whitney, G.G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. Ecology 67(6):1548-1559.

Zhang, Q., K.S. Pregitzer, and D.D. Reed. 1999. Catastrophic disturbance in the presettlement forests of the Upper Peninsula of Michigan. Canadian Journal of Forest Research 29: 106-114.

Appendix A.

Table A1. Fire Cycle (Fire Rotation Period) For Historic Fire Regimes In the Great Lakes Region

Community Type	Fire Rotation Period (Years)	Location	Reference	Notes
Annual or perennial Grassland	5-25	Central North America	Chandler et al. 1983	Source unknown (from Table 6.1)
Jack pine barrens	60	Wisconsin-Michigan	Heinselman 1981	Estimated
Jack pine barrens	15-60	Great Lakes	Chandler et al. 1983	Source unknown (from Table 6.1)
Aspen savanna/woodland	10	Minnesota	Chandler et al. 1983	Source unknown (from Table 6.1)
Red pine/white pine	74-112	Lake Duparquet, Quebec	Bergeron 1991	Based on 37 fires along lakeshore (1688-1988)
Mixed boreal conifer/hardwood	63-99	Lake Duparquet, Quebec	Bergeron 1991	Based on 56 fires on islands (1688-1988)
Jack pine	80-170	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
Jack pine	130	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Jack pine/black spruce	50	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
Jack pine/black spruce	100	Quebec	Chandler et al. 1983	Source unknown (from Table 6.1)
Jack pine/black spruce	60	Ontario	Chandler et al. 1983	Source unknown (from Table 6.1)
Aspen/birch/fir	80	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
Red – jack – white pine	130-260	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
Red pine/jack pinewhite pine	160	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Pine/oak	170-350	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
Red pine/white pine	180	N. Minnesota (BWCA)	Heinselman 1981	Revised estimate based on Van Wagner 1978
Red pine/white pine	150	N. Minnesota (Itasca)	Frissel 1973	
Red pine/white pine	320	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Tamarack	190	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Aspen/birch	210	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Black spruce peatland	150	N. Minnesota (LakeAgassiz)	Heinselman 1981	Estimated

Table A1 cont. Fire Cycle (Fire Rotation Period) For Historic Fire Regimes In the Great Lakes Region

Community	Fire Rotation	Location	Reference	Notes
Black spruce	100	Ontario	Chandler et al. 1983	Source unknown (from Table 6.1)
Sugar maple/hemlock	900	Michigan UP (Porcupine Mtns)	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-1980
Sugar maple/hemlock	550	Michigan UP (Huron Mtns)	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-1980
Northern hardwoods/pine/hemlock	1400-2800	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
Northern hardwoods	2600	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Northern hardwoods	1000±	New Hampshire	Bormann & Likens 1979	Estimated
Sugar maple/hemlock	1700	Michigan UP (Sylvania Tract)	Frelich & Lorimer 1991	Based on surface & stand replacing fires 1870-1980
Swamp conifers	3000-6000	N. Lower Michigan	Whitney 1986	Based on GLO records of fires
White cedar	1700	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Lowland hardwood/conifer	1100	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Mixed lowland conifers/hdwds	580	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Black spruce	890	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires
Wetland shrub/marsh	410	Michigan UP (Luce District)	Zhang et al. 1999	Based on GLO records of fires

Table A2. Fire Return Intervals For Historic Fire Regimes In the Great Lakes Region

Community Type	Fire Return Interval (Years)		Location	Reference	Notes
	Surface (Low-Mod Intensity)	Stand-Replacing (High Intensity)			
Prairie	Annual (more or less)		S. Minnesota (Bigwoods area)	Grimm 1984	Anecdotal; highly climate dependent
Prairie	Annual (more or less)		S. Wisconsin (Green Co.)	Leitner et al. 1991	Anecdotal
Prairie	Annual (more or less)		S. Wisconsin	Curtis 1959	Anecdotal
Tallgrass prairie	3-5		Michigan,Wisconsin, Minnesota	Collins 1990	Used in a conceptual model of community responses to fire
Sedge meadows	Annual (more or less)		S. Wisconsin (Jefferson Co.)	Curtis 1959	Anecdotal; meadows maintained by adjacent prairie fires
Red pine/jack pine/oak barrens		24 (range 8-41)	NW Wisconsin (Douglas Co.)	Vogl 1970	Based on 4 major wildfires since 1871 (anecdotal)
Jack pine/oak barrens	Annual		NW Wisconsin (W Burnett Co.)	Vogl 1964	Drought period of 1930s (anecdotal)
Pine barrens	Annual		NW Wisconsin	Murphy 1931	Anecdotal
Jack pine barrens	15		Wisconsin-Michigan	Heinselman 1981	Estimated
Oak savanna/open woodlands	16		S. Wisconsin (Green Co.)	Leitner et al. 1991	Estimated for areas west of Pecatonica River
Oak savanna/open woodlands	16		SE. Wisconsin	Dorney 1981b	Areas west of major waterways
Oak openings/barrens	Annual (more or less)		S. Wisconsin	Curtis 1959	Anecdotal

Community Type	Fire Return Interval (Years)		Location	Reference	Notes
	Surface (Low-Mod Intensity)	Stand-Replacing (High Intensity)			
Red pine/jack pine	19 ± 5		N. Lower Michigan (Mack Lake)	Simard & Blank 1982	Based on fire scars, 37 fires (1824-1980)
Red pine/jack pine/white pine	9 (range 2-32)		N. Minnesota (Itasca)	Frissell 1973	Based on fire scars, 32 fires (1650-1922)
Red pine/white pine	26 ± 24		N. Minnesota (Itasca)	Clark 1990	Fire scars (1700-1920)
	13 ± 8				Charcoal analysis (1240-1440)
	9 ± 3				Charcoal analysis (1440-1600)
	13 ± 10				Charcoal analysis (1640-1920)
Red pine/mixed hdwd conifer	37 (range 3-102)		Northern Vermont ridge	Engstrom & Mann 1991	Based on fire scars, 20 fires (1815-1987)
Red pine	29 (range 14-46)		Sault Ste.Marie, Ontario	Alexander et al. 1979	Based on 5 fire scars (1759-1877) from 1 tree
Red pine/mixed hdwd conifer	30 (range 11-67)		Quebec (48 28 N)	Bergeron & Brisson 1990	Based on 11 fires (1799-1971) on islands
Red pine/jack pine	4		Lake Duparquet, Quebec	Bergeron 1991	Based on 56 fires on islands (1688-1988)
Red pine/white pine	22 ± 12		UP Michigan (Pictured Rocks NL)	Loope 1991	Based on fire scars from living trees & stumps
Red pine/white pine	36		N. Minnesota (BWCA)	Heinselman 1981	Revised from Heinselman 1973
White pine/red pine/aspen	11 (range 1-62)		Ontario, Algonquin Park	Cwynar 1977	Based on fire scars, 25 fires (1696-1960)
White pine/red oak/maple	13 (range 5-76)		S. Ontario (Bracebridge Region)	Guyette et al. 1995	Based on fire scarred stumps, 15 fires (1664-1852)
Mixed boreal conifer/hdwd	8		Lake Duparquet, Quebec	Bergeron 1991	Based on 37 fires along lakeshore (1688-1988)
Mixed boreal conifer/hdwd	2 (range 1-5)		Isle Royale	Hansen et al. 1973	Based on recorded lightning fires (1950-1965)

Community Type	Fire Return Interval (Years)		Location	Reference	Notes
	Surface (Low-Mod Intensity)	Stand-Replacing (High Intensity)			
Mixed pine/boreal conifer/hdwd	6 (range 1-53)		N. Minnesota (BWCA)	Heinselman 1973	Based on even-aged types & fires scars (1542-1971)
Jack pine/red pine		26 (range 12-60)	N. Lower Michigan (Mack Lake)	Simard & Blank 1982	Based on 6 fire years + 2000 fire
Jack pine/red pine/white pine		35 (range 9-89)	N. Minnesota (Itasca)	Spurr 1954	Based on 6 cohort-producing fires (1714-1886)
Jack pine/ birch/spruce		27 (range 4-47)	S of Lake Abitibi, Quebec	Dansereau & Bergeron 1993	Based on 10 cohort-producing fires (1760-1923)
Jack pine/black spruce		34	N. Alberta (Wood Buffalo NP)	Larsen & MacDonald 1998b	Based on 16 fires (1429-1934); charcoal & pollen analysis
White spruce		69 (range 30-130)	N. Alberta (Wood Buffalo NP)	Larsen & MacDonald 1998a	Based on 12 fires (1185-1940); charcoal & pollen analysis
Mixed boreal conifer/hdwd		26 (range 1-74)	Lake Duparquet, Quebec	Bergeron 1991	Based on 8 fires along lakeshore (1760-1944))
Mixed boreal conifer/hdwd		23 (range 3-46)	Lake Abitibi, Quebec	Bergeron & Dansereau 1993	Based on 10 fires (1760-1964)
Mixed pine/boreal conifer/hdwd		9 (range 1-38)	N. Minnesota (entire BWCA)	Heinselman 1973)	Based on dates of stand origin (1595-1971)
Mixed boreal conifer/hdwd		65 (range 20-100)	N. Minnesota (Lake of the Clouds)	Swain 1973	Based on charcoal & pollen analysis past 1,000 years
Paper birch/aspen		65	N. Minnesota (BWCA-Hug Lake)	Swain 1980	Based on 6 fires (1580-1970); charcoal & pollen analysis
White pine/ hemlock/ hardwoods		250+	New Hampshire (Harvard Tract)	Henry & Swan 1974	Based on fire origin of 1 stand but maybe blown down first

White pine/mixed conifer hdwd		83	Ontario, Algonquin Park	Cwynar 1978	Based on sediment core analysis (850-1249 AD)
Birch/white pine/hemlock		120 (range 40-230)	N. Wisconsin (Hell's Kitchen Lake)	Swain 1978	Based on 14 fires (350-1840 BP); charcoal & pollen analysis
N. hdwds/hemlock/white pine		400+	N. Wisconsin (Forest Co.)	Stearns 1949	Virgin stands studied **may have** originated from fire in 1500s
N. hdwds/hemlock/white pine		1700	Michigan UP (Sylvania Tract)	Davis et al. 1993	Based on 2 fires since 3500 yrs BP; charcoal & pollen analysis

Appendix B. Comparison of GLO and FIA Tree Species Within Biophysical Units

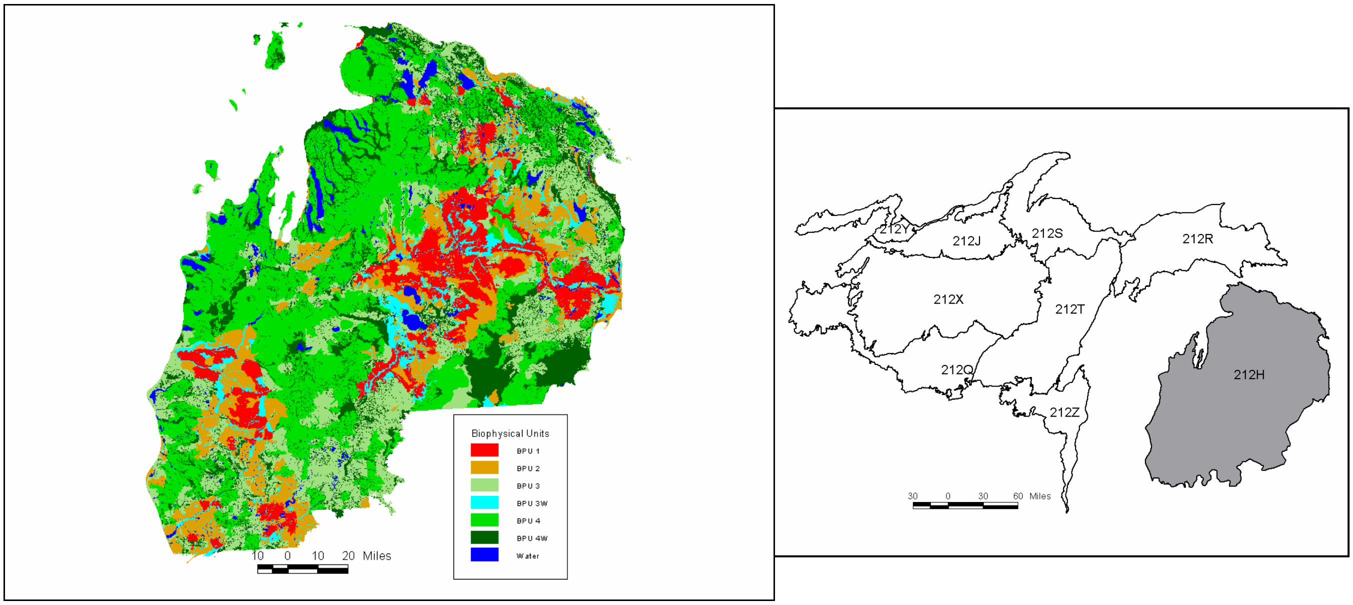

Figure B1. Biophysical Units of Section 212H

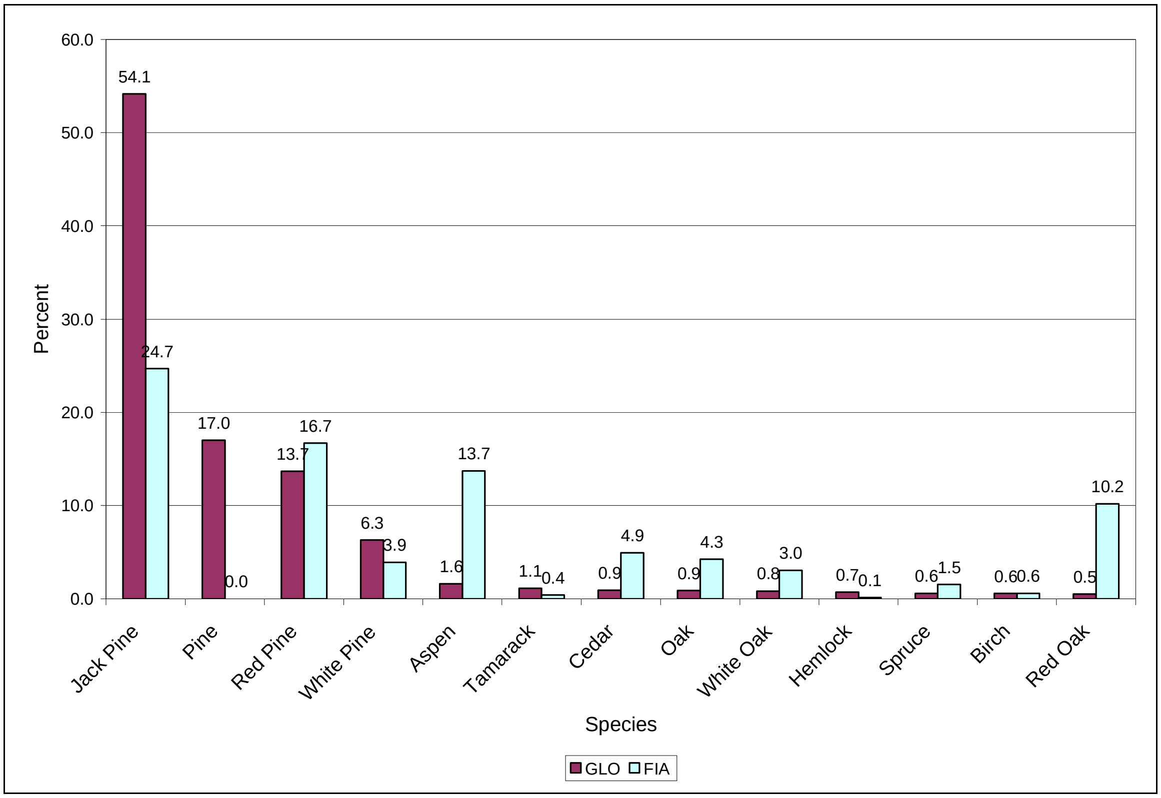

Figure B2. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212H

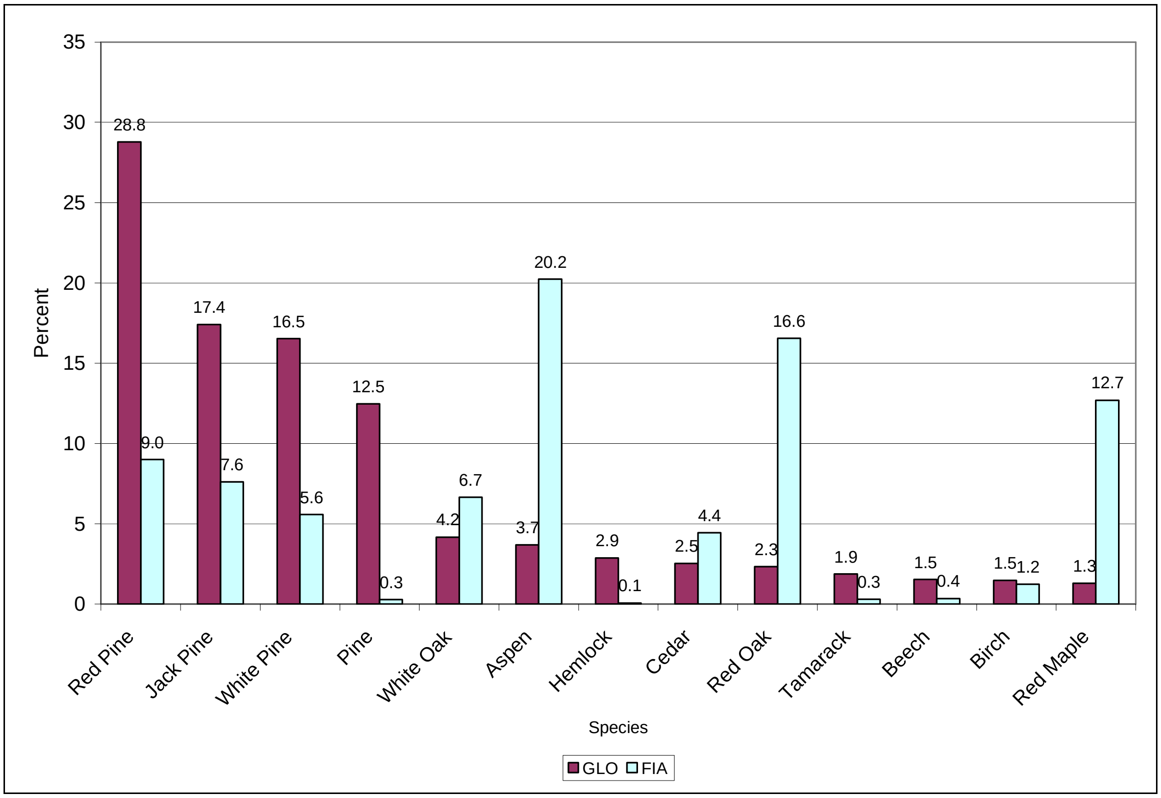

Figure B3. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212H

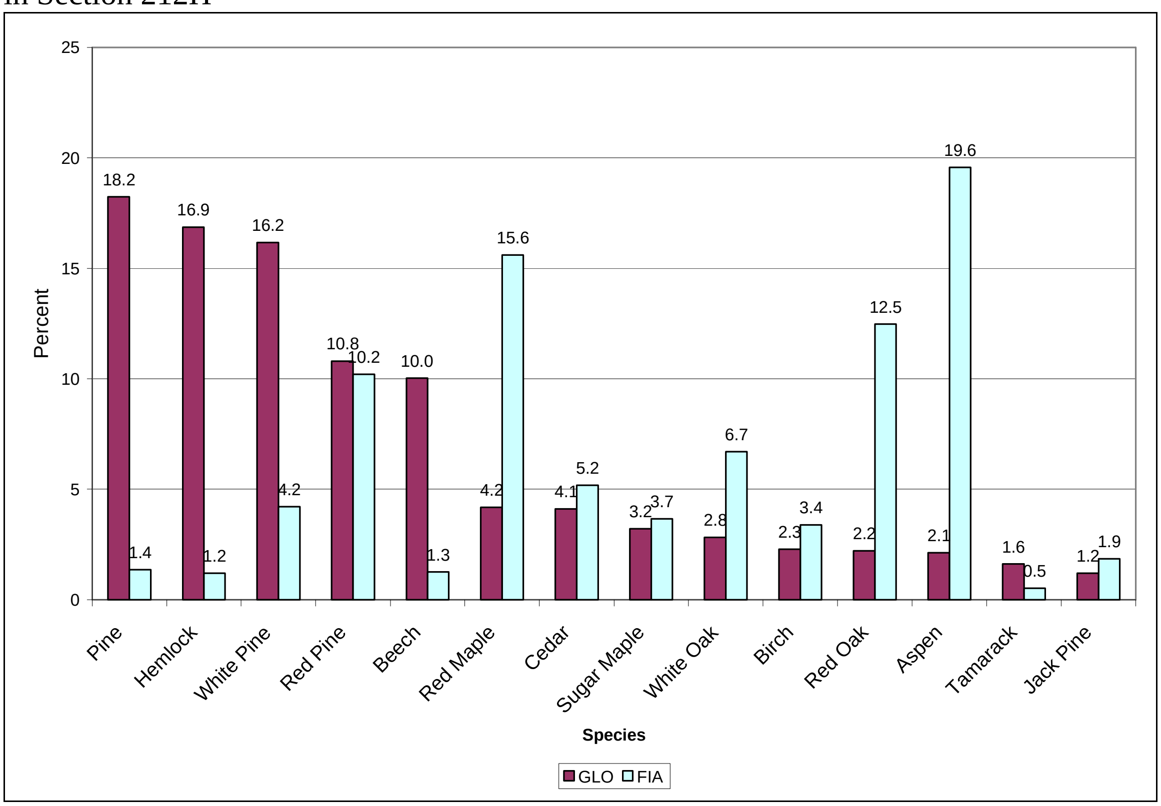

Figure B4. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212H

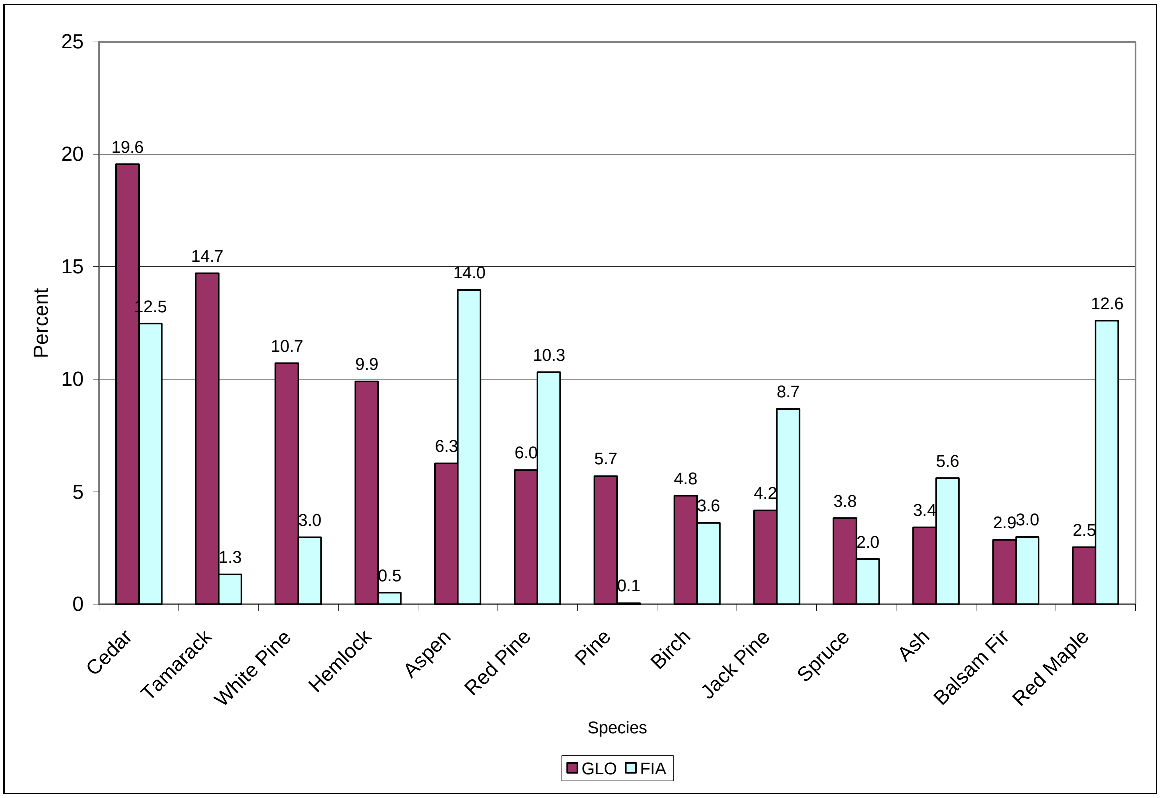

Figure B5. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212H

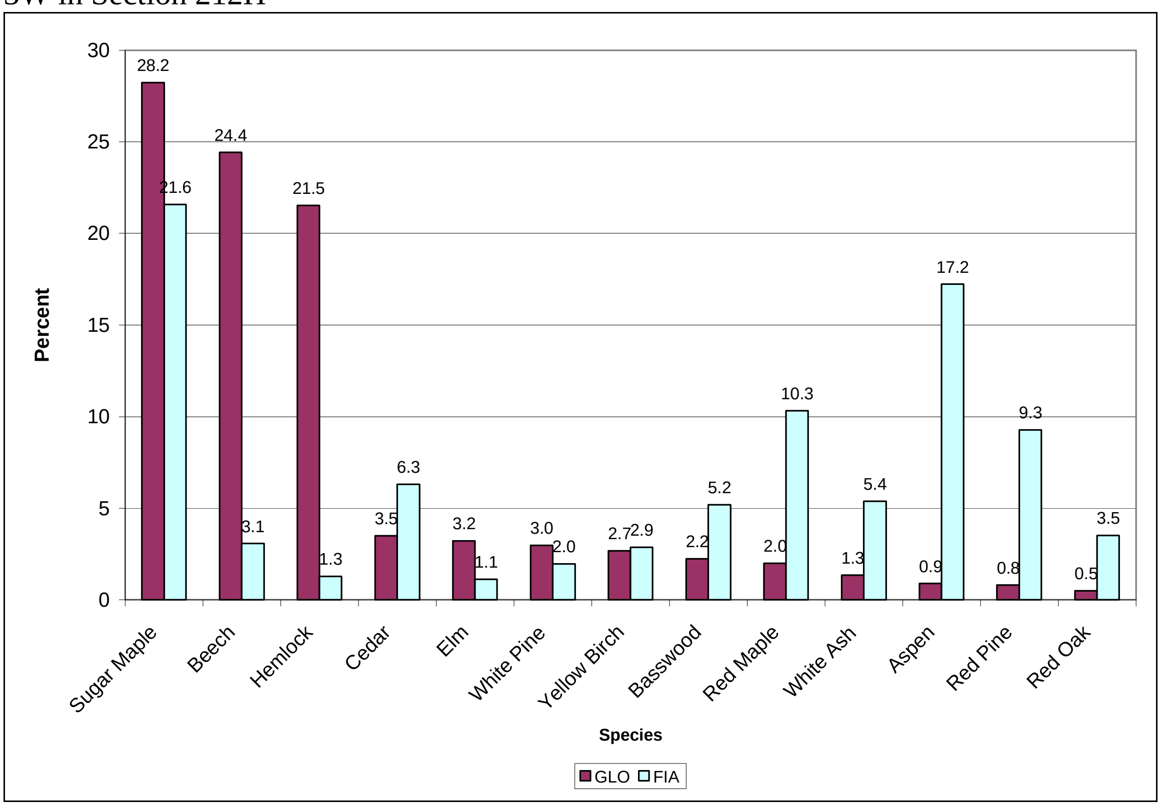

Figure B6. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212H

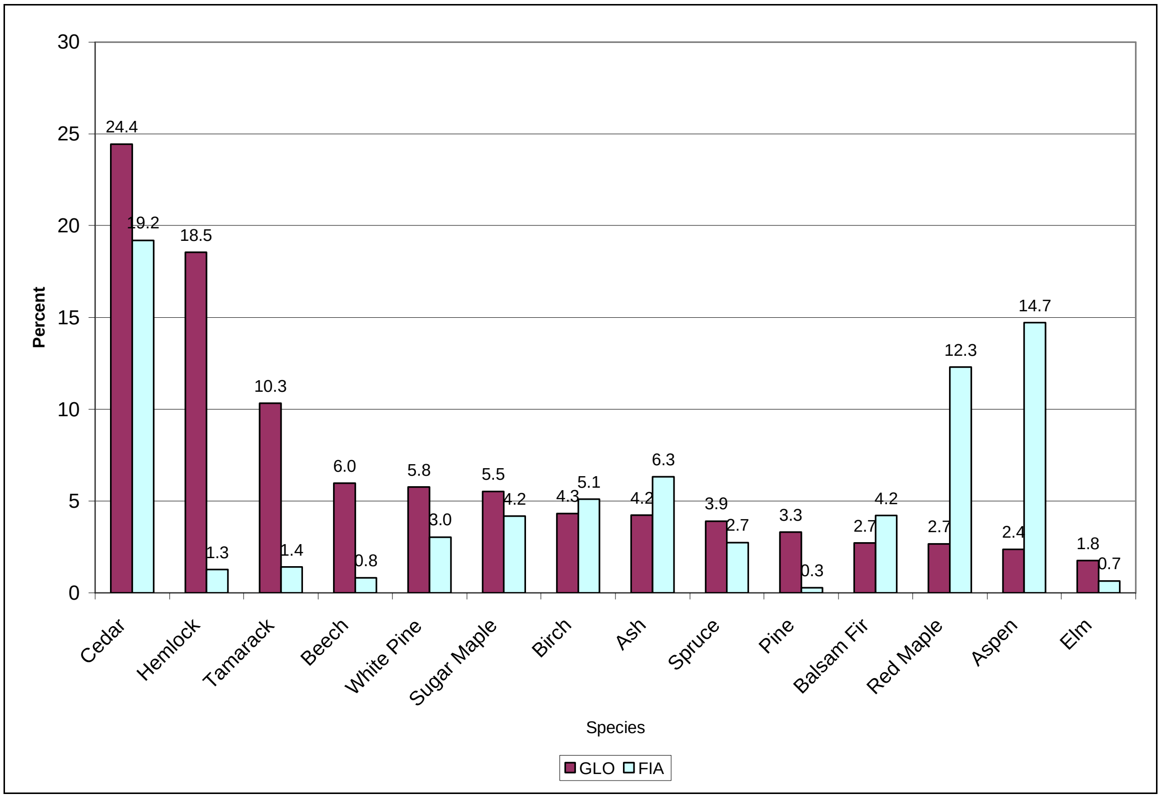

Figure B7. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212H

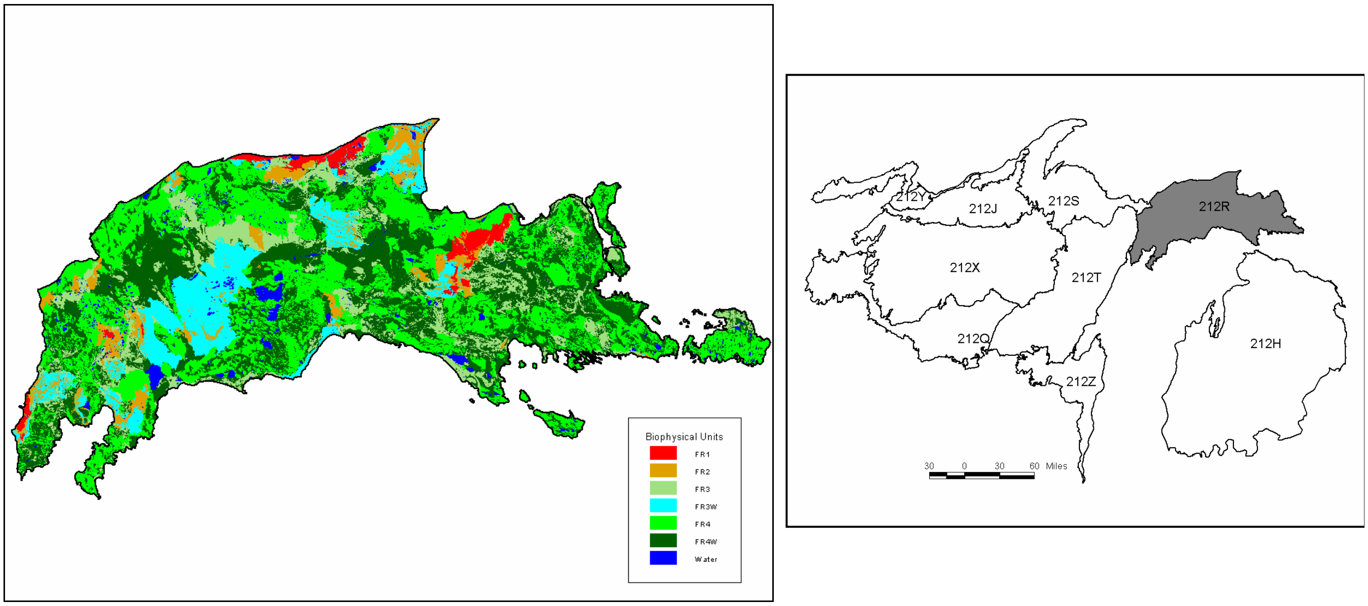

Figure B8. Biophysical Units of Section 212R

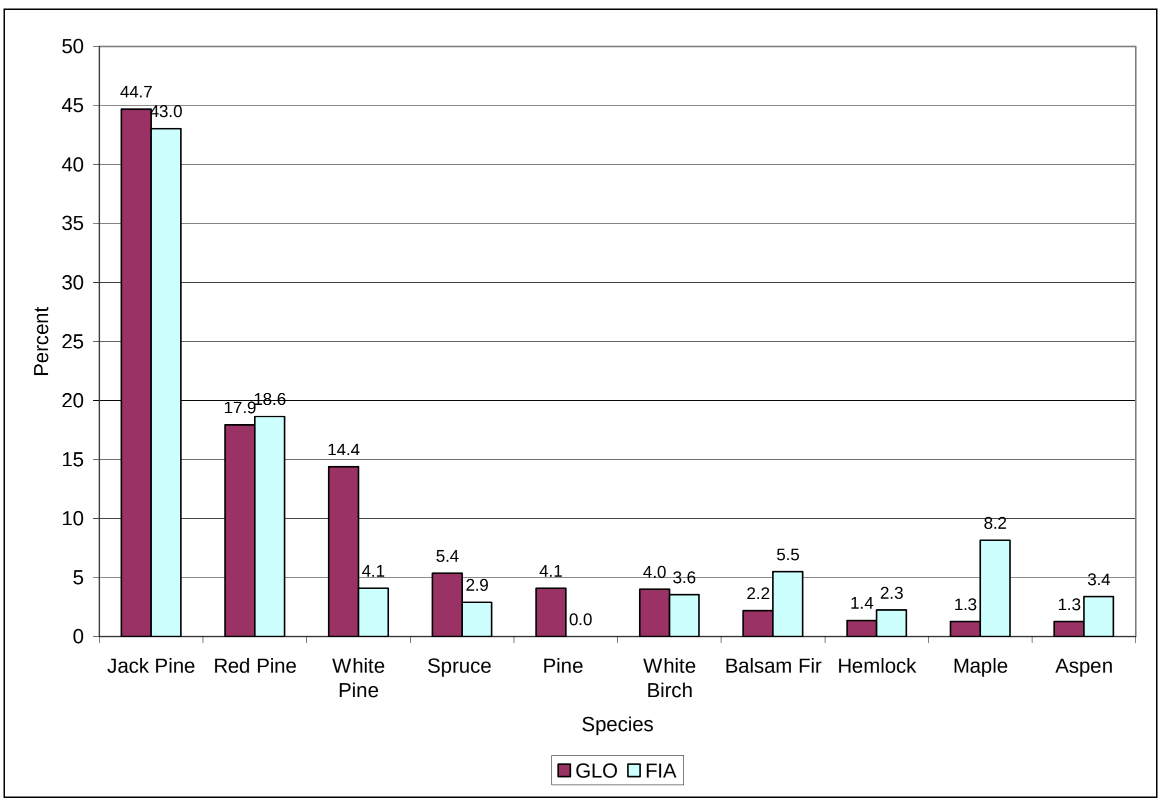

Figure B9. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212R

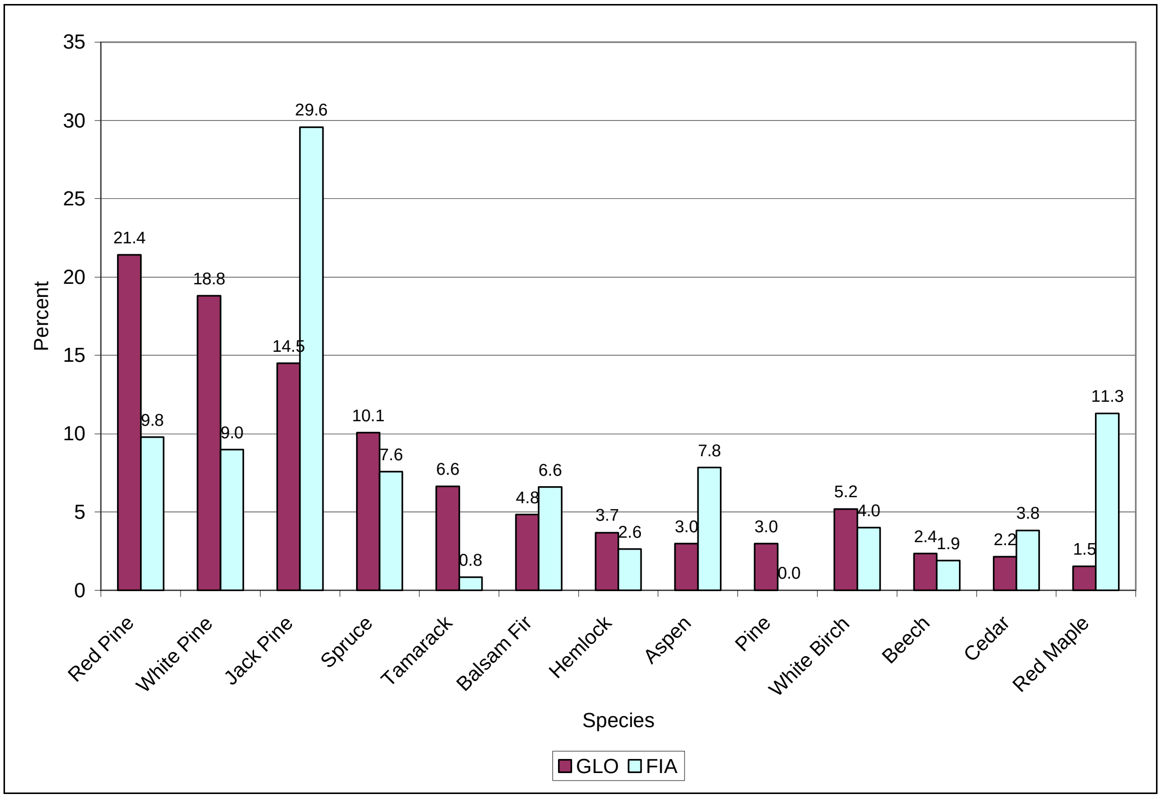

Figure B10. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212R

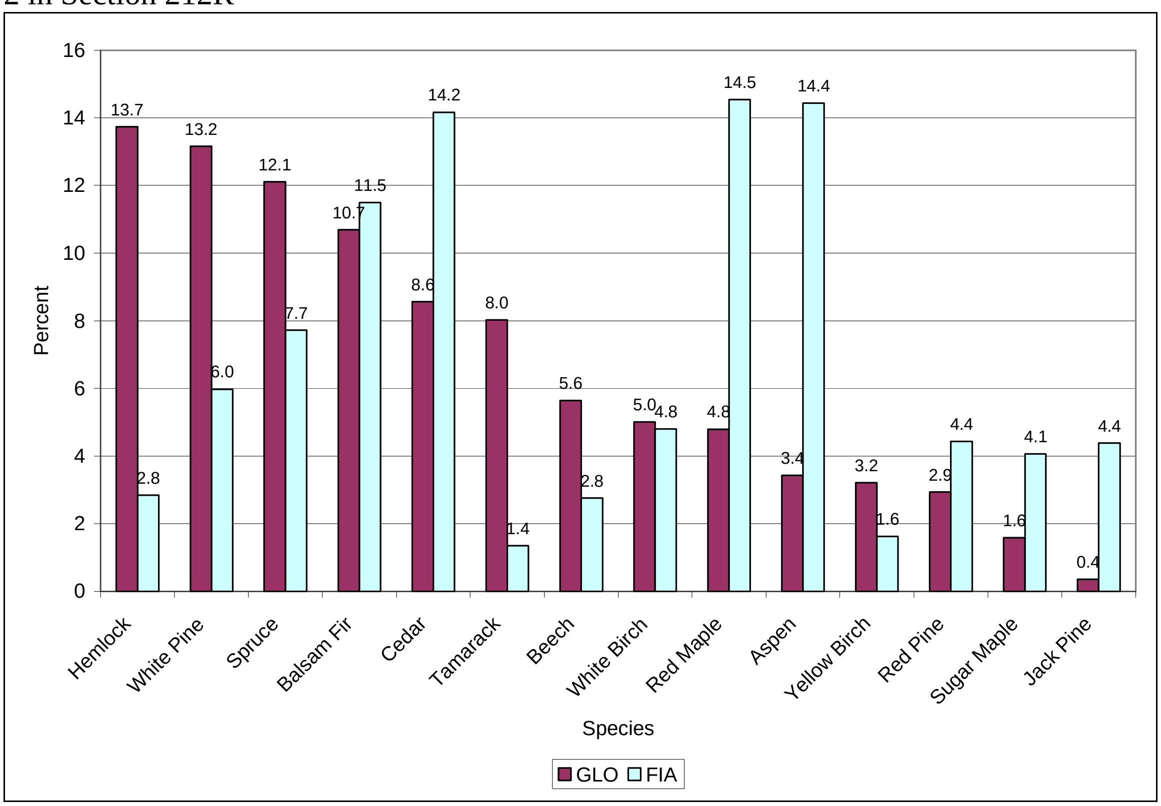

Figure B11. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212R

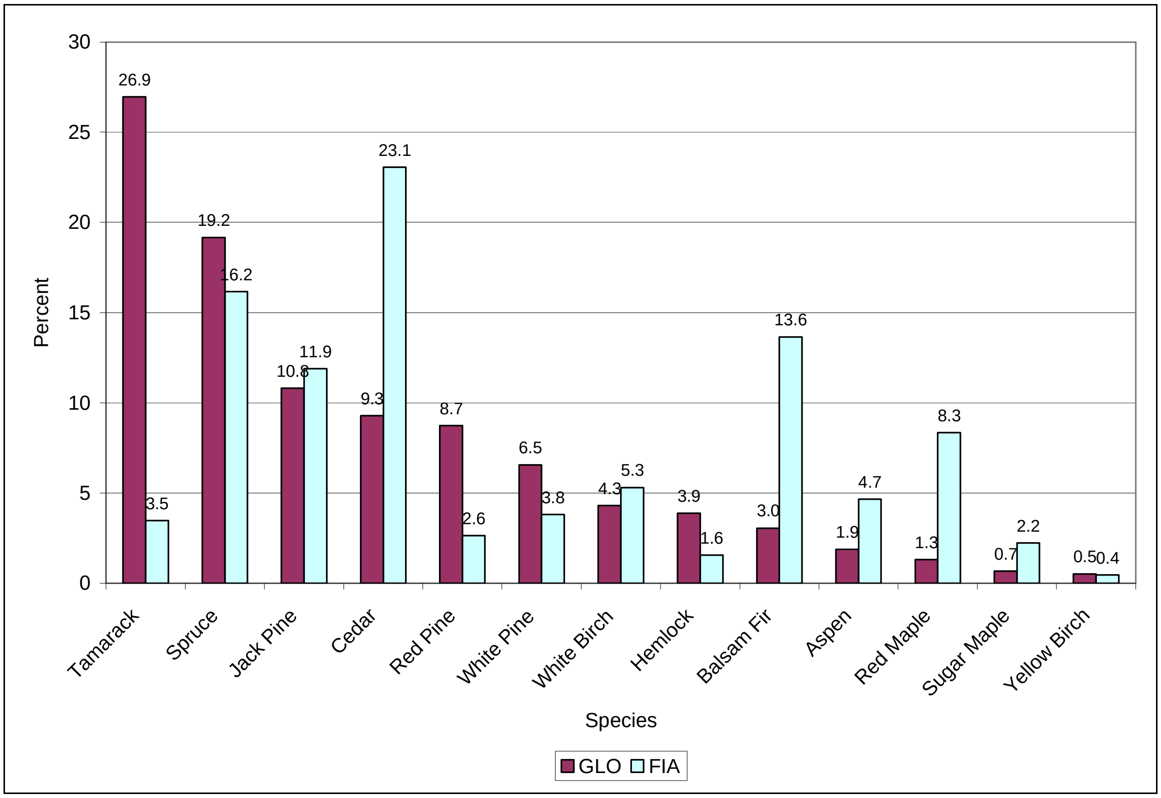

Figure B12. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212R

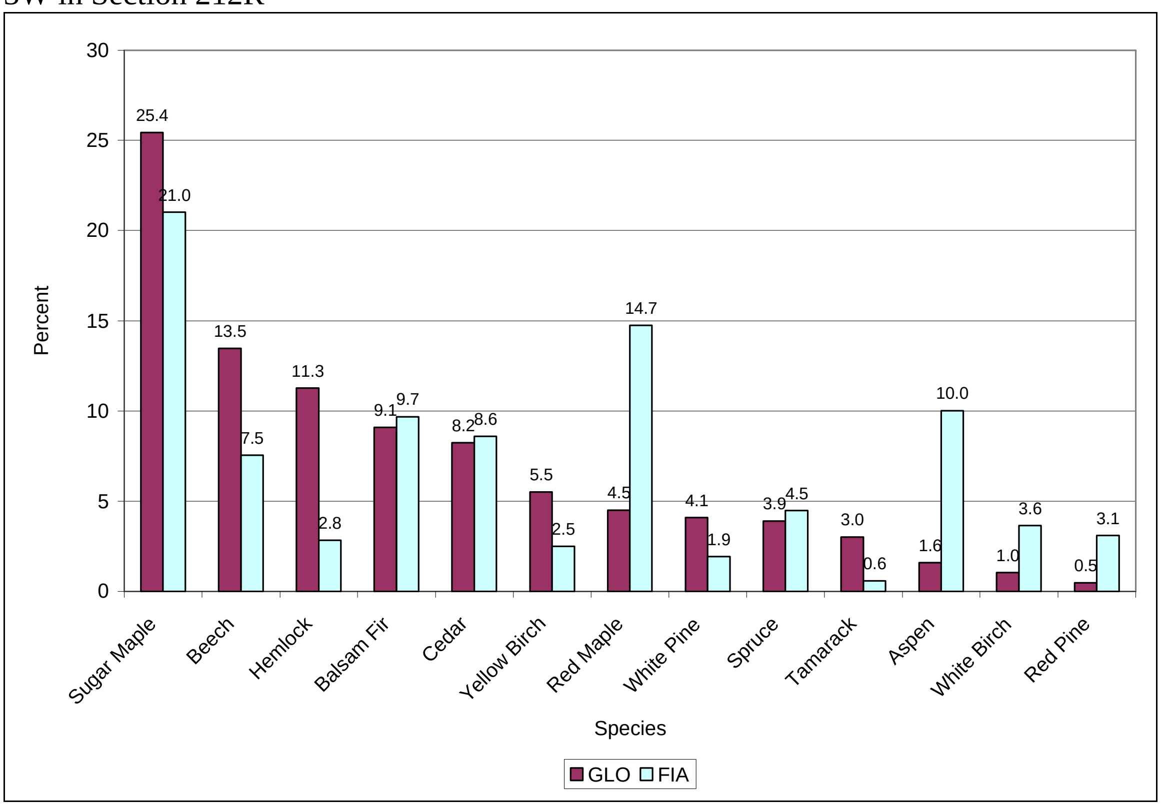

Figure B13. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212R

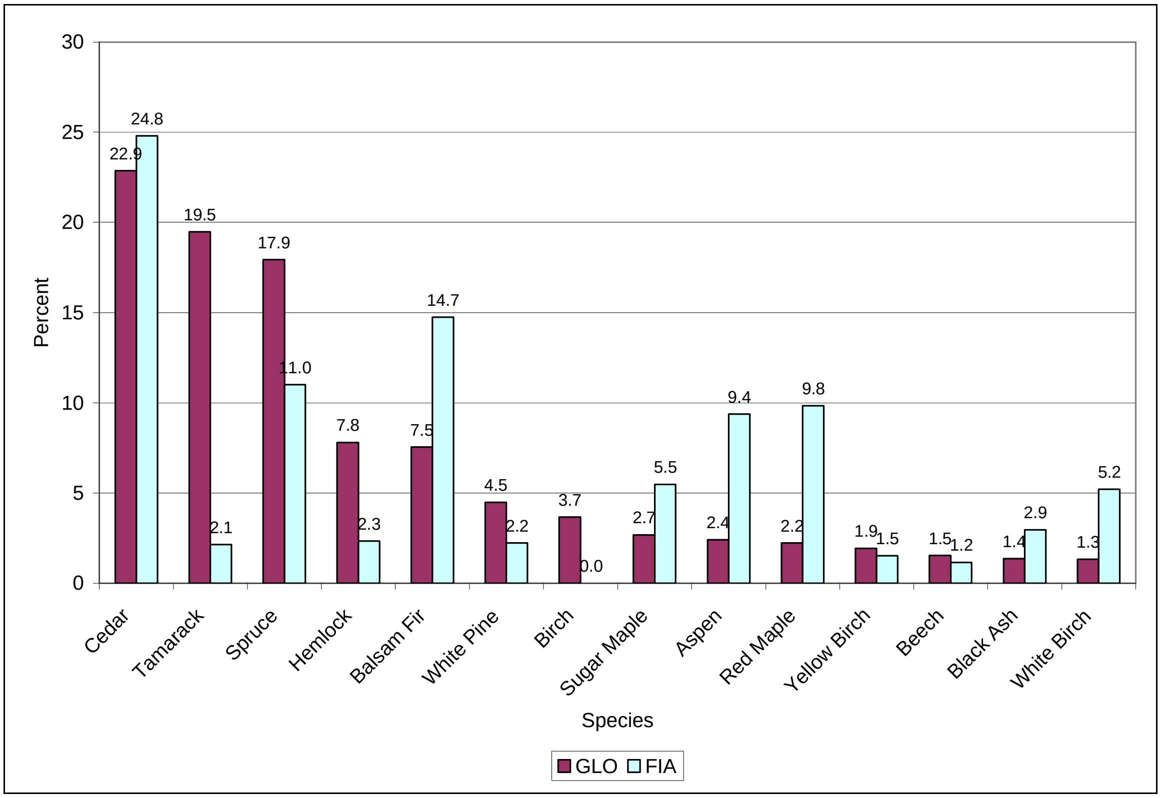

Figure B14. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212R

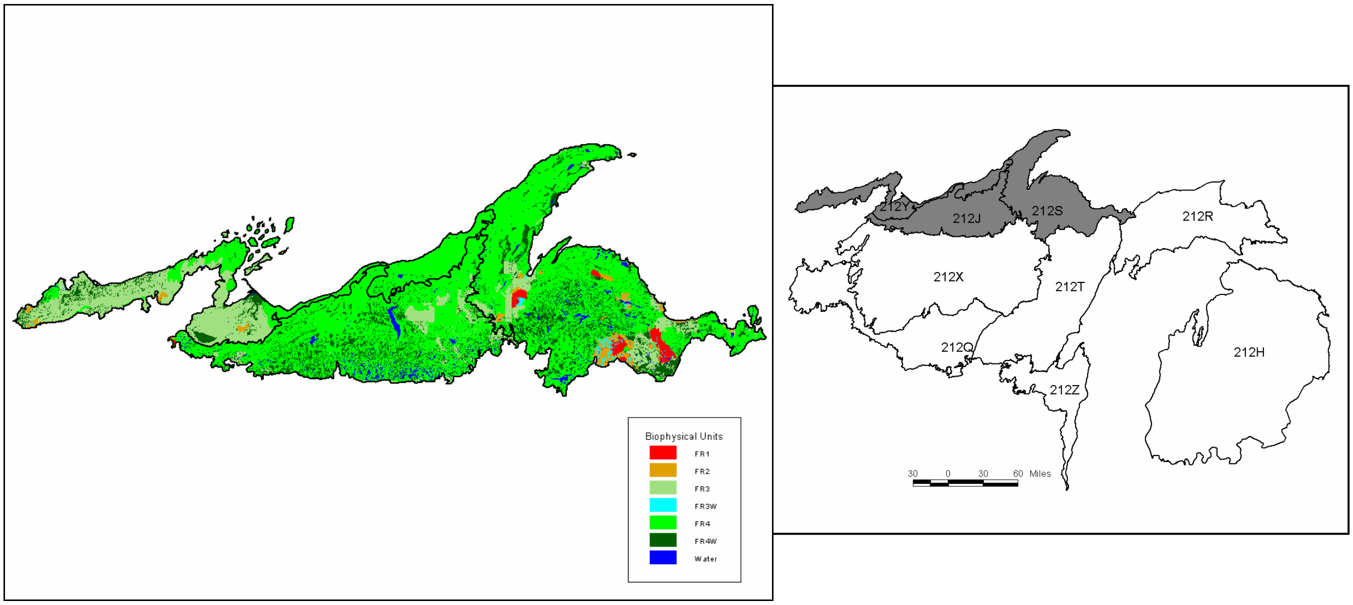

Figure B15. Biophysical Units of Sections 212 S, J, and Y

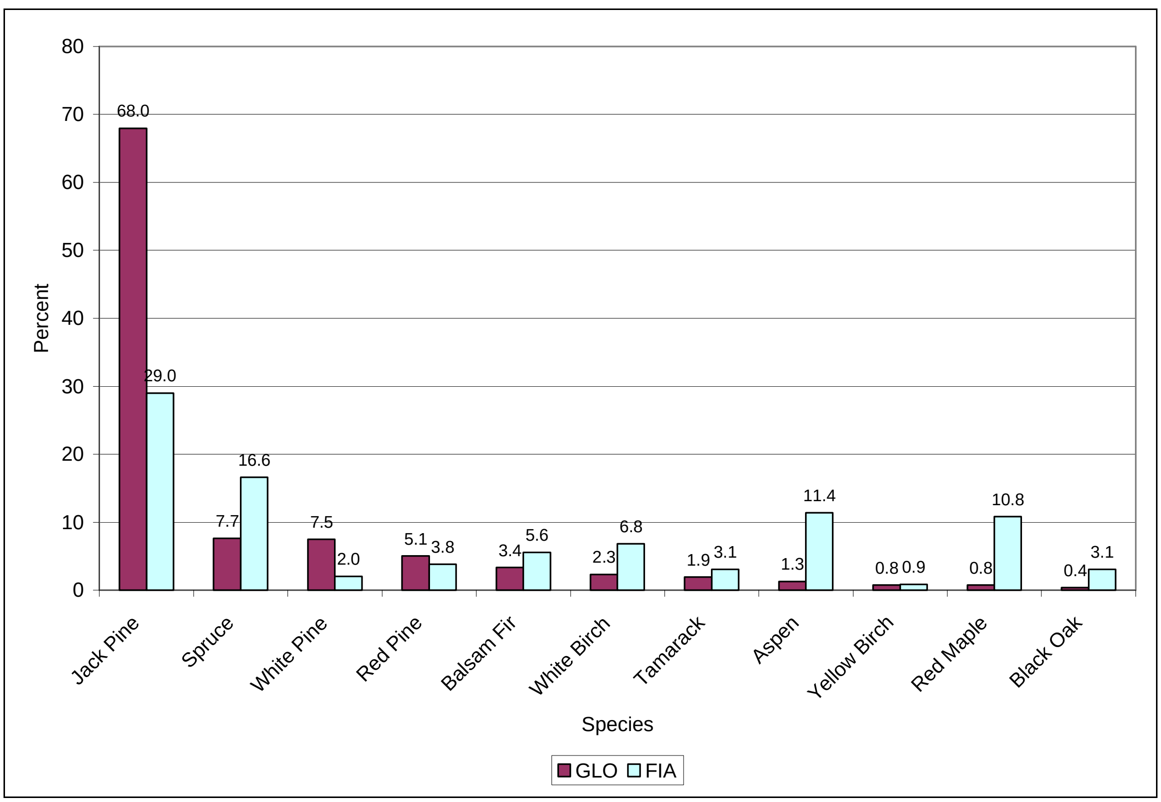

Figure B16. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Sections 212S, J, and Y

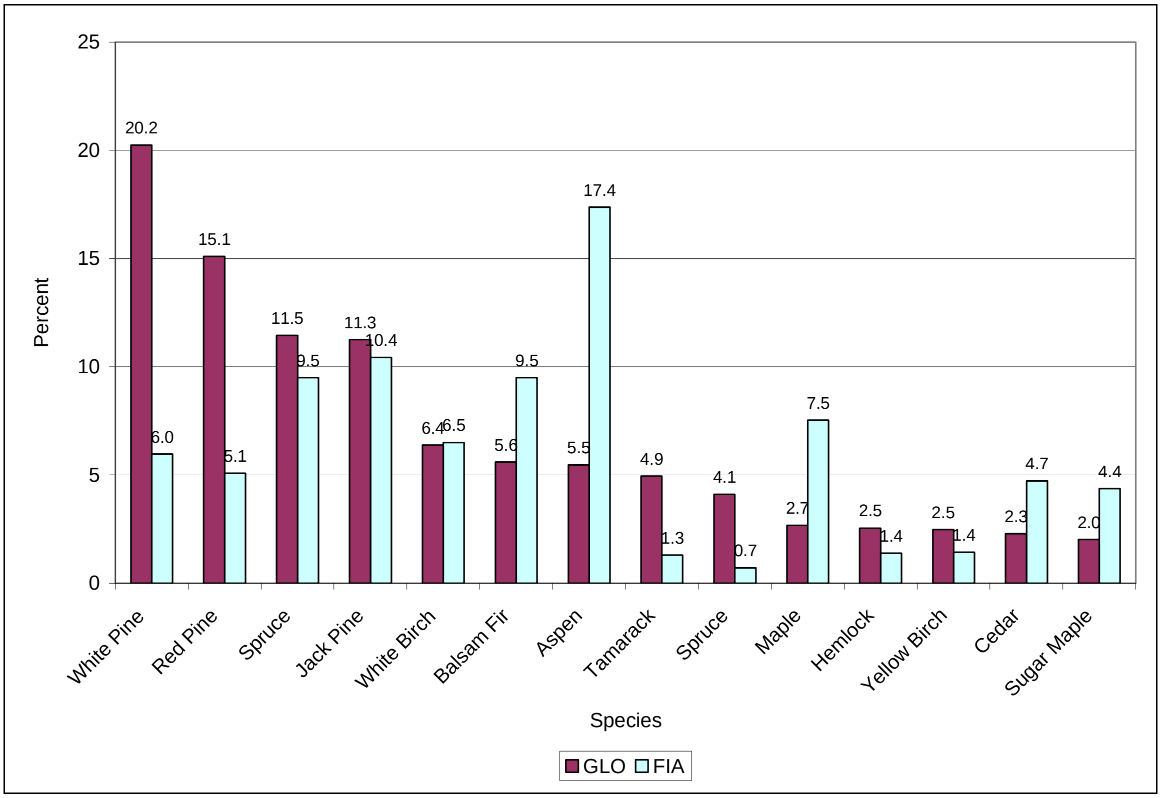

Figure B17. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Sections 212S, J, and Y

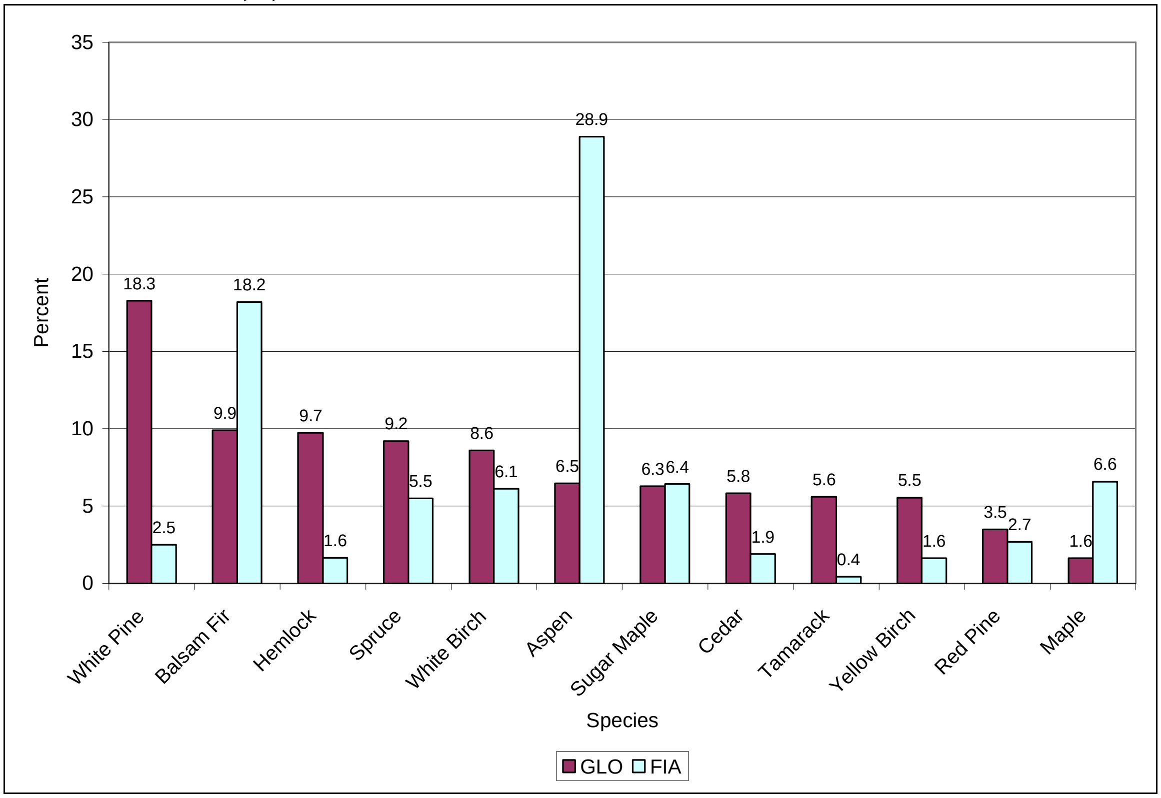

Figure B18. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Sections 212S, J, and Y

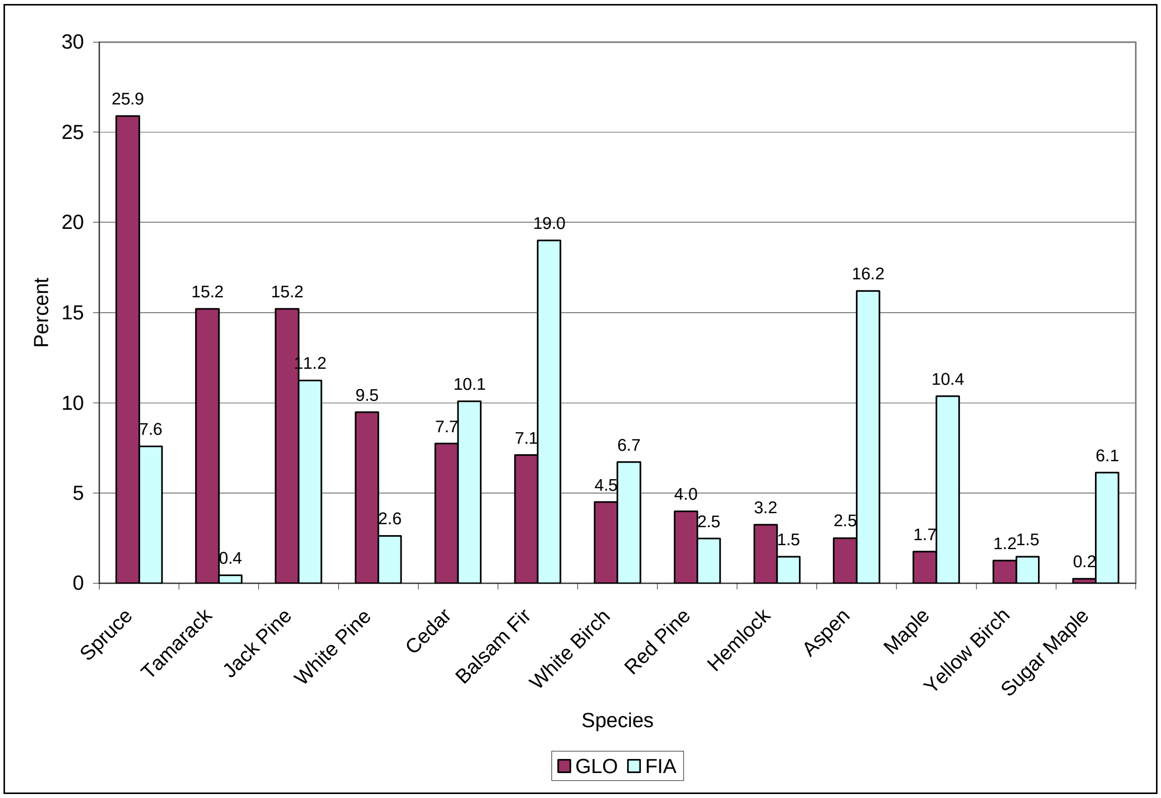

Figure B19. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Sections 212S, J, and Y

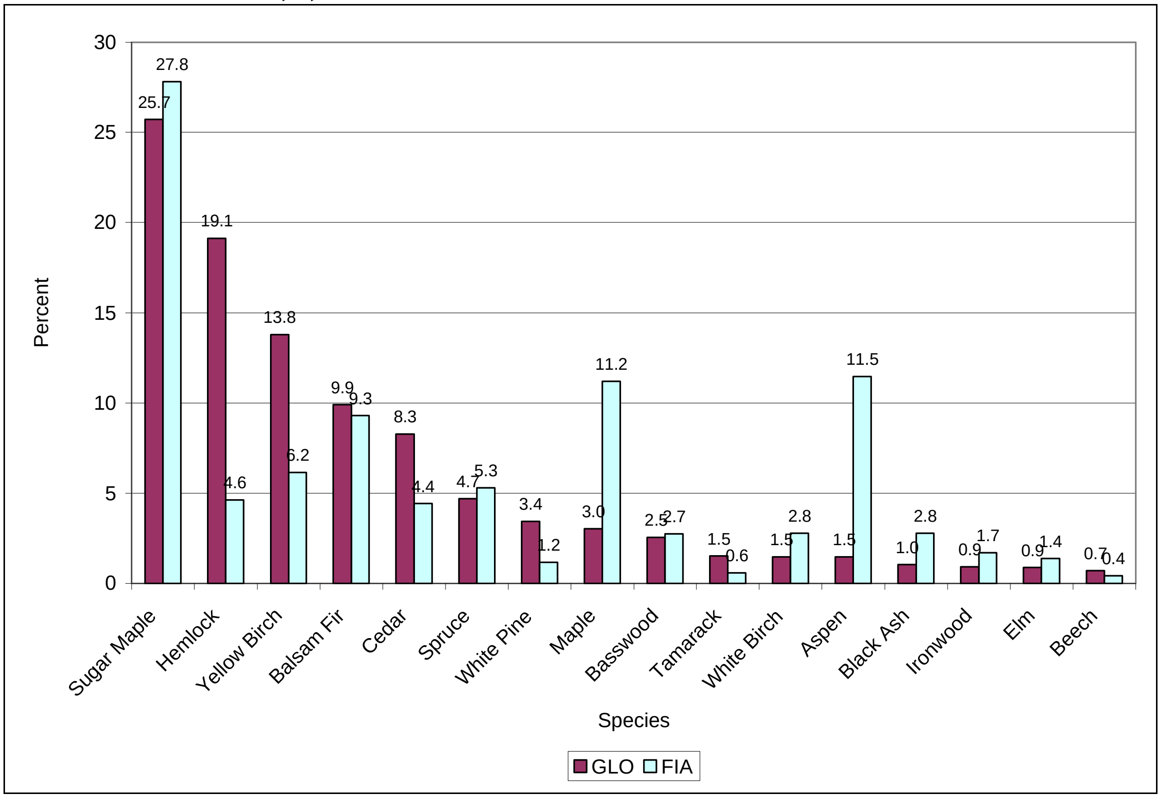

Figure B20. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Sections 212S, J, and Y

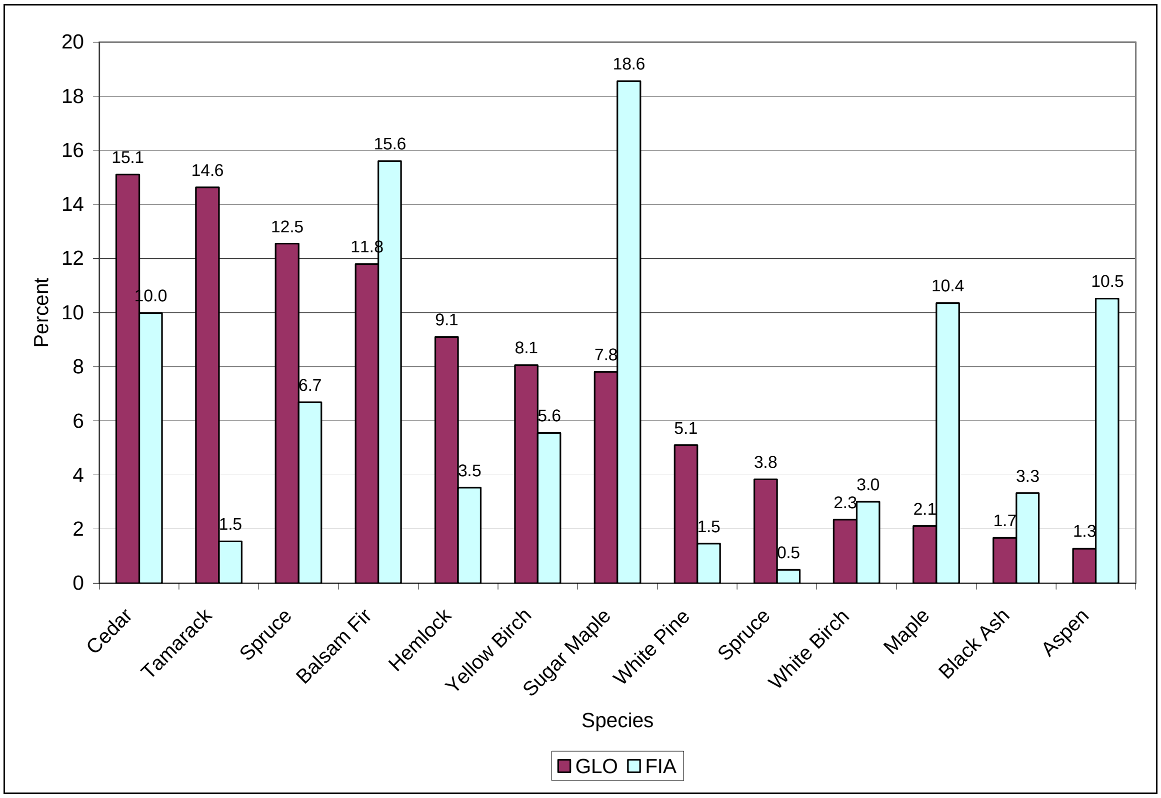

Figure B21. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Sections 212S, J, and Y

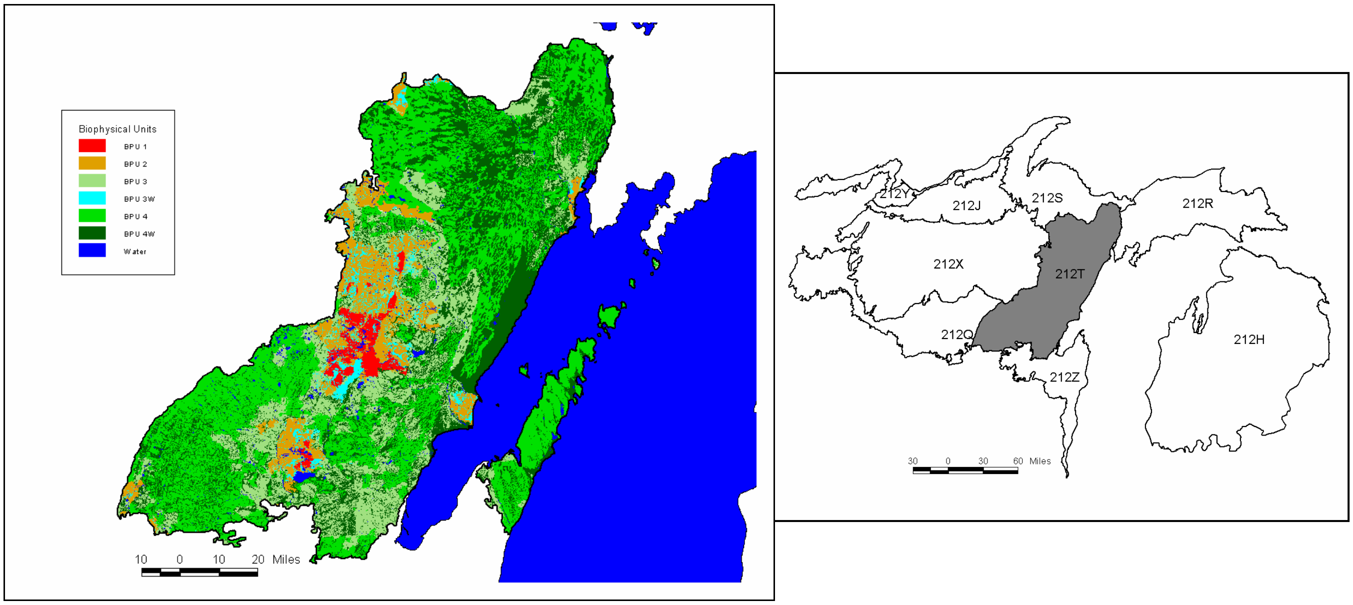

Figure B22. Biophysical Units of Section 212T

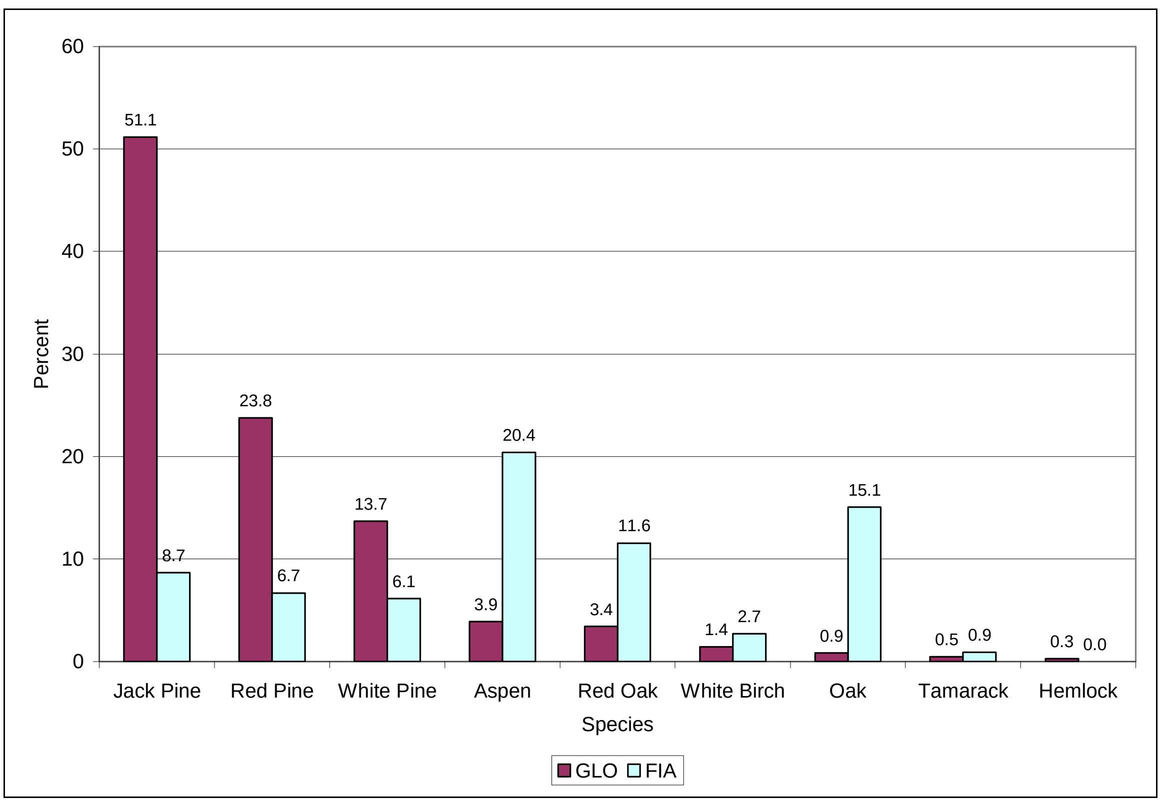

Figure B23. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212T

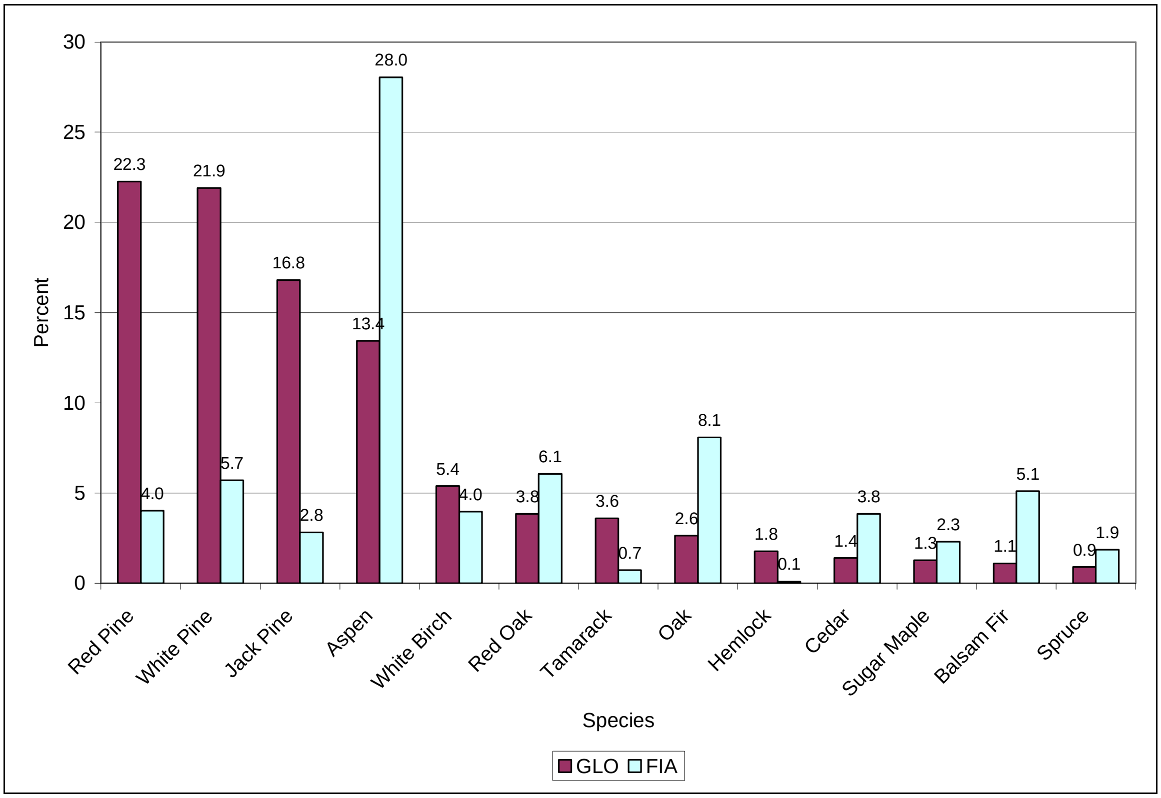

Figure B24. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212T

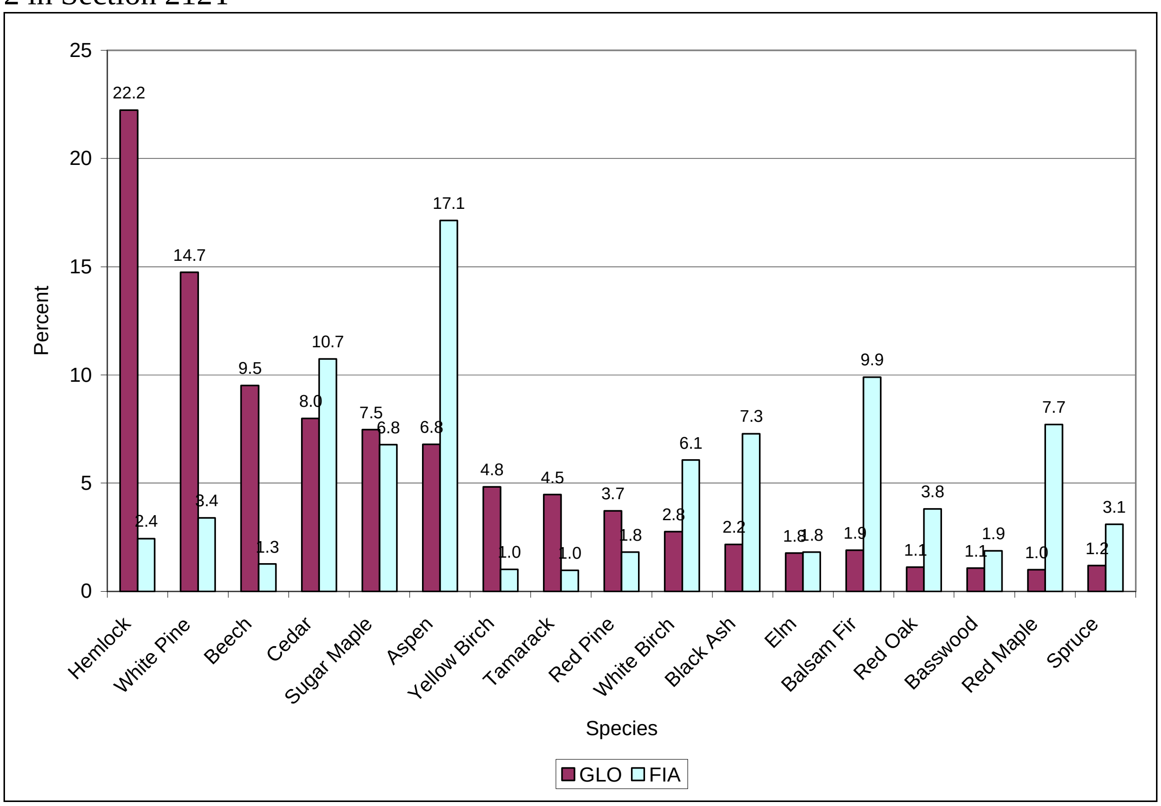

Figure B25. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212T

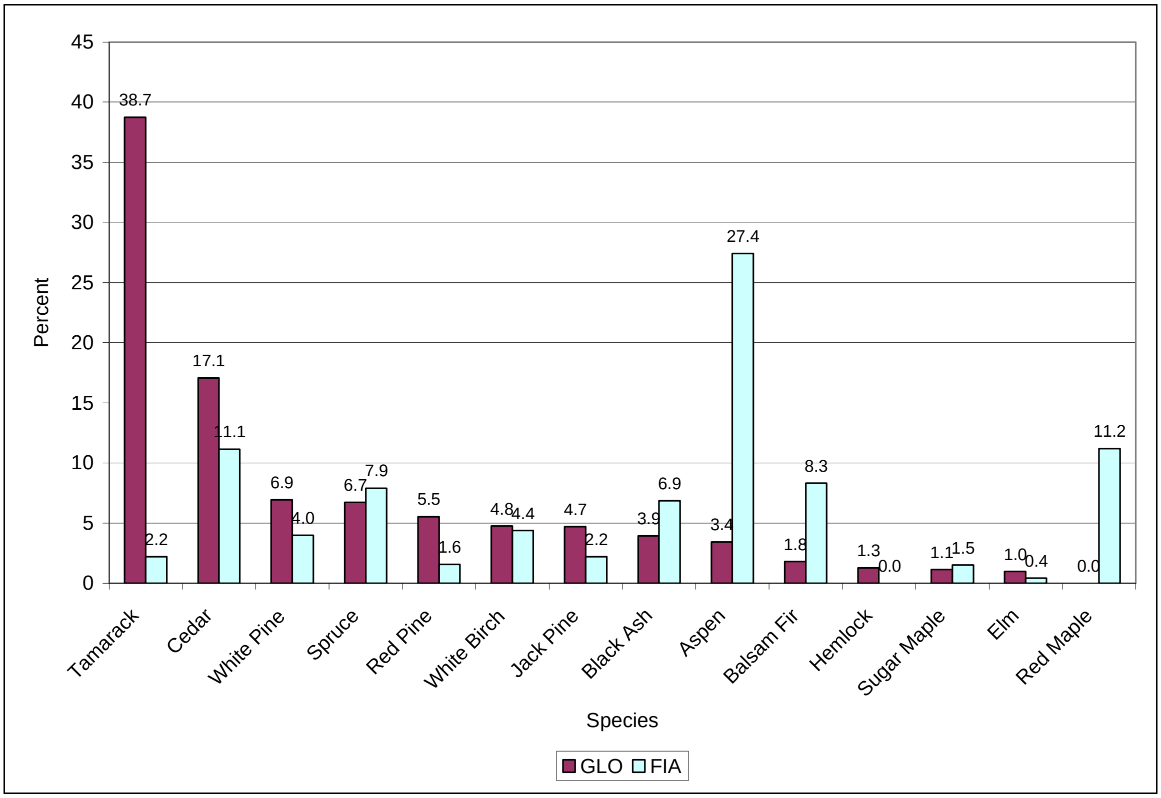

Figure B26. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212T

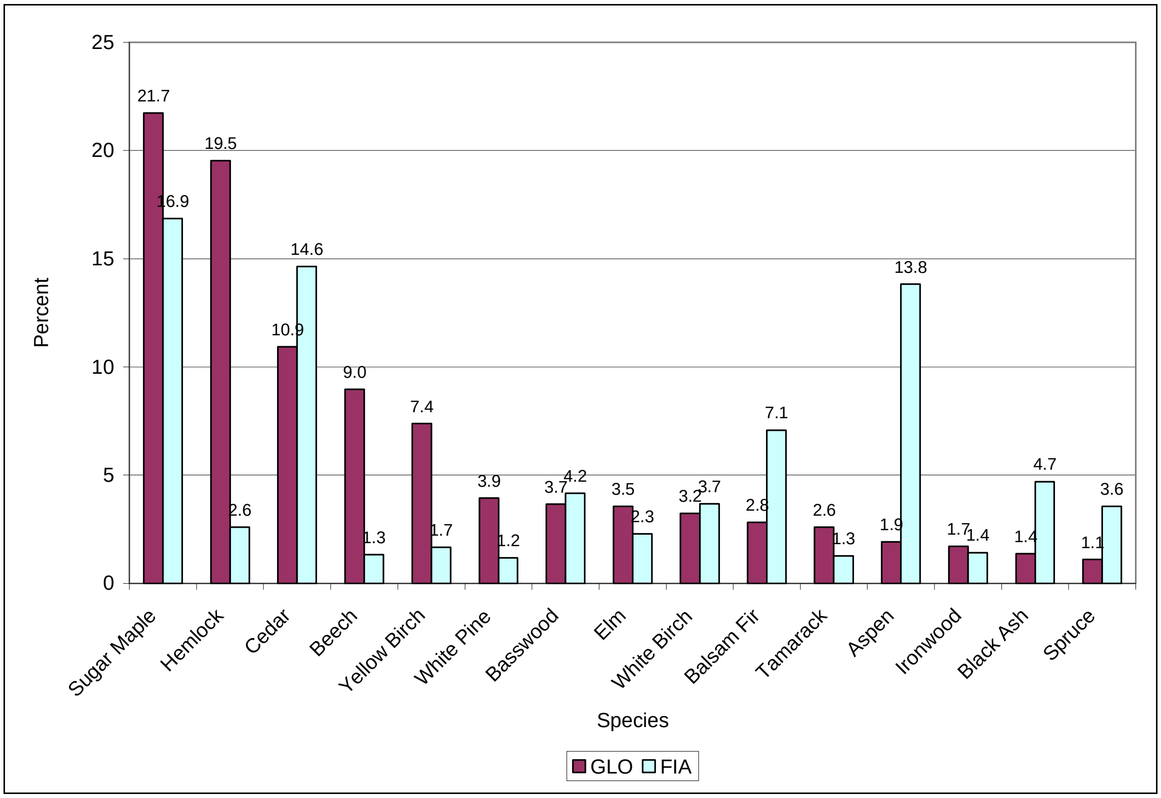

Figure B27. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212T

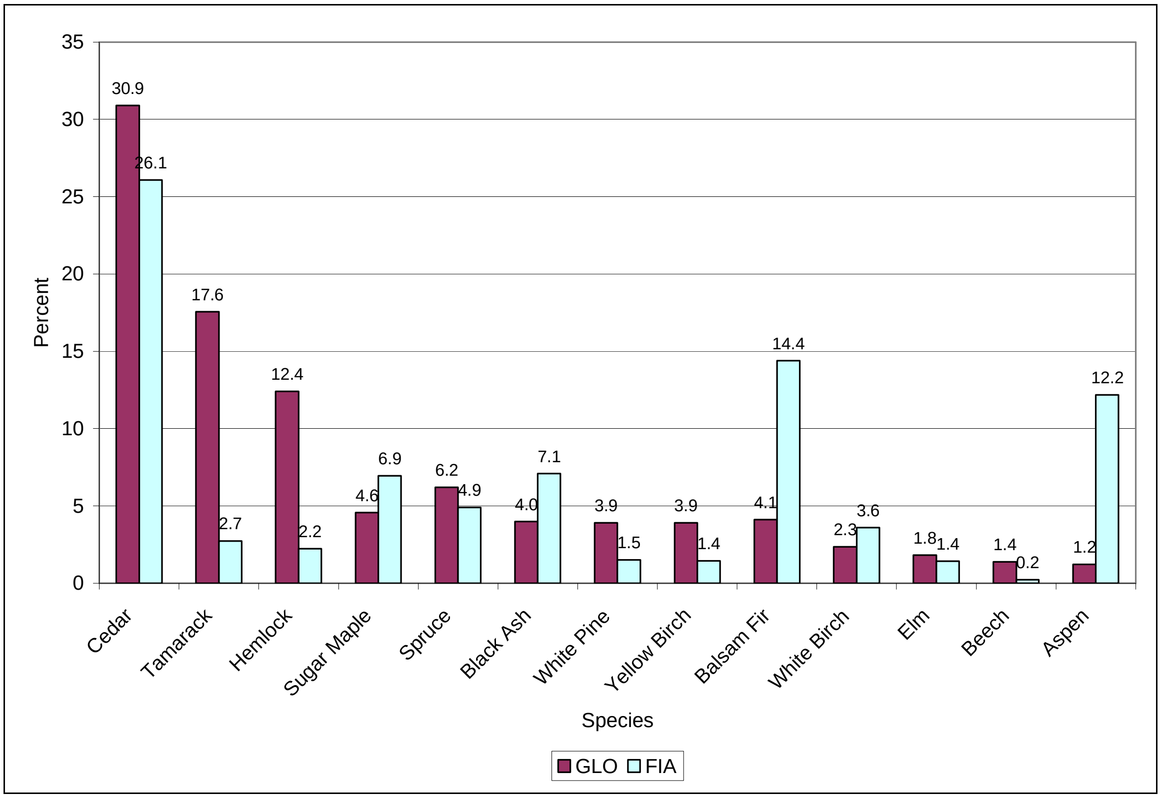

Figure B28. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212T

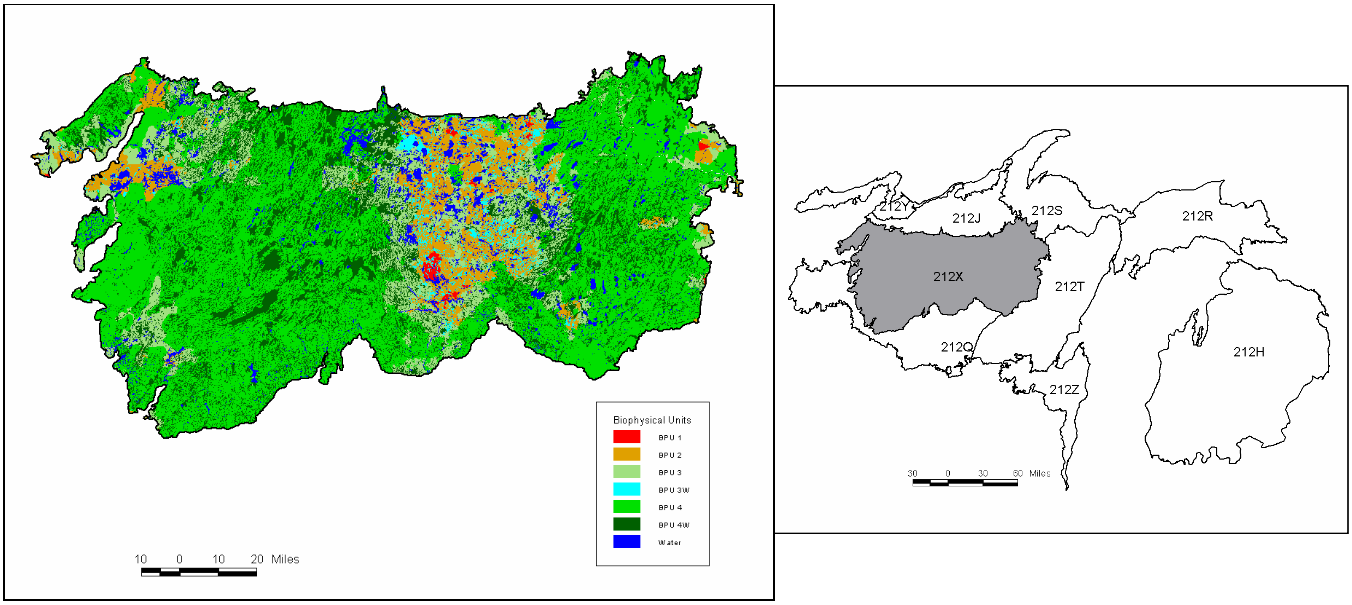

Figure B29. Biophysical Units of Section 212X

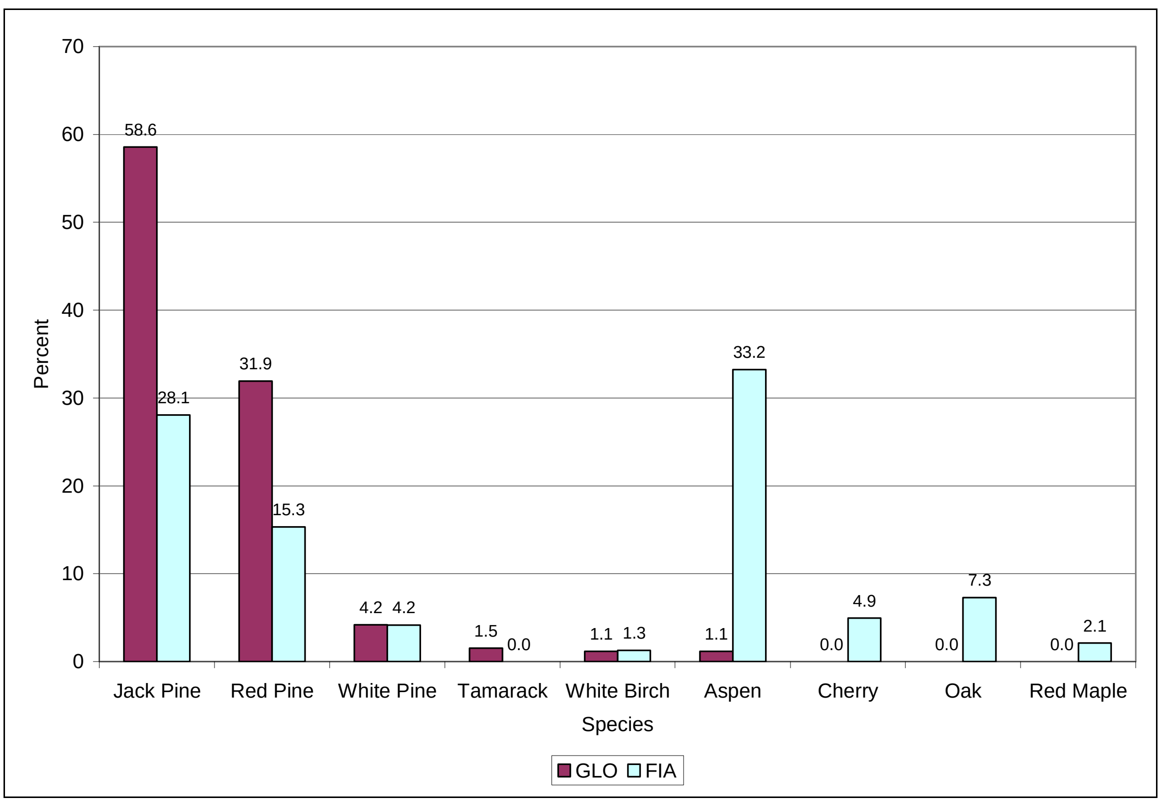

Figure B30. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212X

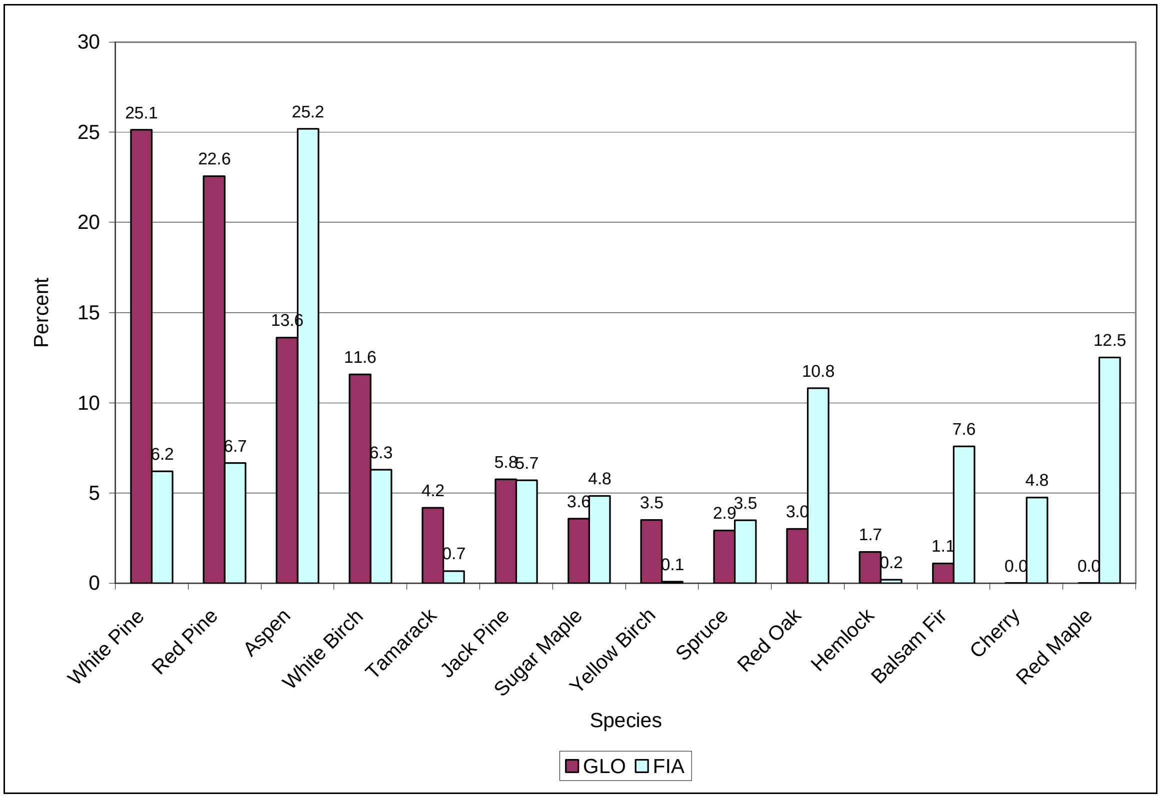

Figure B31. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212X

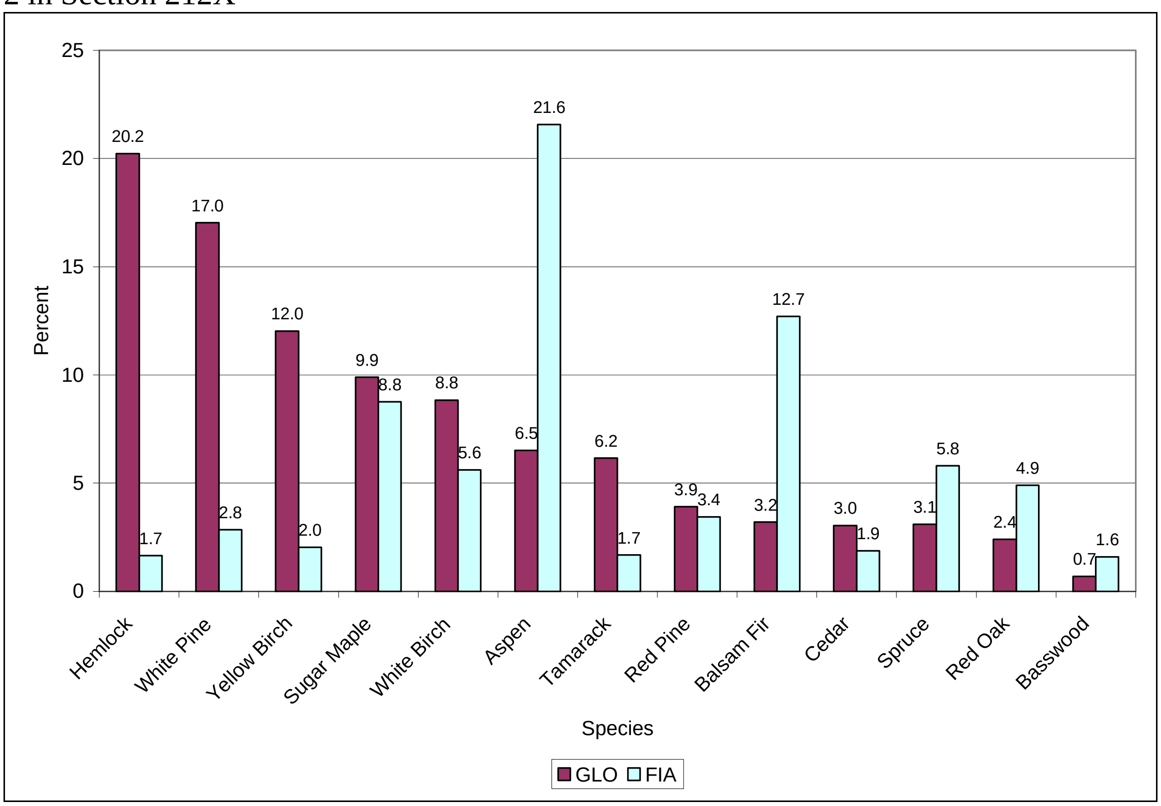

Figure B32. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212X

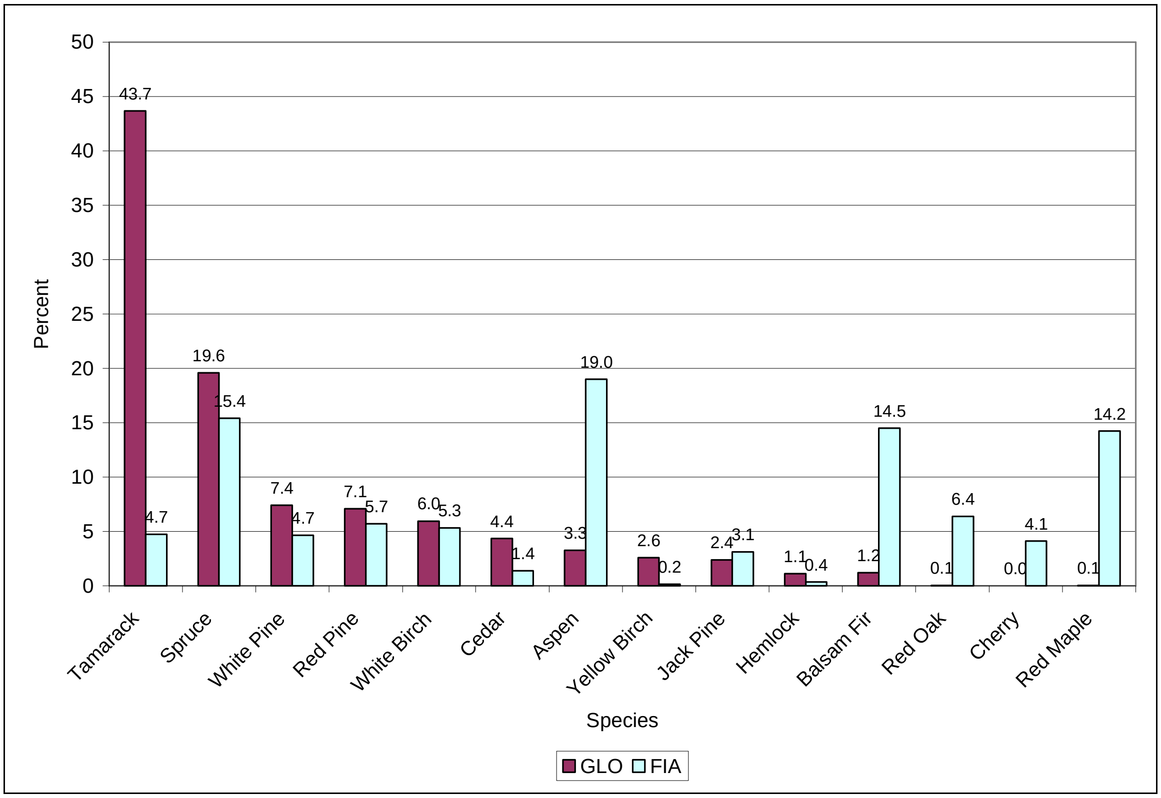

Figure B33. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212X

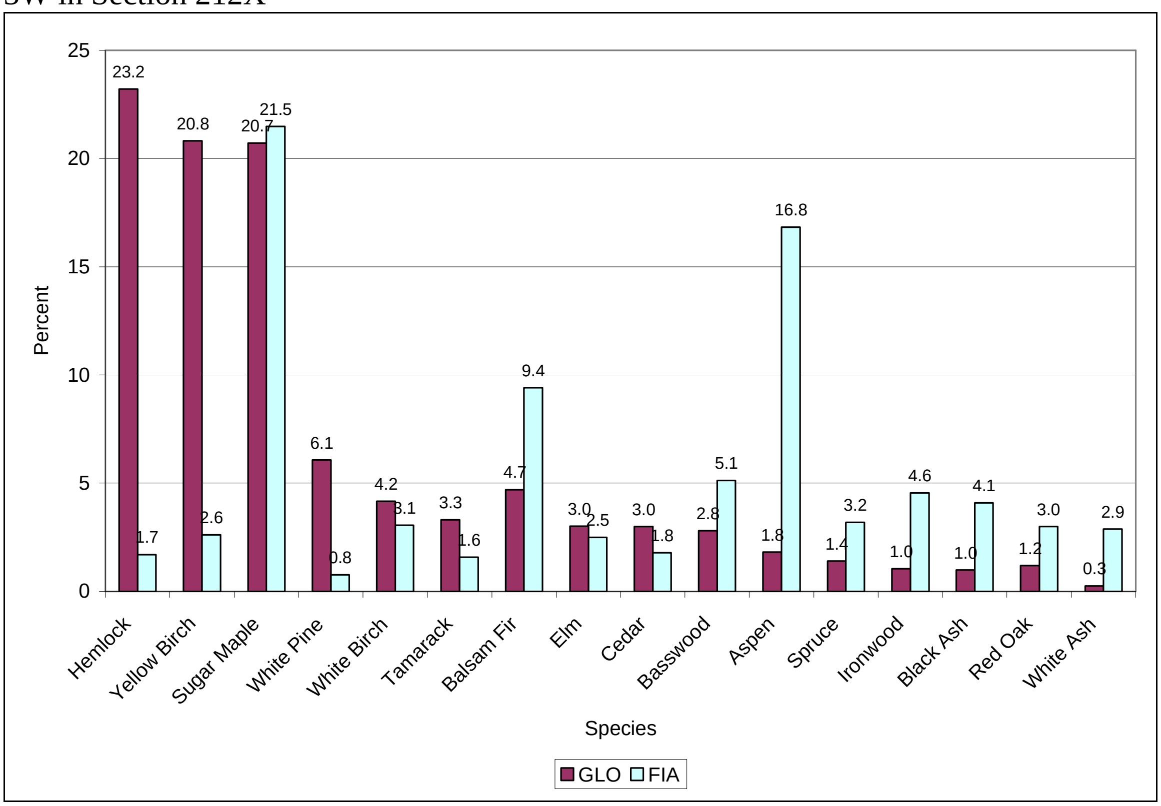

Figure B34. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212X

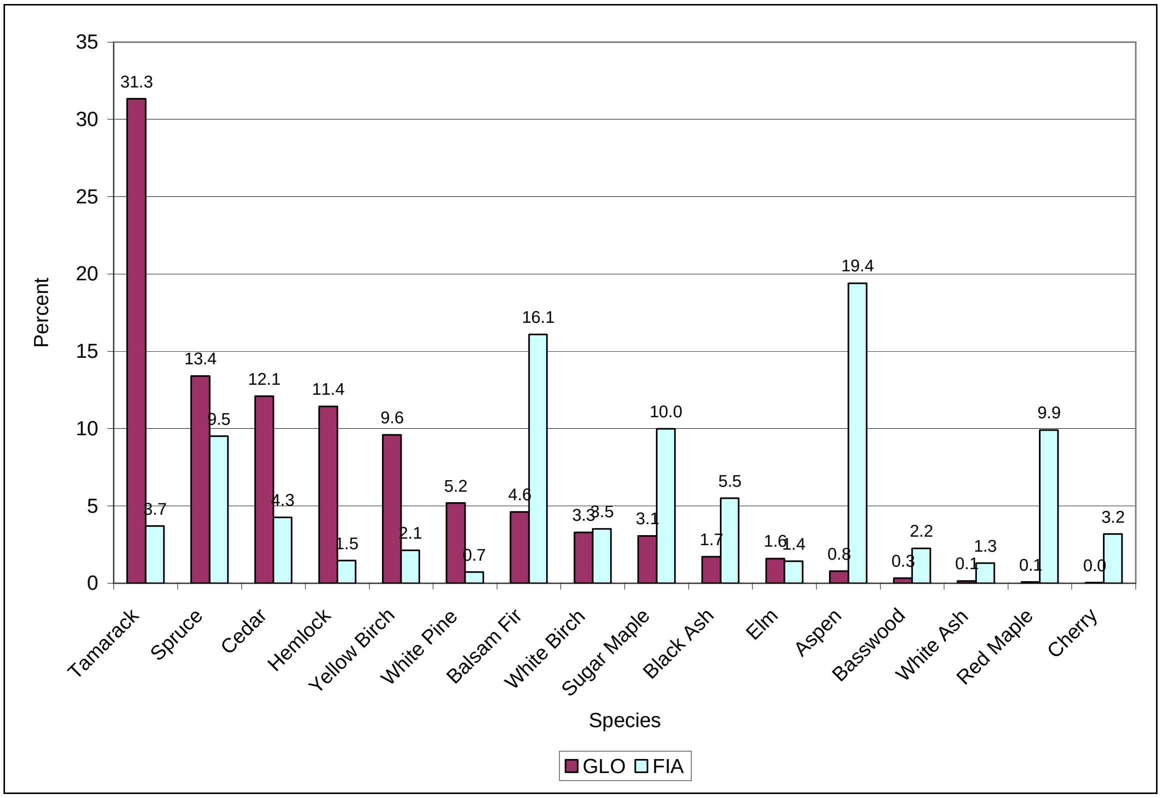

Figure B35. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212X

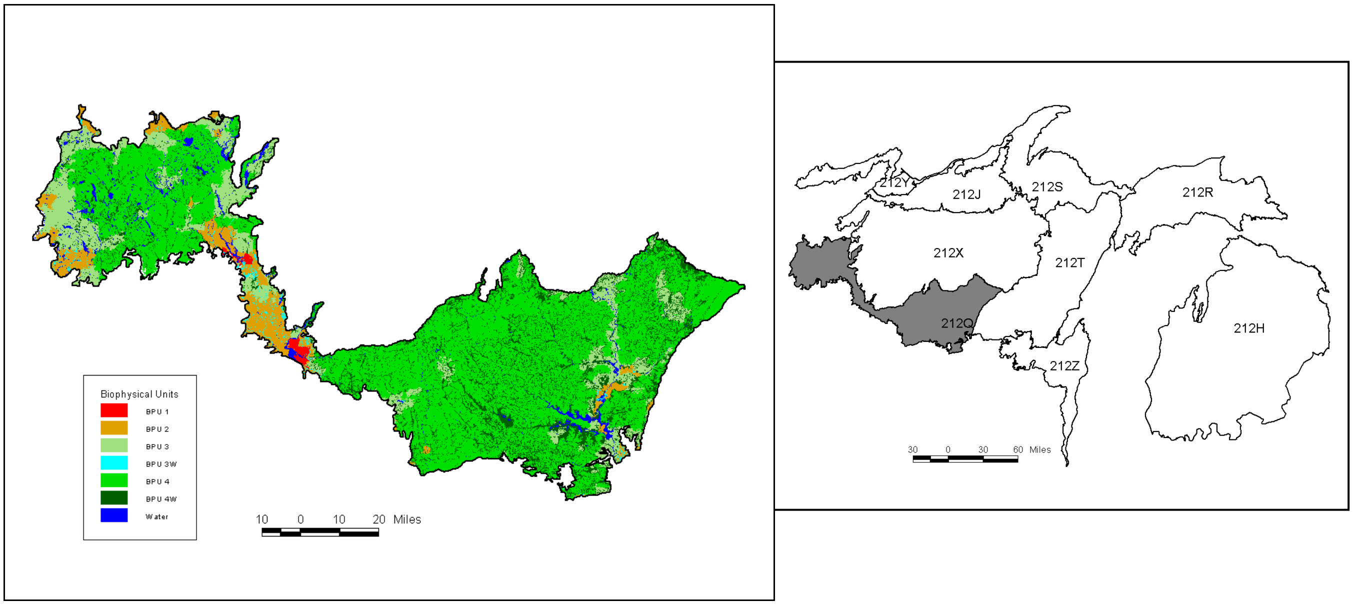

Figure B36. Biophysical Units of Section 212Q

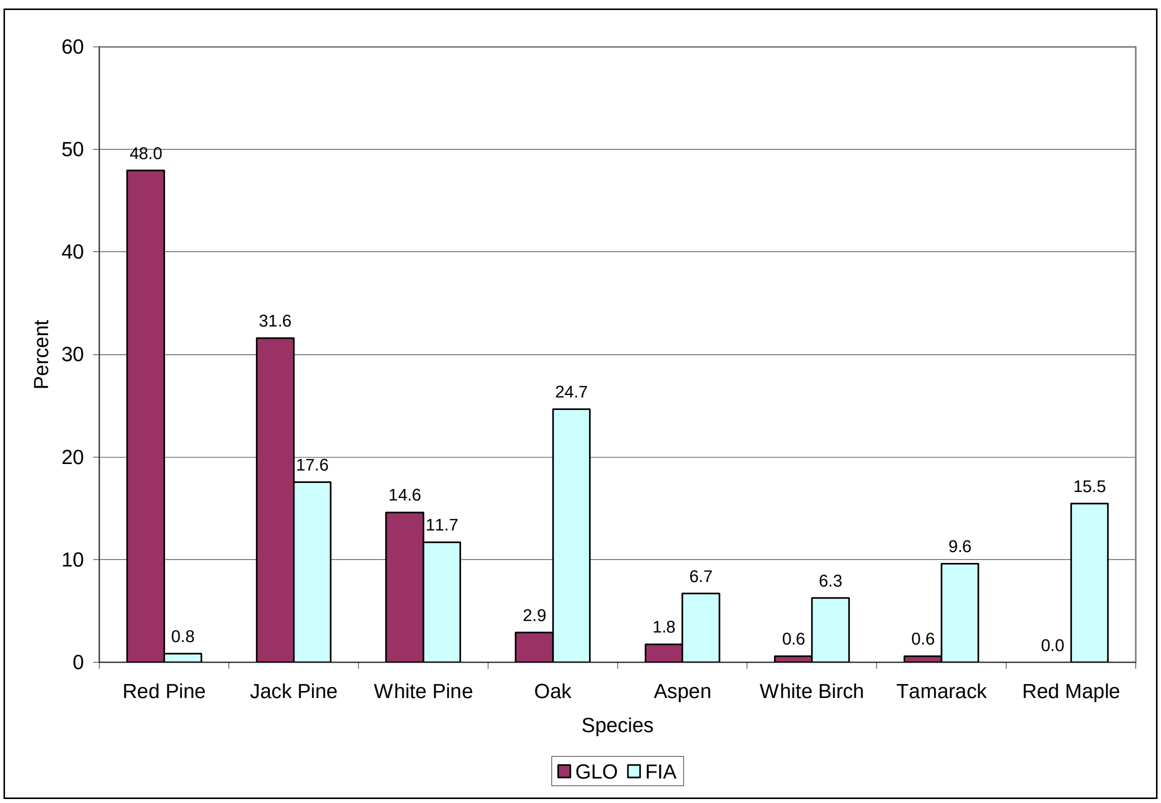

Figure B37. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212Q

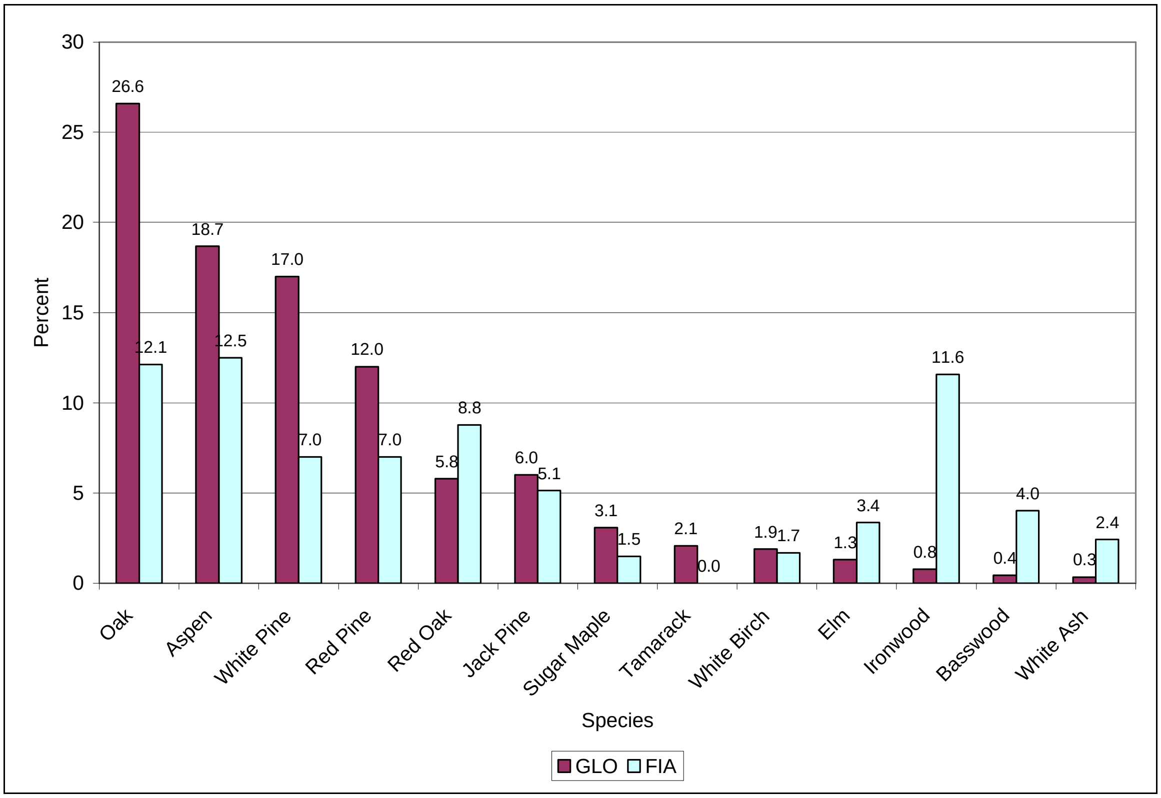

Figure B38. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212Q

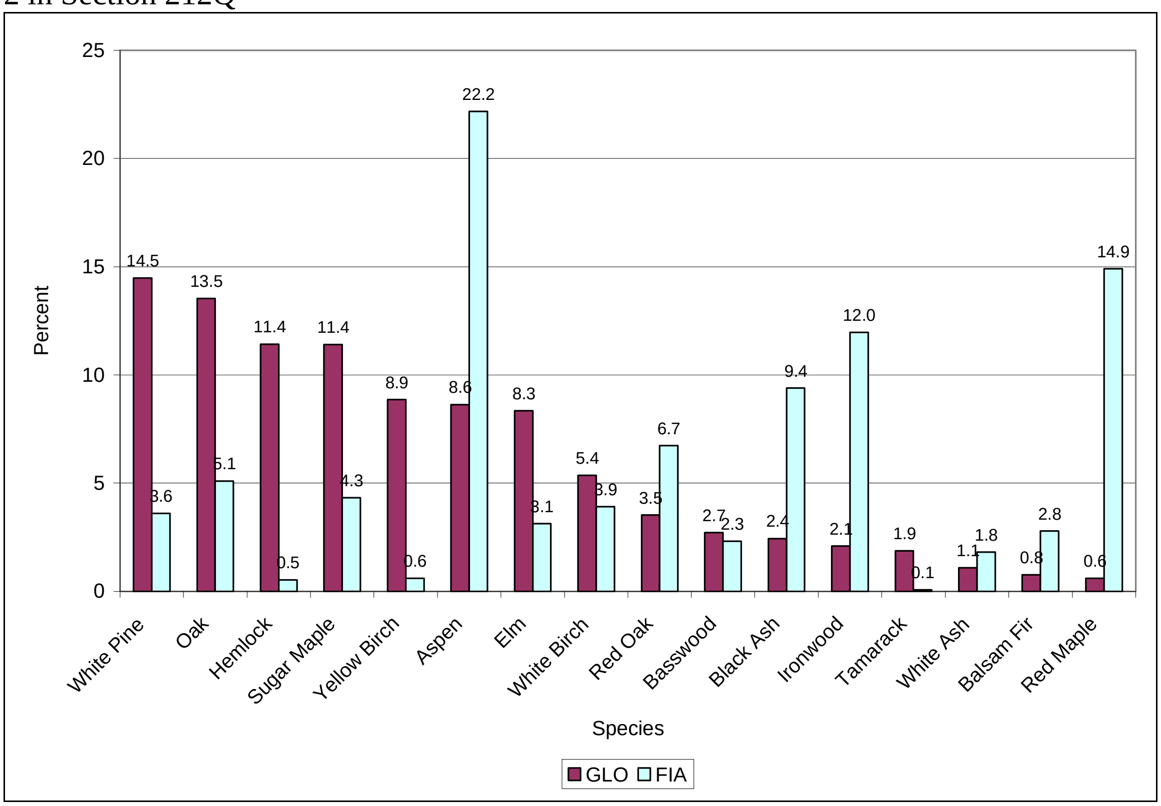

Figure B39. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212Q

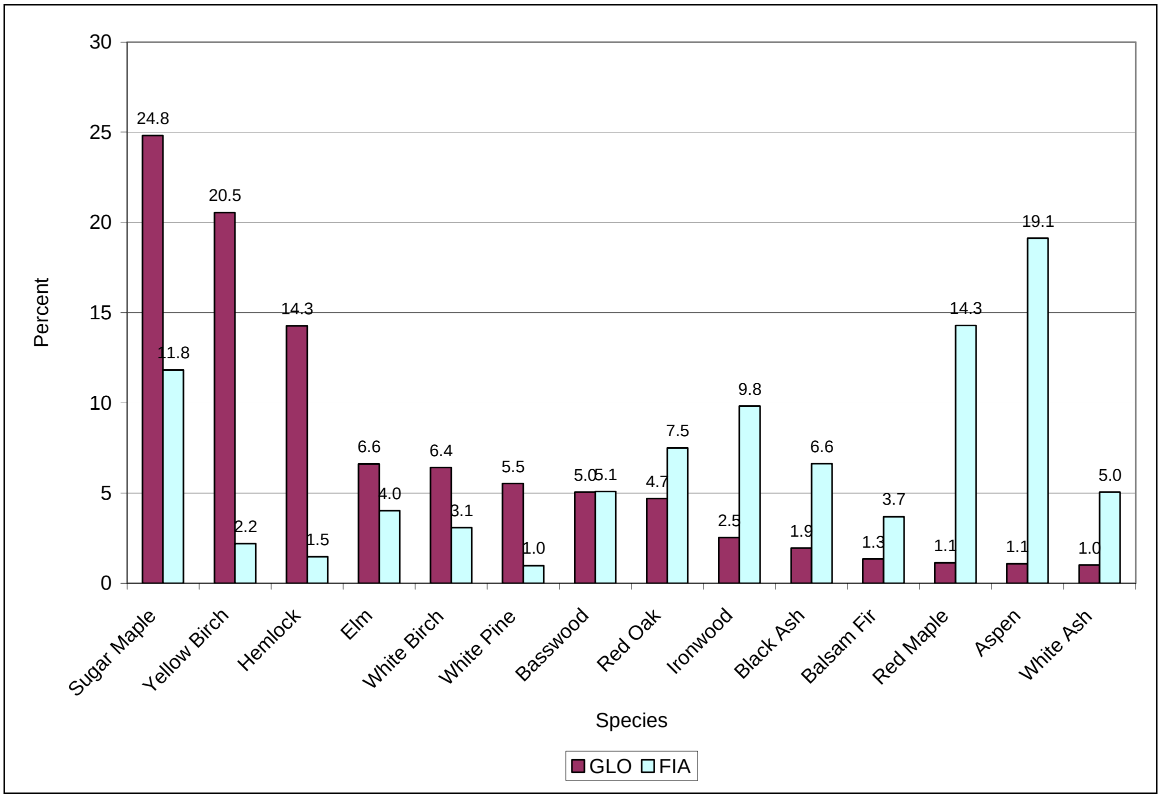

Figure B40. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212Q

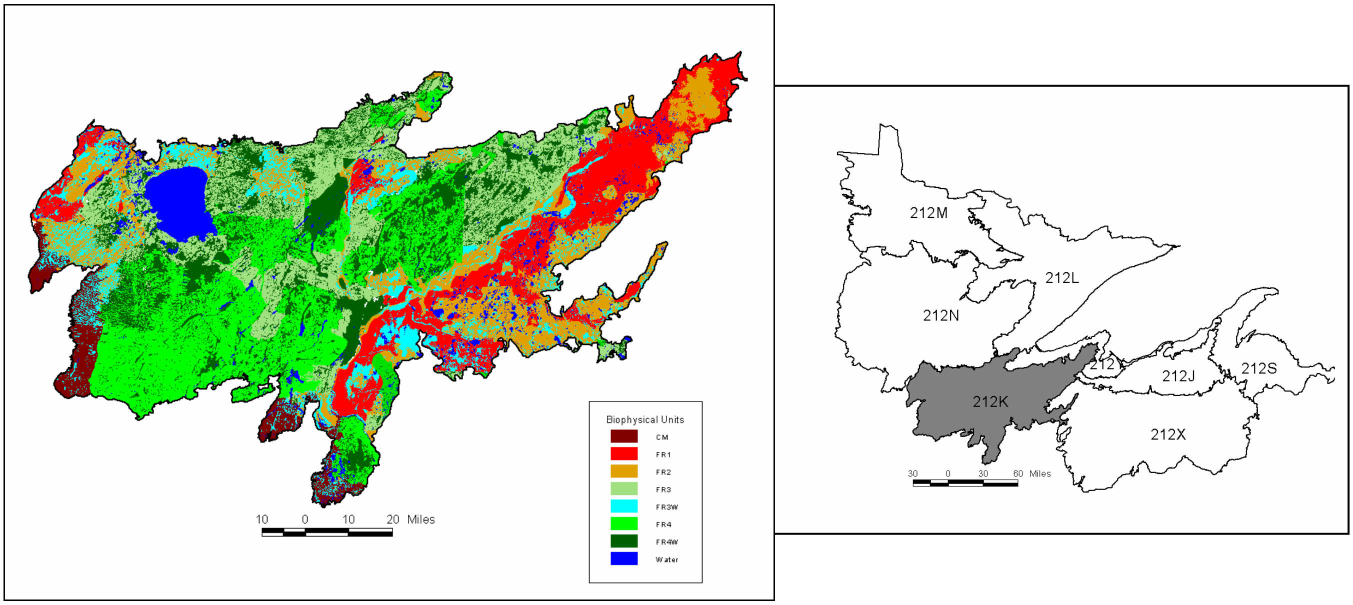

Figure B41. Biophysical Units of Section 212K

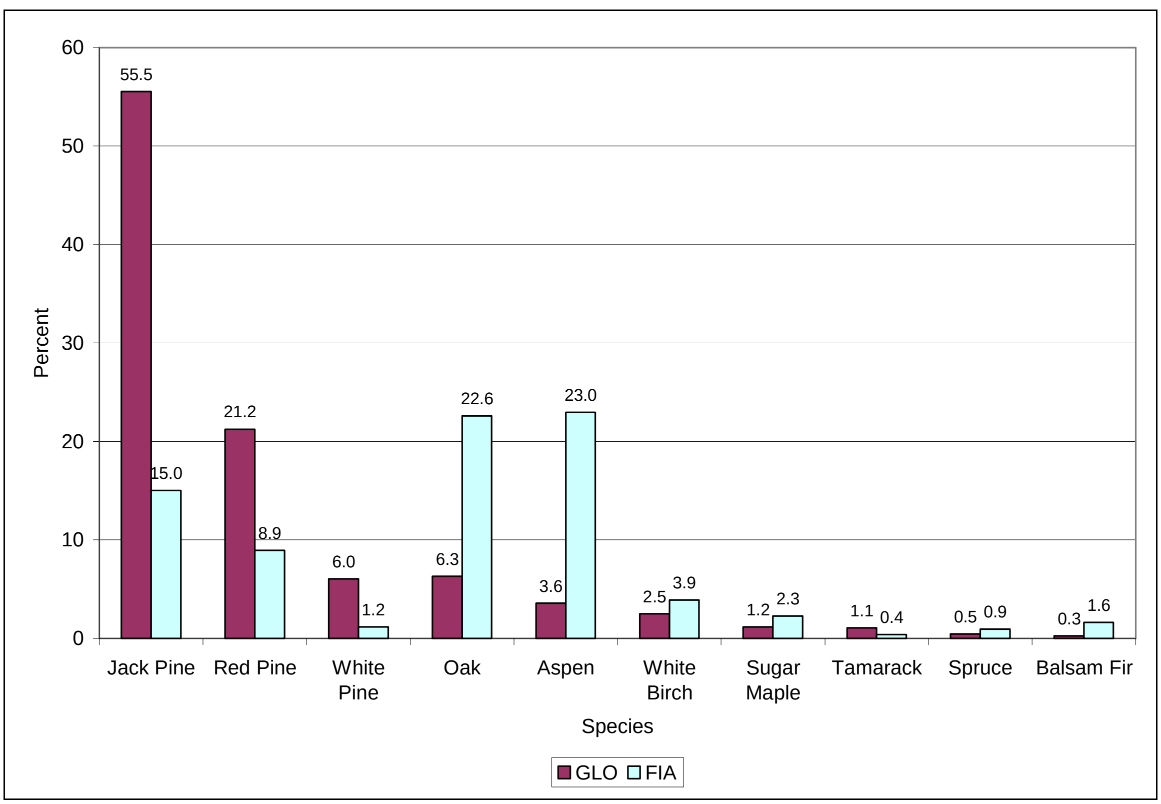

Figure B42. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212K

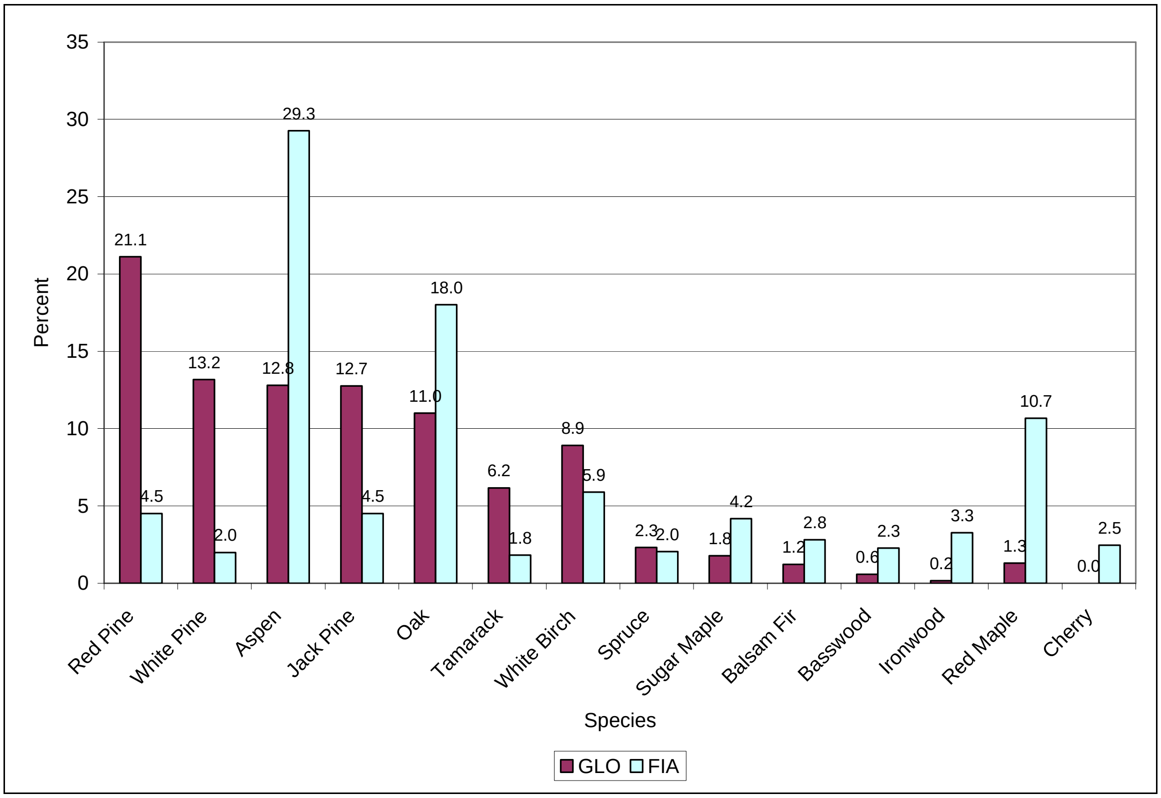

Figure B43. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212K

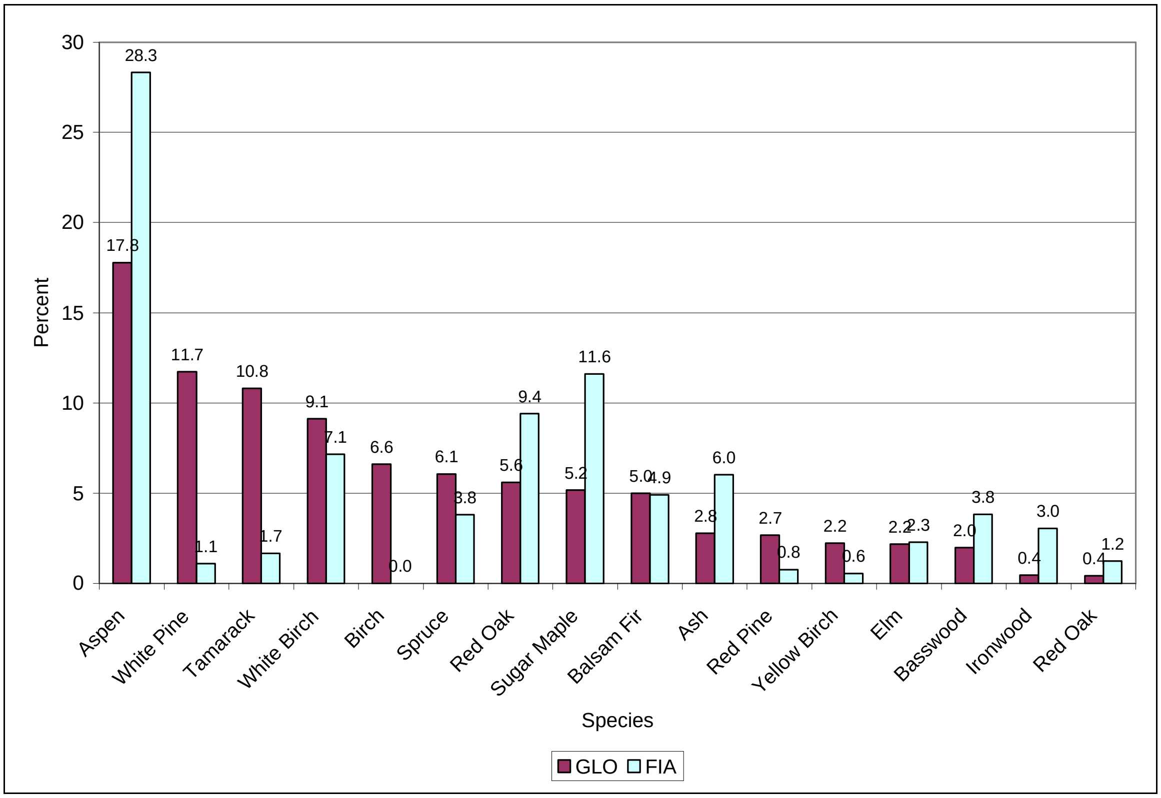

Figure B44. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212K

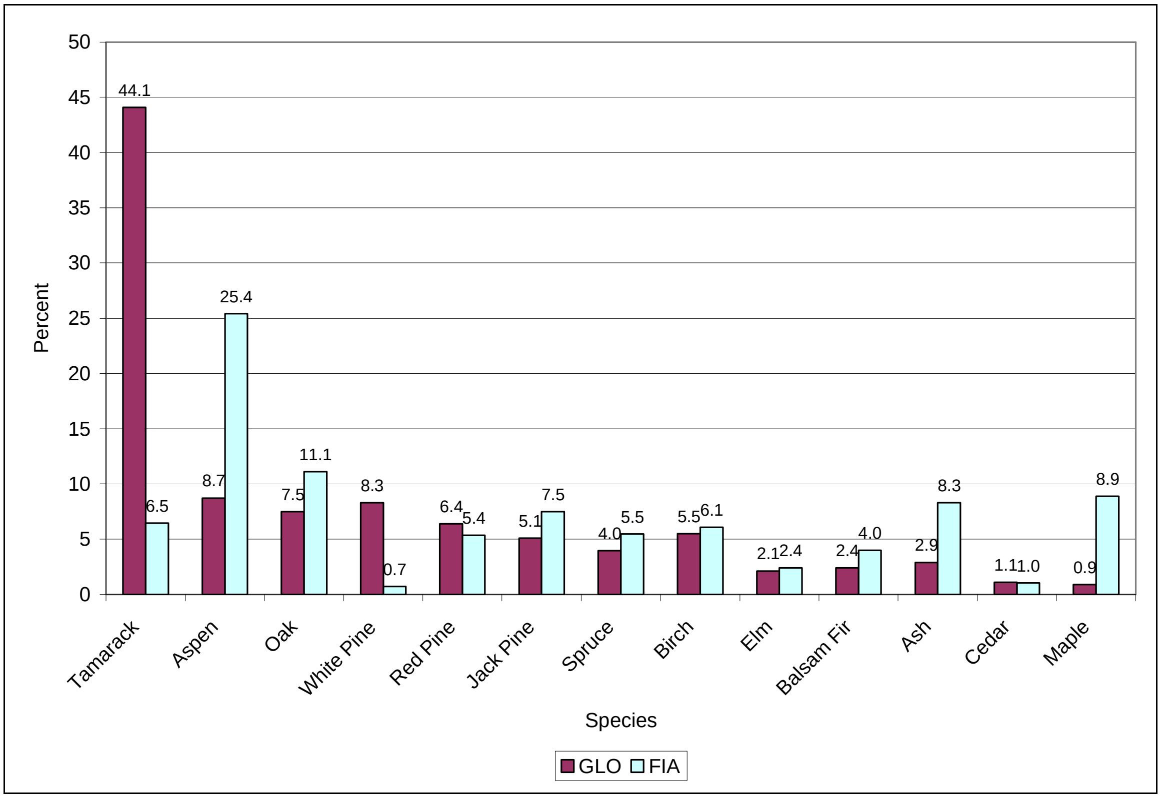

Figure B45. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212K

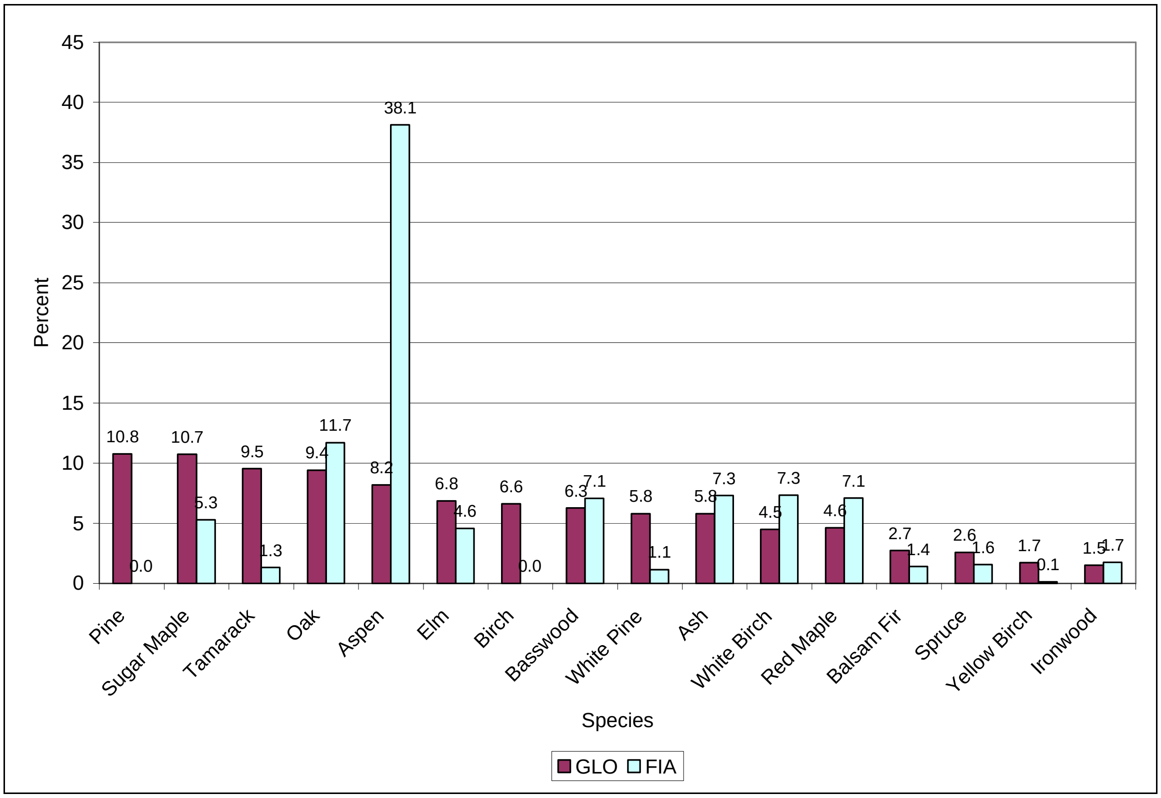

Figure B46. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212K

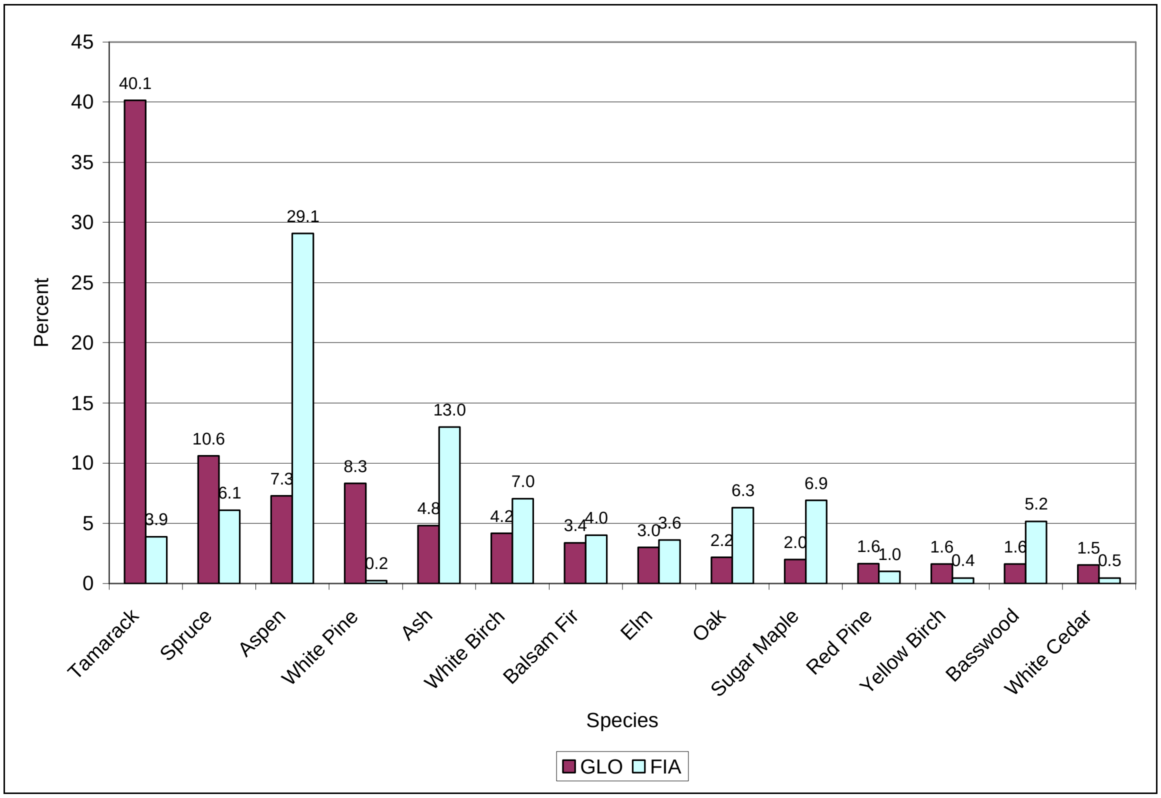

Figure B47. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212K

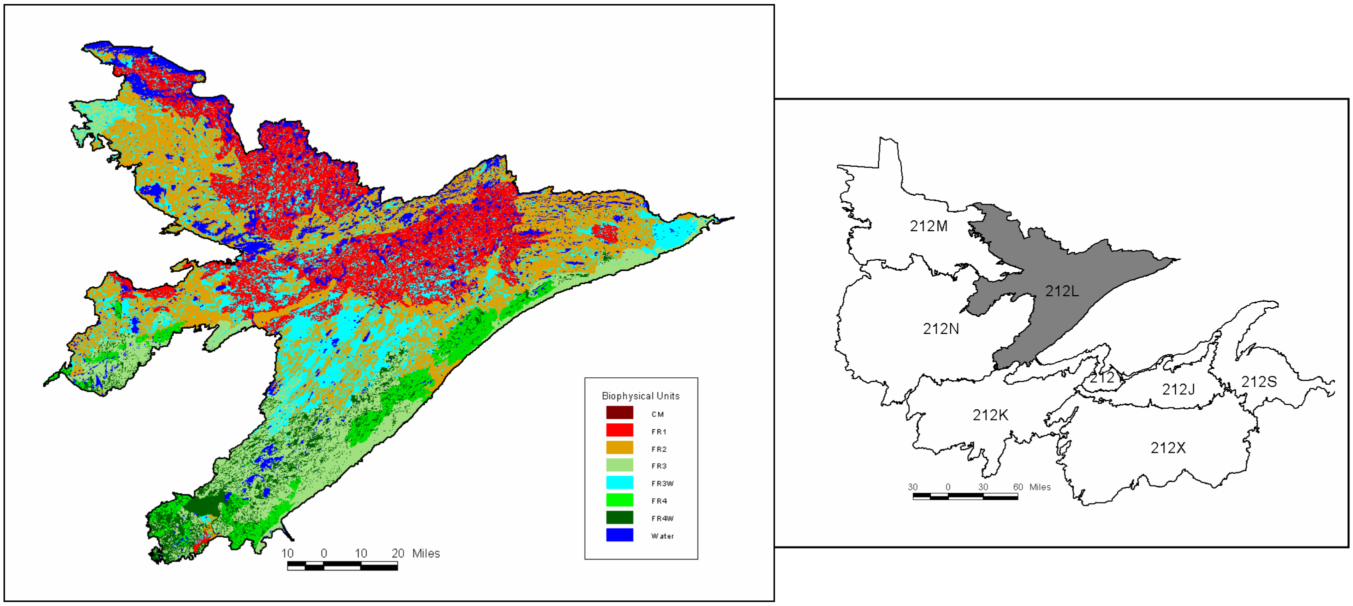

Figure B48. Biophysical Units of Section 212L

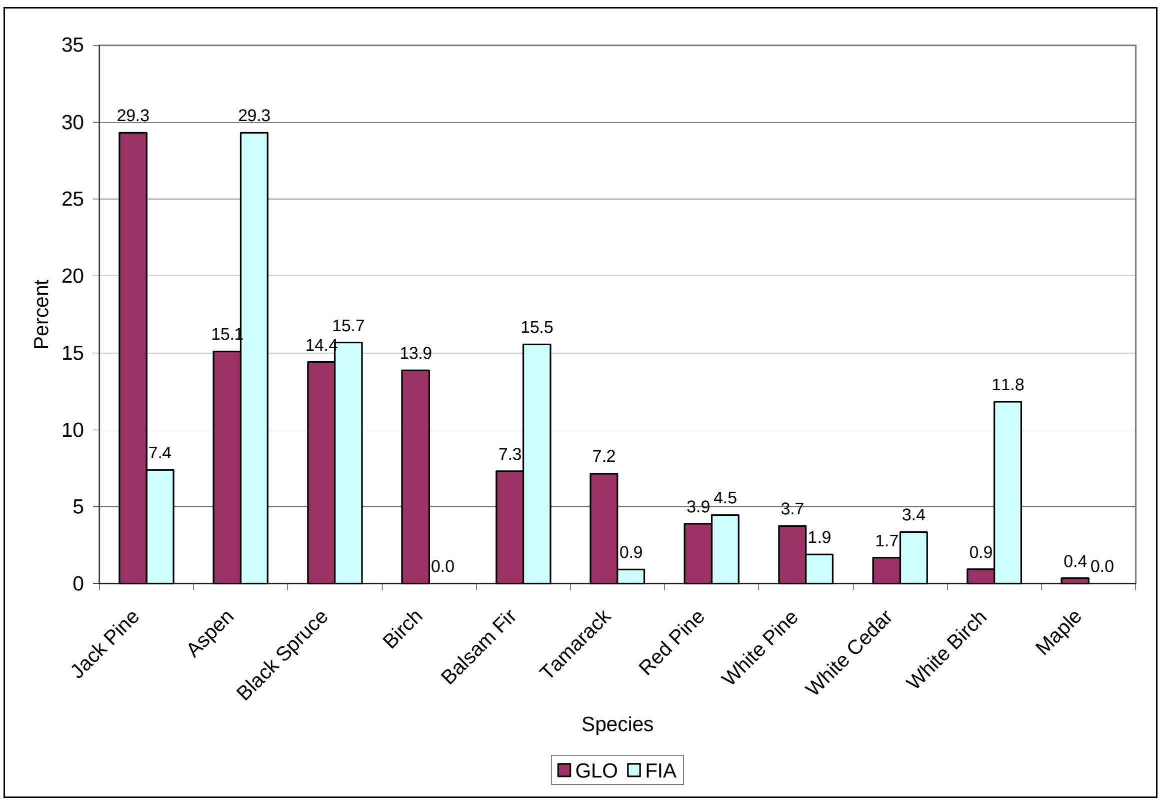

Figure B49. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212L

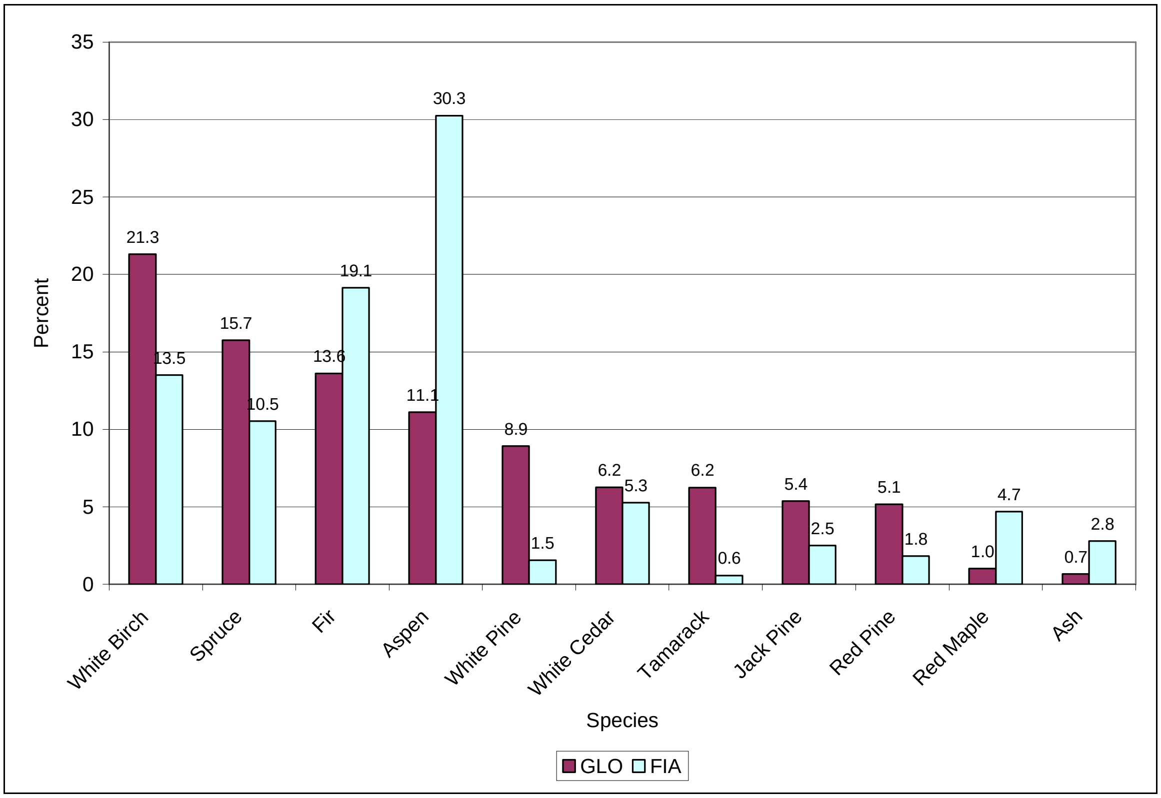

Figure B50. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212L

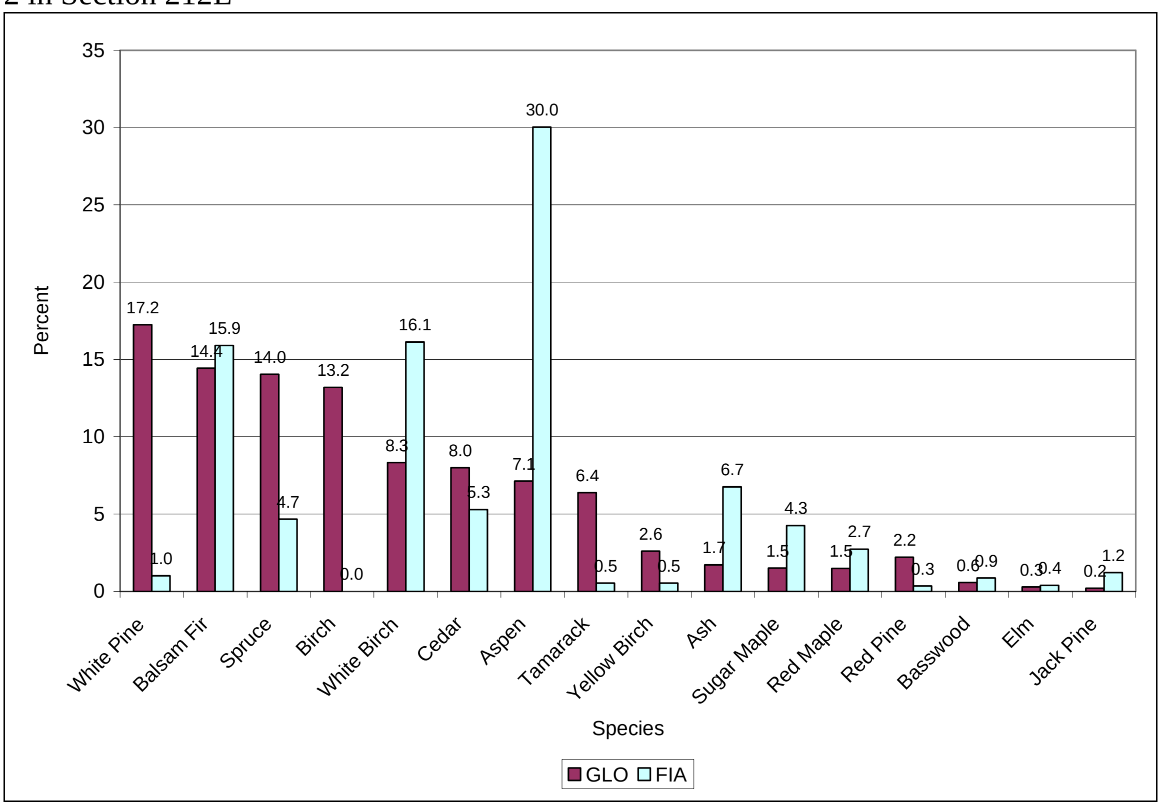

Figure B51. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212L

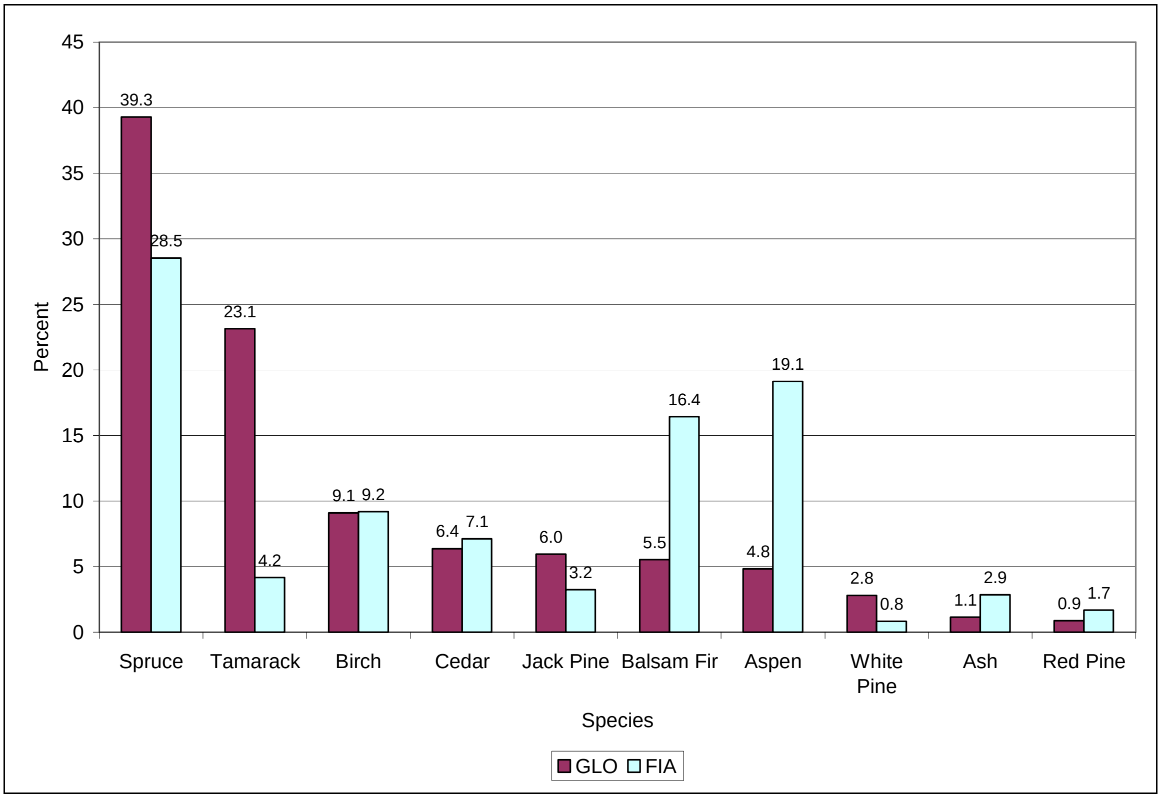

Figure B52. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212L

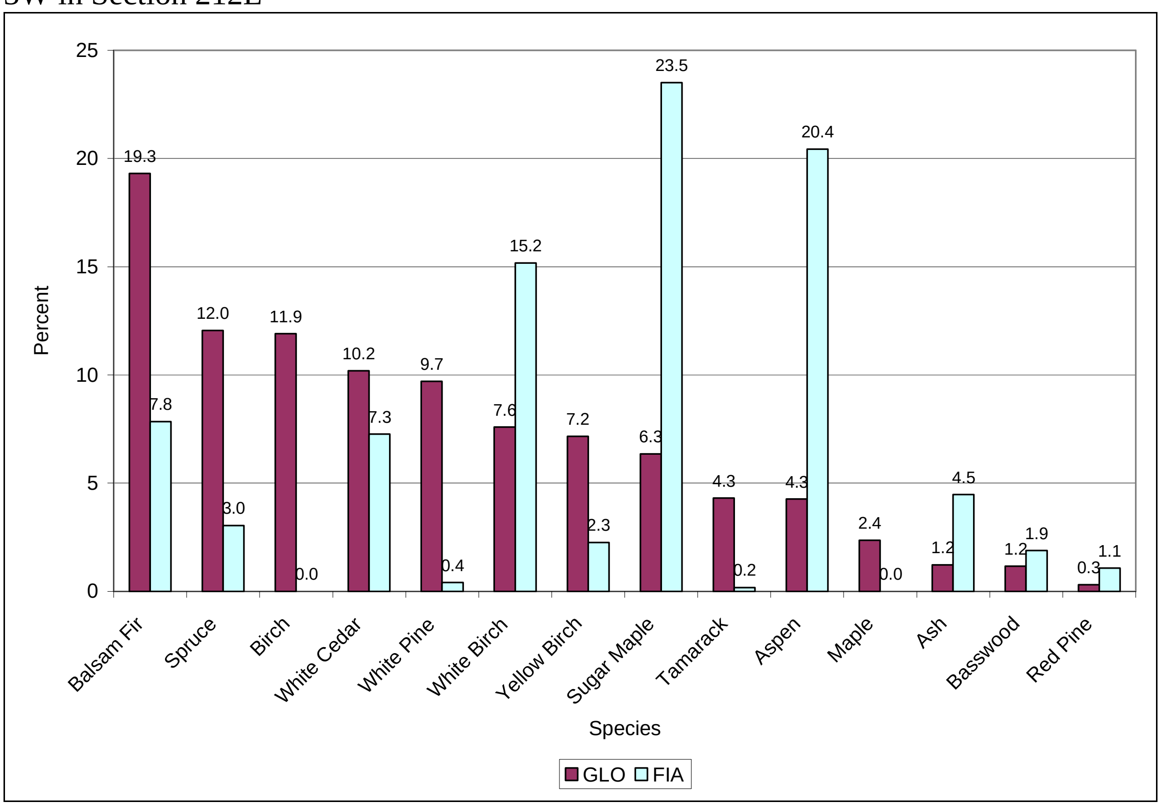

Figure B53. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212L

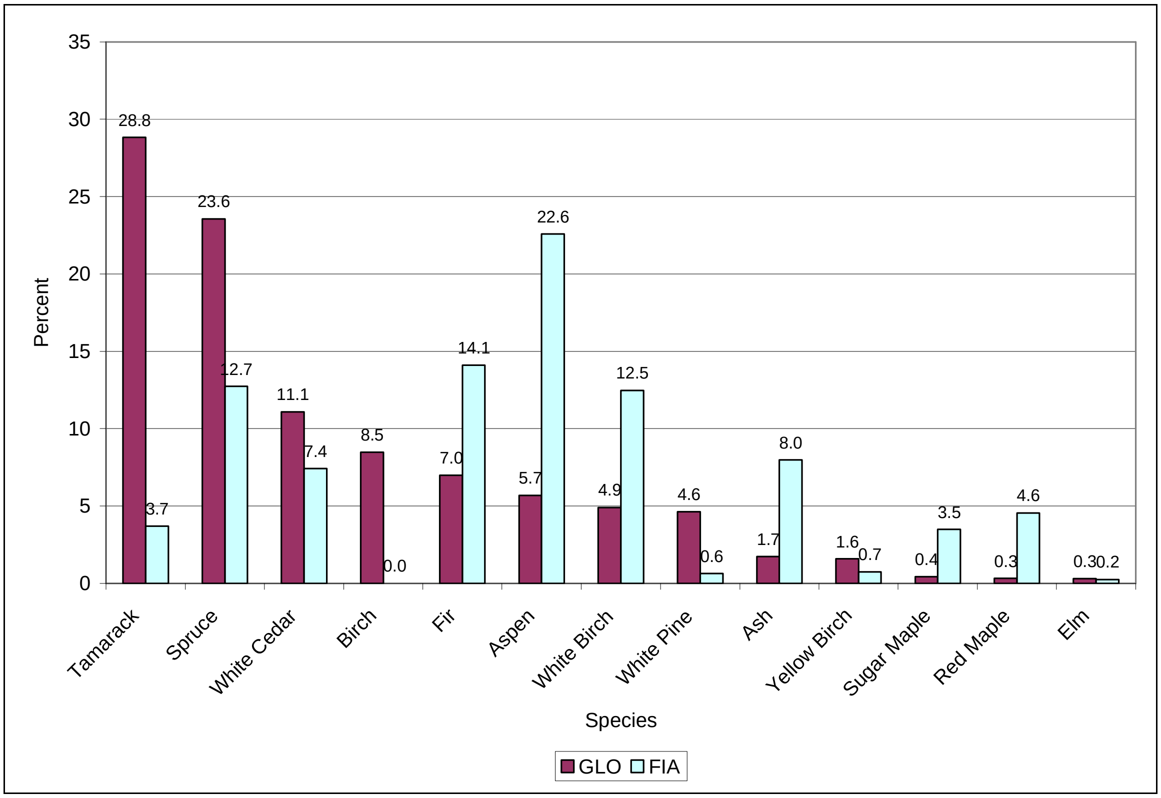

Figure B54. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212L

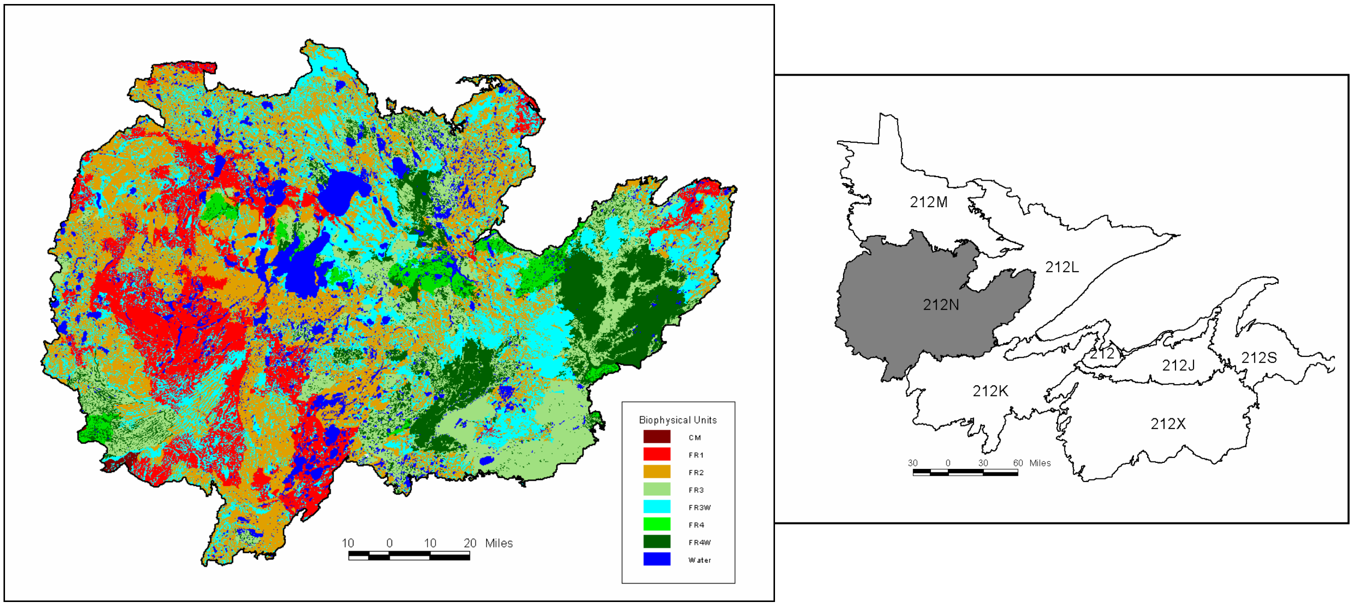

Figure B55. Biophysical Units of Section 212N

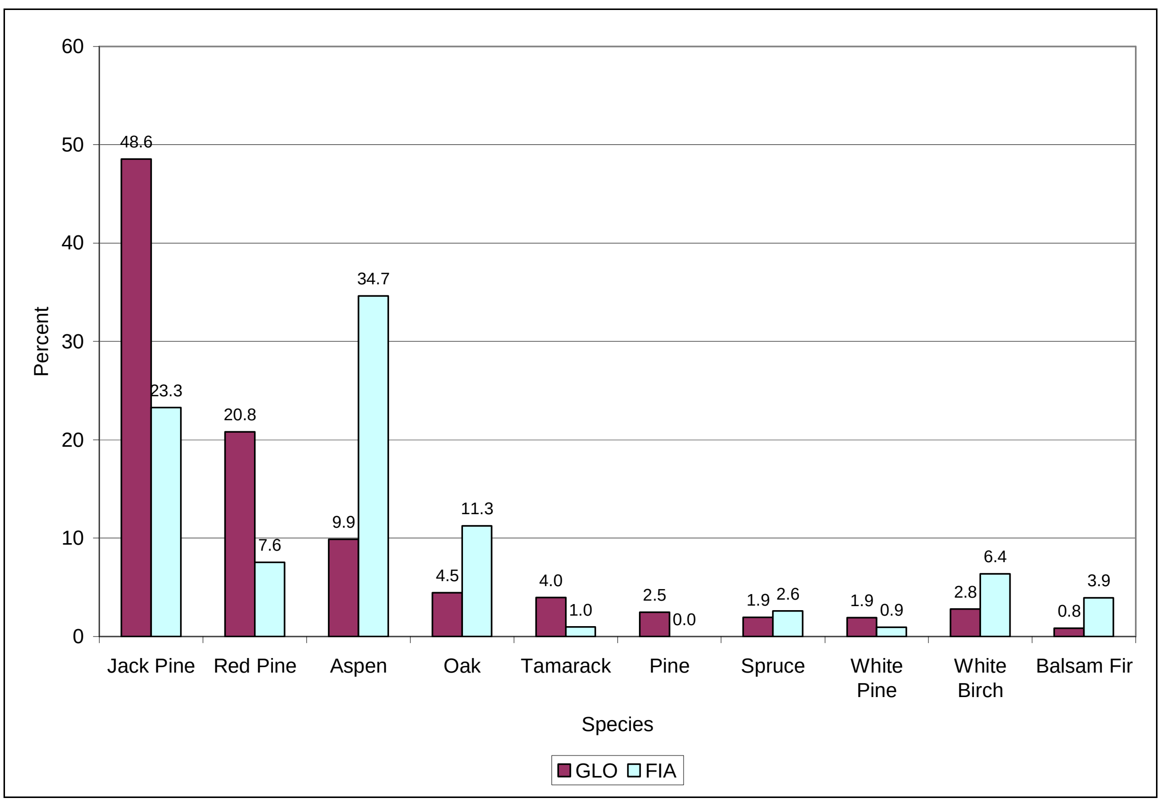

Figure B56. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212N

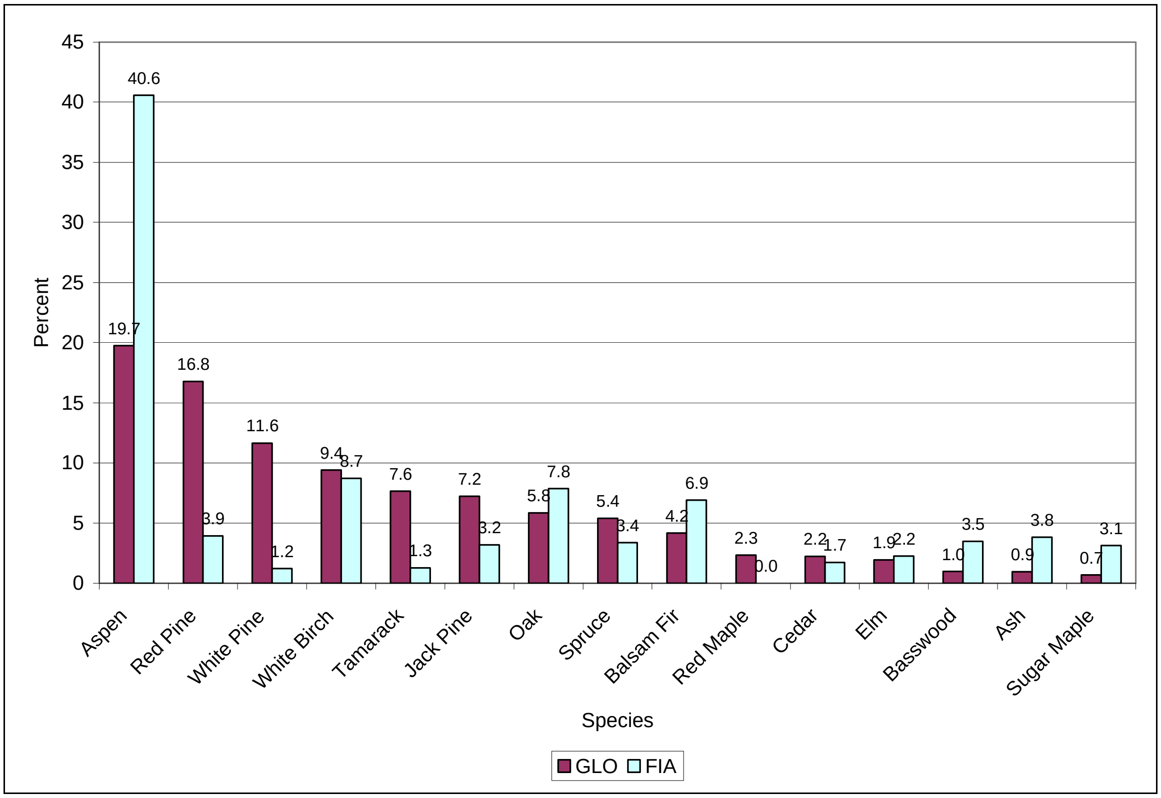

Figure B57. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212N

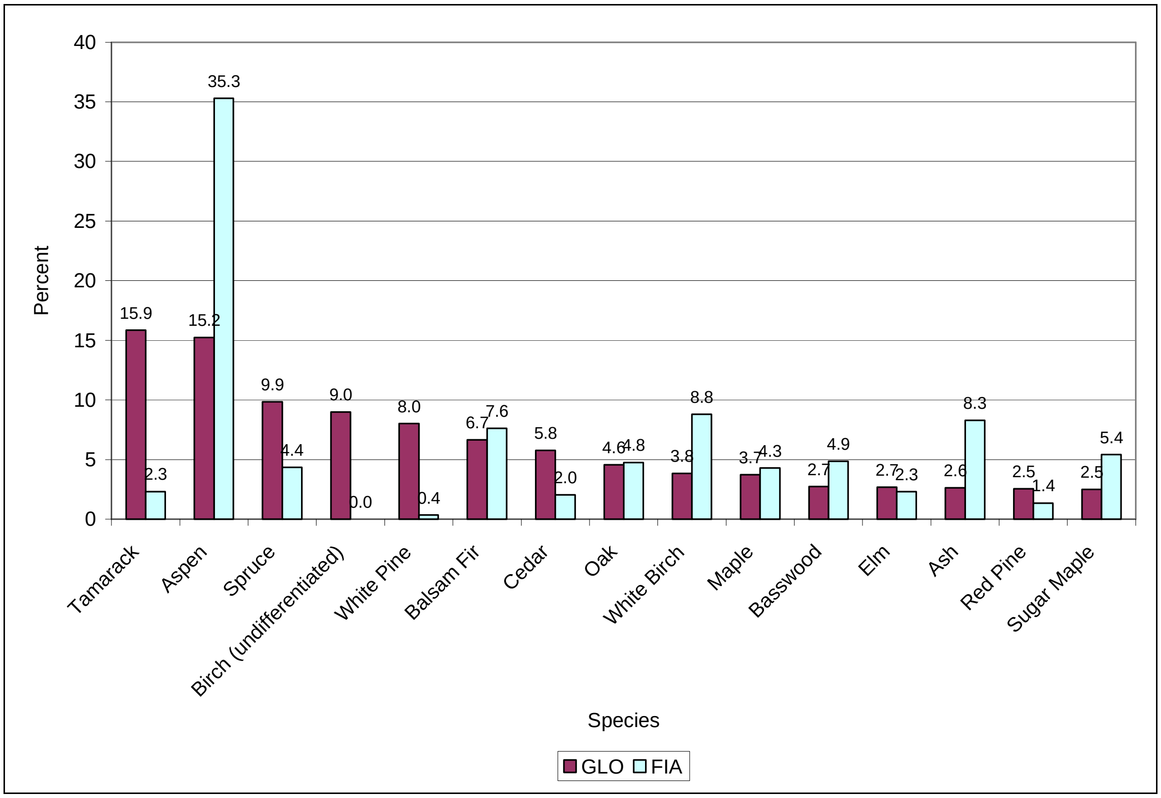

Figure B58. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212N

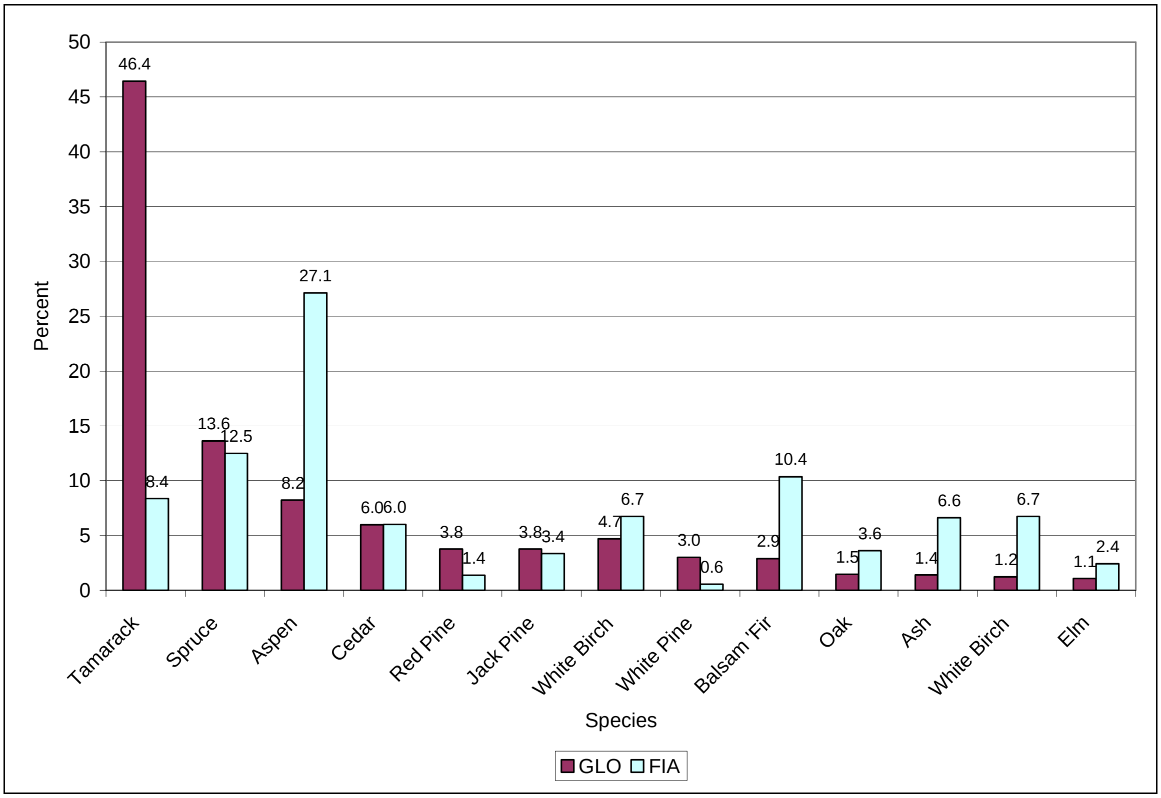

Figure B59. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212N

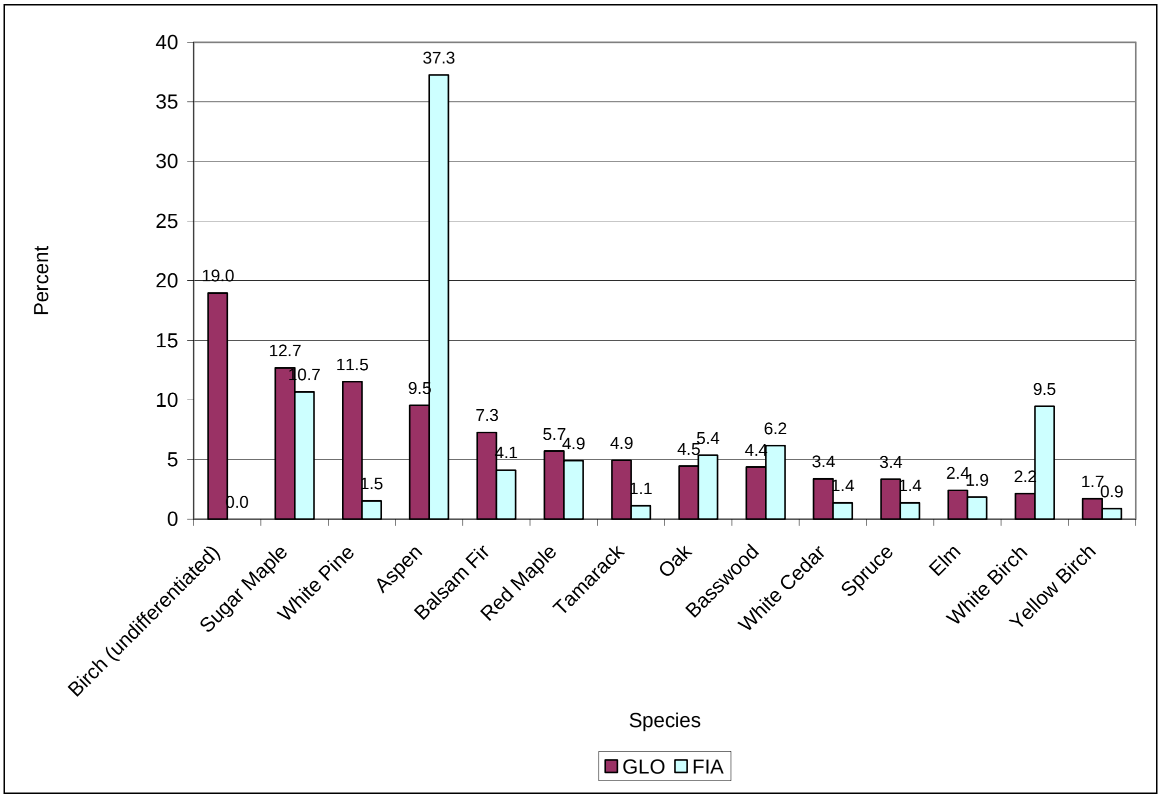

Figure B60. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4 in Section 212N

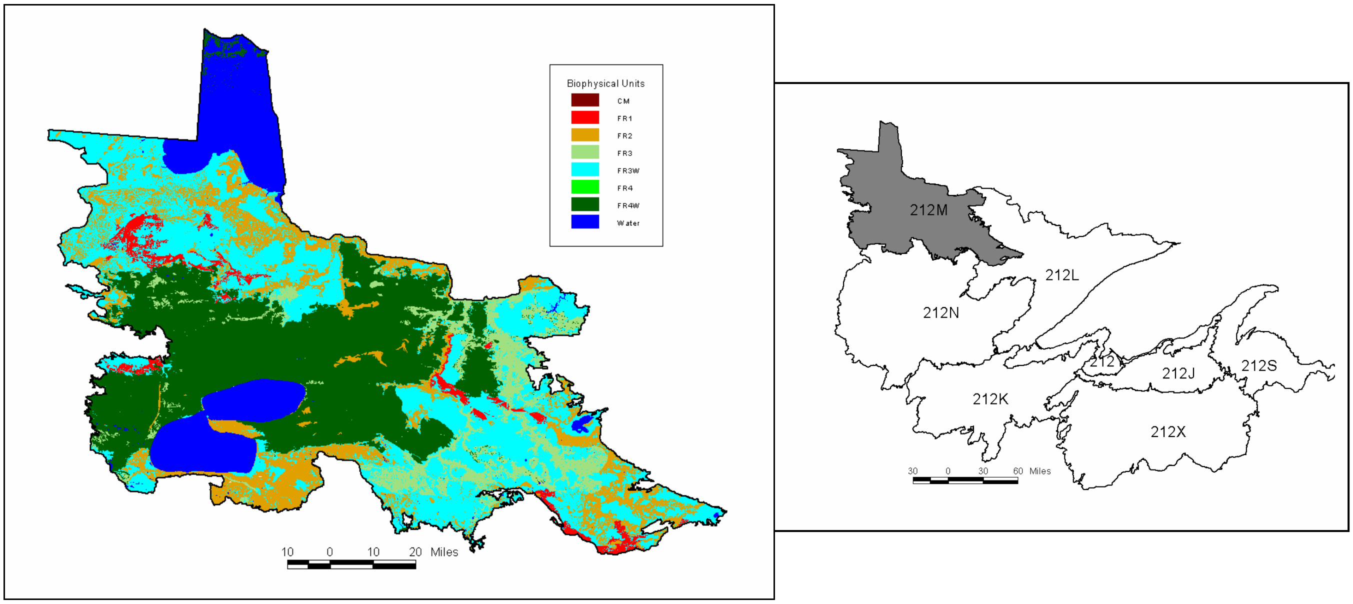

Figure B61. Biophysical Units of Section 212M

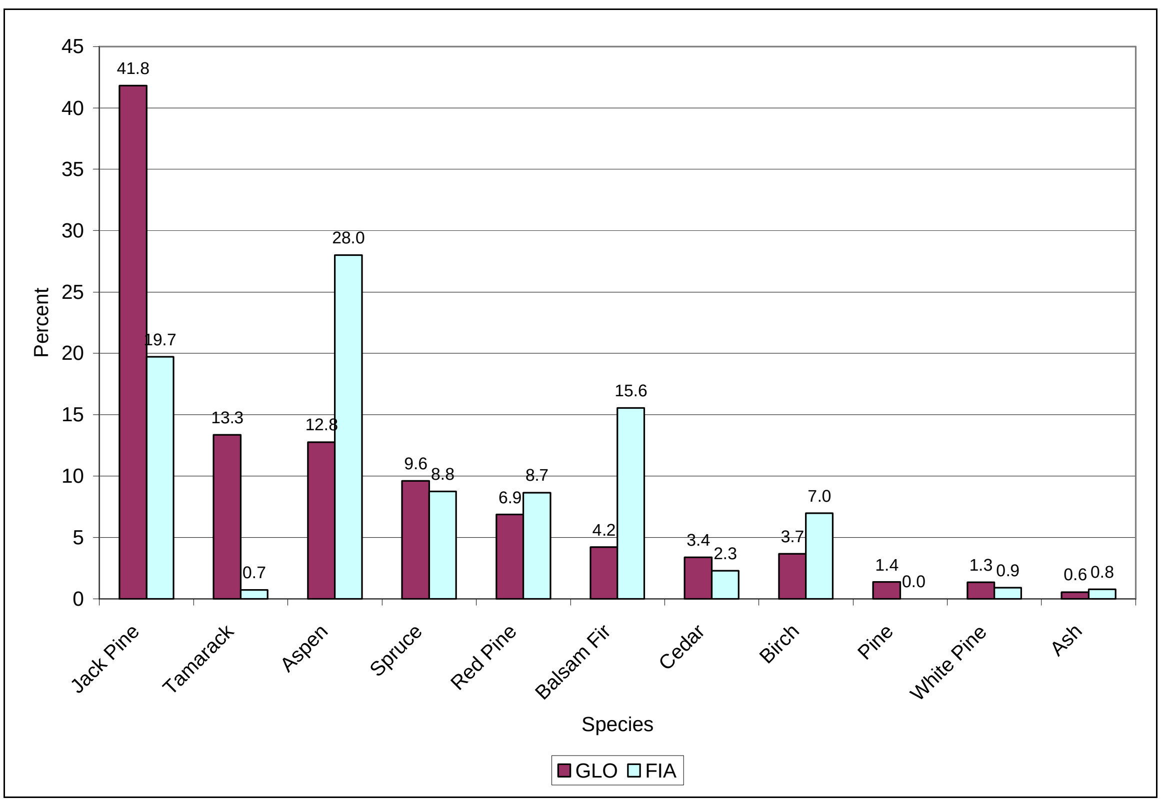

Figure B62. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 1 in Section 212M

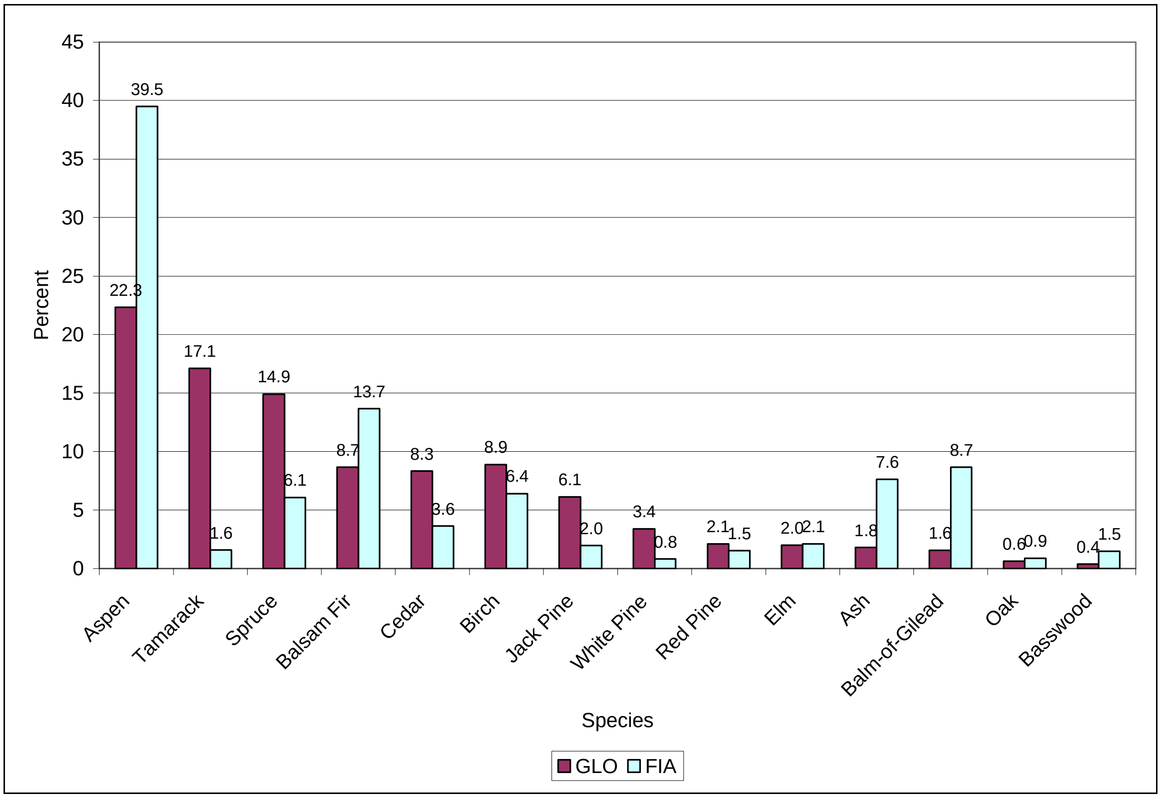

Figure B63. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 2 in Section 212M

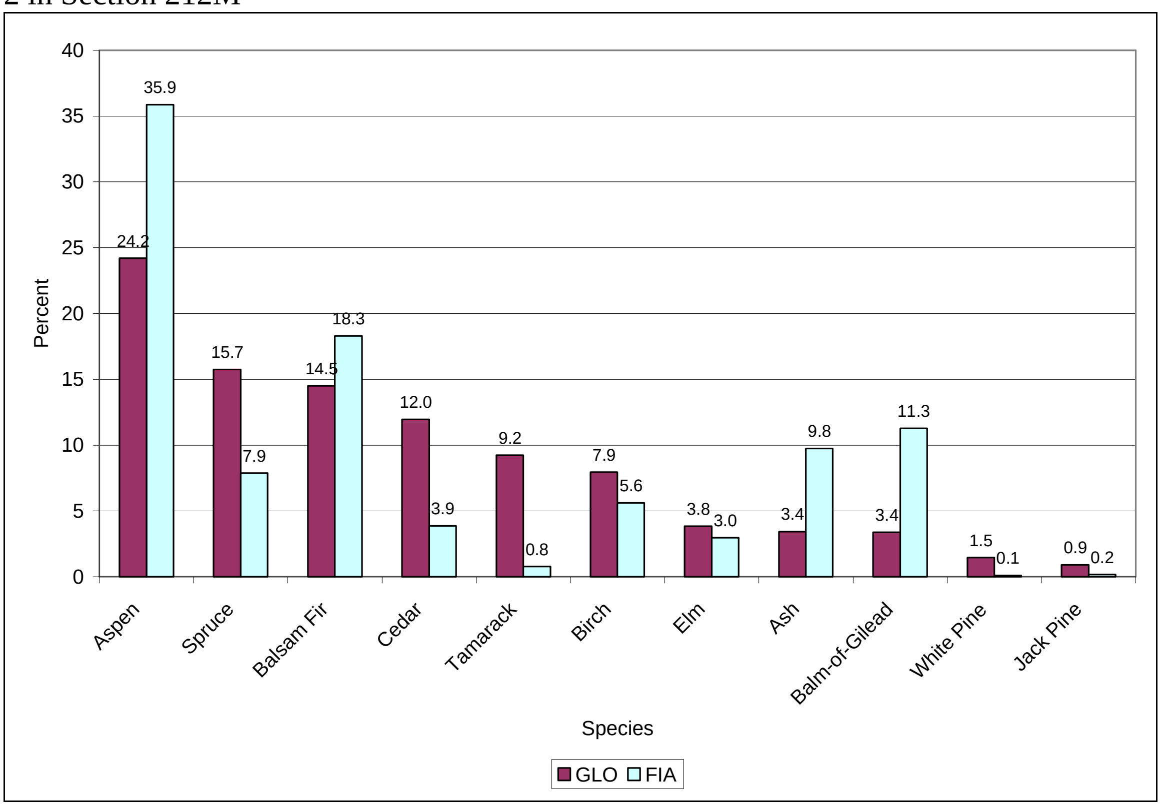

Figure B64. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3 in Section 212M

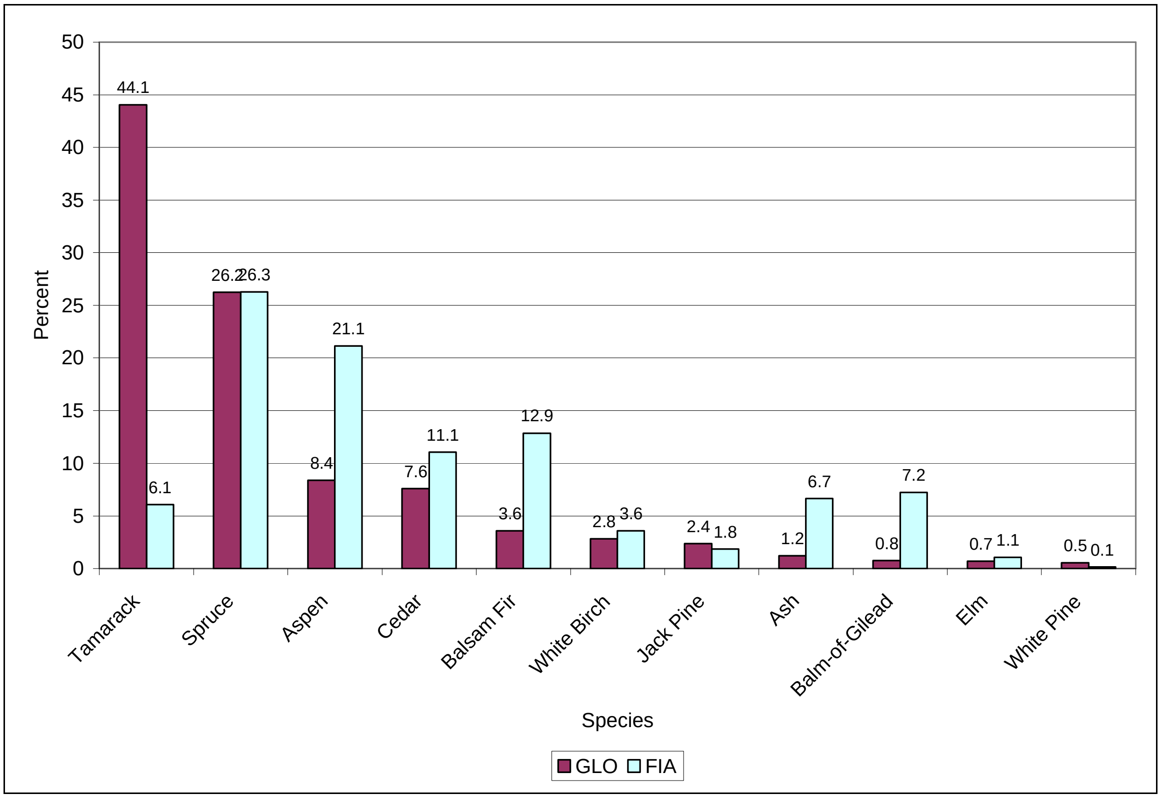

Figure B65. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 3W in Section 212M

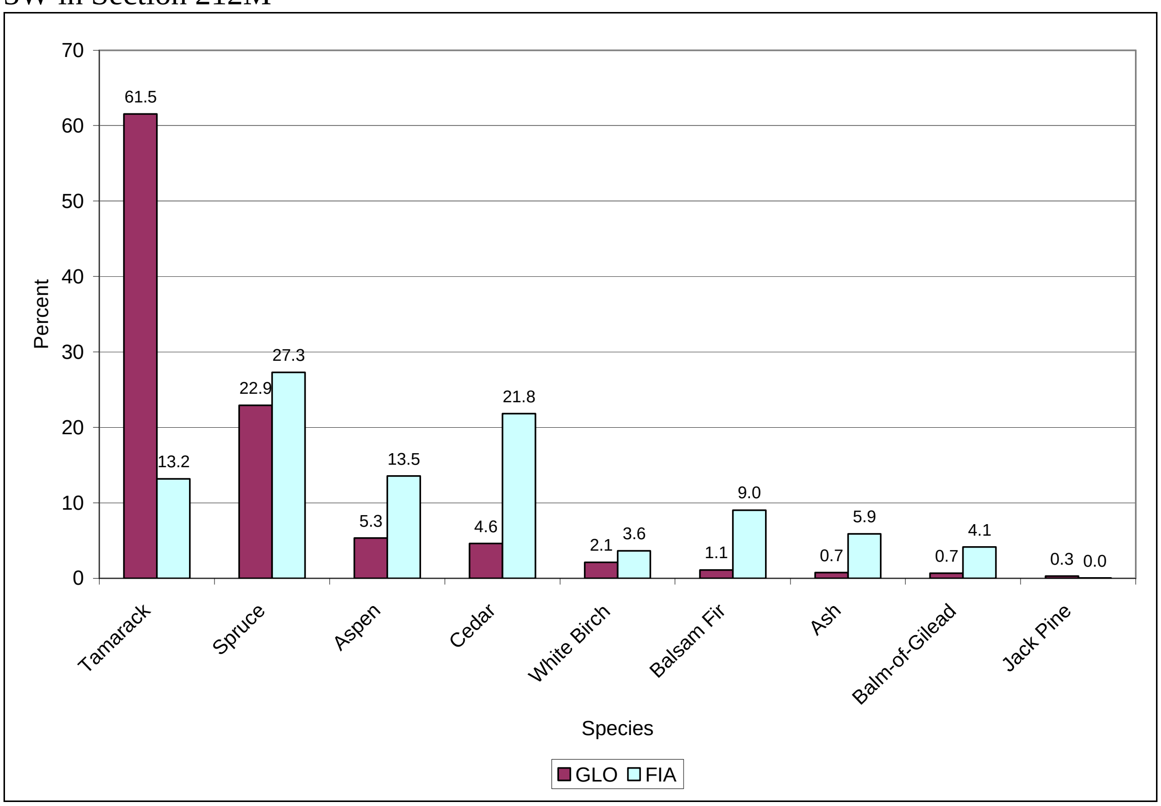

Figure B66. Comparison of GLO and FIA Tree Species Percentages in Biophysical Unit 4W in Section 212M