Modelling Historical Landscape Patterns on the Hinton Wood Products FMA Area

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1.0 Introduction

The evolution of forest management in North America has been an ongoing process, but one that has inevitably been moving towards the means of sustaining all forest values. Forest management is now expected to manage for a wide range of biological values including water and nutrient conservation, toxin filtration, carbon cycling, fish and wildlife habitat, food, pharmaceuticals, and timber (Davis 1993).

Under the auspices of this task, the concept of the using forest patterns created by natural processes as management guides is gaining favour in North America (Franklin 1993). The theory is certainly attractive: by maintaining the type, frequency, and pattern of change on a given landscape, we are more likely to sustain historical levels of the various biological goods and services. So-called "coarse-filter" knowledge can also be applied directly and immediately to planning and management programs.

Natural pattern knowledge can be applied to a wide range of forest management planning issues, at all levels of planning. Hinton Wood Products (HWP) has been one of the leaders in this regard, investing in operational scale natural pattern research (e.g. Andison 2012a), trying to understand the nature of the gap between managed and natural landscapes (e.g. Andison 1998 and Pickell et al. 2013), and integrating this knowledge into both strategic and tactical planning.

HWP is interested in expanding its use of natural pattern knowledge at landscape scales. The historical dynamics of older forest, caribou habitat, and those parts of the landscape that are not actively "managed" are of particular concern. Developing this type of historical knowledge is particularly challenging because no reliable pre-industrial snapshots exist due to the combined impacts of fire control, cultural disturbance activities, and poor historical records. What we do know about the disturbance history of these types of landscapes suggests that they are highly dynamic, and the age-class distribution can vary widely over time (Turner and Dale 1991). This means that historical levels of old forest and habitat will be highly dynamic. For this reason, defining the historical range of landscapes is a fairly fundamental requirement of a natural pattern-based approach to forest management. More generally, it is one of the foundations of the genre of ecosystem-based approaches (Booth et al. 1993, Grumbine 1994, Long 2009).

In the absence of detailed and multiple historical data and/or photos, the only means left to capture explore the dynamics of forest ecosystem patterns at the landscape scale is spatial simulation modelling. In its simplest form, spatial models

allow one to explore how known (empirical-based) probabilities of key variables intersect in time and over space to create multiple possible landscape mosaics. In theory, it is much easier to study and document historical *processes* than it is historical landscape *patterns*.

As part of HWPs previous long-term forest management plan, a spatial modelling exercise using LANDMINE (Andison 1998) was completed to help define a series of likely historical landscape snapshots. The primary goal of this preliminary modelling exercise was to define a range of historical landscape conditions with which to use as a guide for defining long-term old forest level objectives.

This report summarizes the results from the second iteration of spatial modelling completed on the HWP landscape. This second iteration of spatial modelling captures:

1) The inclusion of two adjacent woodland caribou habitat areas in the modelling study area,
2) The inclusion of old forest patch sizes,
3) An updated spatial dataset and current landscape condition,
4) A different set of input assumptions, designed to match the forest management planning scenario modelling exercise proposed by HWP, and,
5) An expanded set spatial output summary parameter requirements.

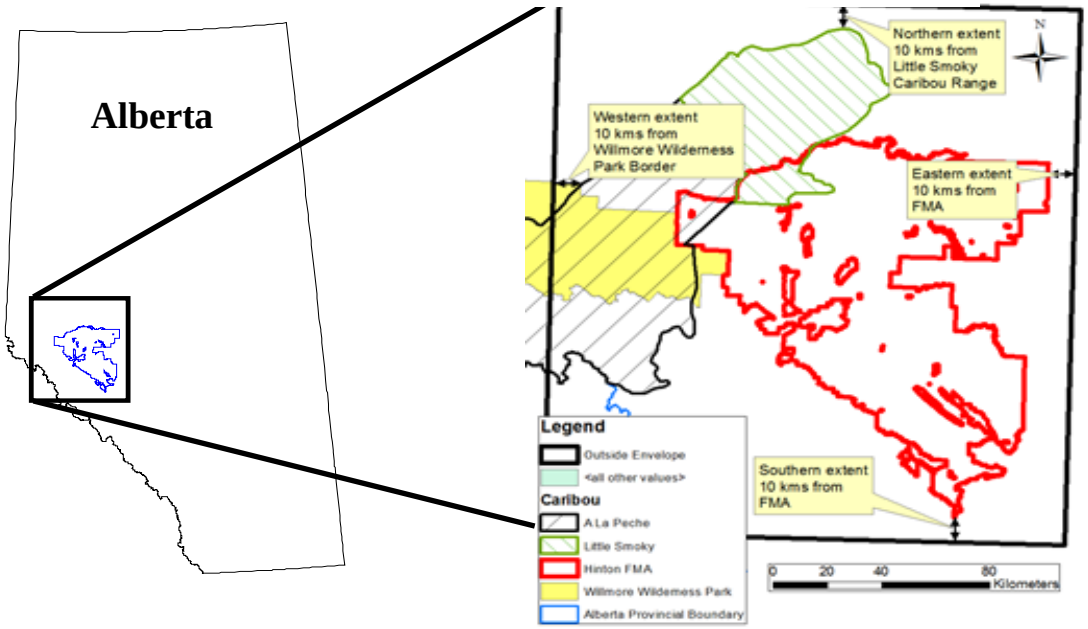
2.0 Study Area

The study area for virtually all spatially-explicit landscape simulation modelling exercises requires a perfect rectangle. This project is no different.

The study area is 192 km from east to west, and 214 km from north to south, which is 4,112,600[1]. Of this, 3,874,600 ha, or 94% is in Alberta, and the other 6% in BC. The size and dimensions of the study area were chosen based on two criteria; 1) no study area boundary shall be further than 10 km from the boundary of the HWP FMA area (to account for edge effects wrt landscape dynamics, and 2) to include all relevant Alberta portions of the A La Peche and Little Smokey woodland caribou ranges (Figure 1).

[1] All of the areas reported in this section are based on GIS overlays from various sources of a range of precision levels. It is likely that the numbers reported here will differ in small ways from those from other, related HWP FMP documents.

Figure 1. Spatial extent of the study area.



The study area includes parts of six ecological zones, or Natural Subregions (NSRs) of Alberta (NRC 2006), and three Ecoregions of BC (Table 1). In Alberta, 76% of the study area are accounted for by the Lower Foothills, Upper Foothills, and Sublapine Natural Subregions, and the rest in small areas of Alpine, Montane and Central Mixedwood (Table 1).

The transition from east to west across the study area is noteworthy. Elevation increases by more than 2,700m from the Central Mixedwood to the continental divide, after which it decreases on the BC side. Topography shifts from flat to very steep, climate from warm wet summers to short cold summers, and vegetation changes from boreal mixedwood, to pure, dense pine, to open grown spruce and fir, to only very occasional shrubs (Table 2).

Table 1. Summary of the study area by ecological zone.

Province	Ecological Zone	Geographic Area			
		Study Area		HWP FMA	
		Ha.	Pct.	Ha.	Pct.
Alberta	Central Mixedwood	89,900	2	0	0
	Lower Foothills	1,152,300	28	303,800	31
	Upper Foothills	1,168,200	28	548,500	55
	Alpine	398,500	10	200	0
	Montane	161,400	4	18,900	2
	Subalpine	904,300	22	118,000	12
	Provincial sub-total	***3,874,600***	***94***	***989,400***	***100***
BC	Western Continental Ranges	226,000	5	0	0
	Southern Rocky Mtn Trench	9,000	0	0	0
	Northern Columbia Mountains	3,000	0	0	0
	Provincial sub-total	***238,000***	***6***	***0***	***0***
TOTALS		**4,112,600**	**100**	**989,400**	**100**

Table 2. Overview of characteristics of the NSRs in the study area (from NSR 2006).

Natural Subregion	Elevation	Topgraphy	Climate	Vegetation
Central Mixedwood	200-1050m	Level to gently undulating	Short warm summers, long cold winters	Upland mixedwood, Sw, Pj, and bog forests + wetlands
Lower Foothills	650-1625m	Gently rolling with plateaus	Cold snowy winters	Mesic dense mixedwood forest (Pt, Pl, Sw, Pb)
Upper Foothills	950-1750m	Tolling to steeply sloped	Short wet summers, snowy cold winters	Dense Pl forest (low elev) to Sb, Sw forest (high elev.)
Montane	825-1850m	Flat mountain valleys to moderate slopes	Cool summers, warm winters	Closed mixed, Pl, D. Fir forest (low elev.) to Pl forest (high elev.)
Subalpine	1300-2300m	Rolling to very steep	Short cool summers, long snowy winter	Closed Pl forest (low elev.) to Se, L, and Abies island forest + krummholz (high elev.)
Alpine	1900-3650m	Steep to vertical	Short cold summers, very windy	Occational low shrubs, no trees

The high number of ecological zones in the study area manifests itself as a variety of leading vegetation types. The most common vegetation type was the pine-leading forest type (36%). Black spruce-larch and white spruce-fir forest types accounted for another 16% and 12% respectively (Table 3). MIxedwood forest (i.e. tree species combinations usually involving both hardwood and softewood species) account for 9% of the study area and deciduous forests another 7%. Seven percent of the study area is non-forested shrub, and the remaining 13% has no vegetation (Table 3).

Table 3. Summary of major vegetation types on the study area and on the HWP FMA.

Major Land Type	Study Area		HWP FMA	
	Ha.	Pct.	Ha.	Pct.
Deciduous leading forest	267,700	7	86,008	9
Mixedwood leading forest	357,800	9	89,500	9
Pine-leading forest	1,493,800	36	460,292	47
Sw-fir leading forest	474,500	12	140,156	14
Sb-Larch leading forest	659,400	16	184,380	19
Naturally non-forested	289,100	7	23,404	2
Naturally non-vegetated	511,000	12	1,304	<1
Open water	59,400	1	4,416	<1
TOTAL	**4,112,700**	**100**	**989,460**	**100**

The dominant natural disturbance vector and agent of change on the study area is wildfire (Payette 1993, Johnson 1992).

The study area also includes all or parts of two woodland caribou ranges; 1) The entire 308,600 ha area of the Little Smokey range, and 2) most of the almost ½ million ha of the A La Peche range that resides in Alberta (Table 4). The differences between the two ranges are worth noting. For example, while both are dominated by pine-leading vegetation types, the Little Smokey area includes 38% by of black spruce – larch forest, while 40% of the A La Peche area is non forested (Table 4).

Within the study area rectangle sits the Hinton Wood Produces Forest Management

Agreement (FMA) area, which covers approximately 989,400 hectares. Most (55%) of the HWP FMA lies within the Upper Foothills NSR, with another 31% in the Lower Foothills NSR, and 12% in the Subalpine NSR (Table 1). On the HWP FMA, all but 2% of the landbase is forested, almost half of which is pine leading. Both deciduous and mixedwood forest account for only 9% of the FMA area (Table 3).

Table 4. Summary of caribou herd zones within the study area, and the HWP FMA.

Vegetation Type	Area by Caribou Herd Zone			
	A La Peche		Little Smokey	
	Ha.	Pct.	Ha.	Pct.
Deciduous leading forest	5,800	1	3,900	1
Mixedwood leading forest	4,500	1	15,400	5
Pine-leading forest	208,900	42	137,600	45
Sw-fir leading forest	37,200	8	22,900	7
Sb-Larch leading forest	36,000	7	117,600	38
Total forest area	**292,400**	**59**	**297,400**	**96**
Naturally non-forested	82,000	17	9,000	3
Naturally non-vegetated	112,900	23	700	0
Open water	0	0	1,500	0
Other non-vegetated	7,800	2	0	0
Total non-forest area	**202,700**	**41**	**11,200**	**4**
TOTAL AREA	**495,100**	**100**	**308,600**	**100**
Area within HWP FMA	***21,500***	***4***	***35,200***	***11***

It is important to note that the HWP FMA is not an intact spatial entity. The outer boundary of the HWP FMA is 1,034,400 ha, while the FMA area proper is only 989,400 ha (Table 5). The difference of approximately 45,000 ha are internal spatial "donuts" of non-FMA land that include Switzer provincial park, the Hinton town site, surface mines, and several small independent leases (Table 5).

The HWP FMA landbase is also differentiated from a management perspective by major land types. We received a spatial data layer that included riparian zones, uplands, and wetlands (please see HWP FMP documents for the definitions of each). *Riparian zones,* account for 34% of the greater HWP FMA area, are those parts of the landscape that are defined by buffers of various distances on water features. Wetlands only account for 1% of the greater HWP FMA area, and are based on forest inventory calls.

Table 5. Summary of the greater HWP FMA area.

Greater HWP FMA Area Land Component	Area	
	Ha.	Pct.
Contributes to the AAC within the HWP FMA	678,000	69
Does not contribute to the AAC within the HWP FMA	311,400	31
HWP FMA area	**989,400**	**100**
Embeded "dounts" within the HWP FMA	45,000	
HWP FMA greater area	**1,034,400**	

Everything else is considered to be uplands forest, and accounts for 65% of the HWP FMA (Table 6). Note that *upland* is not necessarily the same thing as *harvestable area*.

Table 6. Summary of land types within the greater HWP FMA area.

Major land types within the greater HWP FMA	Area	
	Ha.	Pct.
Riparian zones	351,000	34
Wetlands	6,300	1
Uplands	677,300	65
TOTAL Greater HWP FMA area	**1,034,600**	**100**

As all forest management agencies in Canada

do, HWP calculates sustainable harvest levels based on that part of the landbase that has in the past, and will likely in the future, produce merchantable timber over a reasonable period of time within reasonable (spatial) access, at a reasonable cost and low level of risk as regards environmental damage or other ecological / social costs. Thus, certain parts of boreal landscapes that do not meet these criteria are by law excluded from AAC calculations. In the case of HWP, the areas of the landscape that are "masked-out" from forest management activity considerations accounts for about 136,800 ha, or almost 20% of the FMA area (Table 7).

Table 7. Summary of major forest management types within the greater HPW FMA

Forest management types within the HWP FMA	Upland area		Riparain area		Wetland area		TOTAL
	Hectares	%	Hectares	%	Hectares	%	
Contributing (contributes to AAC calculations)	533,200	80	125,700	36	3,500	55	662,516
Passive (does not contribute to AAC calculations)	136,800	20	220,000	64	2,900	45	359,784
TOTAL Greater HWP FMA area	**670,000**	**100**	**345,700**	**100**	**6,400**	**100**	**1,022,300**

Note that there is strong relationship for the HWP FMA between "contributing" land and "upland".

3.0 Methods

Several steps are involved in estimating the natural range of landscape conditions on the study area.

3.1 The Model

LANDMINE is a spatially explicit, Monte-Carlo raster-based landscape simulation model that was developed for landscapes with known historic disturbance regime attributes. The main purpose of LANDMINE is to generate a large number of likely historical landscape scenes from which the natural range of key landscape condition patterns can be captured. The main value of LANDMINE output is the collective patterns from a large number of runs as opposed to any individual landscape scene.

The patterns generated by LANDMINE are largely driven by probability distribution functions for both fire frequency and fire size, and a similar function over space to represent ignition probability. Each of these equations is generated using empirical, historical data. Thus a key assumption of LANDMINE is the veracity of these equations since within them is the natural range of variation of all combinations of historical burning patterns. For example, over hundreds of years, a landscape

simulation model that uses individual fire data and weather (e.g. BFOLDS) should create exactly the same *range of patterns* (i.e., not the exact same patterns) as a model that uses equations capturing cumulative fire behaviour *for the same, known historical period*.

Once the ignition point and fire size is determined, LANDMINE uses a dispersal algorithm to spread fires from one pixel to another in such a way that fire movement responds probabilistically to various input layers such as fuel-type, topography, and wind. For example, fire movement favours uphill movement, older forest, higher percentages of conifer, prevailing wind direction, and so on. Controlling layers can be added or removed depending on available data. The nature of the fire movement can also be calibrated to create different fire shapes and residual numbers, sizes, and locations to match existing data as available. It is important to understand that the fire growth model in LANDMINE is not meant to capture the burn patterns of individual fires as precisely as possible (compared to the *Prometheus* model, for example), but rather to represent long-term fire patterns.

Each decision within LANDMINE is stochastic, meaning that LANDMINE never burns the same way twice. Clarke et al. (1993) also demonstrated that this method of growing disturbances created fractal images, meaning that the model could use spatial data at any scale of resolution.

Succession is managed via a simple vital attributes succession module that includes a set of self-defined rules that governs successional pathways either probabilistically or deterministically depending on stand composition and/or age. For example, aspen-white spruce stands will shift towards white spruce stands over many decades.

LANDMINE is thus a powerful landscape *disturbance model* (*i.e*., it is good for exploring long-term disturbance regime trends over space and time). LANDMINE was developed in 1996 (Andison 1996), and has since been used nine times across western boreal Canada including the Hintion Wood Products FMA (Andison 1998), the Prince George TSA in BC (Andison and Marshall 1999). the Sunpine FMA (Andison 2004), the Alpac FMA (Andison 2005a), the RSDS north-eastern Alberta landscape (2005b), the Mistik Management FMA in Saskatchewan (Andison 2007a), the Tolko-Footner FMA (Andison 2007b), the Alberta Newsprint FMA (Andison 2012b), and the AlPac FMA for a second time (Andison 2014). For more information on LANDMINE, please see Appendix A.

3.1 Spatial Data

This particular spatial modelling exercise require a “natural” starting position, which means it has no past or present cultural activities such as roads, harvesting, or land conversion. This was achieved via a process as follows:

a) Cultural features were replaced by natural vegetation from previous known vegetation attributes where they existed from maps, records, or as information embedded within inventory data layers.
b) Linear cultural features were filled in by “snapping” similar vegetation types and ages on either side
c) Any remaining cultural polygons were assigning the age and cover-type attributes of the adjacent polygon with the greatest length shared boundary.

The model ran for at least 500 iterations (5,000 years) before capturing output to ensure that any bias associated with any outstanding spatial data issues were eliminated.

3.2 Model Assumptions

Ideally, models should be chosen, populated, and calibrated based on the objectives, not the other way around. Furthermore, each modelling exercise should focus on achieving the desired objectives with the least possible number of explanations, equations, and assumptions. In this case the modelling objectives from HWP were general in nature;

1) Define the natural range of variation (NRV) for the (non-spatial) areas of major seral-stages X major vegetation types:
    a. For the FMA as a whole,
    b. By the natural subregions with the FMA
    c. By upland / riparian / wetland (URW) types within the FMA
    d. By the Contributing & Passive (CP) areas, and
    e. By the two existing woodland caribou herd boundaries.
2) Define the natural range of variation (NRV) for the (spatial) sizes of old forest for:
    a. All old forest combined, and
    b. “Old” forest as defined by each of the four main forest types.

The interest is thus only in very broad landscape patterns. This suggests a moderate to low spatial resolution the bare minimum number of rules and

assumptions within the model. Accordingly, the model used a 4 ha spatial resolution, and a 10 year temporal resolution (to match strategic forest management activities). The impacts of topography were excluded, and ignition probability was spatially random. Succession rules were turned off given the general nature of the questions being asked, and the fact that vegetation types on foothills landscapes tend to be far more stable over time given the prevalence of pure conifer stands. The two stand types that are the most likely to change over time (i.e., mixedwood and white spruce leading) account for only 9% and 7% of the study area respectively (Table 3).

Although we now believe that boreal stands do not necessarily "break up" beyond a certain time since the last fire, for this exercise pixels not disturbed for at least 400 years were reset to zero based on the assumption that over such a long period of time such areas would be subject to other disturbance agents such as pathogens, disease, wind, snow, or ice.

The vegetation types and seral-stages adopted match those used by HWP in the associated long-term plan (Table 8). It is important to understand that the chosen age breaks are meant to broadly represent stages of stand development, and reflect the major tree species attributes such as tolerance to competition and light, growth rates, and senescence rates and causes. However, given that these rules only use age thresholds, one cannot assume that "Old forest" is the same thing as "Old growth" (the determination of which would require a number of stand-scale features).

Table 8. Vegetation types and seral-stage rules used in the model

Vegetation Type	Includes AVI Calls:	Seral Stage (yrs since last disturbance)				
		Young	Pole	Early Mature	Late Mature	Old
Pine	Pl, Pl/Sb, Pl/Fb, Pl/Sw	<20	20-69	70-119	120-159	>159
White spruce	Sw, Sw/Pl, Sw/Fb, Se, Se/Sb, Fb	<20	20-49	50-99	100-159	>159
Black spruce	Sb, Lt, Sb/Lt, Sb/Se	<30	30-89	90-109	110-189	>189
Mixedwood	Aw/Sw, Aw/Pl, Sw/Aw, Al/Aw	<20	20-59	60-109	110-149	>149
Deciduous	At, At/Pb, Pb/At, Pb	<20	20-59	60-109	110-149	>149

A second seral-stage classification was used based on Alberta provincial age-classes as follows: Young, <40 years, Pole, 40-80 years, Mature 80-120 years, and Old 120+.

Non-forested land was included in the spatial modelling, but not tracked and summarized for the output.

3.3 Defining and Calibrating Fire Regime Parameters

LANDMINE needs a number of fire regime parameters, either as input, or for calibration. The list includes long-term fire cycle (LTFC), decadal fire frequency, fire size and fire ignition probability distribution functions, and fire growth factors. Note that in each case, we are interested only in the *pre-industrial* estimates of each parameter, which excludes the impacts of fire control or other cultural influences.

3.3.1 Historic fire cycle

The fire cycle is the average number of years required to burn the number of hectares represented by the landscape. For a 100,000 ha landscape, that means the number of years for a total of 100,000 ha of fires to burn. Thus some areas burn several times during a fire cycle and others not at all. One could argue that each landscape has many different fire cycles over time. For the purposes of this study, the long-term fire cycle is defined as the average over 1-300 years, and more specifically the most recent 1-300 years without human influence.

Fire cycle is not an input to LANDMINE, but rather is used to help calibrate the model to match the desired historical long-term dynamics.

Fire cycles have been the focus of considerable research in the boreal forest. In a national overview, Ward and Tithecott (1993) found a range of fire cycles of between 20 and 500 years for the boreal forest, although in most areas the estimate is somewhere between 50 and 150 years. This study area has several different natural LTFCs. In general, fire cycles lengthen as one moves from low to high elevations. Based on a reconstructed 1950 landscape from a time-since-fire map of the HWP FMA, Andison (2000) calculated average ages of 111, 82, and 76 years for the Subalpine, Upper Foothills, and Lower Foothills areas respectively. The average age is equivalent to a fire cycle assuming that fire is age-invariant (i.e., the probability of burning does not increase with forest age) (Van Wagner 1978).

The most recent version of the Alberta forest inventory data that included the ages from this time-since-fire map was used to “roll back” landscape ages one decade at a time from the 1950 natural baseline. This is a simple, non-spatial technique that assumes that the area underneath that which burned in the most recent decade was distributed proportionally to the remaining 10-year age-classes (including an “older than” class). The results suggested a 70 year fire cycle for the Lower Foothills, 85 years for the Upper Foothills, and 106 years for the Subalpine (Table 9).

Table 9. Existing and estimated original areas disturbed by decade for the 1950 HWP landscape using the roll-back technique.

Period (years)	Existing and Estimated Original % of Forest Area Burned							
	Lower Foothills		Upper Foothills		Subalipne		Landscape	
	Existing	Estimated Original	Existing	Estimated Original	Existing	Estimated Original	Existing	Estimated Original
1941-50	0.1	0.2	0.2	0.2	0.2	0.4	1.3	1.3
1931-40	1.3	1.4	1.5	1.6	0.4	0.4	1.3	1.4
1921-30	6.2	6.7	2	2.1	9.3	9.5	4.0	4.2
1911-20	3.8	4.4	5.6	6.1	3.9	4.3	4.9	5.4
1901-10	3	3.6	0.8	0.9	5.3	6.1	1.9	2.2
1891-00	9.2	11.4	18	20.7	25.1	30.5	16.2	19.2
1881-90	30.1	41.5	27.7	39.2	16.9	28.7	27.3	38.8
1871-80	5.1	11.7	3.9	8.8	2	4.7	4.0	9.2
1861-70	18.5	47.9	10.7	26.5	0.1	0.2	11.8	29.6
Average	**8.6**	**14.3**	**7.8**	**11.8**	**7.0**	**9.4**		
LTFC (yrs)	116	70	128	85	142	106		

Although very broad, the results of these studies provide some invaluable guidance. For example, even if we assume that none of the fires in the last 150 years over-burned areas of previous fires, the long-term fire cycle is still 116-142 years (Table 9). Since this assumption is impossible, while one may argue about the details of how actual decadal fire level estimates were made, the actual LTFCs must, by definition, be far less. Furthermore, keep in mind that the raw data used for these estimates was not based on forest inventory, but rather a dedicated field-based study, initiated in the 1960's to determine the date of the last stand-replacing fire.

In support of these fire cycle estimates, although the results are not yet published, the preliminary output from a national-scale two-day workshop on historical fire regimes determined that the LTFC average for the lower elevation Foothills part of the Alberta boreal ranged between 70-100 years (from east to west).

More recent fire history research in Alberta foothills suggests that fire frequency may be far greater than we are assuming, largely associated with lower severity fires (Amoroso et al. 2011, M.P. Rogeau, pers. comm.). The working hypothesis at this time is that fire control in the Alberta foothills has been particularly successful because it has experienced a mixed severity fire regime. Those wildfires of lower to moderate severity (that may be key pattern) are the ones most likely to be contained by even moderate fire control efforts.

The fire cycle decision is important because it affects the amounts of old forest that

survives. Longer fire cycles will generate more older forest. In the end, for this modelling exercise, I chose to use LTFCs of 70, 85, and 100 years for the Lower Foothills / Central Mixedwood, Upper Foothills, and Subalpine zones respectively. Given the recent evidence, if anything these estimates are on the high side, which means they will err on the side of caution regarding the amount of older forest.

3.3.2 Fire Frequency

LANDMINE requires periodic levels of fire activity as a model input (i.e., amount of area burned per time period). This can be calculated in a number of ways including applying the average or median LTFC, sequentially from a pre-defined list, probabilistically about an average, or probabilistically from an equation. For this study, a single, landscape scale cumulative probability equation was generated using estimates of the total amount of decadal fire from the last column in Table 9.

$$Historical\ Area\ Burned\ per\ Decade = 10^{(0.04+1.71P)}$$

Where P = a random number between 0-1, SEE = 0.05, R^2 =0.99

This equation is meant to create a natural range of fire activity that reflects that experienced historically (See Appendix B for more details). The other option would have been to generate three different equations from the decadal data in Table 9.

3.3.3 Fire Sizes

The (maximum allowable) fire size is predetermined as a LANDMINE input. As with frequency, this can be defined in a number of ways. In this case, a cumulative frequency distribution was created from the Alberta historic wildfire database (http://wildfire.alberta.ca/wildfire-maps/historical-wildfire-information/historical-wildfire-database). Only those fires that occurred prior to 1970 were included to minimize any bias associated with fire control. Although it is likely that the Foothills Natural Region has one or more unique fire size distributions, the number of wildfires in the foothills area was insufficient to make this estimate. The equation used in LANDMINE is as follows (see Appendix B for more details):

$$FireSize = 10^{(-4.2+6.3\times(-\frac{\ln(1-RN)}{100})^{0.2})}$$

Where RN = a random number between 0 and 100.

This equation allows for a very high probability of very small fires and very low chances of very large ones – consistent with the pattern of fire sizes observed virtually across the boreal forest in Canada (Ward and Tithecott, 1993, Taylor *et al.* 1994). Note also that any wildfire may go "out" if it runs out of available fuel, or the

probability of fire spread drops below some pre-defined threshold.

3.3.4 Fire ignition

The historical probability of ignition varies significantly across this particular study area. More importantly, given that a single equation is being used to represent fire frequency, and another single equation to represent fire size, the only way to create differential burning levels by zone is to use differential ignition probabilities. These are input parameters within LANDMINE, but require calibration.

The starting positions for these calibrations can be estimated in two ways. First, ignition probabilities can be created using the relative long-term *burn fractions* (i.e. the annual percent of area burned) from each zone in the study area. This will create higher levels of fire activity in zones with higher burn fractions (Table 10).

Table 10. Two ways of estimating ignition probability on a landscape with complex fire history patterns.

Ecological Zone	% Area	Burn-Fraction Based Ignition				Lightning Based Ignition		
		LTFC	LT Burn Fraction	BF-area	Standardized Probability	Lightning density	Lightning-area	Standardized Probability
LF / Montane	32	70	1.4	45.7	43	56	1792.0	44
SA	22	100	1.0	22.0	21	34	748.0	18
UF	28	85	1.2	32.9	31	44	1232.0	30
Central	2	70	1.4	2.9	3	56	112.0	3
Other	16	1000	0.1	1.6	2	10	160.0	4

The second method creates similar weights using historical lightning strike data. The data in the “Lightning density” column in Table 10 are technically the average number of strikes per 1,000 ha from 10 years of historical data. However, the details are irrelevant – only that they represent a relative measure of historic lighting activity.

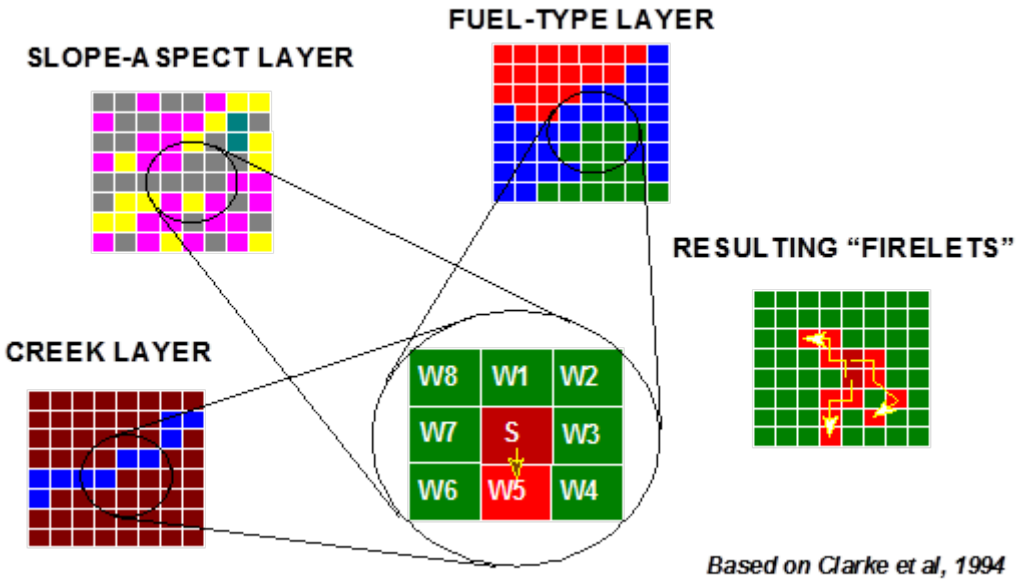
The shaded columns in Table 10 are standardized (to go from 0-100) probabilities weighted by a) the area in each zone in the study area, and b) either burn fraction or lighting density. The numbers are quite consistent. The ones from the burn fraction were used to initiate the first set of runs in LANDMINE.

3.3.5 Fire spread

Fire growth in LANDMINE occurs via a cellular automaton process similar to that used by several other spatially explicit disturbance dynamics models. From the point of ignition, fire spreads in one of eight directions to an adjacent neighbour. This new pixel can spread fire in the same way creating strings of fire, or “firelets” (Figure 2). The length / lifetime of firelet is a decaying function, the parameters of

which are set in the model. Only a proportion of new burned pixels become new firelet sources. Some may only spawn a single new burned pixel, and others may run for 5-10 new pixels before going out. At any one time, there can be dozens or even hundreds of firelets burning.

Figure 2. Fire growth in LANDMINE.



If the probabilities of burning are the same for each pixel, this becomes one possible version of "neutral diffusion model". However, in LANDMINE the scores for each pixel can be defined to reflect differences in fuel type, soil conditions, wind, or topography. In this particular version of LANDMINE, the vegetation types and ages are converted into FBP fuel types used by the Canadian Fire Behaviour Prediction System (FCFDG 1992). The scores used for each pixel are the rate of spread associated with the 95th percentile of historical fire weather. Fairly high, but not extreme fire weather benchmarks were used to reflect the most likely burning conditions. Again, the absolute numbers are less important than creating a relative ranking for the probability of fire spread.

One advantage to this method of spreading fire is that by changing the probabilities of creating new firelets, the duration of a firelet, and the number of firelets burning at once, it is possible to control not only the shape of the disturbance, but the amount, size, and spacing of internal island remnants. The version of LANDMINE used for this study creates 0-20% island remnant area within individual fires, averaging about 8%.

The firelet concept in LANDMINE borrows heavily on the work by Keith Clark. See Clark et al. (1994) for more details.

There is one last relevant fire spread parameter in LANDMINE worth noting. LANDMINE can create "spot" fires, either when it hits non-vegetated pixels, or randomly during the burning of particularly large fires. As with island remnants, the frequency of spotting can be changed within the model by altering burning probabilities. For the same of simplicity, for this version of LANDMINE, spotting probability was set very low.

3.4 Calibration

Before collecting and process any model output, it was necessary to ensure that the model was emulating the desired historical fire regimes reasonably well. Recall from above that the target LTFCs were 70, 85, and 100 years for the Lower Foothills, Upper Foothills, and Subalpine zones respectively. Available calibration parameters that would influence these numbers include the equation shape used to establish decadal burn probabilities, and the ignition probabilities. It took almost 400 runs to do this. The set of 100 runs used to calculate the output for this study has LTFCs of 72, 82, and 98 years for the three zones within the HWP FMA respectively. The LTFC of higher elevation forest (outside of the FMA, but still inside the study area) was almost 150 years.

3.5 Output and Analyses

One hundred post-calibration runs were used to capture landscape conditions, which is the equivalent of 1,000 years. Each landscape scene was measured in several ways. The non-spatial summaries involved a simple count of each pixel in each of the vegetation type X seral stage classes as per Table 8. These were summarized as percentages of each seral-stage in each vegetation type. For example, the amount of Young, Pole, Early Mature, Late Mature, and Old forest always added up to 100% for each of the five major forest types. The 100 samples were used to generate frequency distributions and a number of simple statistics. The current condition (as of 2012) for each class was also added to the summaries. Non-spatial summaries were completed for a) the FMA as a whole, b) the Passive and Active portions of the FMA, c) the Upland, Riparian, and Wetland portions of the FMA, d) the Natural Subregions of the FMA, and e) the two woodland caribou herd zones in the study area (i.e., A La Peche and Little Smokey).

The spatial summaries captured include patch sizes of the seral stages. Pixel

membership in a “patch” of forest was defined only by adjacency. Thus, any “young” or “old” pixel (as per the age rules defined in Table 8) can only be grouped with any other young or old pixel that is one of its eight neighbours. Forest patch sizes were calculated two ways:

a) All old forest pixels combined, and

b) Old forest pixels from one of the five main forest types.

If a forest patch crossed the FMA boundary, only that portion of patch within the HWP FMA boundary was counted. This created a negative bias on patch sizes, but it does allow the output to be compared directly to management planning scenarios. Forest patch sizes were only calculated for the entire FMA.

4.0 Results

4.1 Model Validation

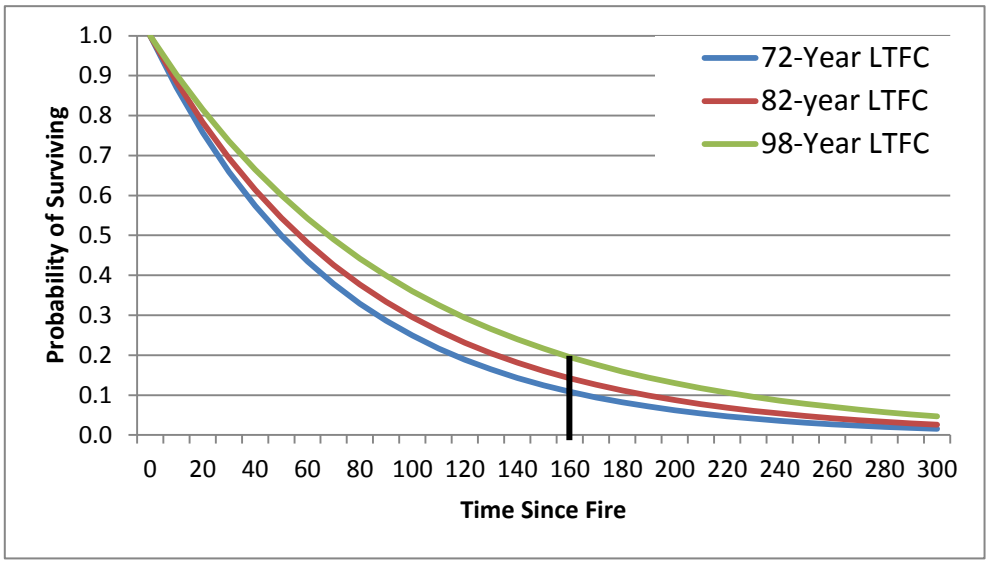
Models that predict how a large number of inputs interact over time and space are difficult to validate. In many cases it is only possible through the validation of the various inputs. However, in this case, we are fortunate that landscape condition prediction models have been around for almost 40 years. The simplest of these is the negative exponential age model (Van Wagner 1978) which offered a simple method of calculating the probability of forest surviving a given number of years under different long term fire cycle assumptions (Figure 3). This same equation could be used to predict the average amount of forest expected to survive beyond different times. For example, in Figure 3, the negative exponential model predicts that under a 98 year fire cycle assumption, approximately 22% of the forest will survive beyond 160 years, and 11% with a 72-year fire cycle assumption.

The negative exponential model is fairly crude and includes some questionable assumptions. Most notably, it assumes that fire is *age invariant*, which means that fire is equally likely to burn forest of any age. This assumption was subsequently addressed by expanding the negative exponential equation into a Weibull function (Yarie 1981). Nor does the negative exponential model account for other critical details such as fuel-type differences, topographic complexity, or fuel-type discontinuities.

However, it is still a useful reality check for exactly these types of spatial modelling exercises. To compare the LANDMINE results to the negative exponential model, I calculated the average amount of “old” forest generated in each of the five

vegetation types for the three Natural Subregions (Table 11). This is essentially an "older than" age-class, which is comparable to the negative exponential model output. I then calculated the predicted amount of forest older than 150, 160, and 190 years from the negative exponential equation using the three LT fire cycles.

Figure 3. Negative exponential age-class model scenarios comparable to the study area.



The results suggested that the LANDMINE model was creating older forest levels consistent with those from the far simpler non-spatial model. The total average amount of old forest from the simulations was in each case close to the estimates from the negative exponential equations. Furthermore, the differences could in part be explained by differences in fuel type. For example, in the Lower Foothills, LANDMINE generated 5.7% more Old deciduous forest than that predicted by the negative exponential model. Given the low flammability of deciduous forests, this is logical.

Table 11. Percent of Old forest predicted by Landmine for each vegetation type and Natural Subregion, and the percent of forest older than 150, 160, and 190 years from the negative exponential model.

Vegetation Type	Natural Subregion		
	Lower Foothills	Upper Foothills	Subalpine
Deciduous (150 yrs)	18.2	19.3	22
Mixedwood (150 yrs)	14.9	17.5	24.7
Pine (160 yrs)	10.8	18	24.7
White Spruce (160 yrs)	10.7	14.1	21
Black Spruce (190 yrs)	5.8	10.8	13.7
All	11.9	16.1	22.7
Neg. exp @ 150 yrs	12.5	16.1	21.6
Neg. exp @ 160 yrs	10.8	14.1	19.5
Neg. exp @ 190 yrs	7.1	9.9	14.4

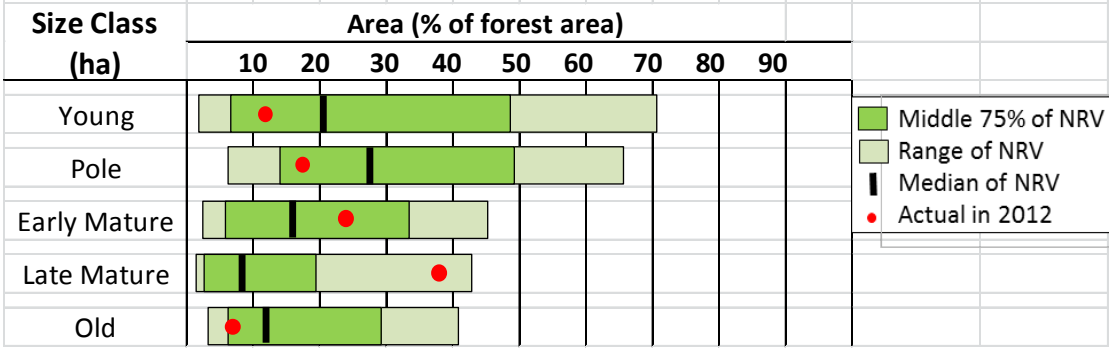
4.2 Non-spatial results

The Figures in this Section all follow the same format. The light green bars capture the full range of NRV, from minimum to maximum. The darker green bars capture the middle 75th percentage of the observations of NRV. In other words, the distance between the dark and light green bars in the graphs to follow is 12.5% of the observations on each end of the extreme. The dark black bar represents the median historical levels, and the red dot is the current condition as of 2012. For more detail on these results and others, please see Appendix A.

4.2.1 Overall

Several things are obvious visually from Figure 4. First, both the natural range and the middle 75th percentile are very wide. The 75th percentile of Young forest spans 6-48%, and Old forest from 7-29% (Figure 4). Second, most of the historical distributions are (positively) skewed, which means that the average in each case would be to the left of the black bars, in some cases significantly so. Thus, in this case, medians are superior measures of central tendency compared to averages.

Figure 4. Summary of the historical range of seral-stage area of all forest for the Gross area of the HWP FMA



The third notable pattern from Figure 4 is that the amount of Late Mature forest is beyond the upper boundary of the 75th percentile, while the amount of Old forest is on the lower boundary of its 75th percentile. The most likely explanation for this is the lack of disturbance over the last several decades. Note the (relatively low) current condition of both Young and Pole in Figure 4. Over enough time, low disturbance levels will push a large pulse of forest into progressively older age classes. However, the exact age of this older pulse is debatable. The current condition estimates were made using forest inventory ages, which consistently and significantly under-estimate the age of the very oldest forest stands (Andison 1999b) which is why “older than” age-classes are used. Thus, if anything, there

may be less Late Mature forest and more Old forest than the current condition dots suggest in Figure 4. Given this bias, it may be more informative to lump the Late Mature and Old together when considering these results. Doing so gives us a current condition of 45%, which is just slightly beyond the middle 75th percentile of NRV, and almost double the median of NRV.

The modelling results by major vegetation types follow the same general pattern, although with some notable differences (Figures 5-9). As regards NRV, keep in mind that the ranges shown reflect not only relative differences in burn probability for different fuel types and topographic positions, but also differences in the chosen age thresholds. For example, the main reason why there is much more Young black spruce (Figure 9) relative to the other forest types is that Young black spruce includes forest up to 30 years of age, compared to only 20 years for the other forest types. Similarly, the threshold for Old is 30-40 years higher than that of the other vegetation types, which is part of the reason why the NRV of Old black spruce is lower than that of other forest types.

It is also interesting to note that there is less Young NRV and more Old NRV deciduous (Figure 5) forest relative to mixedwood (Figure 6), despite the fact that their seral-stage thresholds are identical. The most likely explanation for this is that deciduous forest is less likely to burn than mixedwood.

In terms of current condition, a similar pattern of low levels of Young and Old forest, and high levels of Late Mature are prevalent, although again with some differences. The current level of Old white spruce is particularly high, although this is somewhat complicated by the fact that this class likely includes some Old forest that would have been classified as either deciduous or mixedwood when they were younger (Kabzems and Garcia 2004, Brassard et al. 2008). This is one of the biases associated with turning succession “off” in this set of simulations.

The most “natural” age-class distribution on the HWP FMA is that of pine leading forest type (which is also the dominant forest type on the landscape). The current level of Young forest is at the median of NRV, and it has the lowest amount of Mature + Old forest (34%), although still much higher than the 22% median of NRV. Given the lack of wildfire activity on this landscape, this is likely a result of (sustainable) harvesting levels. In contrast, there is no evidence of disturbance activity in black spruce forest types, and only very small levels of recent disturbance overall in both the deciduous and mixedwood types.

Figure 5. Summary of the historical range of seral-stage area of aspen forest for the Gross area of the HWP FMA

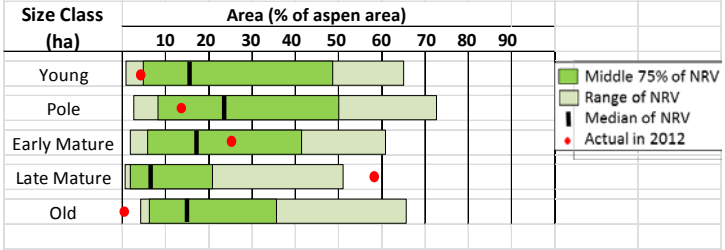


Figure 6. Summary of the historical range of seral-stage area of mixed forest for the Gross area of the HWP FMA

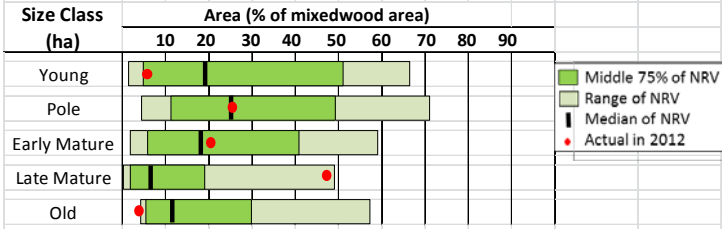


Figure 7. Summary of the historical range of seral-stage area of pine forest for the Gross area of the HWP FMA

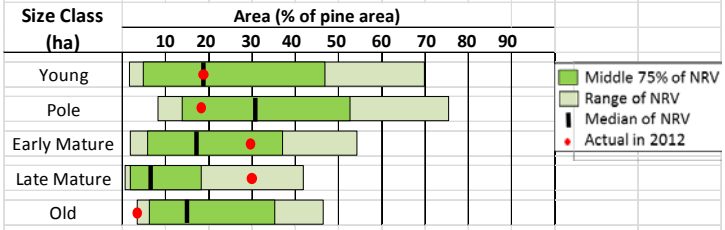


Figure 8. Summary of the historical range of seral-stage area of white spruce forest for the Gross area of the HWP FMA

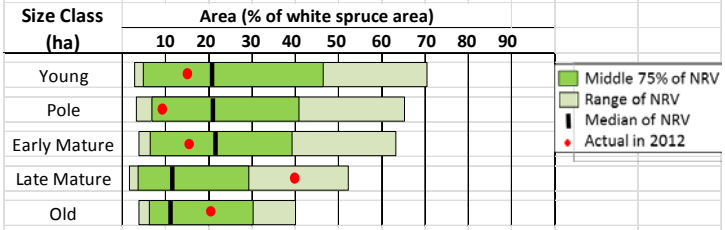
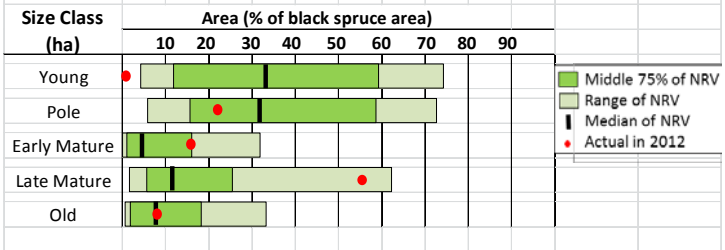


Figure 9. Summary of the historical range of seral-stage area of black spruce forest for the Gross area of the HWP FMA



4.2.2 Natural Subregion Summaries

NRV levels for the different Natural Subregions are largely driven by the historical LT fire cycles used to calibrate the model. For example, shorter fire cycles in the Lower Foothills result in larger Young forest levels and less Old (Figure 10). There is less Young forest in both the Subalpine and Upper Foothills, and the Subalpine has significantly more Old forest than either the Upper or Lower Foothills (Figure 11). The amount of Young forest in the Subalpine and Upper Foothills are similar, but only because of a much higher proportion of black spruce in the Upper Foothills.

Figure 10. Summary of the historical range of seral-stage area of forest of the Lower Foothills area of the HWP FMA.

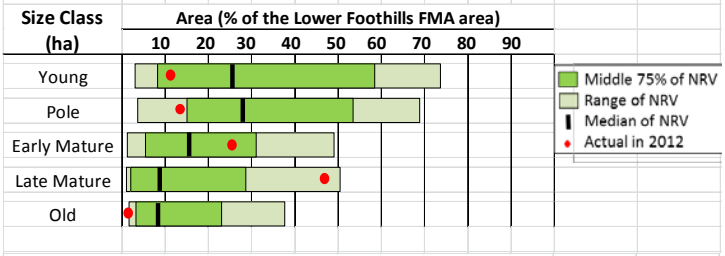


Figure 11. Summary of the historical range of seral-stage area of forest of the Subalpine area of the HWP FMA.

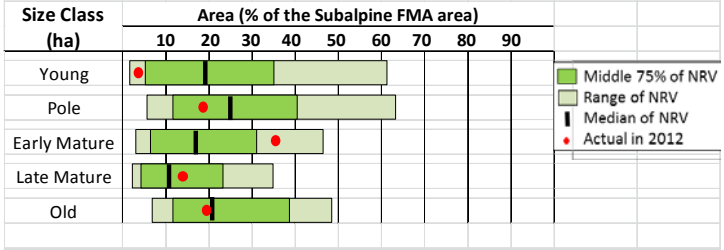
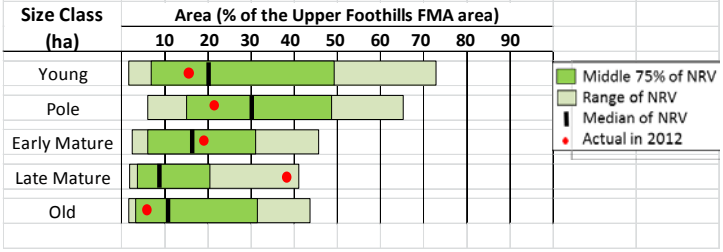


Figure 12. Summary of the historical range of seral-stage area of forest of the Upper Foothills area of the HWP FMA.



The Natural Subregion results found here are consistent with those found for the landscape as a whole with some exceptions. For example, the Subalpine had very high levels of Old white and black spruce and almost 80% of the white spruce forest in the Subalpine is Late Mature and Old. Consistent with the overall results, current conditions are within the middle 75th percentile only about half of the time, largely due to prolonged periods of low disturbance. Note that the shaded results in Fig. 18 and 19 have less than 1,000 ha, and are not considered meaningful.

Figure 13. Summary of the historical range of seral-stage area of aspen forest of the Lower Foothills area of the HWP FMA

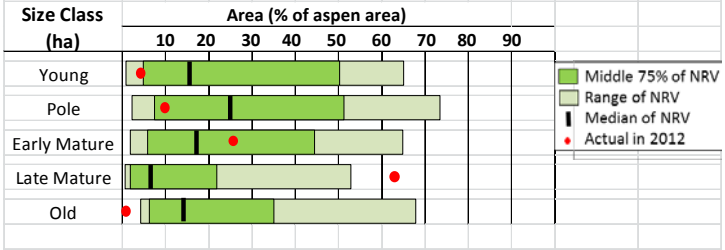


Figure 14. Summary of the historical range of seral-stage area of mixed forest for the Lower Foothills area of the HWP FMA

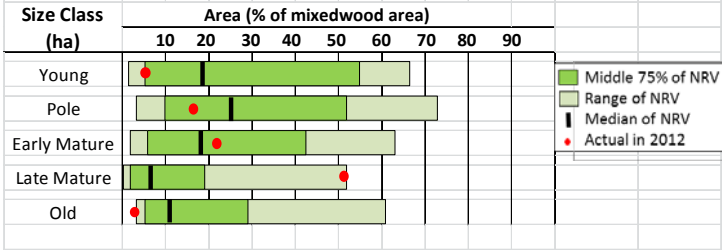


Figure 15. Summary of the historical range of seral-stage area of pine forest for the Lower Foothills area of the HWP FMA

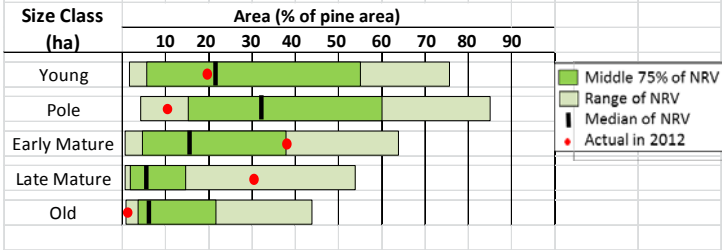


Figure 16. Summary of the historical range of seral-stage area of white spruce forest for the Lower Foothills of HWP FMA

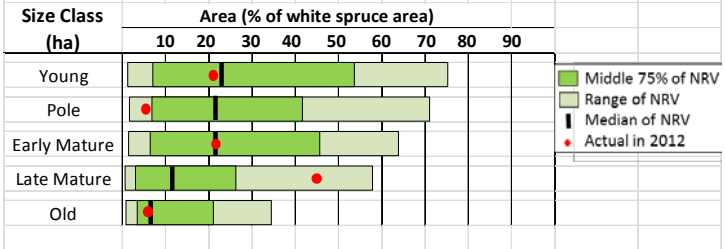


Figure 17. Summary of the historical range of seral-stage area of black spruce forest for the Lower Foothills of HWP FMA

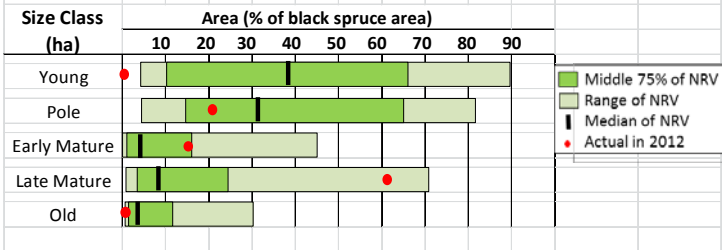


Figure 18. Summary of the historical range of seral-stage area of aspen forest of the Subalpine area of the HWP FMA

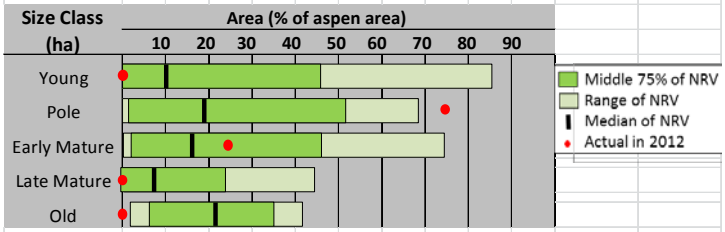


Figure 19. Summary of the historical range of seral-stage area of mixed forest for the Subalpine area of the HWP FMA

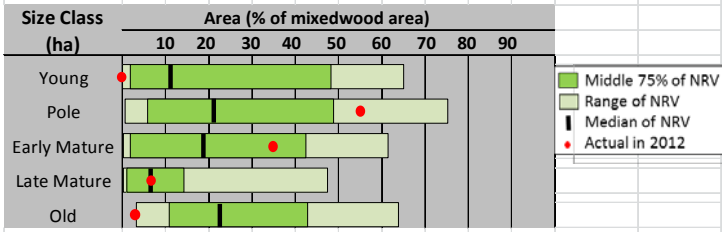


Figure 20. Summary of the historical range of seral-stage area of pine forest for the Subalpine area of the HWP FMA

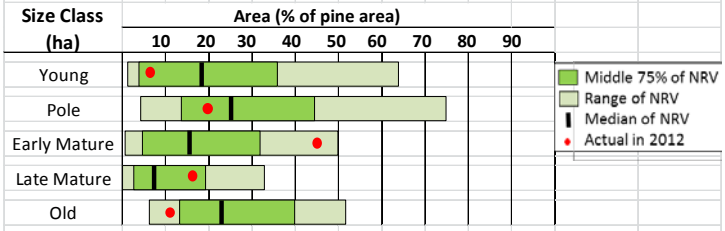


Figure 21. Summary of the historical range of seral-stage area of white spruce forest for the Sublpine area of the HWP FMA

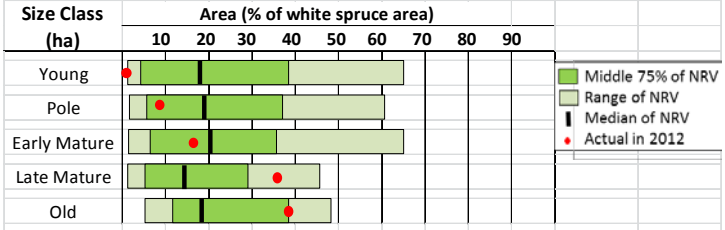


Figure 22. Summary of the historical range of seral-stage area of black spruce forest for the Subalpine area of HWP FMA

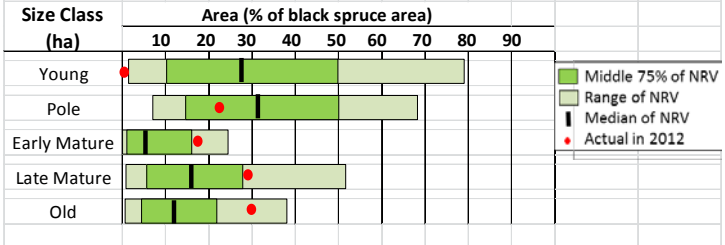


Figure 23. Summary of the historical range of seral-stage area of aspen forest of the Upper Foothills area of the HWP FMA

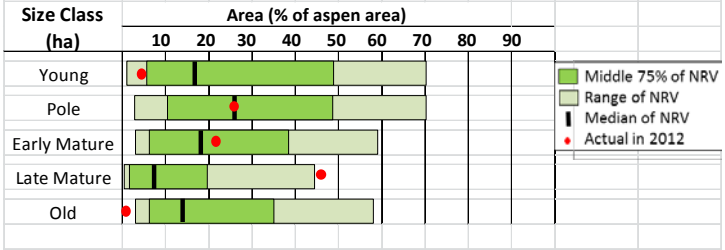


Figure 24. Summary of the historical range of seral-stage area of mixed forest for the Upper Foothills area of the HWP FMA

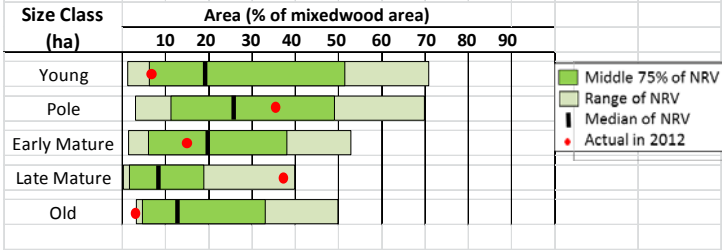


Figure 25. Summary of the historical range of seral-stage area of pine forest for the Upper Foothills area of the HWP FMA

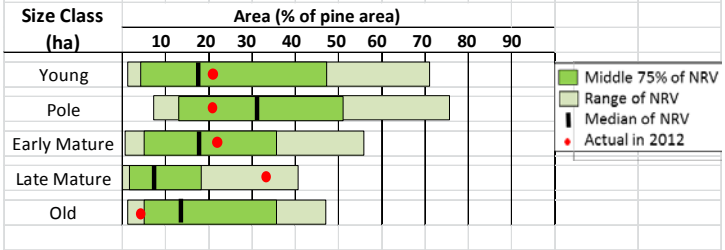


Figure 26. Summary of the historical range of seral-stage area of white spruce forest for the Upper Foothills of the HWP FMA

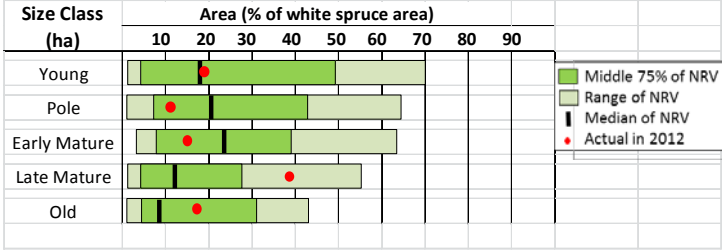
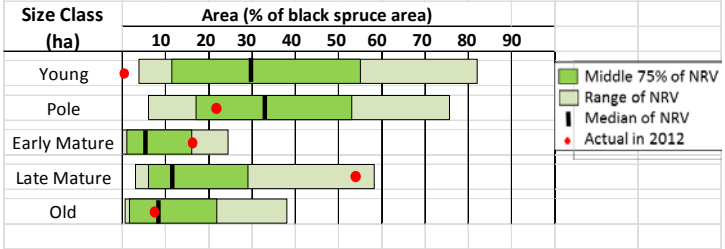


Figure 27. Summary of the historical range of seral-stage area of black spruce forest for the Upper Foothills area of HWP FMA



4.2.3 Contributing vs. Passive Landbase Summaries

The differences between NRV for the Contributing bits of the landscape and those of the Passive bits only reflect differences in the relative dominance of Natural Subregions and vegetation types. As one would expect, the current condition for the Contributing part of the landscape is much closer to NRV relative to that of the Passive areas. In fact, if the oldest two seral-stages were combined (as recommended), all current conditions would be within the middle 75^{the} percentile - most within 10% of the median (Figure 28). However, it is interesting to note that the amount of Late Mature and Old forest is still well above the NRV median.

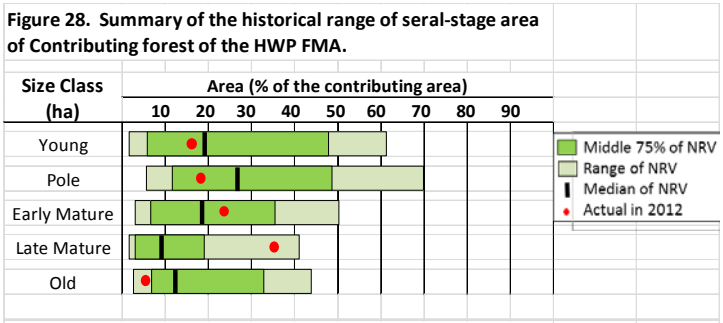


Figure 28. Summary of the historical range of seral-stage area of Contributing forest of the HWP FMA.

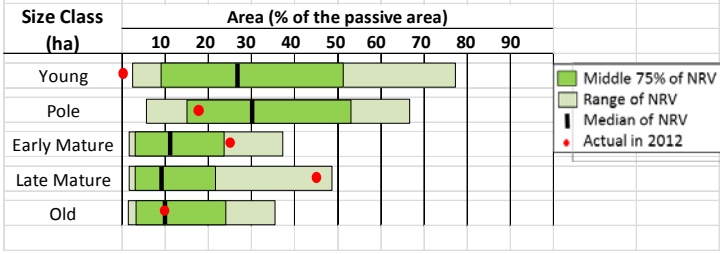


Figure 29. Summary of the historical range of seral-stage area of Passive forest of the HWP FMA.

In contrast, the Contributing part of the landscape is beyond the lower end of NRV for Young forest, and almost beyond NRV for Late Mature (Figure 29). Ove 55% of the Passive landscape is Late Mature or older, compared to less than 20% Young or Pole.

The breakdown of Contributing-Passive by vegetation type reveals several distinctive patterns. For example, both mixedwood (Figure 31) and black spruce (Figure 34) forest types show very low levels of Young. This follows logically given that the very small amount of black spruce on the FMA has never specifically been targeted for harvesting, and mixedwood forests only more recently so. On the other hand, the current condition of none of the other vegetation types exceeds the median NRV by more than a few percentage points. The very high current levels of Late Mature and Old black spruce in the Contributing landbase is also noteworthy (Figure 34).

The amount of Young forest in each of the forest types within the Passive landbase are very close to zero (Figures 35-39), which is consistent with the impacts of no harvesting plus highly effective fire control. The amount of Late Mature + Old white spruce is almost 75% (Figure 38), and almost 60% for both mixedwood and black spruce (Figures 36 and 39 respectively).

Figure 30. Summary of the historical range of seral-stage area of aspen forest for the Contributing area of the HWP FMA

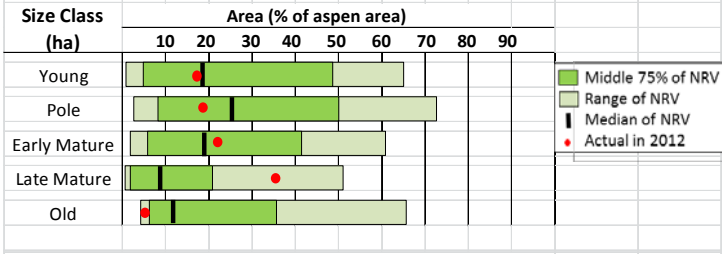


Figure 31. Summary of the historical range of seral-stage area of mixed forest for the Contributing area of the HWP FMA

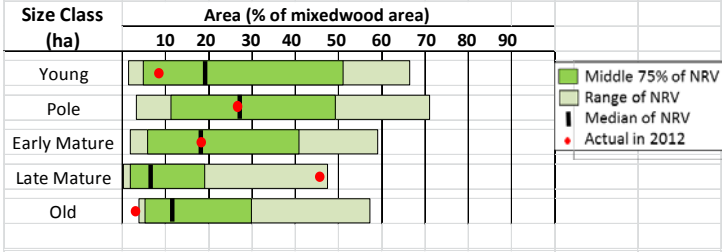


Figure 32. Summary of the historical range of seral-stage area of pine forest for the Contribuing area of the HWP FMA

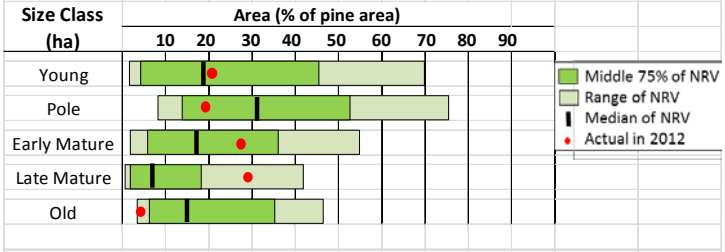


Figure 33. Summary of the historical range of seral-stage area of white spruce forest for the Contributing area of HWP FMA

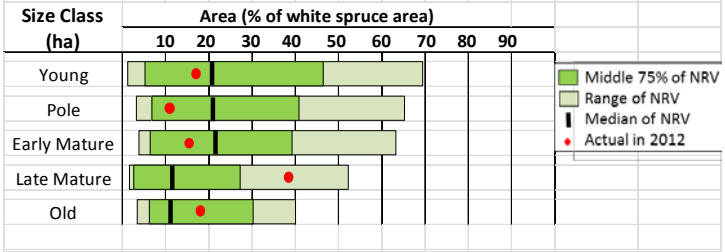


Figure 34. Summary of the historical range of seral-stage area of black spruce forest for the Contributing area of HWP FMA

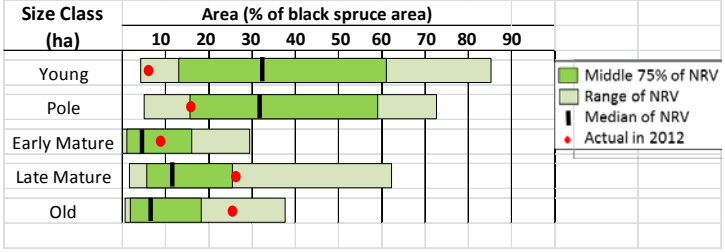


Figure 35. Summary of the historical range of seral-stage area of aspen forest for the Passive area of the HWP FMA

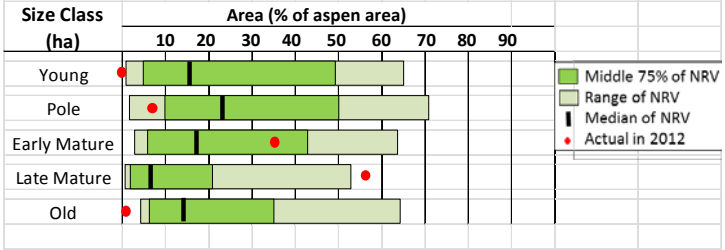


Figure 36. Summary of the historical range of seral-stage area of mixed forest for the Passive area of the HWP FMA

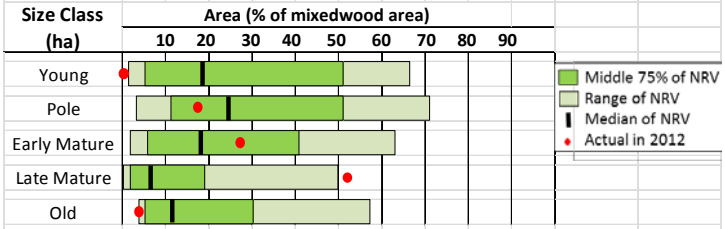


Figure 37. Summary of the historical range of seral-stage area of pine forest for the Passive area of the HWP FMA

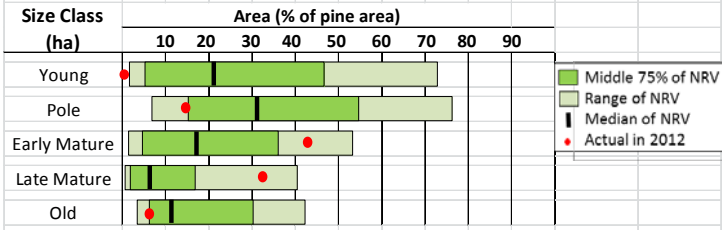


Figure 38. Summary of the historical range of seral-stage area of white spruce forest for the Passive area of HWP FMA

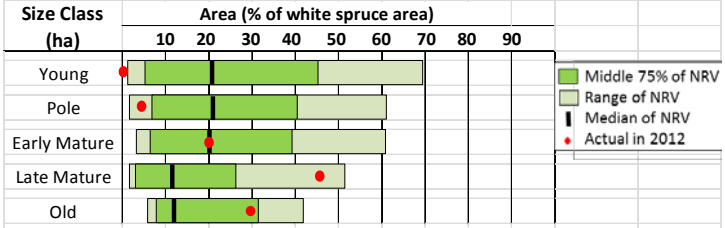
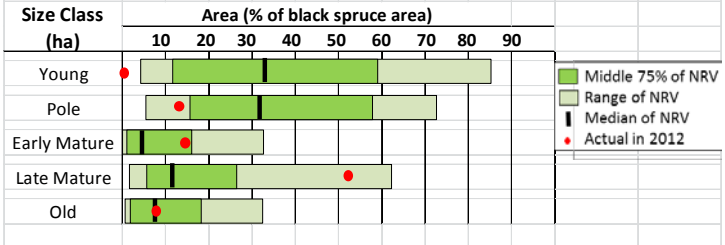


Figure 39. Summary of the historical range of seral-stage area of black spruce forest for the Passive area of HWP FMA



4.2.4 Upland, Riparian and Wetland Summaries for the Gross FMA Area

Predictably, both NRV and current condition for the Upland seral-stage patterns are similar to those of the Contributing landbase, while those of both the Riparian and Wetland portions of the landbase are similar to those of the Passive areas. Upland current condition for each seral-stage is well within NRV when Late Mature and Old forest are combined (Figure 40), although as above, the current condition of Late Mature + Old is still moderately above the NRV median. The much lower levels of Young forest in both the Riparian and Wetland areas has created a significant amount of Late Mature + Old (Figures 41 and 42). However, it is interesting to note that if anything, the current condition of the Riparian forest deviates further from NRV relative to that of Wetlands.

Figure 40. Summary of the historical range of seral-stage area of upland forest of the Gross HWP FMA area.

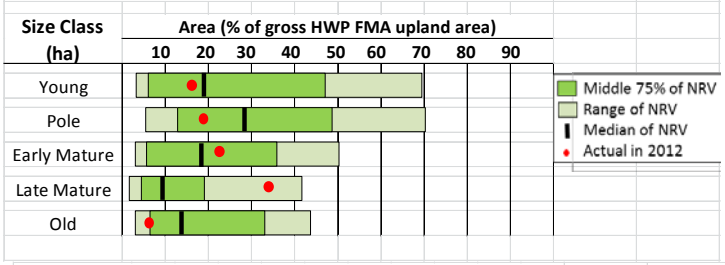


Figure 41. Summary of the historical range of seral-stage area of riparian forest of the Gross HWP FMA area.

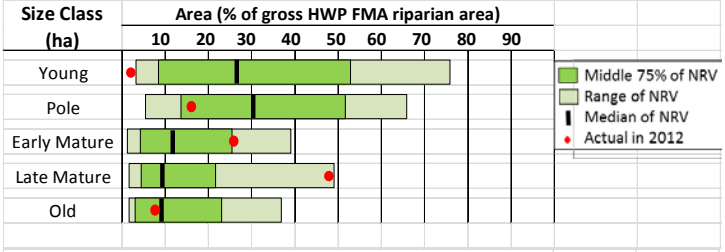
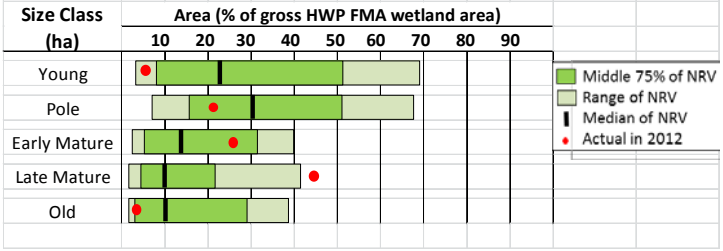


Figure 42. Summary of the historical range of seral-stage area of wetland forest of the Gross HWP FMA area.



The species specific summaries (Figures 43-57) follow the same general patterns found here. Note that any results shown in shaded grey are associated with areas less than 1,000 hectares.

Figure 43. Summary of the historical range of seral-stage area of upland aspen forest of the Gross area of the HWP FMA

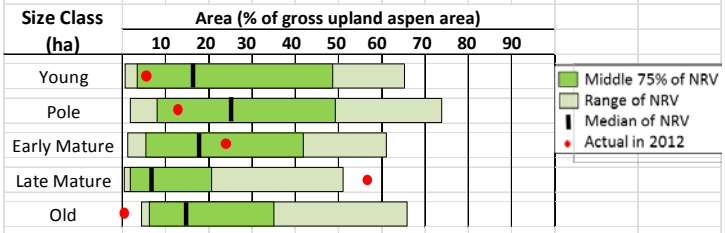


Figure 44. Summary of the historical range of seral-stage area of upland mixed forest of the Gross area of the HWP FMA

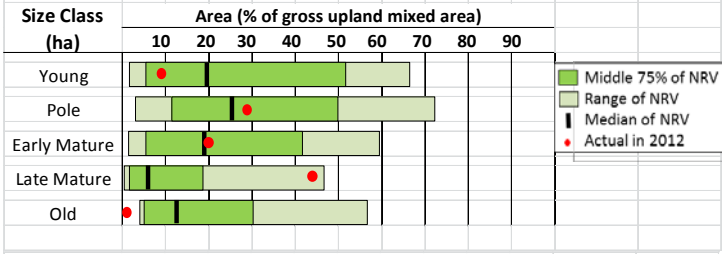


Figure 45. Summary of the historical range of seral-stage area of upland pine forest of the Gross area of the HWP FMA

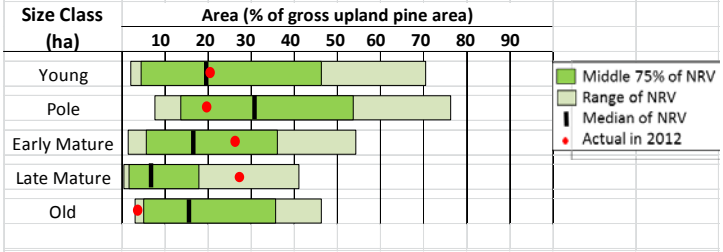


Figure 46. Summary of the historical range of seral-stage area of uplane white spruce forest of the Gross area of the HWP FMA

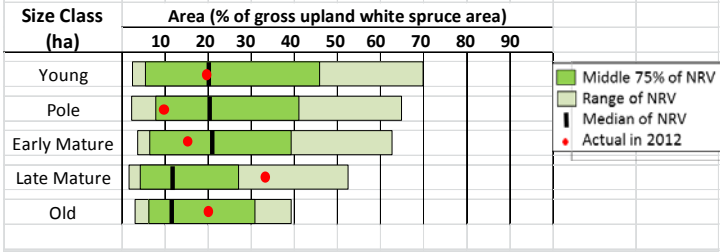


Figure 47. Summary of the historical range of seral-stage area of upland black spruce forest of the Gross area of the HWP FMA

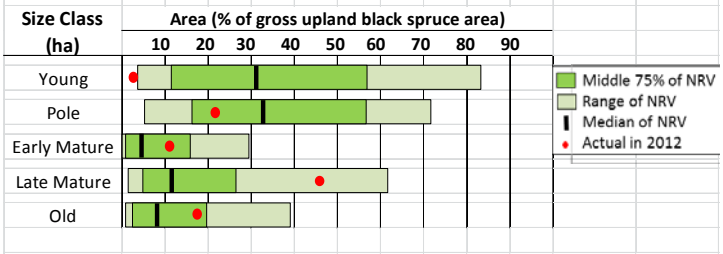


Figure 48. Summary of the historical range of seral-stage area of riparian aspen forest of the Gross area of the HWP FMA

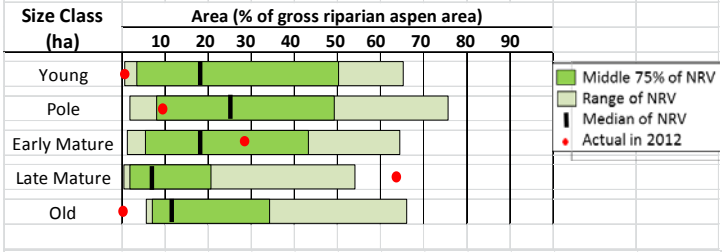


Figure 49. Summary of the historical range of seral-stage area of riparian mixed forest of the Gross area of the HWP FMA

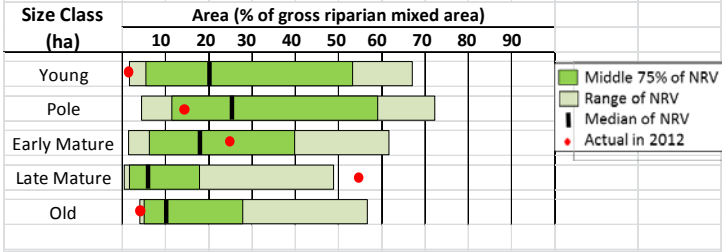


Figure 50. Summary of the historical range of seral-stage area of riparian pine forest of the Gross area of the HWP FMA

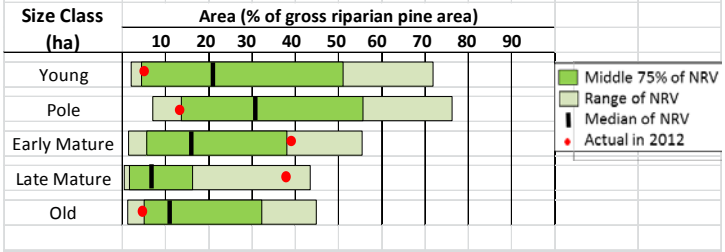


Figure 51. Summary of the historical range of seral-stage area of riparian white spruce forest of the Gross area of the HWP FMA

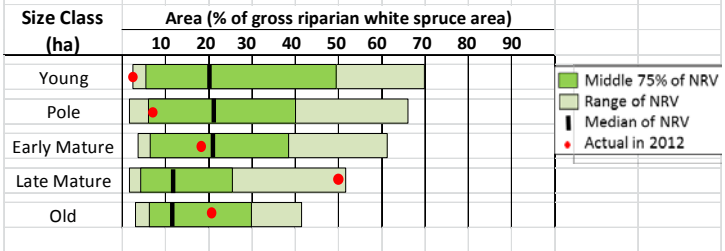


Figure 52. Summary of the historical range of seral-stage area of riparian black spruce forest of the Gross area of the HWP FMA

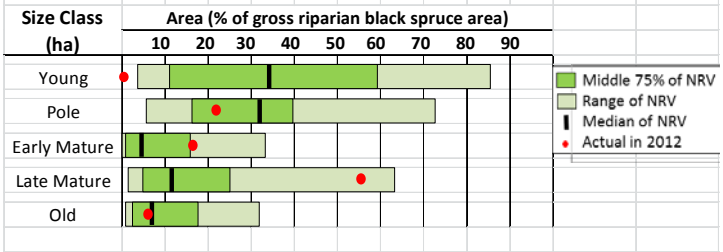


Figure 53. Summary of the historical range of seral-stage area of wetland aspen forest of the Gross area of the HWP FMA

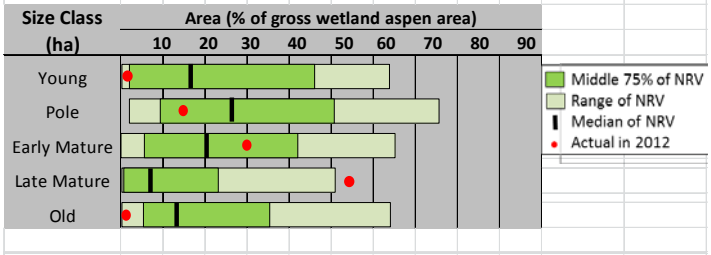


Figure 54. Summary of the historical range of seral-stage area of wetland mixed forest of the Gross area of the HWP FMA

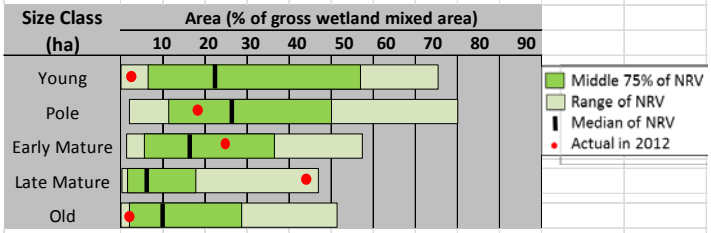


Figure 55. Summary of the historical range of seral-stage area of wetland pine forest of the Gross area of the HWP FMA

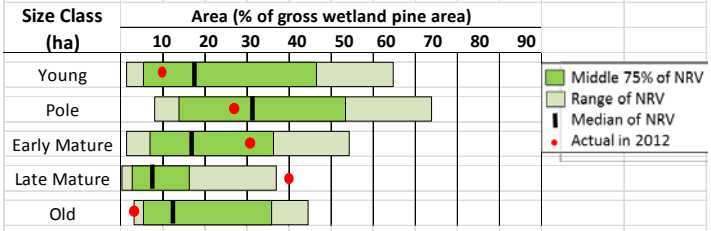


Figure 56. Summary of the historical range of seral-stage area of wetland white spruce forest of the Gross area of the HWP FMA

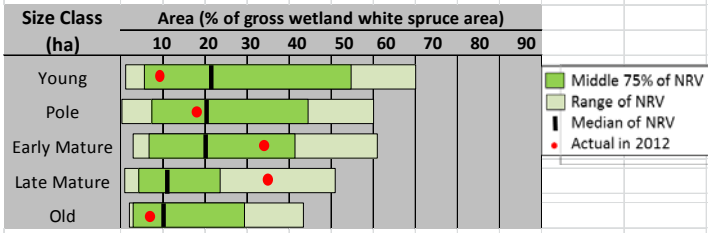
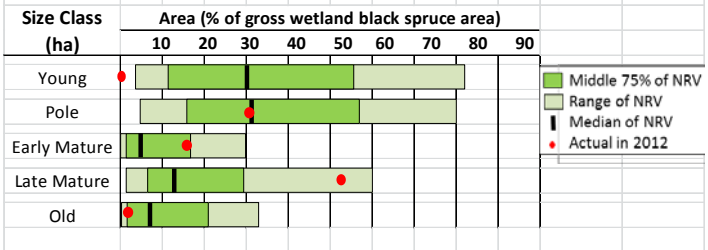


Figure 57. Summary of the historical range of seral-stage area of wetland black spruce forest of the Gross area of the HWP FMA



4.2.5 Upland, Riparian and Wetland Summaries for the Contributing FMA

This *Upland Contributing* landbase (Figure 58) is of particular importance in this study because 100% of it is managed by timber harvesting. It represents that idealized part of every landscape that classic forest management planning focuses on, including the calculation of allowable cut. In other words, this is the portion of the landscape that forest management is most responsible for, and to which they must demonstrate responsible management. In the case of the HWP FMA, the current conditions align quite well with the median NRV – assuming that Late Mature and Old are combined. This suggests that the anthropogenic disturbance levels are sustainable, given the very low levels of wildfire activity on this landscape since 1950.

Figure 58. Summary of the historical range of seral-stage area of upland forest of the Contributing area of the HWP FMA.

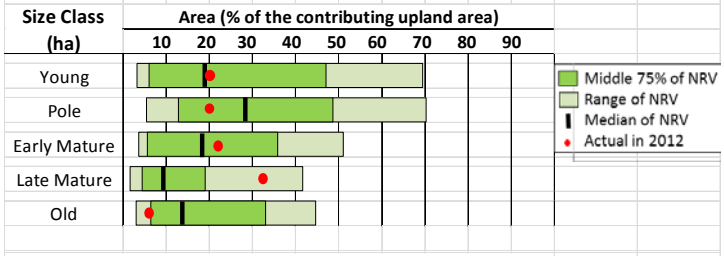


Figure 59. Summary of the historical range of seral-stage area of riparian forest of the Contributing area of the HWP FMA.

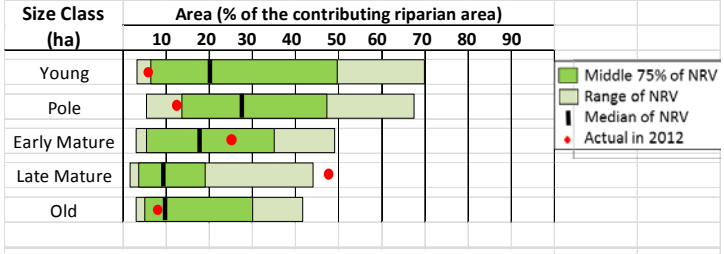
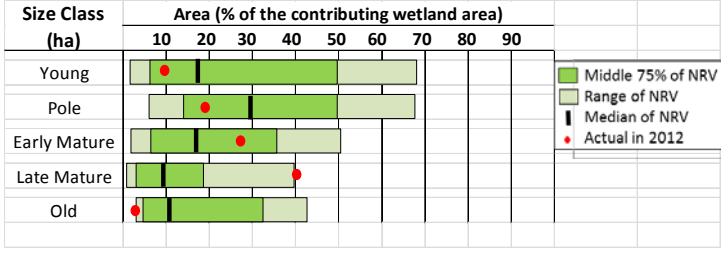


Figure 60. Summary of the historical range of seral-stage area of wetland forest of the Contributing area of the HWP FMA.



Both the Riparian and Wetland portion of the Contributing landbase have less Young and greater areas of Late Mature + Old relative to the Upland area (Figures 59-60).

When the same results are separated by vegetation type (Figures 61-75) Young pine and white spruce leading forest have the greatest amount of young Upland Contributing forest, while the amount of Young deciduous, mixedwood and black spruce is still well below the median NRV (Figures 61-65).

Figure 61. Summary of the historical range of seral-stage area of upland aspen forest of the Contributing part of the HWP FMA

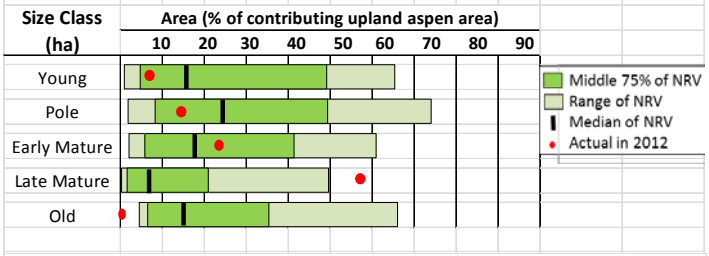


Figure 62. Summary of the historical range of seral-stage area of upland mixed forest of the Contributing part of the HWP FMA

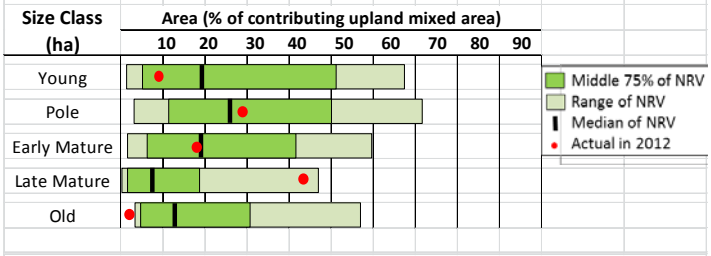


Figure 63. Summary of the historical range of seral-stage area of upland pine forest of the Contributing part of the HWP FMA

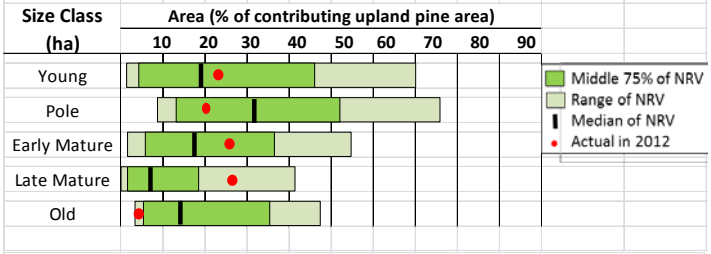


Figure 64. Summary of the historical range of seral-stage area of upland white spruce forest of the Contributing part of the HWP FMA

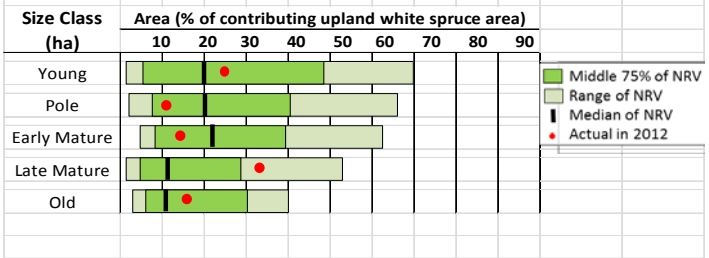


Figure 65. Summary of the historical range of seral-stage area of upland black spruce forest of the Contributing part of the HWP FMA

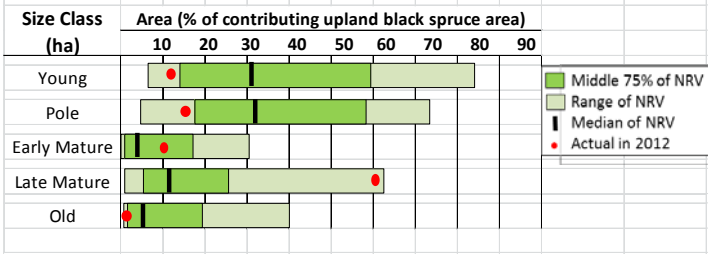


Figure 66. Summary of the historical range of seral-stage area of riparian aspen forest of the Contributing part of the HWP FMA

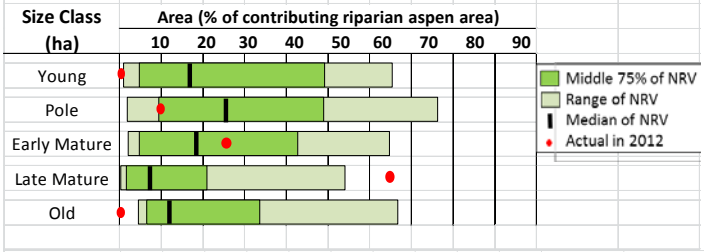


Figure 67. Summary of the historical range of seral-stage area of riparian mixed forest of the Contribuing part of the HWP FMA

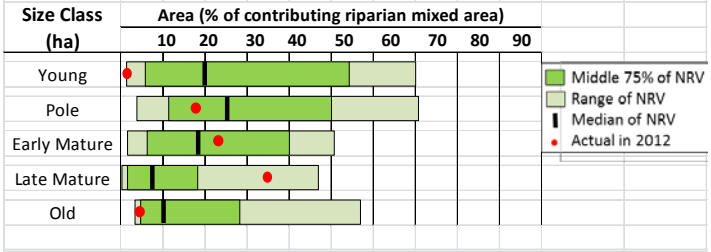


Figure 68. Summary of the historical range of seral-stage area of riparian pine forest of the Contributing part of the HWP FMA

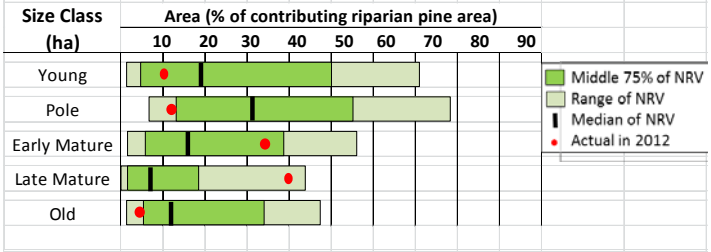


Figure 69. Summary of the historical range of seral-stage area of riparian white spruce forest of the Contributing part of the HWP FMA

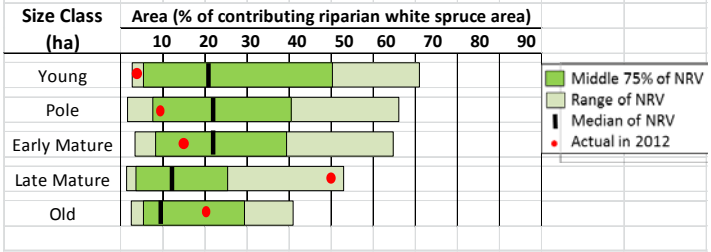


Figure 70. Summary of the historical range of seral-stage area of riparian black spruce forest of the Contributing part of the HWP FMA

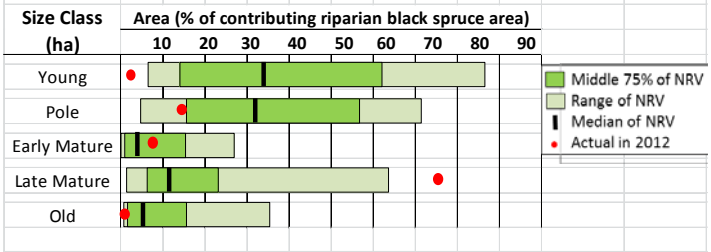


Figure 71. Summary of the historical range of seral-stage area of wetland aspen forest of the Contributing part of the HWP FMA

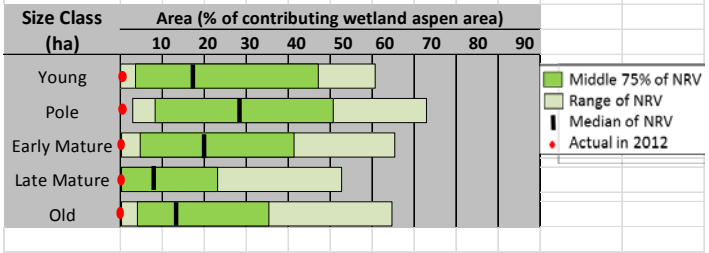


Figure 72. Summary of the historical range of seral-stage area of wetland mixed forest of the Contributing part of the HWP FMA

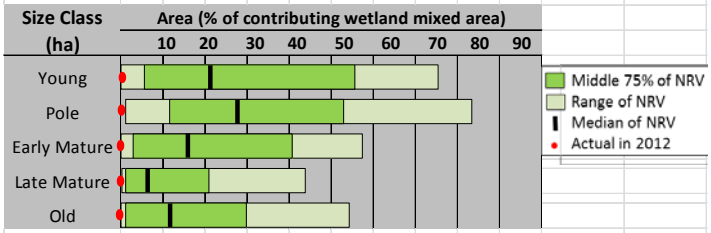


Figure 73. Summary of the historical range of seral-stage area of wetland pine forest of the Contributing part of the HWP FMA

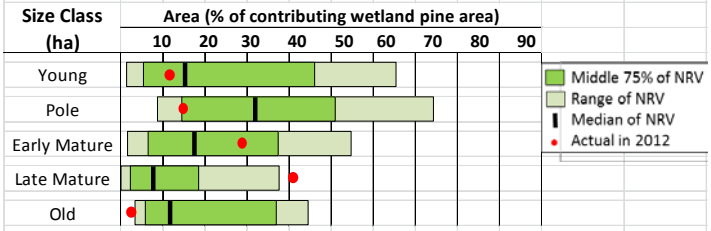


Figure 74. Summary of the historical range of seral-stage area of wetland white spruce forest of the Contributing part of the HWP FMA

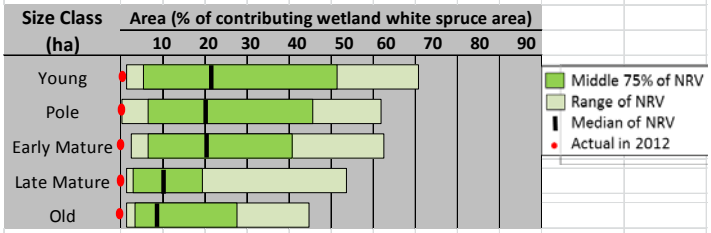
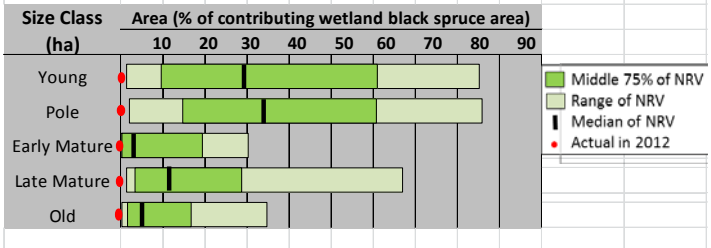


Figure 75. Summary of the historical range of seral-stage area of wetland black spruce forest of the Contributing part of the HWP FMA



4.2.6 Upland, Riparian and Wetland Summaries for the Passive FMA Area

All three sub-components of the Upland Passive parts of the landscape have Young forest levels below the lower bounds of NRV (Figures 76-78). The Late Mature + Old seral-stage levels are all over 50%, which is within NRV, but not within the middle 75th percentile. The details reveal similar patterns (Figures 79-93).

Figure 76. Summary of the historical range of seral-stage area of upland forest of the Passive area of the HWP FMA.

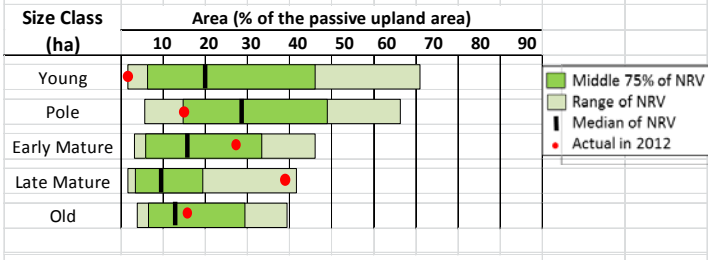


Figure 77. Summary of the historical range of seral-stage area of riparian forest of the Passive area of the HWP FMA.

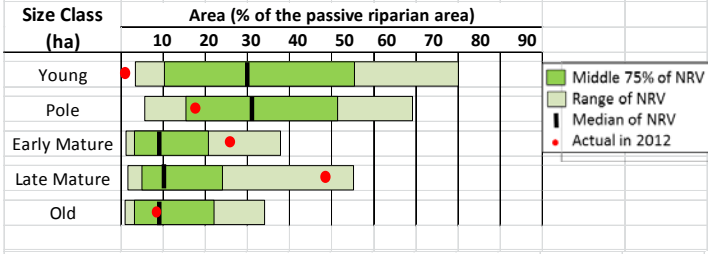


Figure 78. Summary of the historical range of seral-stage area of wetland forest of the Passive area of the HWP FMA.

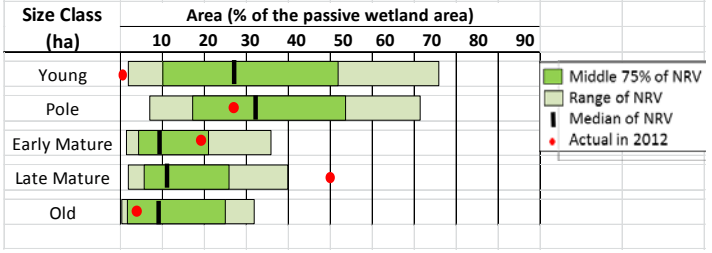


Figure 79. Summary of the historical range of seral-stage area of upland aspen forest of the Passive part of the HWP FMA

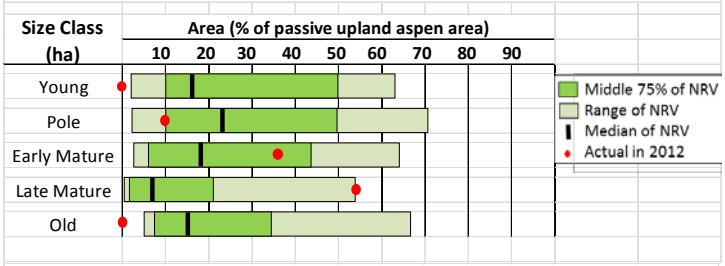


Figure 80. Summary of the historical range of seral-stage area of upland mixed forest of the Passive part of the HWP FMA

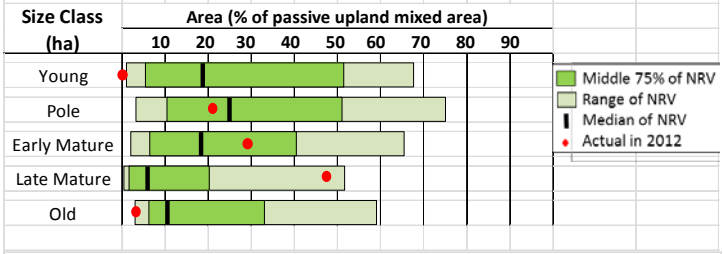


Figure 81. Summary of the historical range of seral-stage area of upland pine forest of the Passive part of the HWP FMA

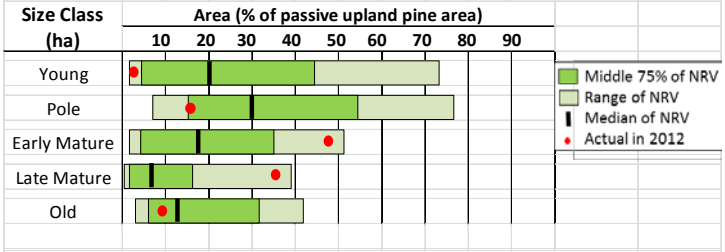


Figure 82. Summary of the historical range of seral-stage area of upland white spruce forest of the Passive part of the HWP FMA

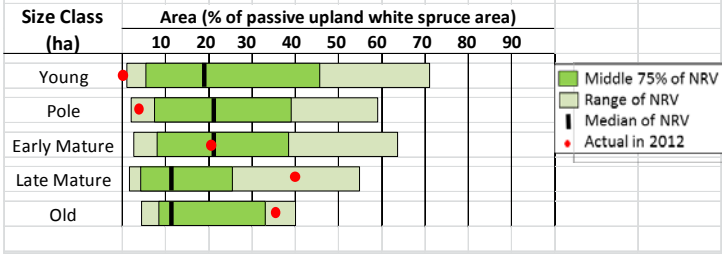


Figure 83. Summary of the historical range of seral-stage area of upland black spruce forest of the Passive part of the HWP FMA

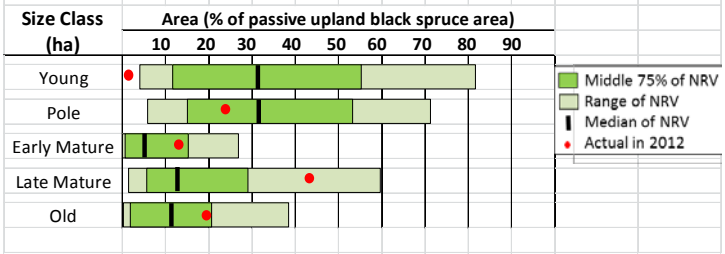


Figure 84. Summary of the historical range of seral-stage area of riparian aspen forest of the Passive part of the HWP FMA

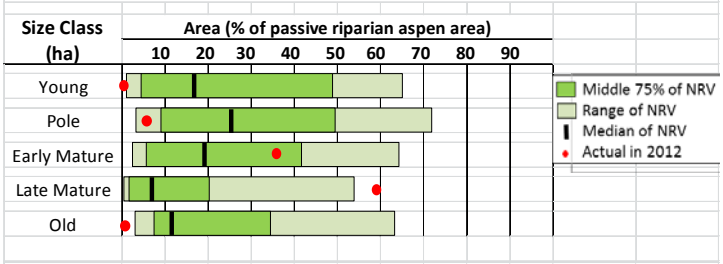


Figure 85. Summary of the historical range of seral-stage area of riparian mixed forest of the Passive part of the HWP FMA

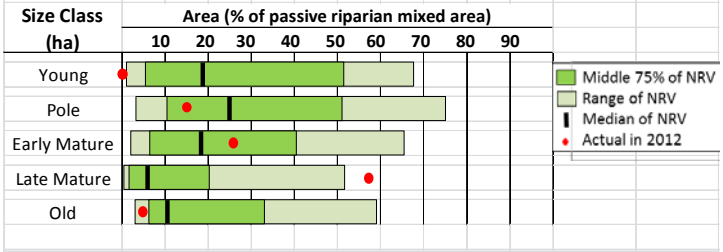


Figure 86. Summary of the historical range of seral-stage area of riparian pine forest of the Passive part of the HWP FMA

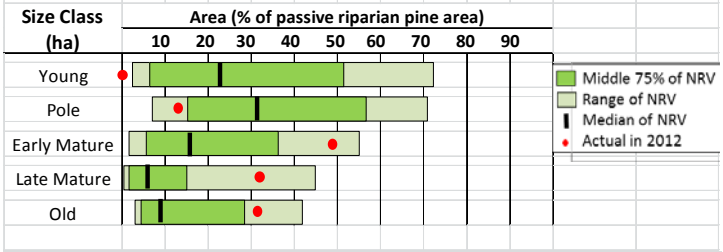


Figure 87. Summary of the historical range of seral-stage area of riparian white spruce forest of the Passive part of the HWP FMA

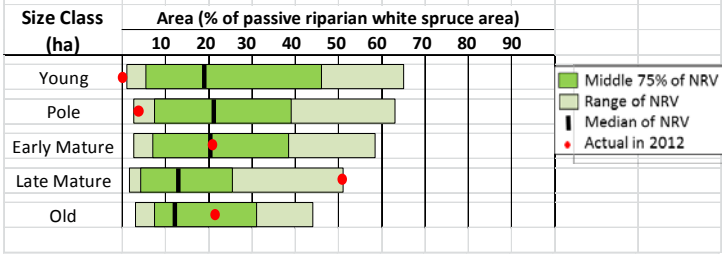


Figure 88. Summary of the historical range of seral-stage area of riparian black spruce forest of the Passive part of the HWP FMA

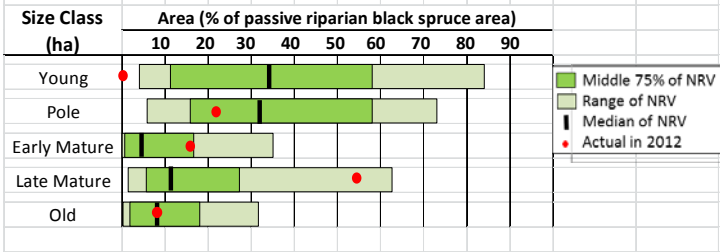


Figure 89. Summary of the historical range of seral-stage area of wetland aspen forest of the Passive part of the HWP FMA

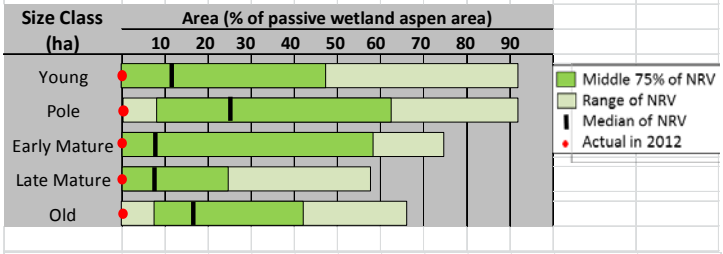


Figure 90. Summary of the historical range of seral-stage area of wetland mixed forest of the Passive part of the HWP FMA

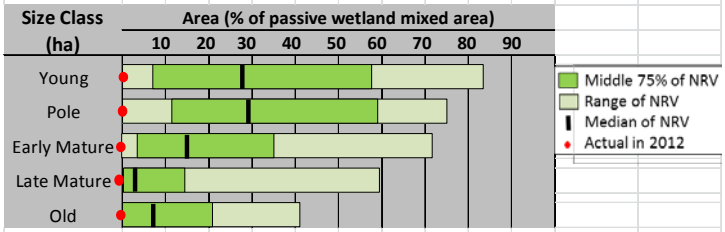


Figure 91. Summary of the historical range of seral-stage area of wetland pine forest of the Passive part of the HWP FMA

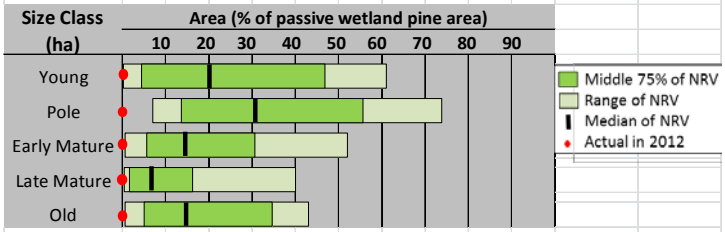


Figure 92. Summary of the historical range of seral-stage area of wetland white spruce forest of the Passive part of the HWP FMA

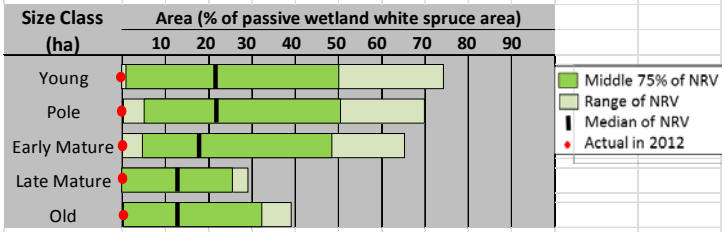
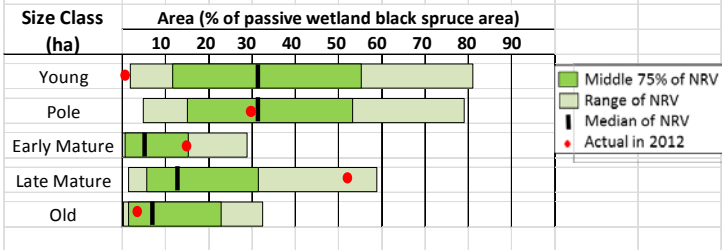


Figure 93. Summary of the historical range of seral-stage area of wetland black spruce forest of the Passive part of the HWP FMA



4.2.7 Caribou Range Summaries Based on HWP Age-Classes

The two caribou ranges in the study area have very different seral-stage NRVs based on their locations. The Little Smoky range includes parts of the Upper Foothills, Lower Foothills, and Subalpine Natural Subregions, while the A La Peche herd area lies much further west, and includes a much larger portion of the Sub-alpine. This means that the average LT fire cycle of the A La Peche area is much higher than the Little Smokey zone, which translates into lower levels of Young forest, and higher levels of Late Mature + Old forest (Figures 94 and 95).

Figure 94. Summary of the historical range of seral-stage area of forest of the Little Smoky caribou range.

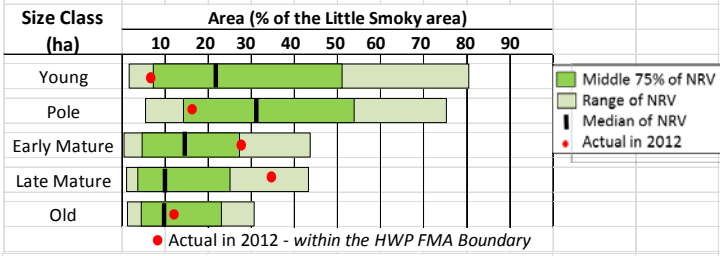
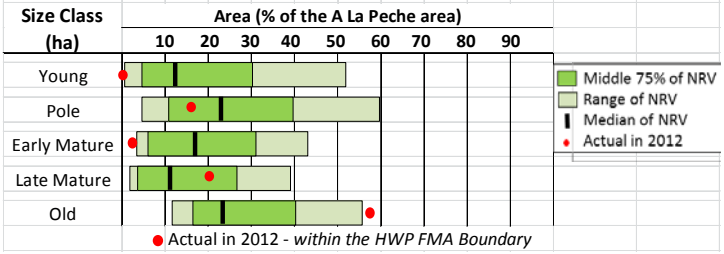


Figure 95. Summary of the historical range of seral-stage area of forest of the A La Peche caribou range.



Of the 100 model runs, the Little Smoky range met the minimum requirements of caribou habitat defined by Environment Canada (2011) 59% of the time compared to 79% of the time for the A La Peche range.

As regards the current conditions, keep in mind that the red dots in Figure 94-95 represent only the area of the respective ranges within the HWP FMA. The current condition numbers reflect the relative level of management activity in each area. Young forest in the A La Peche zone is almost zero, compared to about 7% in the Little Smoky area (Figures 94 and 95).

As with all previous seral-stage patterns, current levels of Young forest are near or below the lower level of NRV, and the amount of Late Mature + Old is on the high end of NRV. The details in Figures 96-105 are consistent with this as well.

Figure 96. Summary of the historical range of seral-stage area of aspen forest of the Little Smoky herd area

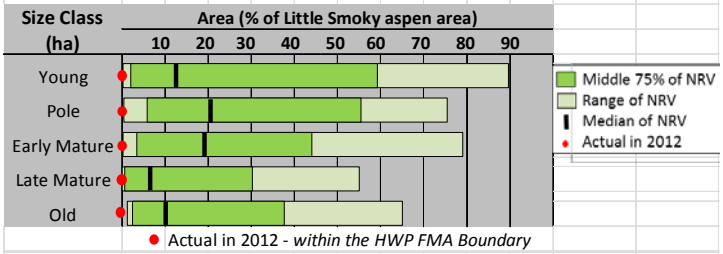


Figure 97. Summary of the historical range of seral-stage area of mixed forest of the Little Smoky herd area

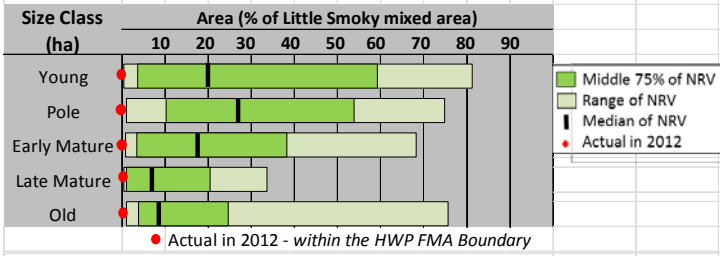


Figure 98. Summary of the historical range of seral-stage area of pine forest of the Little Smoky herd area

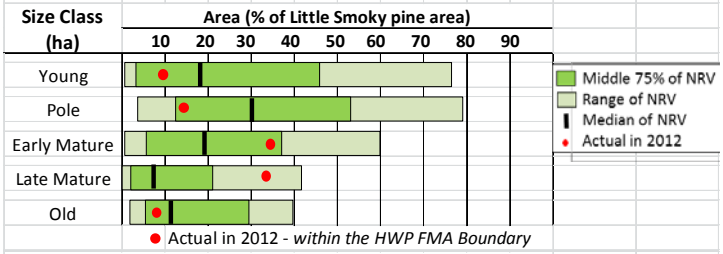


Figure 99. Summary of the historical range of seral-stage area of white spruce forest of the Little Smoky herd area

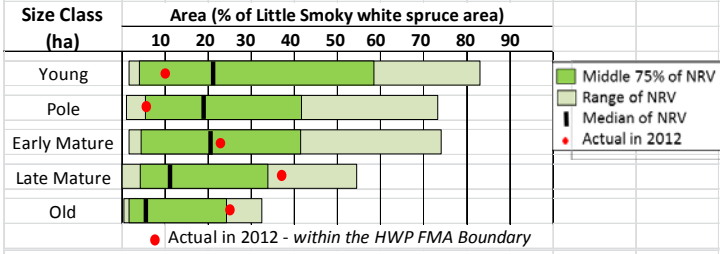


Figure 100. Summary of the historical range of seral-stage area of black spruce forest of the Little Smoky herd area

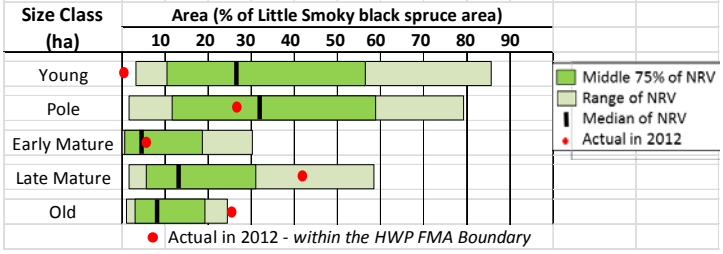


Figure 101. Summary of the historical range of seral-stage area of aspen forest of the A La Peche herd area

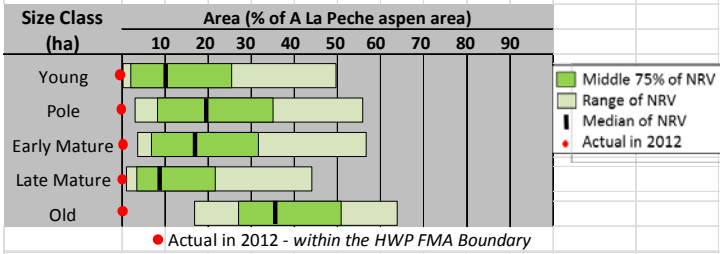


Figure 102. Summary of the historical range of seral-stage area of mixed forest of the A La Peche herd area

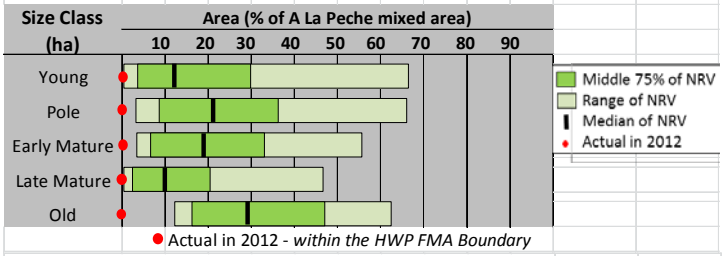


Figure 103. Summary of the historical range of seral-stage area of pine forest of the A La Peche herd area

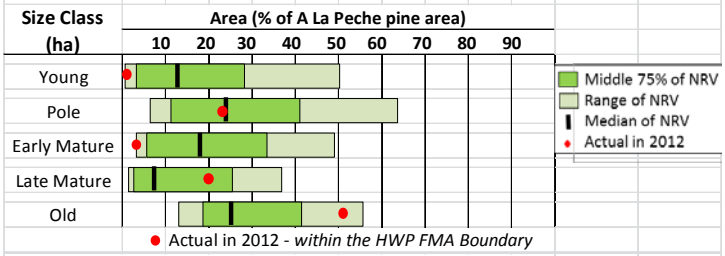


Figure 104. Summary of the historical range of seral-stage area of white spruce forest of the A La Peche herd area

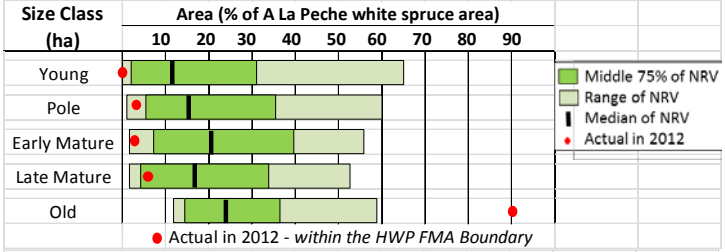
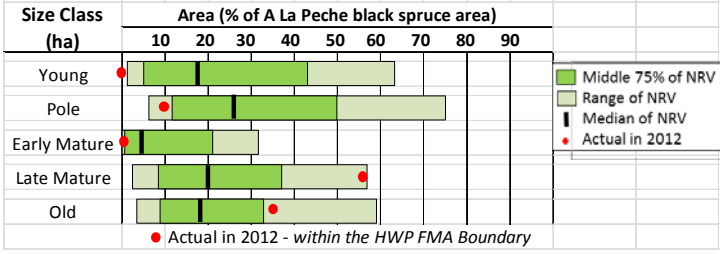


Figure 105. Summary of the historical range of seral-stage area of black spruce forest of the A La Peche herd area



4.2.8 Caribou Range Summaries Based on Provincial Age-Classes

This section presents the identical results to those from Section 4.2.7, but instead of incorporating the five seral-stages as defined by HWP, these results use of the four standardized provincial age-class. Thus, the only differences are artefacts of the choice of age-class definitions; *the natural patterns are no different*.

Figure 106. Summary of the historical range of seral-stage area of forest of the Little Smoky caribou range using provincial seral definitions.

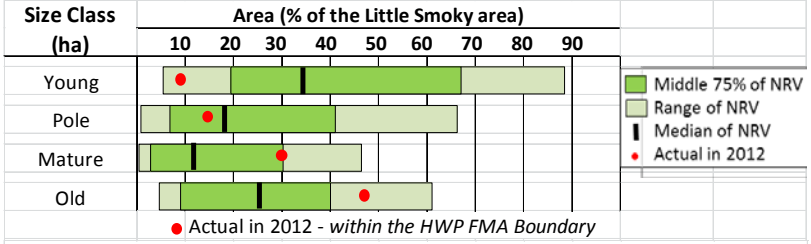
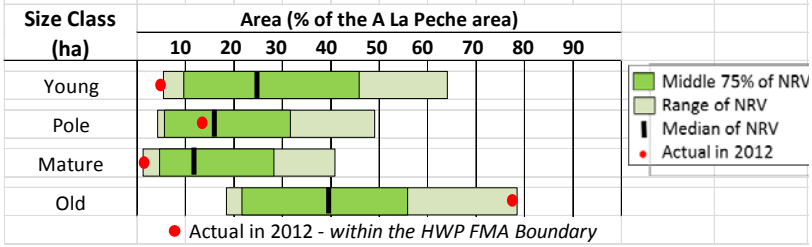


Figure 107. Summary of the historical range of seral-stage area of forest of the A La Peche caribou range using provincial seral definitions.



The current condition patterns noted here confirm that the oldest forest seral-stage (which is also called Old in this case) dominates the landscape. Old forest within the HWP FMA portion of the Little Smokey herd zone represents 48% of the forest, which is beyond the middle 75th percentile of NRV (Figure 106). The Old forest for the A La Peche area within the HWP FMA represents 78% of the forest area (Figure 107).

The forest type details below mirror these same patterns (Figures 108 – 117), although both the white and black spruce areas have a particularly high percentage of Old forest. In the HWP FMA portion of the A La Peche herd area, Old black spruce and white spruce account for over 90% of the forest area, and for the Little Smoky, over 60%.

Figure 108. Summary of the historical range of provincial seral-stage area of aspen forest of the Little Smoky herd area

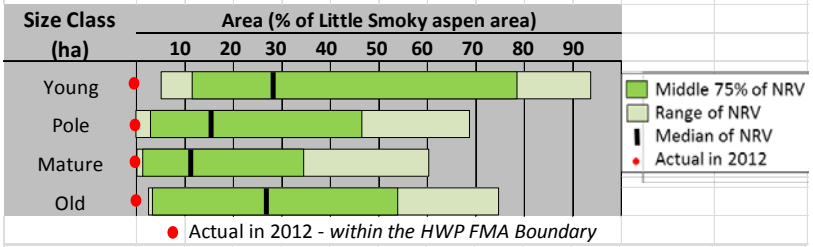


Figure 109. Summary of the historical range of provincial seral-stage area of mixed forest of the Little Smoky herd area

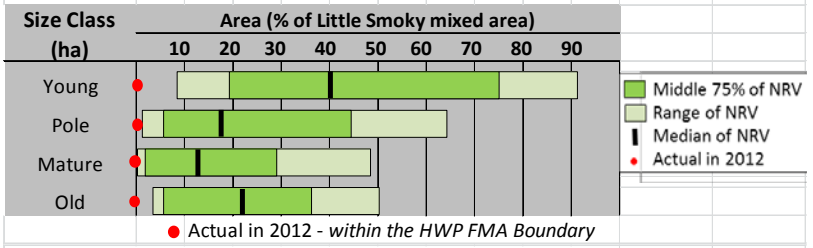


Figure 110. Summary of the historical range of provincial seral-stage area of pine forest of the Little Smoky herd area

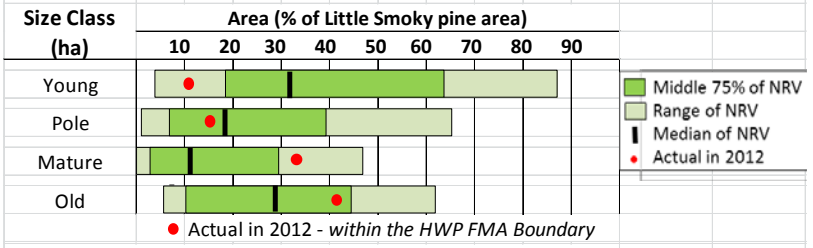


Figure 111. Summary of the historical range of provincial seral-stage area of white spruce forest of the Little Smoky herd area

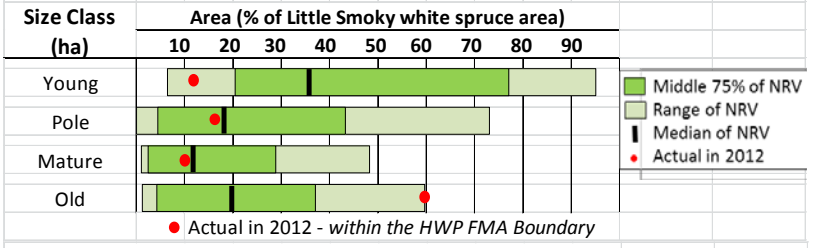


Figure 112. Summary of the historical range of provincial seral-stage area of black spruce forest of the Little Smoky herd area

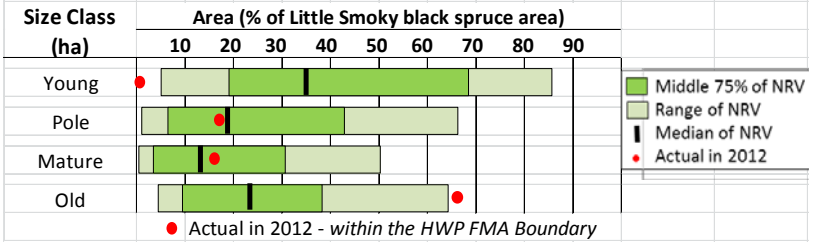
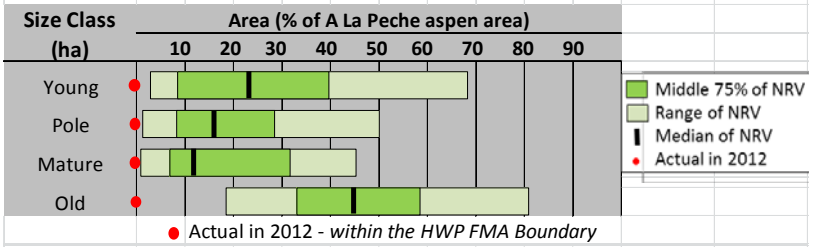
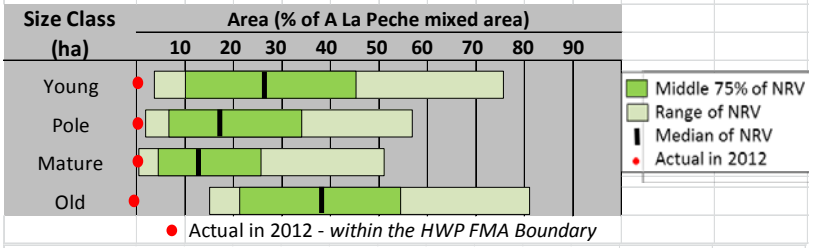


Figure 113. Summary of the historical range of provincial seral-stage area of aspen forest of the A La Peche herd area



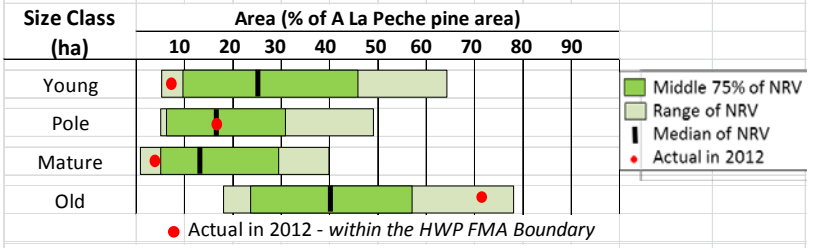
● Actual in 2012 - *within the HWP FMA Boundary*

Figure 114. Summary of the historical range of provincial seral-stage area of mixed forest of the A La Peche herd area



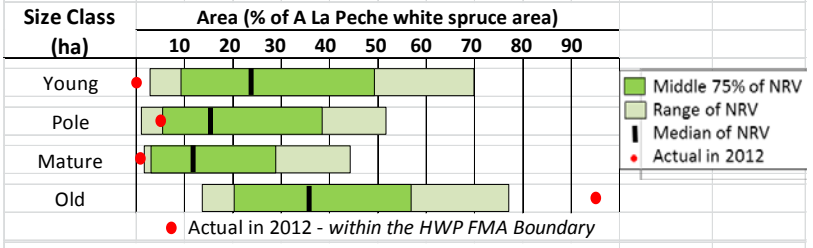
● Actual in 2012 - *within the HWP FMA Boundary*

Figure 115. Summary of the historical range of provincial seral-stage area of pine forest of the A La Peche herd area



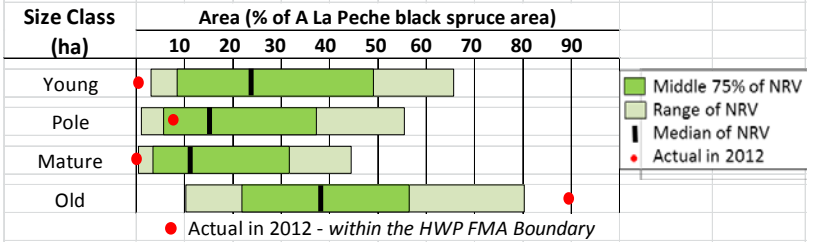
● Actual in 2012 - *within the HWP FMA Boundary*

Figure 116. Summary of the historical range of provincial seral-stage area of white spruce forest of the A La Peche herd area



● Actual in 2012 - *within the HWP FMA Boundary*

Figure 117. Summary of the historical range of provincial seral-stage area of black spruce forest of the A La Peche herd area



● Actual in 2012 - *within the HWP FMA Boundary*

4.3 Spatial results

4.3.1 Overall

The Figures in this Section all follow the same format as described above. The light green bars capture the full NRV range, the darker green middle bar the middle 75th percentile of the NRV, the black bar the NRV median, and the red dot current condition. For more details on these results, see Appendix B.

Overall NRV patterns of patch sizes suggest that large patches account for most of the landscape. The area within the smallest patches contributed very little to the total area of the landscape. For example, the average NRV for Old forest (overall) was 1,486 patches <100 ha in size accounting for 7,433 ha. In contrast, the average NRV of Old forest in patches larger than 10,000 ha was 2.6 patches accounting for over 86,000 ha. Another notable trend is that as forest ages, patch size becomes smaller. This can be seen in the decline of the area in the largest patch sizes as one moves from Young to Old forest in Figures 118-122. For example, while patches of Young forest >50,000 ha (Figure 118) were fairly common historically, Old patches >50,000 ha were relatively rare (Figure 122).

In terms of current condition, the most obvious trend is the extremely large number of very small patches relative to NRV – of all ages (Figures 118-122). The area in patches <100 ha is 4-10 times greatest than the number observed in the modelling exercise. In total, all patches (of all ages) <100 ha account for 67% of the forest area of the FMA, compared to 12% on average historically.

Of particular note, there is over 100,000 ha of Young forest in patches <100 ha, compared to an average of 5,500 ha and a maximum of only 11,600 historically. In fact, there are no Young forest patches larger than 500 ha (Figure 118). In contrast, there are few to very large patches of any age. There are only three Old forest patches larger than 1,000 ha, and none larger than 5,000 ha (Figure 122). While this is not unprecedented historically (see Appendix B), low numbers of large Old forest patches are associated with extremely low levels of Old forest. On average, Old patches larger than 5,000 ha accounted for over 63% of the landscape historically.

Similarly, there are no Late Mature patches larger than 5,000 ha, which is particularly significant given that almost 38% of the forest area of the FMA is Late Mature.

Figure 118. Summary of the area in different patch sizes of young forest for the gross HWP FMA area

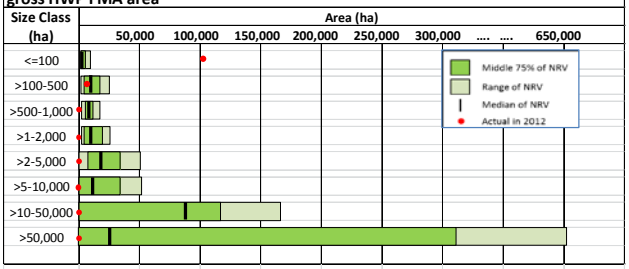


Figure 119. Summary of the area in different patch sizes of pole forest for the gross HWP FMA area

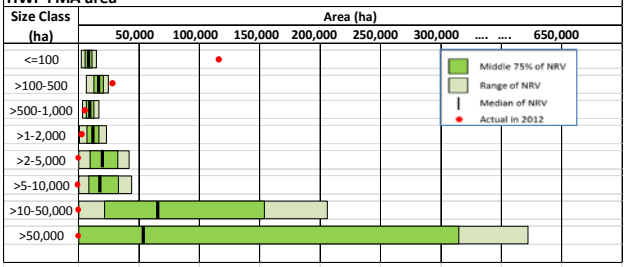


Figure 120. Summary of the area in different patch sizes of early mature forest for the gross HWP FMA area

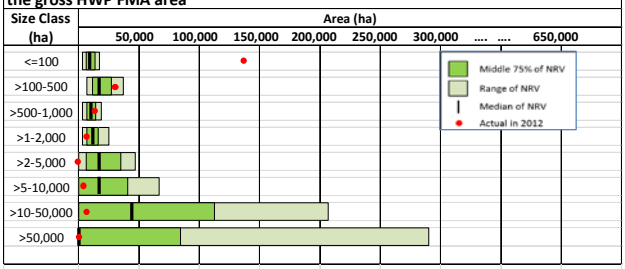


Figure 121. Summary of the area in different patch sizes of late mature forest for the gross HWP FMA area

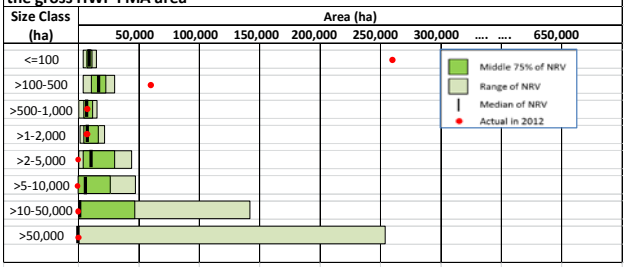
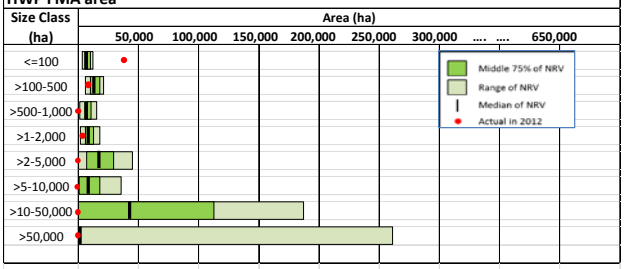


Figure 122. Summary of the area in different patch sizes of old forest for the gross HWP FMA area



4.3.2 Results by Vegetation Type

Breaking patch size down by the five major vegetation types predictably creates far small patches, although to different degrees. The impact is the least dramatic on pine leading forest since it accounts for almost half of the forested area on the HWP FMA (see Table 3) and thus has a greater chance of being spatially contiguous (Figures 123-127). In contrast, deciduous and mixedwood forest each account for only 9% of the FMA (Table 3), and clearly do not naturally occur in large contiguous patches – regardless of age (Figures 128-137). White spruce (which account for 14% of the FMA area) tends to cluster into slightly larger patches (Figures 138-142), but even Young patches rarely exceed 5,000 ha (Figure 138). Although black spruce (Figures 143-147) accounts for only 19% of the FMA, the data suggests that it clusters in space to a moderate degree given that Young patches between 5-10,000 ha were fairly common historically (Figure 143).

Current condition patterns follow those noted above for the landscape as a whole. For all non-pine leading vegetation types, patches larger than 100 ha are rare to non-existent. Even for pine-leading forest, the number of patches larger than 1,000 ha (of any age group) are rare (Figures 123-127). More than 86% of the Young pine on the FMA are in patches less than 100 ha, compared to an average of 5% historically (Figure 123).

Figure 123. Summary of the area in different patch sizes of young pine forest for the gross HWP FMA area

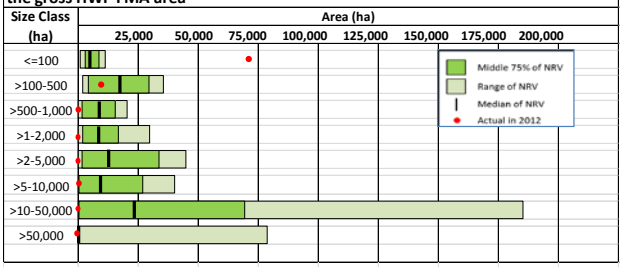


Figure 124. Summary of the area in different patch sizes of pole pine forest for the gross HWP FMA area

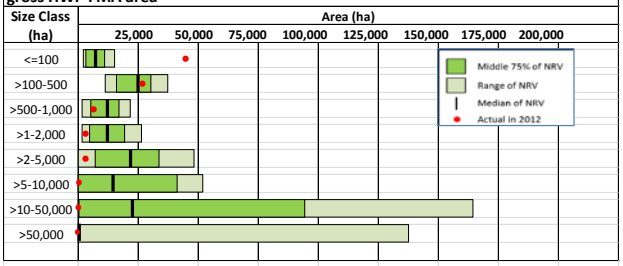


Figure 125. Summary of the area in different patch sizes of early mature pine forest for the gross HWP FMA area

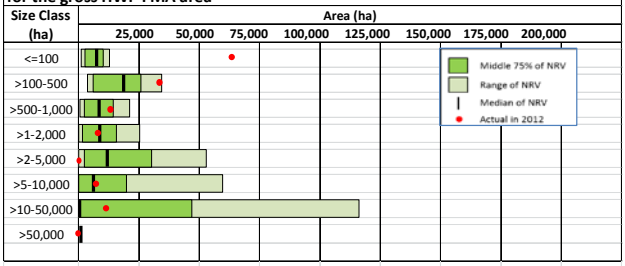


Figure 126. Summary of the area in different patch sizes of late mature pine forest for the gross HWP FMA area

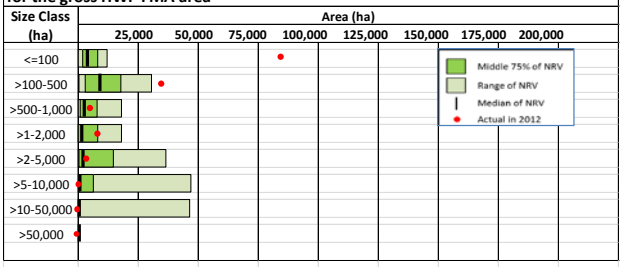


Figure 127. Summary of the area in different patch sizes of old pine forest for the gross HWP FMA area

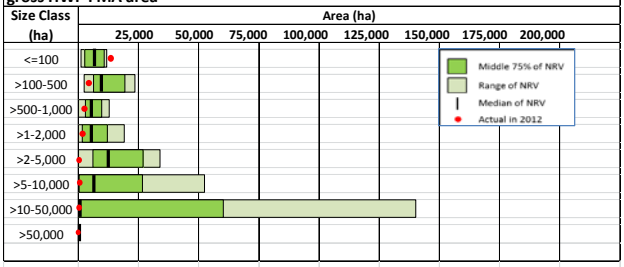


Figure 128. Summary of the area in different patch sizes of young deciduous forest for the gross HWP FMA area

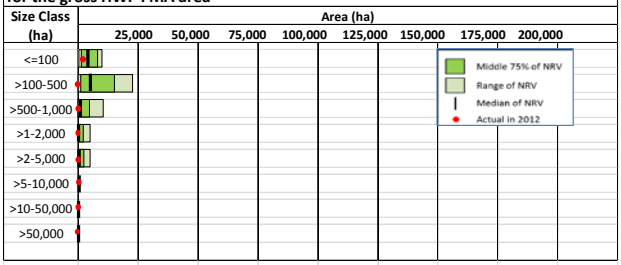


Figure 129. Summary of the area in different patch sizes of pole deciduous forest for the gross HWP FMA area

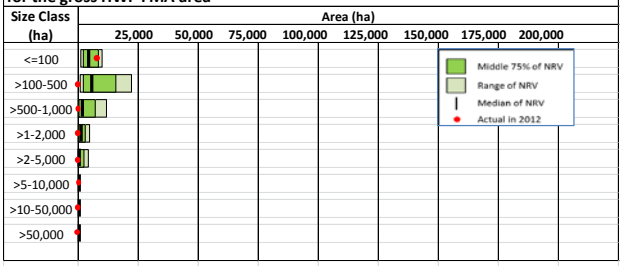


Figure 130. Summary of the area in different patch sizes of early mature deciduous forest for the gross FMA area

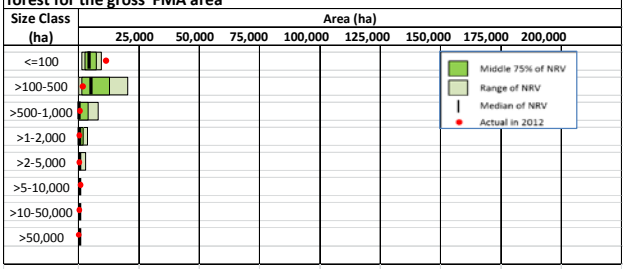


Figure 131. Summary of the area in different patch sizes of late mature deciduous forest for the gross FMA

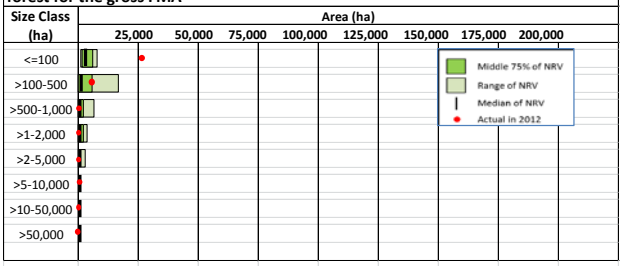


Figure 132. Summary of the area in different patch sizes of old deciduous forest for the gross HWP FMA area

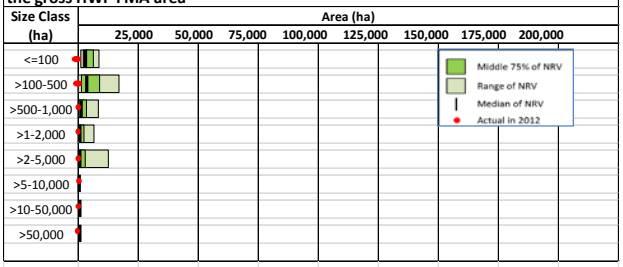


Figure 133. Summary of the area in different patch sizes of young mixedwood forest for the gross HWP FMA area

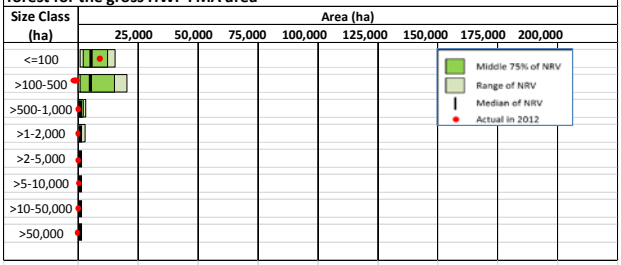


Figure 134. Summary of the area in different patch sizes of pole mixedwood forest for the gross HWP FMA area

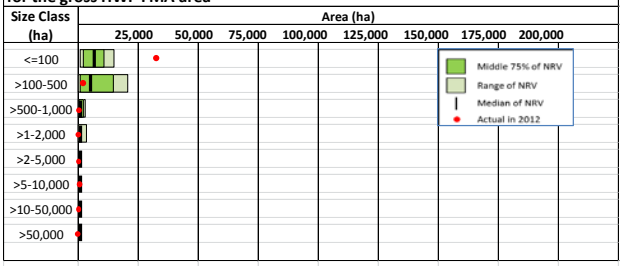


Figure 135. Summary of the area in different patch sizes of early mature mixedwood forest for the gross FMA

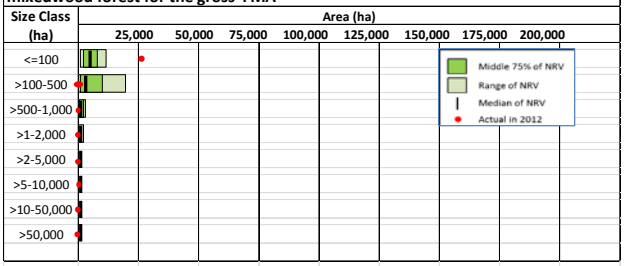


Figure 136. Summary of the area in different patch sizes of late mature mixedwood forest for the gross FMA

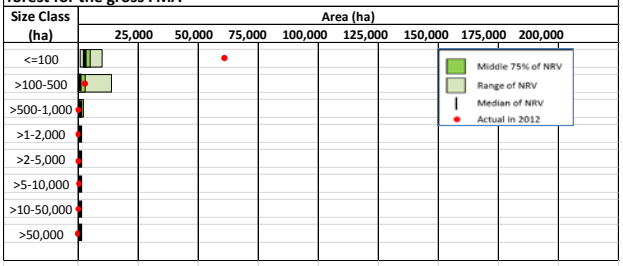


Figure 137. Summary of the area in different patch sizes of old mixedwood forest for the gross HWP FMA area

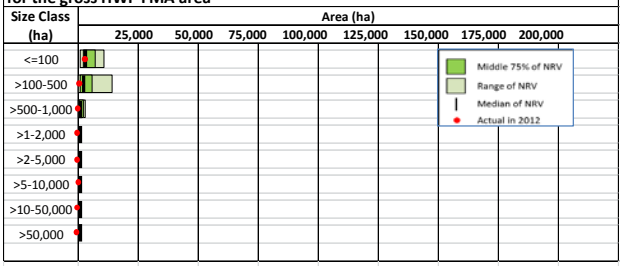


Figure 138. Summary of the area in different patch sizes of young white spruce forest for the gross HWP FMA area

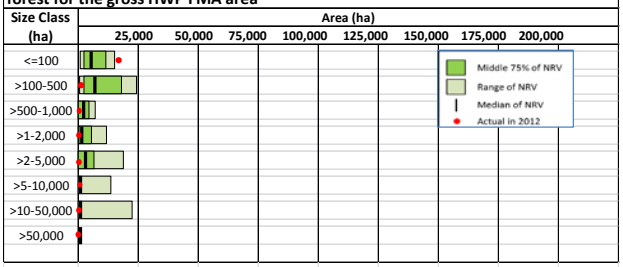


Figure 139. Summary of the area in different patch sizes of pole white spruce forest for the gross HWP FMA area

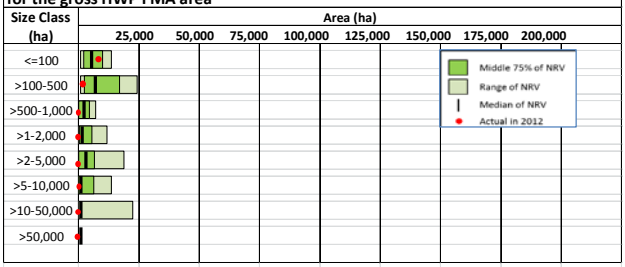


Figure 140. Summary of the area in different patch sizes of early mature white spruce forest for the gross FMA

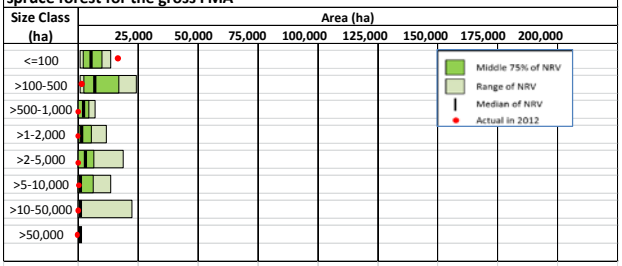


Figure 141. Summary of the area in different patch sizes of late mature white spruce forest for the gross FMA

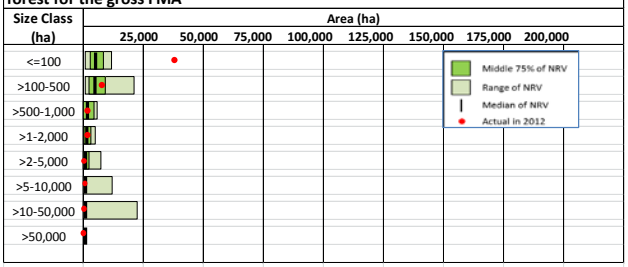


Figure 142. Summary of the area in different patch sizes of old white spruce forest for the gross HWP FMA area

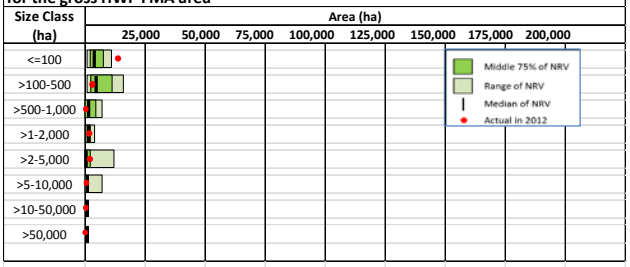


Figure 143. Summary of the area in different patch sizes of young black spruce forest for the gross HWP FMA area

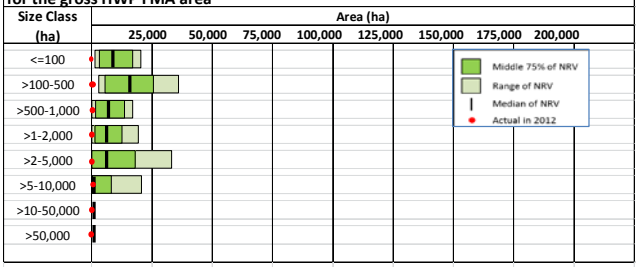


Figure 144. Summary of the area in different patch sizes of pole black spruce forest for the gross HWP FMA area

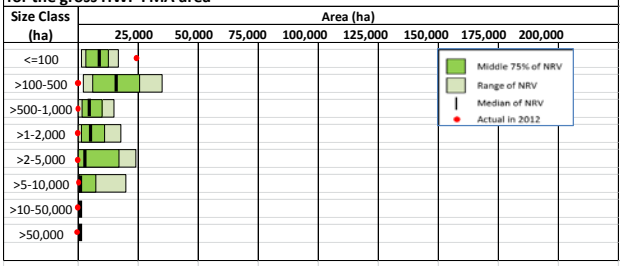


Figure 145. Summary of the area in different patch sizes of early mature black spruce forest for the gross FMA

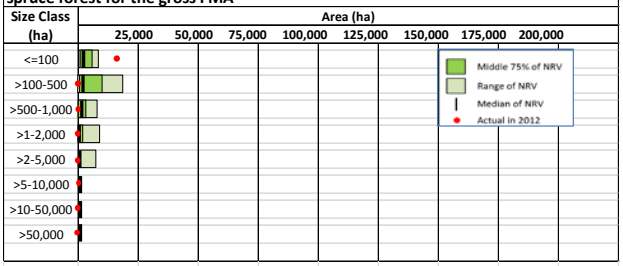


Figure 146. Summary of the area in different patch sizes of late mature black spruce forest for the gross FMA

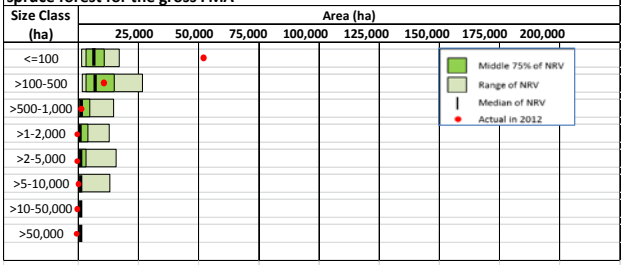
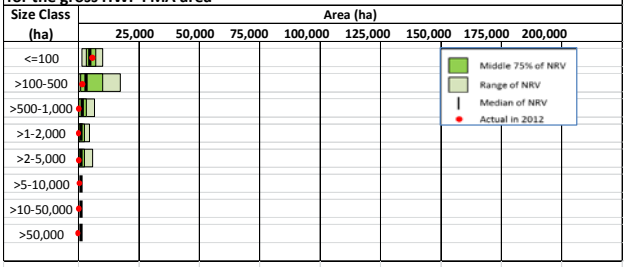


Figure 147. Summary of the area in different patch sizes of old black spruce forest for the gross HWP FMA area



5.0 Discussion

Although this study includes many details, the main patterns are consistent and prominent. Forest disturbance has been (in some cases well) below historical levels for several decades. This is true for even the most active parts of the landscape (e.g. pine leading Contributing forest). Over many years, this can only lead to an abundance of older forest, which is exactly what is observed. Whether this is Old or Late Mature is unimportant. Regardless of whether or not forest inventory ages are underestimating the actual age since the last wildfire, the fact remains that the 45% of the landscape in Late Mature + Old forest stages is approaching the upper end of NRV. Moreover, the results also suggest that the amount of older forest will only increase over time. The already massive amount of Late Mature forest in the various parts of the landscape that are not actively managed (such as the Passive landbase and/or Riparian areas) will continue to increase in the absence of disturbance.

The potential impacts of this trend are manifold. A build-up of older forest creates a more homogenous landscape that is less resilient to external perturbations (Methven and Feunekes 1987). In other words, the HWP landscape is becoming more susceptible to natural disturbances such as mountain pine beetle and wildfire (Odum et al. 1987, Romme 1982) and is more likely to be affected by climate change.

A simplified landscape mosaic also potentially translates into less biodiversity. One of the more obvious threats to this landscape is the loss of Young forest habitat in some vegetation types, landscape elements and ecological zones. There is no evidence to suggest that “old growth” has more biological value than “young growth”. In fact, boreal landscapes boast a significant spike in diversity for the first several years after wildfires, favouring a large number of specialists that are not just adapted to fire, but depend on it. Similarly, the removal or abating of disturbance as a process from some ecosystem types will potentially have significant consequences. For example, disturbances such as wildfires are critical for creating pulses of dead wood that ultimately become important functional elements in small streams (Jones and Daniels 2008).

Another potential risk associated with a landscape with a continually aging forest is the fate of the large pulse of older forest. If we assume that forest inventory ages are accurate, then over the next one or two decades, a large part of the forest will be transitioning from Late Mature to Old, ultimately pushing the amount of Old forest

beyond NRV. If we assume that inventory ages underestimate the ages of older forest, then this may already be the case. Either way, the continual aging of forest in *the lower elevations of* the Alberta Foothills is historically unprecedented. At higher elevations and in places where topography is more complex, there is evidence of *fire refigia*: sites which wildfire repeatedly skips multiple times. On the HWP FMA and parts further east, no evidence of fire refugia has been found. In other words, over time, only a very small portion of the landscape escapes fires for more than several hundreds of years, and then so, only randomly so. For example, using the simple negative exponential model introduced in the previous section, an average of 9% of forest greater than 200 years of age is expected on a landscape with an 82-year LT fire cycle, presumably most of it in very small patches. If we assume (for example) that about half of the Late Mature forest is actually Old, then within the next 10 years, an estimated 30% of the HWP landscape will be older than 200 years of age, and in 40 years almost 50%.

The dynamics of these very old parts of the landscape is largely unknown. In parts of boreal Quebec, where fire cycles exceed 200 years, Old forest dynamics include gap dynamics caused by the death of individual trees which create gaps allowing for the regeneration and/or release of younger trees (Gauthier et al. 1996). It is possible but doubtful that gap dynamics might also apply to Foothills landscapes given the prominence of pine, the regeneration of which rely on the heat from wildfires to open cones, plus access to mineral soil for germination. A more likely scenario is a slow but steady species shift, or perhaps even a shift to non-forest vegetation. Either way, the likely outcome is an (unfamiliar) compositional and structural shift, which translates into an unfamiliar habitat shift.

The seral-stage results for the two caribou ranges confirm the success of past efforts to avoid harvesting in the HWP portions of these areas. Greater than 90% of the HWP part of both herd zones qualify has “high quality caribou habitat” according to Environment Canada (2011). This is good news. However, the current condition is also significantly beyond NRV as regards the amount of older forest, which, given the complexities noted above, may represent a longer-term biological risk to the landscape.

Perhaps of greater interest is that the NRV estimates suggest that these areas were not always high quality woodland caribou habitat. Based on the Environment Canada (2011) habitat recommendations, The A La Peche area was historically only suitable for caribou 79% of the time, and the Little Smokey only 59% of the time – the equivalent of six decades out of every century. Presumably, for the other

four decades, the local caribou either went through a declining phase of their population, or lived elsewhere.

The patch size results are more difficult to interpret. On one hand, clearly one of the primary causes of small patches of older forest is the prevalence of small patches of Young forest (i.e., disturbance). Thus, to some degree the near future of the landscape as regards patch sizes of Old forest is pre-determined. Contiguous Old forest cannot be made by active management, but rather prolonged absence of forest management. The fact that the current condition of Pole and Early Mature patch sizes similarly heavily favours very small patches does not bode well for future Old forest patch sizes.

On the other hand, the current condition estimate did not consider the source of patch isolation. Given the long history of industrial activity on this landscape, linear features such as roads and seismic lines are almost certainly a major cause of patch isolation. Keep in mind that an otherwise contiguous forest area of similar age would be counted as multiple patches if one or more linear features ran through it. This also raises the issue of how a patch *edge* is defined. Right now, a 15-year old 3m seismic line is treated the same as a 50m highway right of way. Thus, the current condition of patch size shown in this study is based on the strictest definition of a patch.

Similarly, one could argue that the ecological differentiation between Late Mature and Old is too subtle to justify separating them for the purposes of capturing patch size. It is not known to what degree current condition of patch sizes would increase if the two oldest seral stages were combined. In any case, there would also be a subsequent increase in the patch sizes of NRV.

6.0 Limitations of this study

As with any research project based on modelling, the results have some limitations. The most prominent are as follows:

1) The LT fire cycle assumptions used in the model may be wrong. Furthermore, it is more likely that fire cycles were shorter than those used in this study based on recent evidence of mixed severity fire regimes. This would increase disturbance levels and decrease Old forest levels. However..
2) The model creates within-fire residuals, but does not allow for partial mortality. Given the same evidence mentioned in point #1 of mixed severity fires, it is likely that partial mortality was more prevalent historically than we

are assuming. This would complicate the definition of seral-stages, but would ultimately create more forest with “old growth” characteristics sooner.

3) Forest succession was turned “off”. The assumption was that over thousands of years, the deviations caused by succession would even out. Whether or not this is true is untested. This would be more likely to influence the relative percentages of deciduous, mixedwood, and white spruce forest types, which collectively account for 32% of the HWP FMA (Lieffers et al. 1996).

4) Patch definitions were rigid and simple. This is of particular interest to the integration of linear features. Since there is no NRV equivalent to linear features, a more informative evaluation of the current condition of patch sizes might include various definitions of *edge*. The result would be an increase in the prevalence of larger patches – to an unknown degree.

5) The likely inaccuracy of the forest inventory data for older forest creates some doubt about the exact nature of current conditions. The most likely scenario is that a moderate portion of the Late Mature is actually Old, which does not fundamentally change the conclusions, but may mean higher landscape risks that the current age data suggest.

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Appendix A: Frequency Distributions of Non-Spatial Model Output

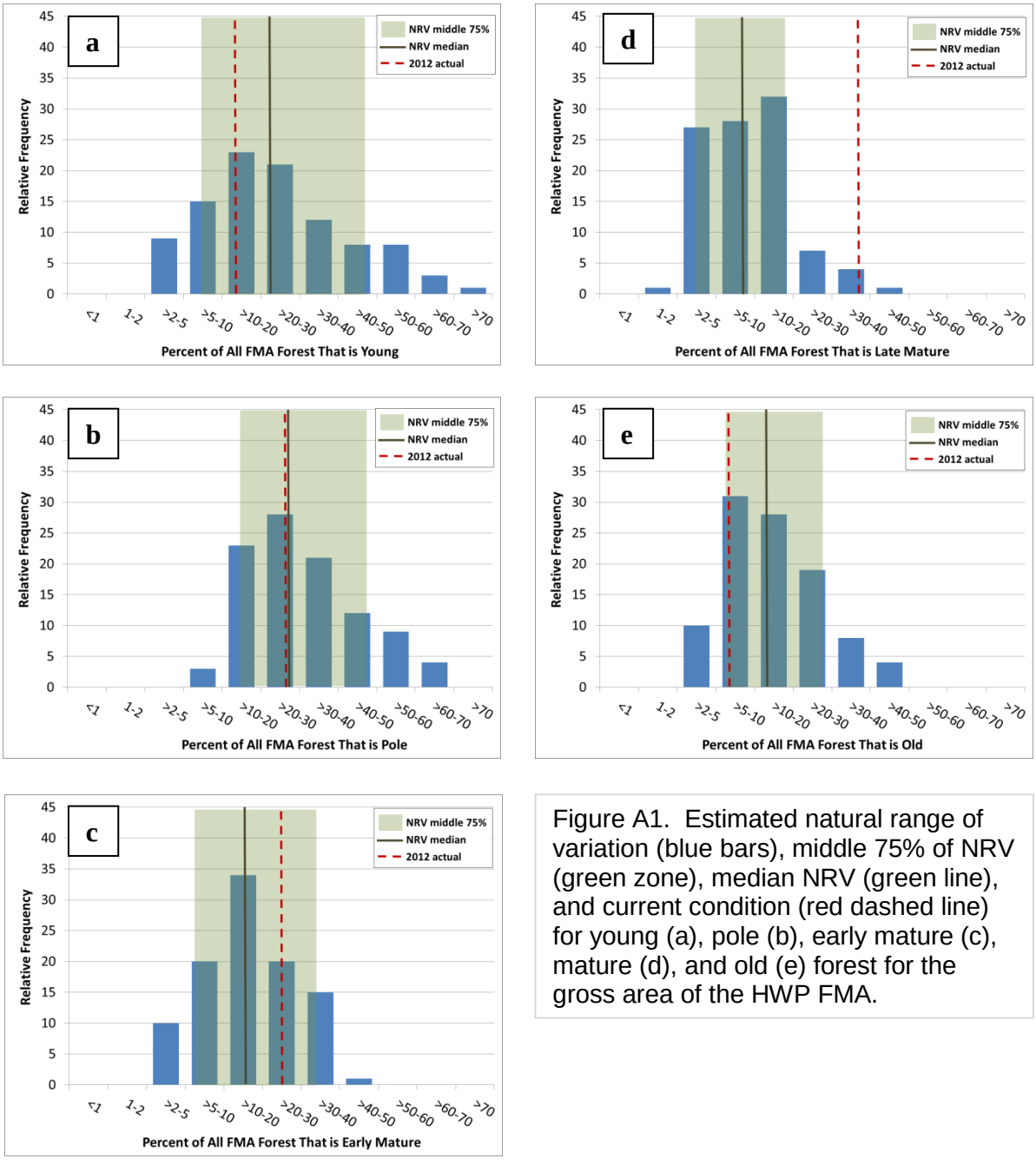
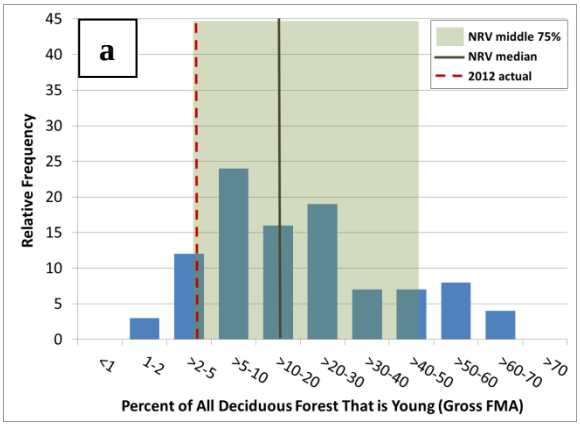
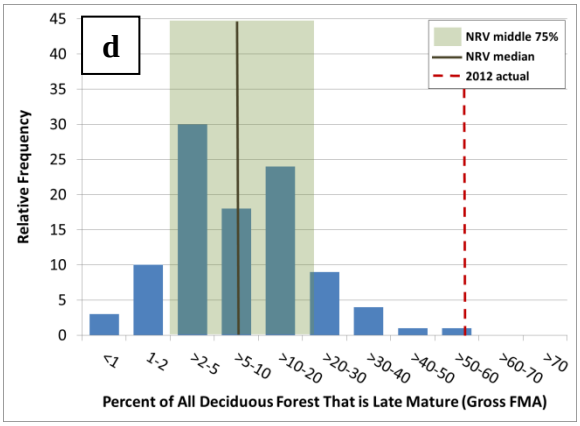


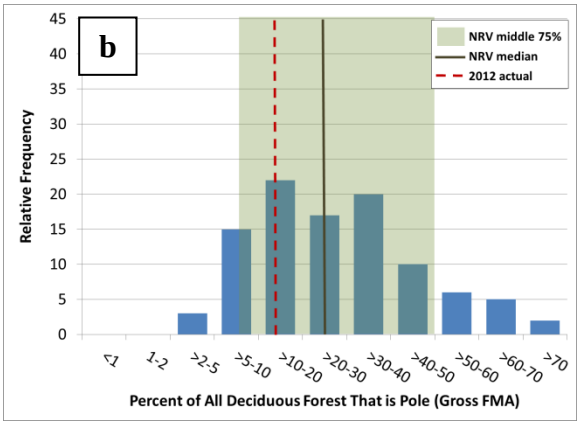
Figure A1. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the gross area of the HWP FMA.

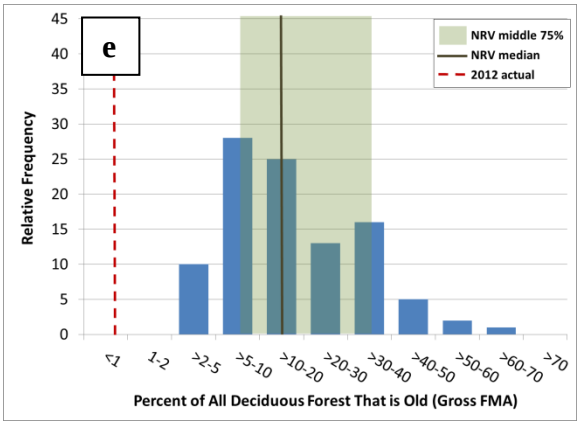
Gross FMA highlights:

- All current conditions are within NRV, but the Late Mature is very close to the upper bounds of NRV.
- All other seral stages are within their respective 75% NRV bounds, although the Old level is close to the lower bound.









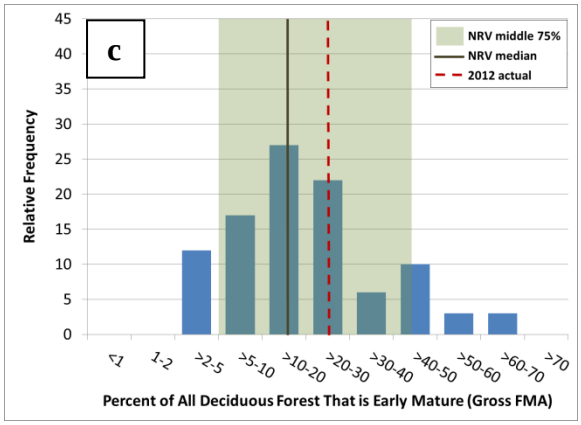
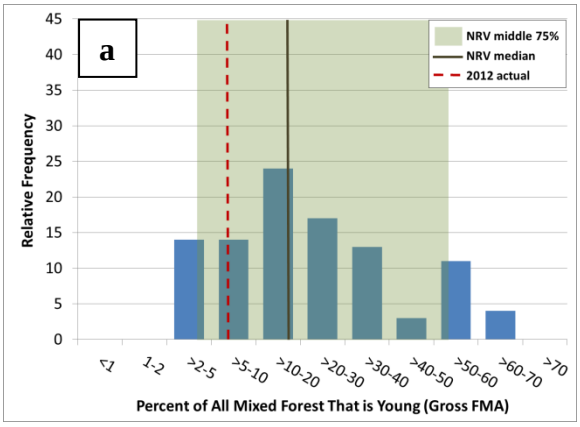
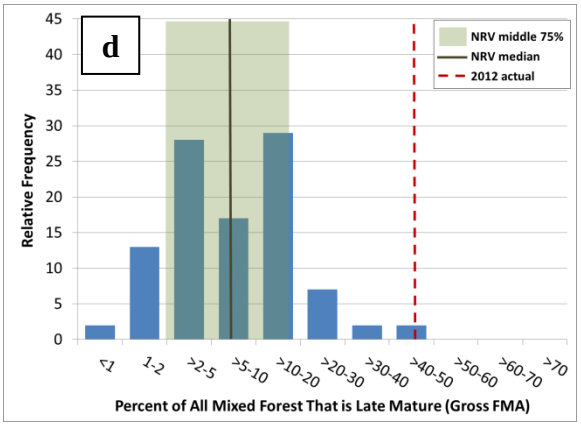


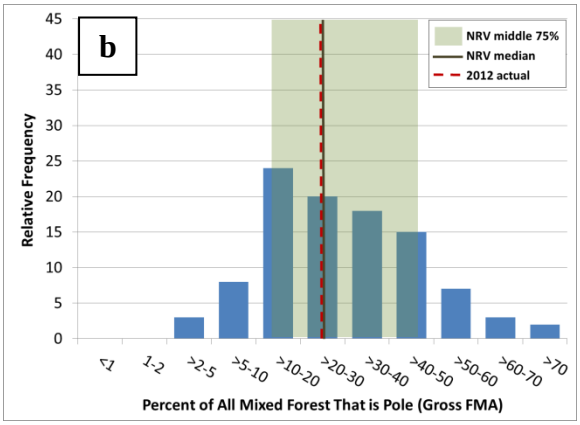
Figure A2. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) aspen (deciduous) forest for the gross area of the HWP FMA.

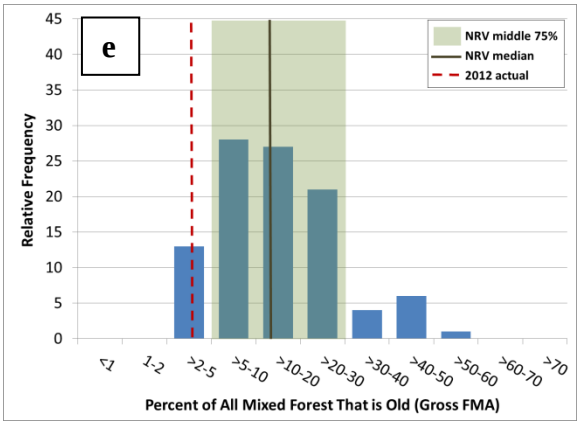
Gross FMA deciduous / aspen forest highlights:

- The current condition of Late Mature is very close to the upper bounds of NRV.
- The current condition of Old is far below the lower bound of NRV.
- The current condition of Young is on the lower boundary of the 75% NRV range.









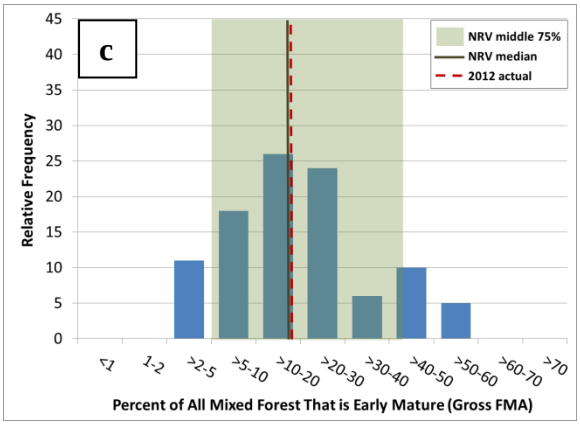
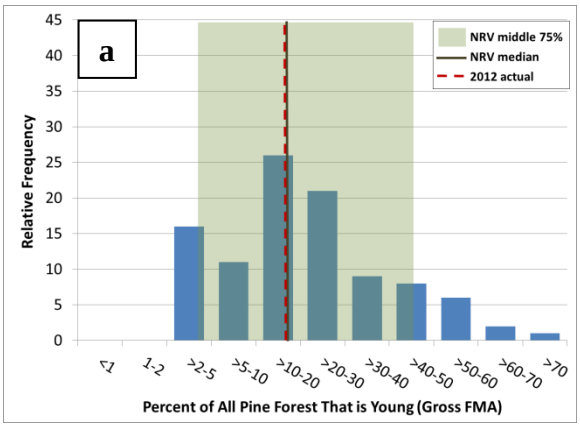
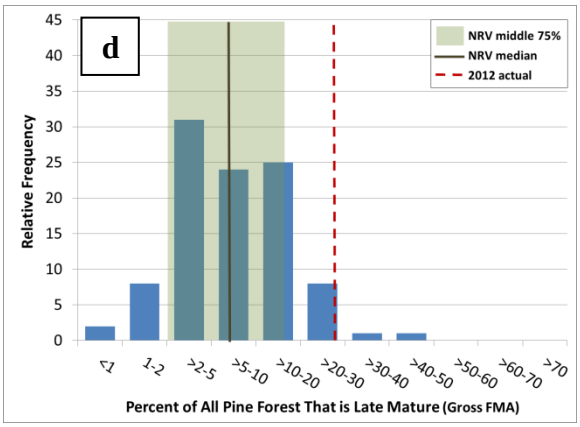


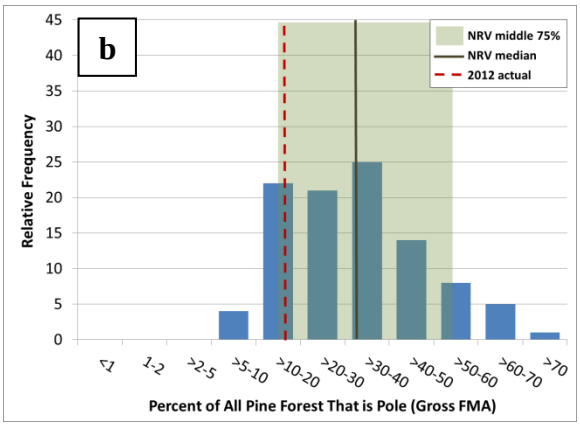
Figure A3. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the gross area of the HWP FMA.

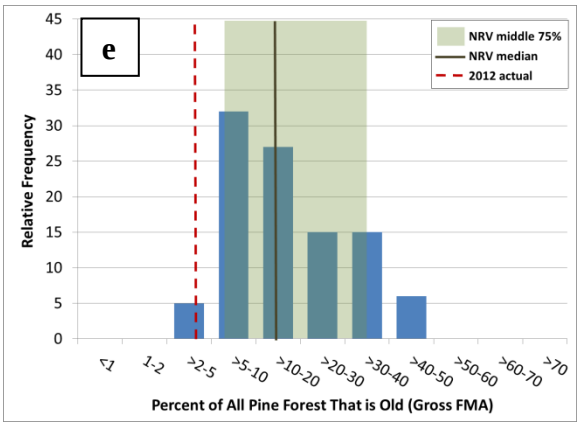
<u>Gross FMA mixedwood forest highlights:</u>

- The current condition of Late Mature is very close to the upper bounds of NRV.
- The current condition of Old is below the lower boundary of the 75% NRV range.









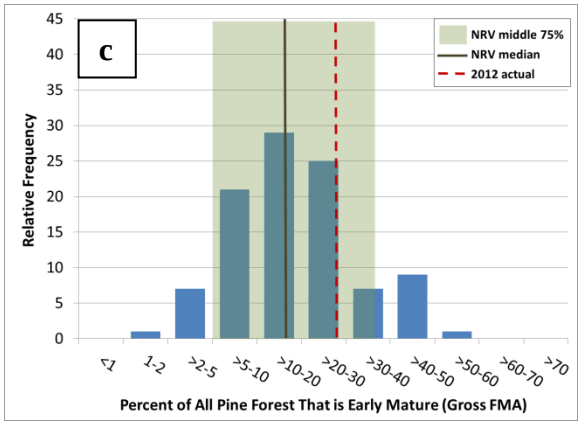
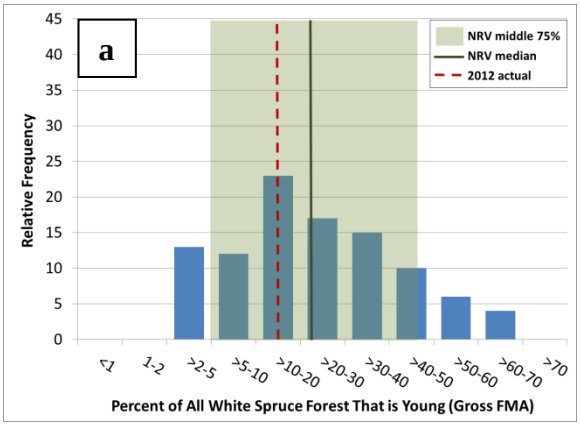
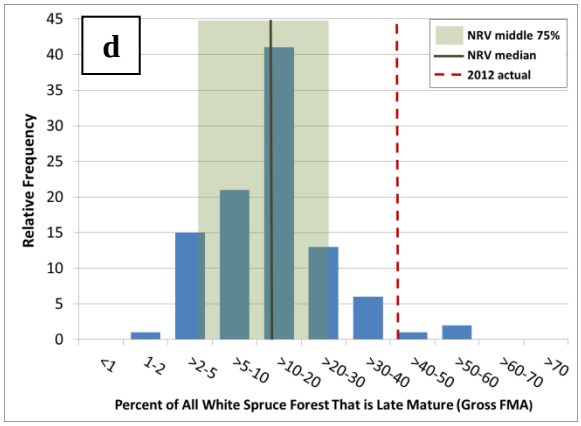


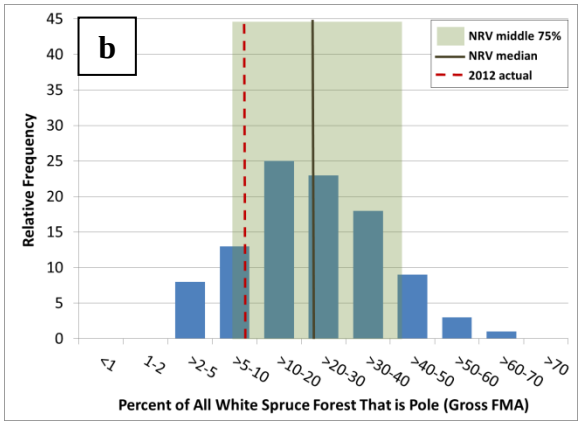
Figure A4. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the gross area of the HWP FMA.

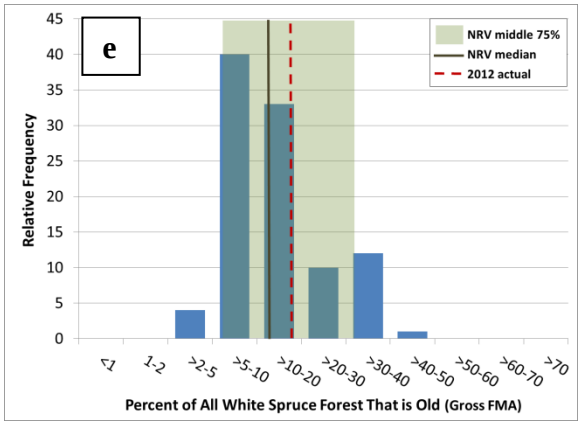
<u>Gross FMA pine forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Pole is on the lower edge of 75% NRV, and Old is beyond the lower bound of 75% NRV.
- The current condition of Late Mature is well beyond the upper boundary of 75% NRV, and close to the NRV boundary.









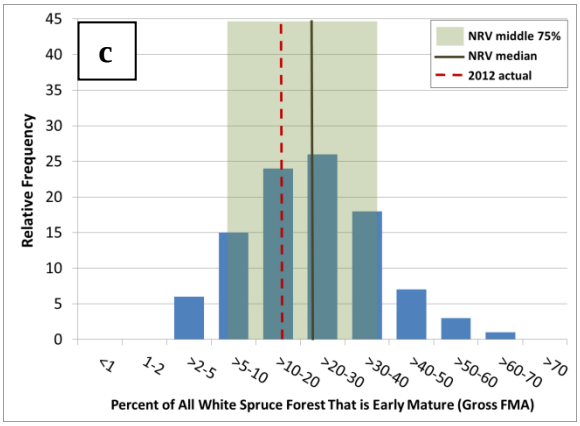
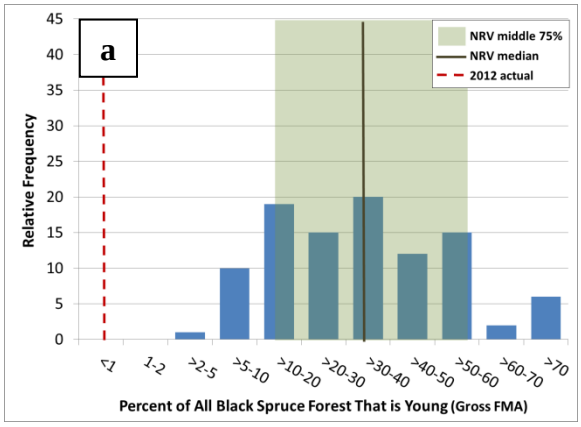
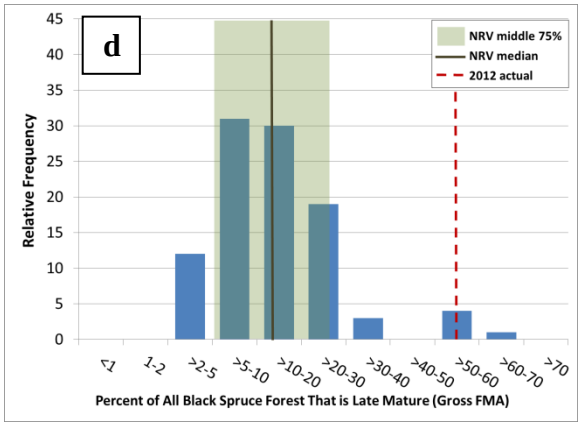


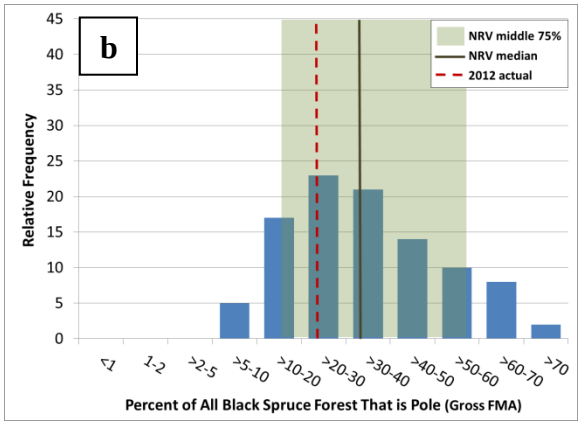
Figure A5. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the gross area of the HWP FMA.

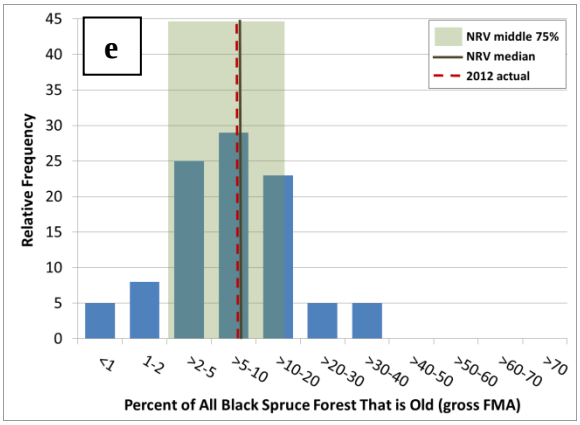
<u>Gross FMA white spruce forest highlights:</u>

- All current conditions are within NRV, although the current condition of Late Mature is close to the upper boundary of NRV.









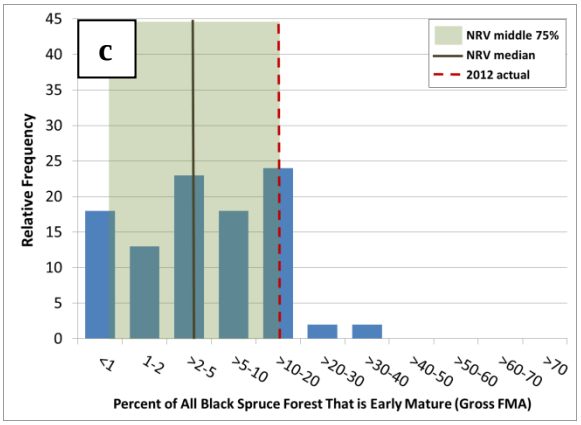
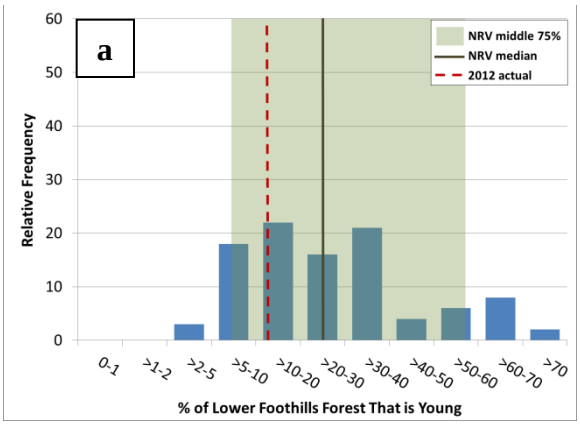
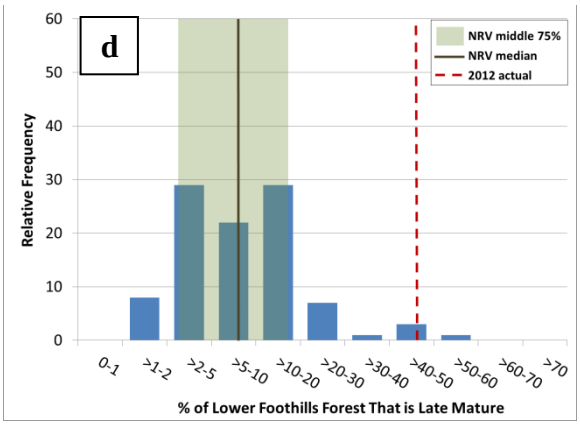


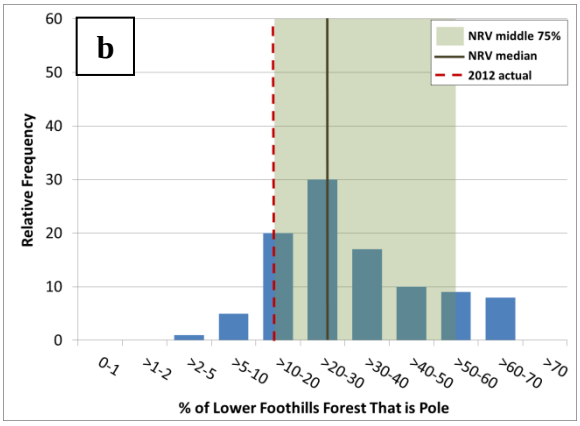
Figure A6. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the gross area of the HWP FMA.

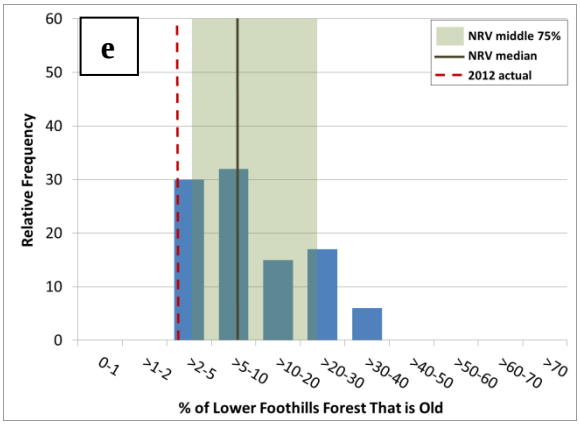
<u>Gross FMA black spruce forest highlights:</u>

- The current condition of Young is well below the lower boundary of NRV, and the current condition of Late Mature is close to the upper boundary of NRV.
- The current condition of Early Mature is on the boundary of the 75% NRV zone.









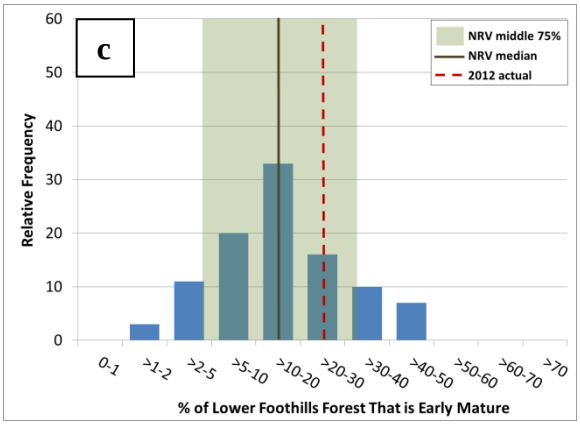
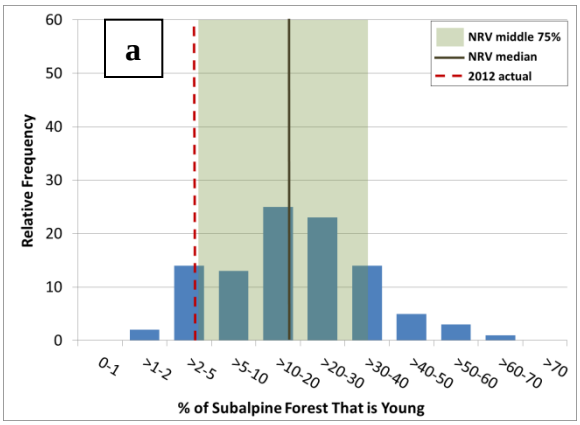
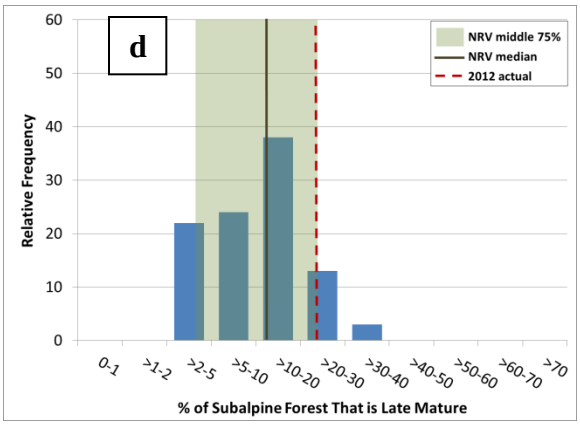


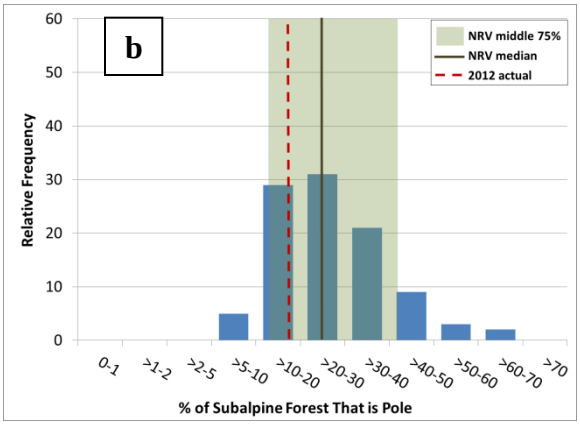
Figure A7. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the Lower Foothills NSR within the HWP FMA.

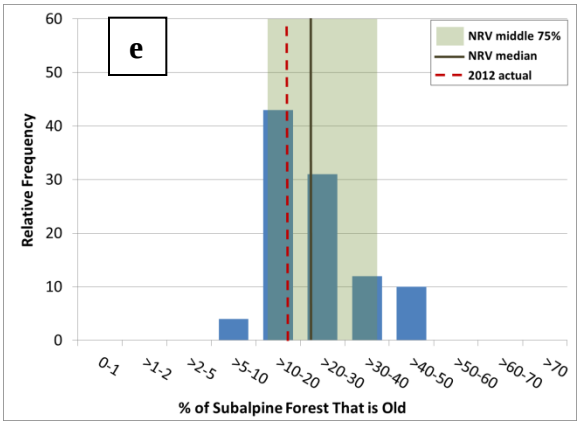
<u>FMA Lower Foothills highlights:</u>

- All current conditions are within NRV
- The current conditions of Pole and Old forest are slightly below the lower boundary of the 75% NRV zone.
- The current condition of Late Mature forest is well beyond the upper boundary of the 75% NRV zone, and almost beyond NRV.









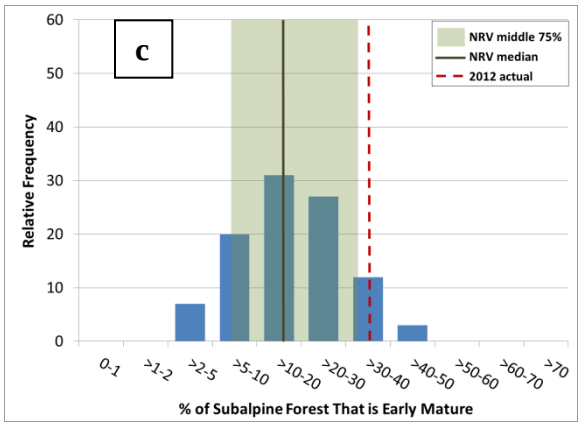
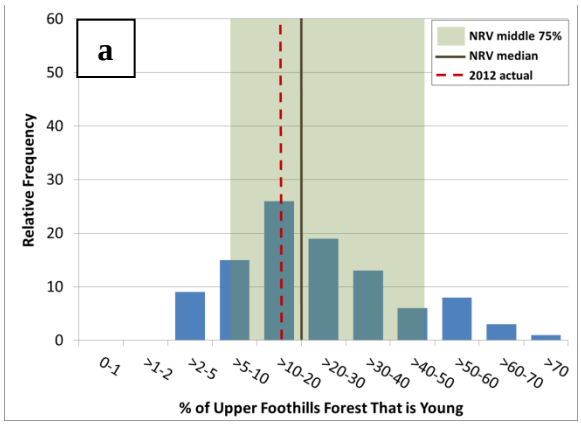
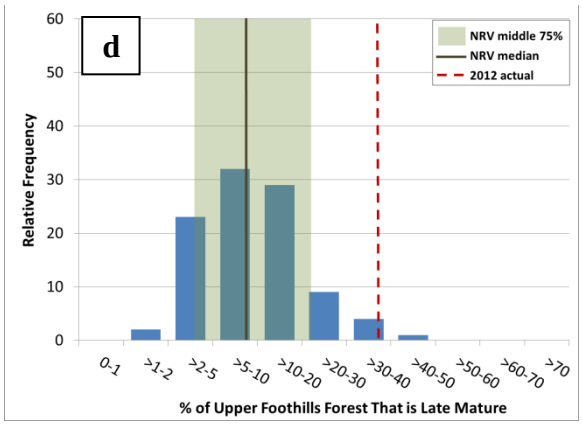


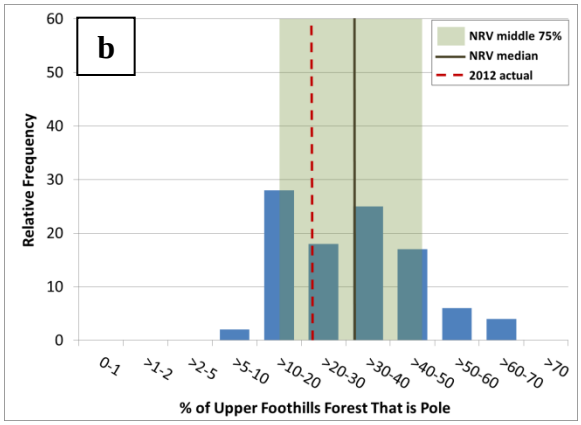
Figure A8. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the Subalpine NSR within the HWP FMA.

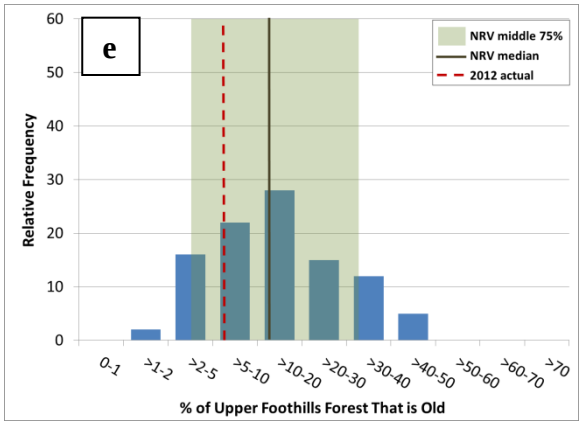
<u>FMA Subalpine highlights:</u>

- All current conditions are within NRV
- The current condition of Young forest is slightly below the 75% NRV zone
- The current conditions of Early Mature and Late Mature forest are slightly beyond the upper bound of the 75% NRV zone.









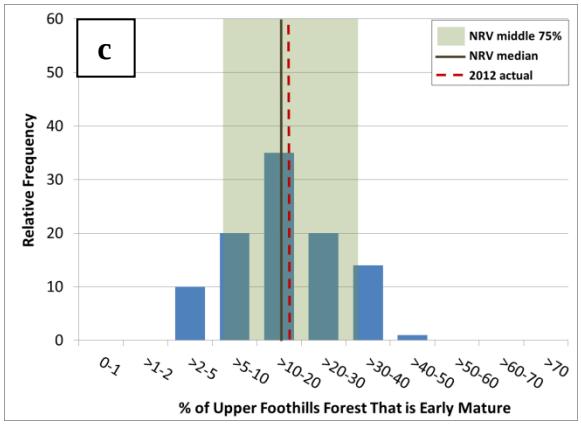


Figure A9. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the Upper Foothills NSR within the HWP FMA.

<u>FMA Upper Foothills highlights:</u>

- All current conditions are within NRV
- The current condition of Late Mature forest is beyond the upper boundary of the 75% NRV zone.

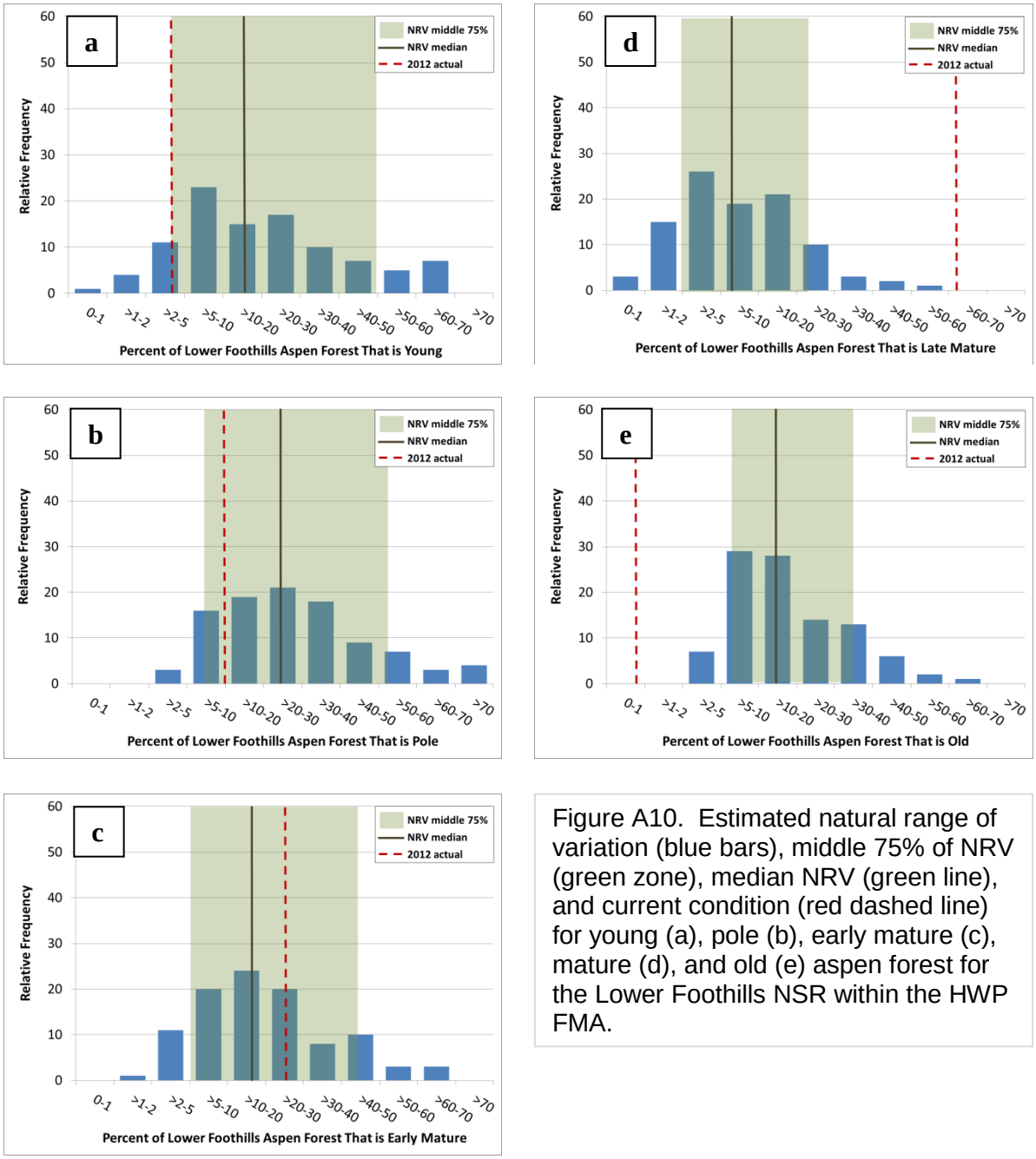


Figure A10. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) aspen forest for the Lower Foothills NSR within the HWP FMA.

<u>FMA Lower Foothills aspen forest highlights:</u>

- The current condition of Late Mature is beyond the upper bounds of NRV
- The current conditions of Old is below the lower bounds of NRV
- The current condition of Young is slightly below the lower bounds of 75% NRV

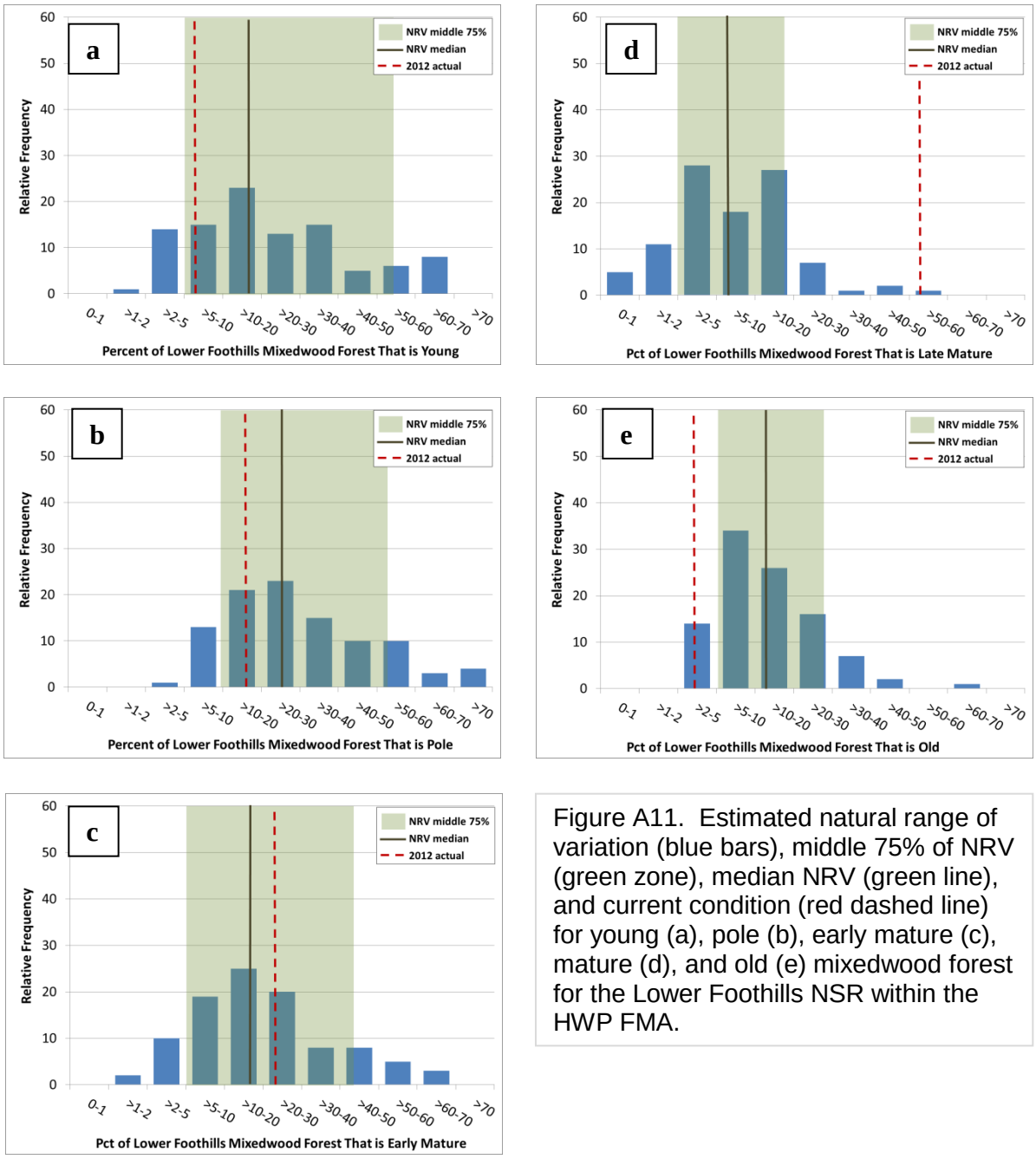
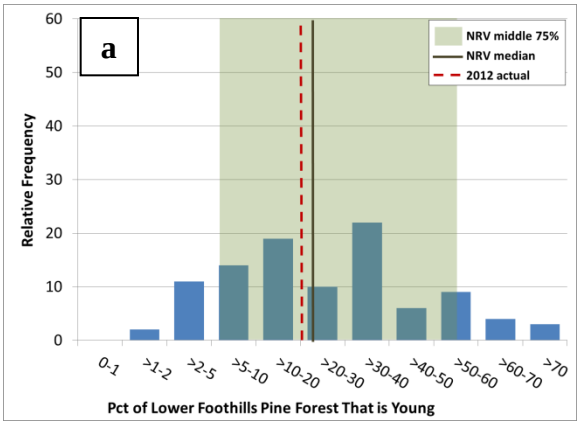
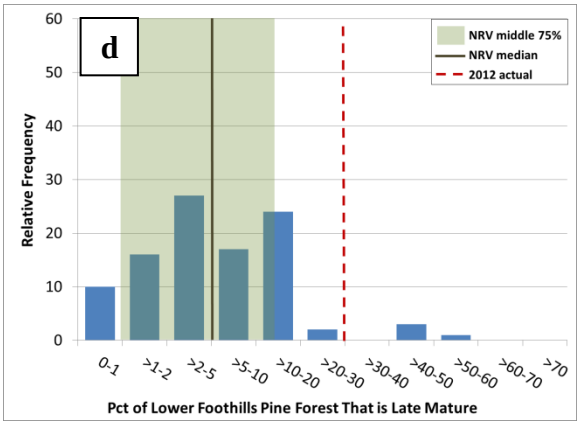


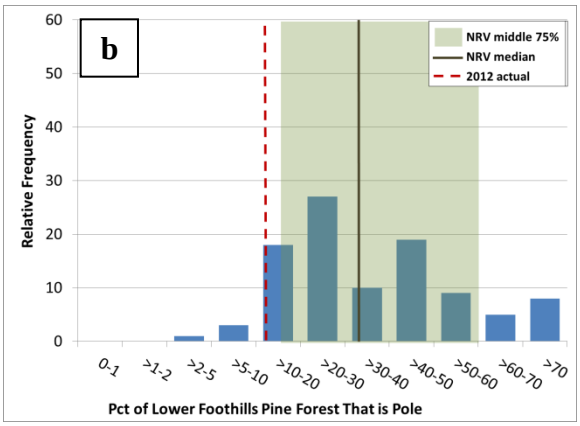
Figure A11. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the Lower Foothills NSR within the HWP FMA.

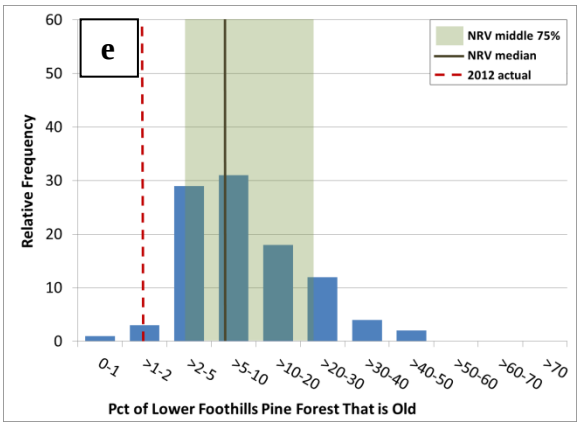
<u>FMA Lower Foothills mixedwood forest highlights:</u>

- The current condition of Late Mature is beyond the upper bounds of NRV
- The current conditions of Old is below the lower bounds of NRV
- The current condition of Young is slightly below the lower bounds of 75% NRV









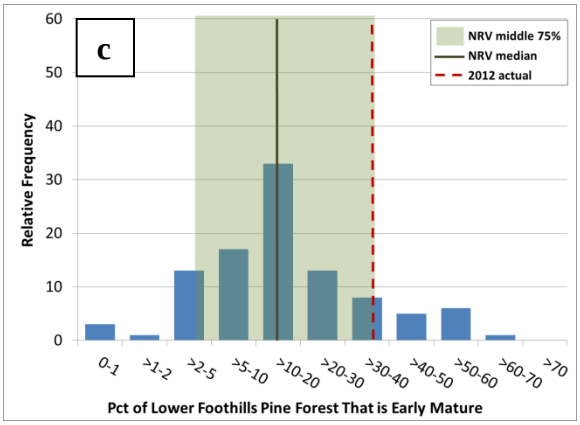
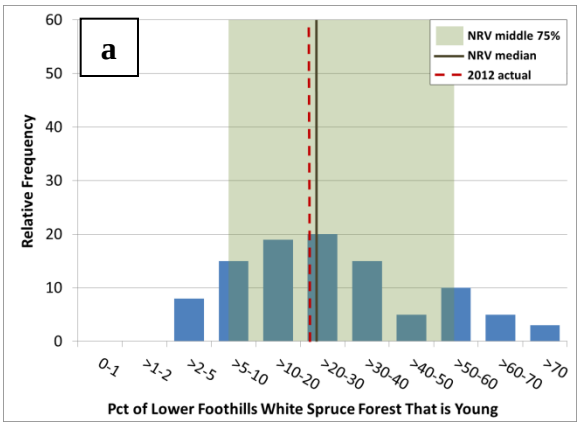
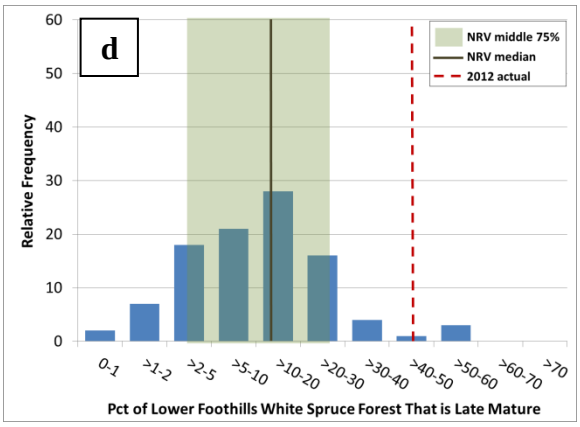


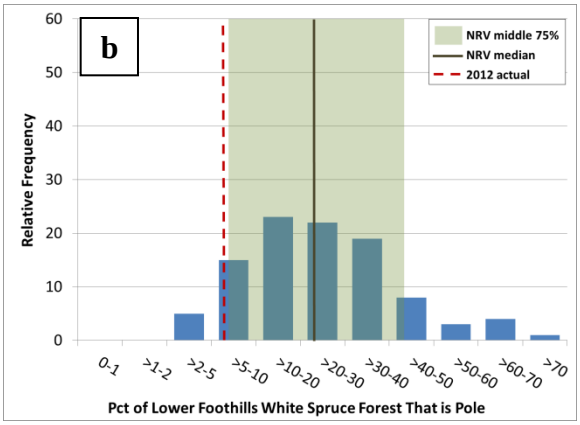
Figure A12. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the Lower Foothills NSR within the HWP FMA.

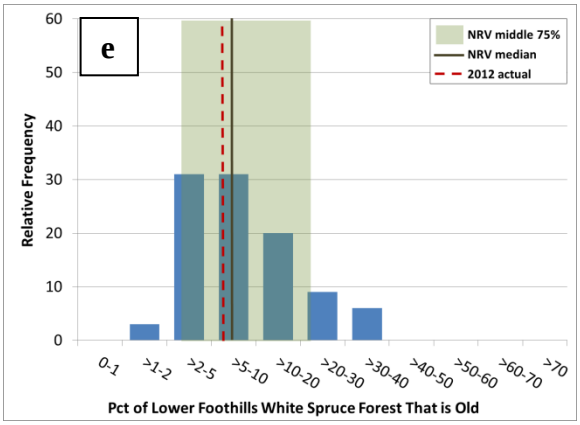
<u>FMA Lower Foothills pine forest highlights:</u>

- All current conditions are within NRV
- The current conditions of Pole and Old are beyond the lower boundaries of 75% NRV, and are close to being beyond NRV.
- The current condition of Late Mature is above the upper bound of 75% NRV, and close to being beyond NRV.









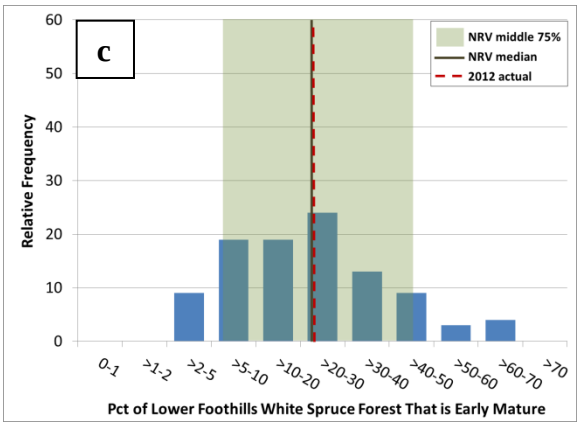
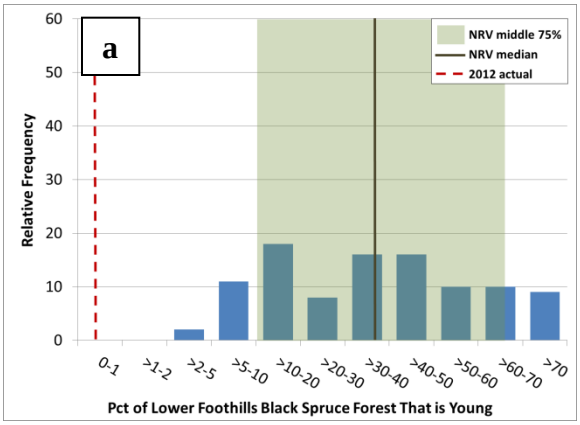
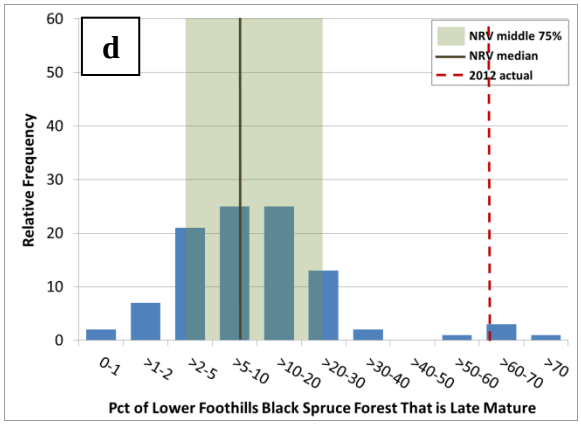


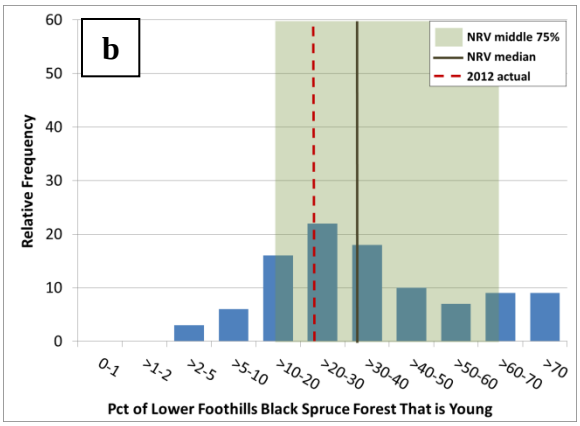
Figure A13. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the Lower Foothills NSR within the HWP FMA.

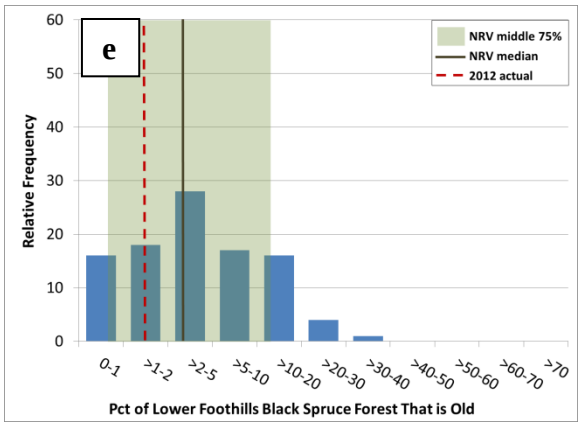
<u>FMA Lower Foothills white spruce forest highlights:</u>

- All current conditions are within NRV
- The current condition of Pole beyond the lower boundaries of 75% NRV.
- The current condition of Late Mature is above the upper bound of 75% NRV, and close to being beyond NRV.









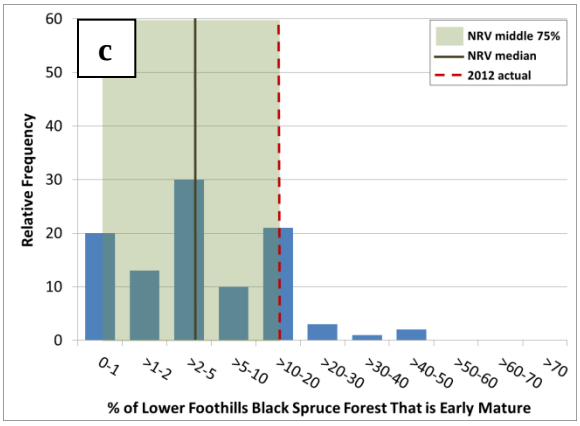


Figure A14. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the Lower Foothills NSR within the HWP FMA.

<u>FMA Lower Foothills black spruce forest highlights:</u>

- All current conditions of the amount of Young forest is (well) below NRV.
- The current condition of Late Mature is above the upper bound of 75% NRV, and close to being beyond NRV.

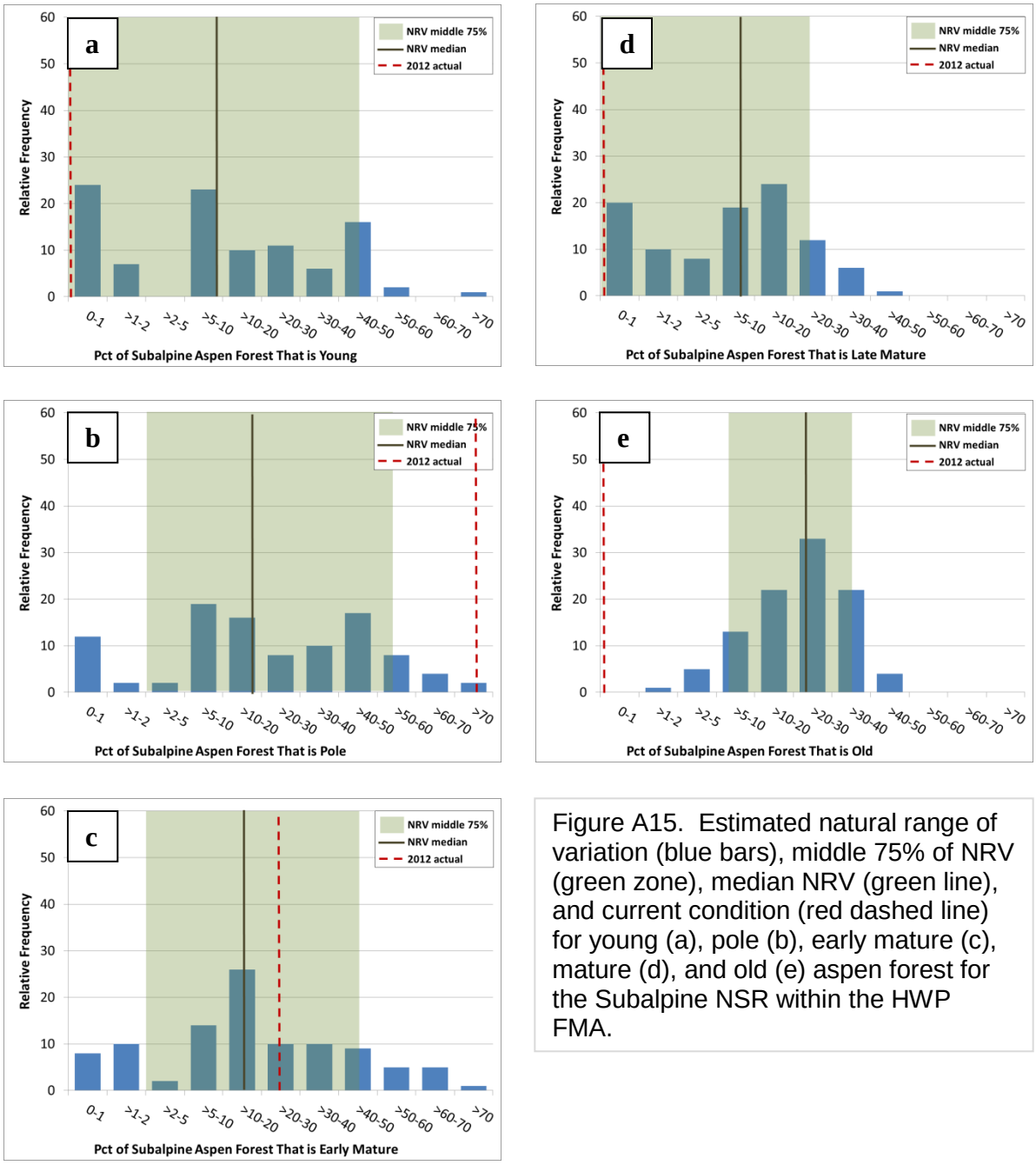
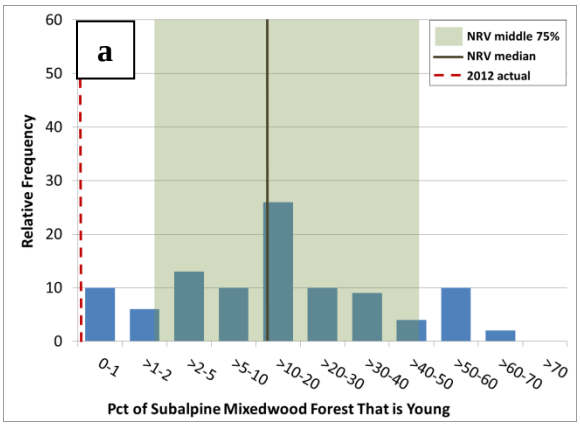
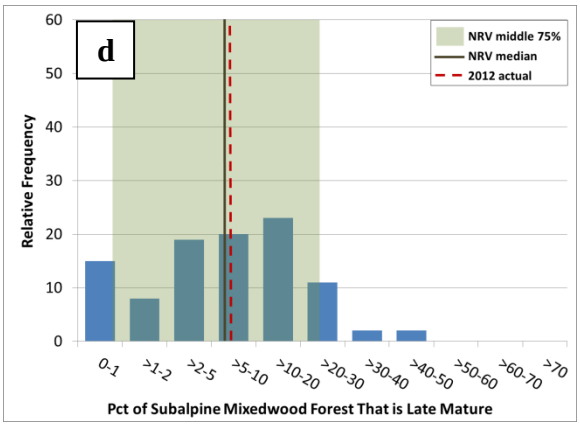


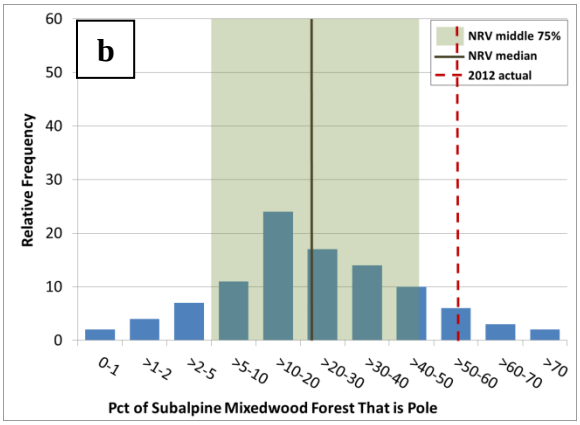
Figure A15. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) aspen forest for the Subalpine NSR within the HWP FMA.

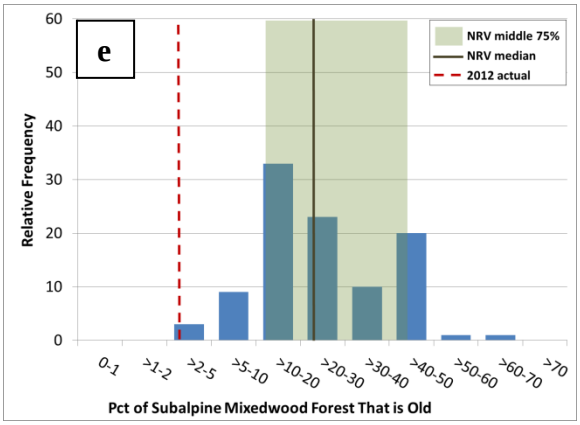
<u>FMA Subalpine aspen forest highlights:</u>

- NOTE: There are only 200 ha of aspen leading forest in the Subalpine.
- NRV is extremely wide for such very small land areas.
- The current condition of zero area in several seral-stages is within NRV.









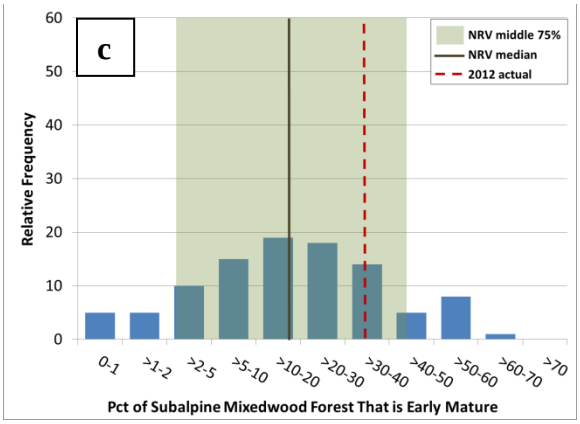


Figure A16. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the Subalpine NSR within the HWP FMA.

<u>FMA Subalpine mixedwood forest highlights:</u>

- NOTE: There are only 2,000 ha of mixedwood leading forest in the Subalpine.
- NRV is extremely wide for such small land areas.
- The current condition of zero Young forest, and >50% Pole forest are both unusual, but still within NRV.

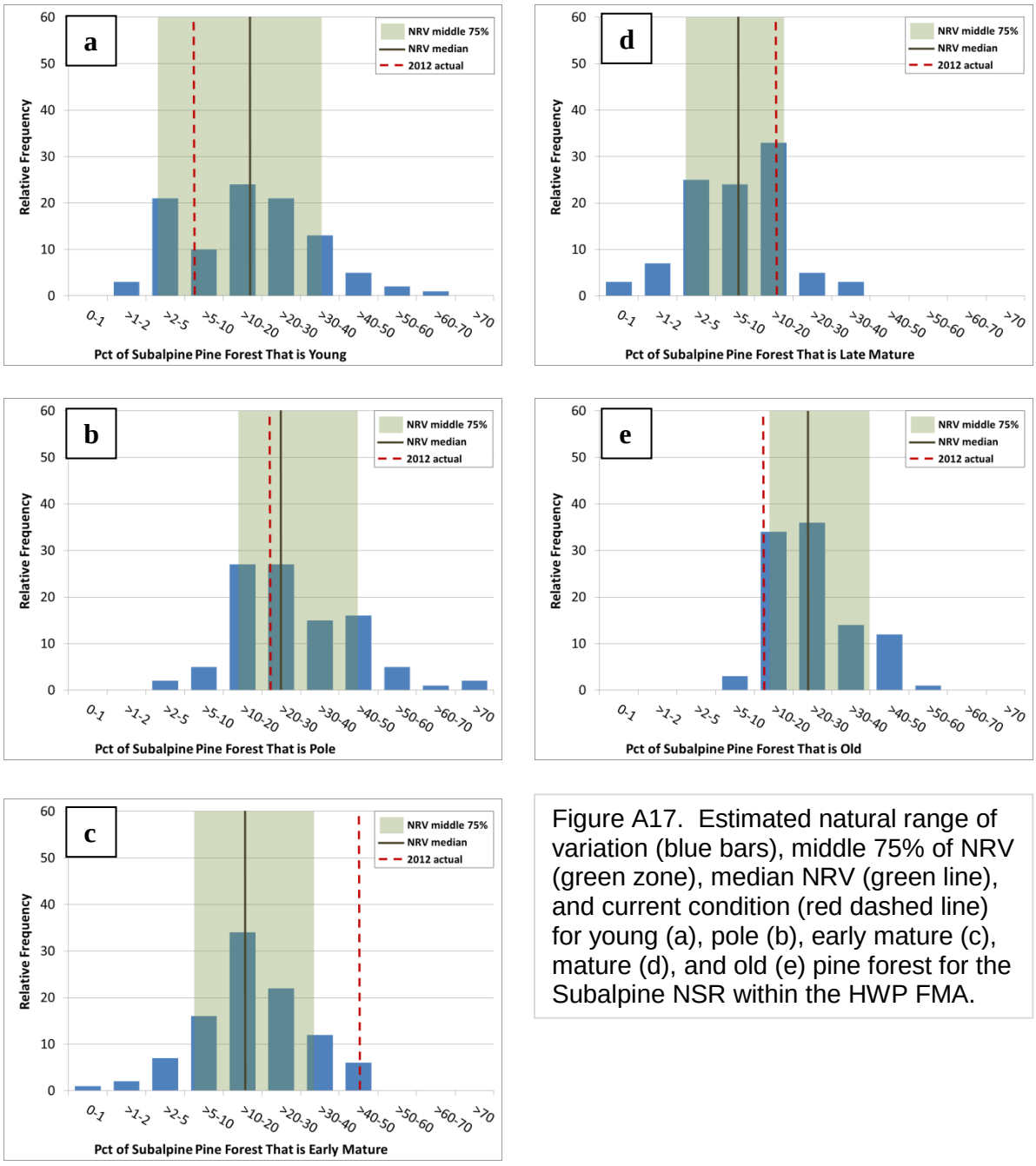
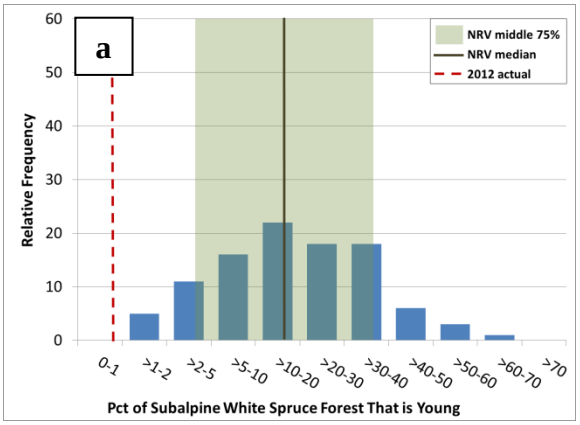
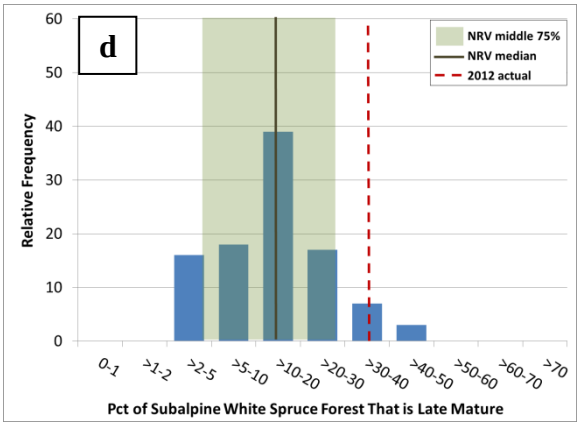


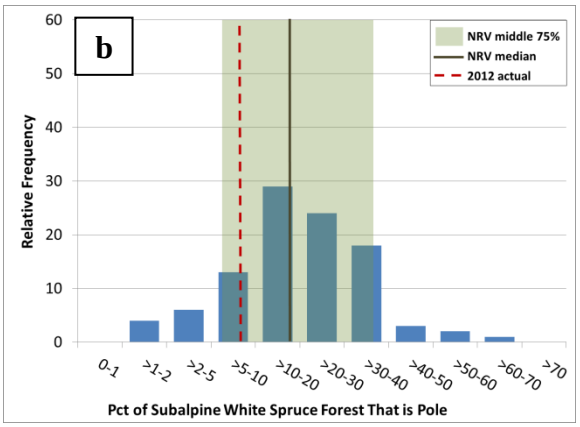
Figure A17. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the Subalpine NSR within the HWP FMA.

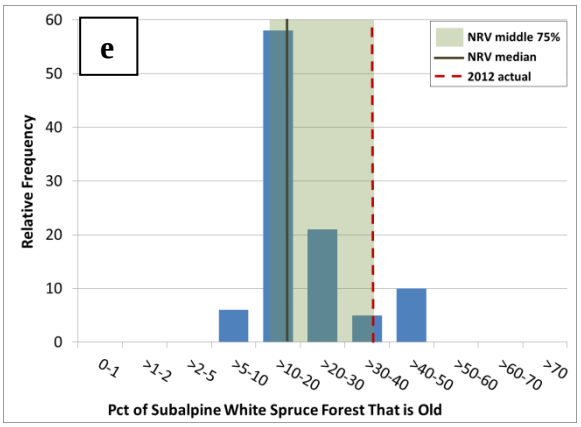
FMA Subalpine pine forest highlights:

- All current conditions are within NRV
- The current conditions of Old forest is slightly below the lower boundary of the 75% NRV zone.
- The current condition of Early Mature forest is well beyond the upper boundary of the 75% NRV zone, and almost beyond NRV.









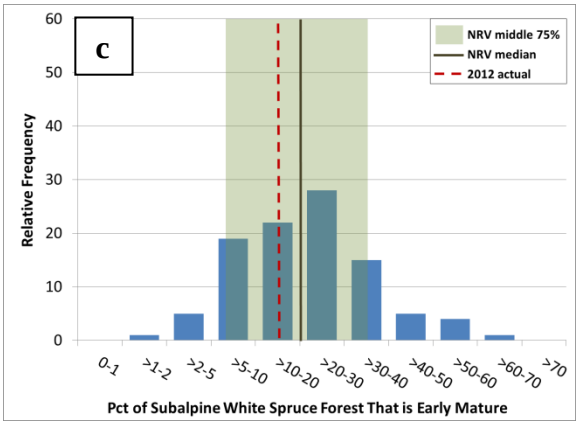


Figure A18. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the Subalpine NSR within the HWP FMA.

<u>FMA Subalpine white spruce forest highlights:</u>

- The current condition of Young forest is below the lower boundary of NRV.
- The current condition of Late Mature forest is beyond the upper boundary of the 75% NRV zone, and the current condition of Old forest is on the upper boundary of the 75% zone.

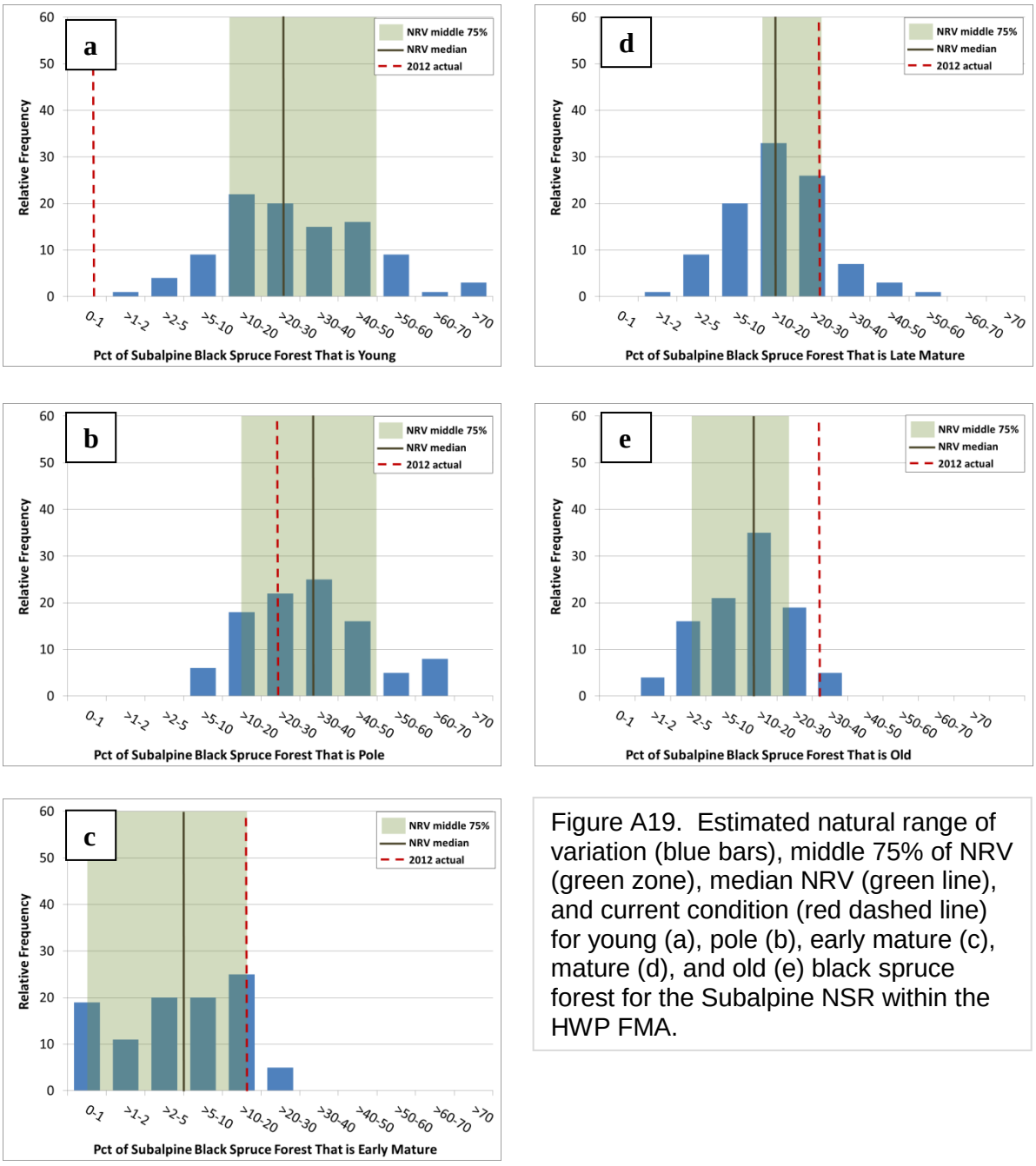


Figure A19. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the Subalpine NSR within the HWP FMA.

<u>FMA Subalpine black spruce forest highlights:</u>

- The current condition of Young forest is below the lower boundary of NRV.
- The current condition of Old forest is well beyond the upper boundary of the 75% NRV zone, and the current condition of both Early Mature and Later Mature forest are on the upper boundary of the 75% zone.

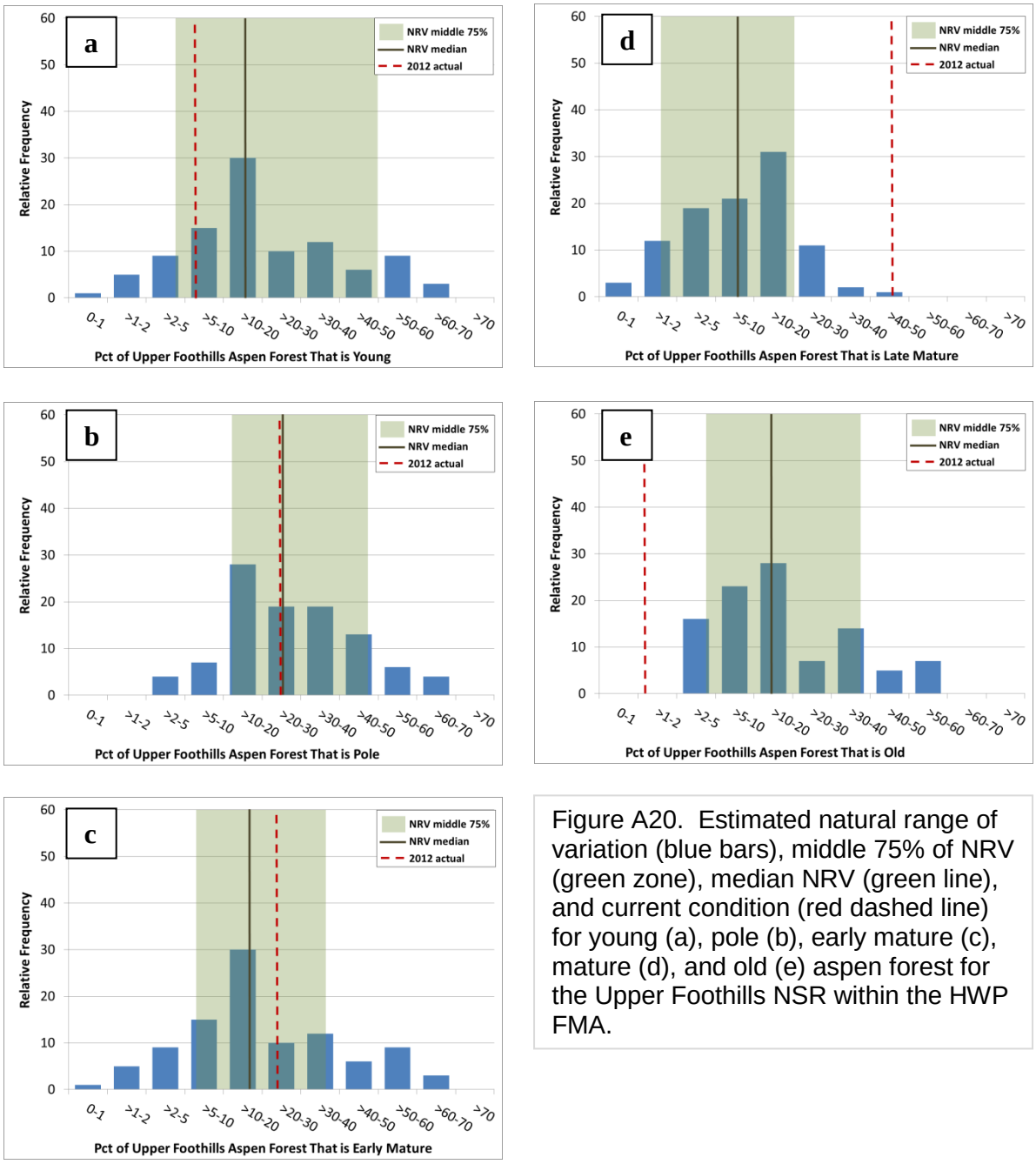
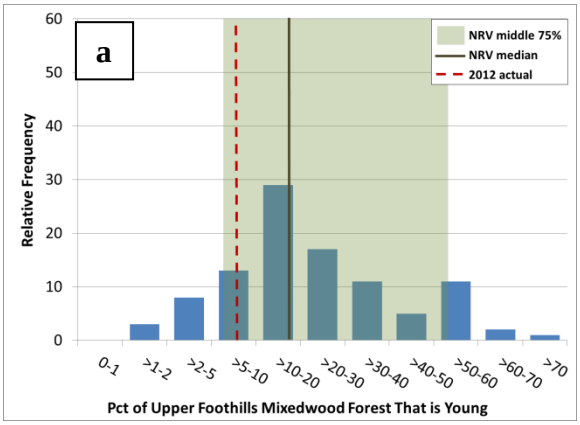
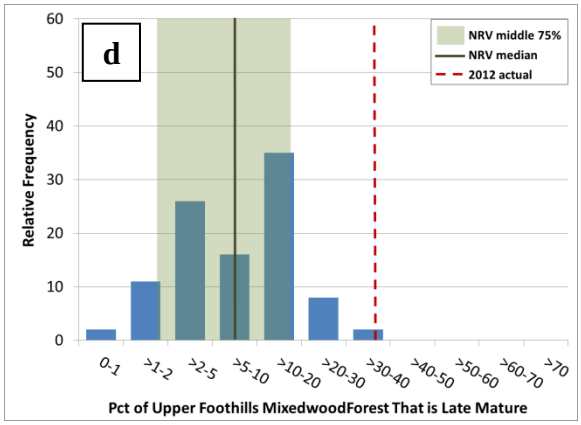


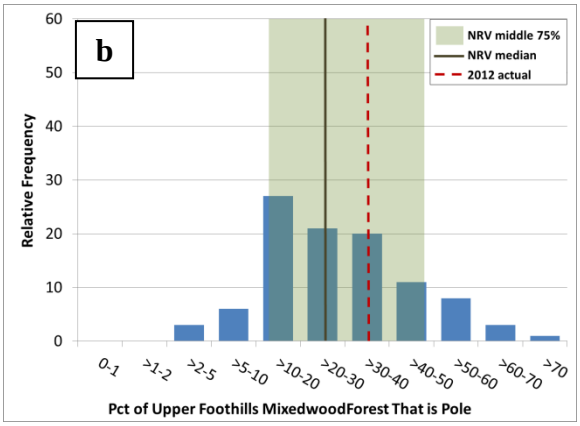
Figure A20. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) aspen forest for the Upper Foothills NSR within the HWP FMA.

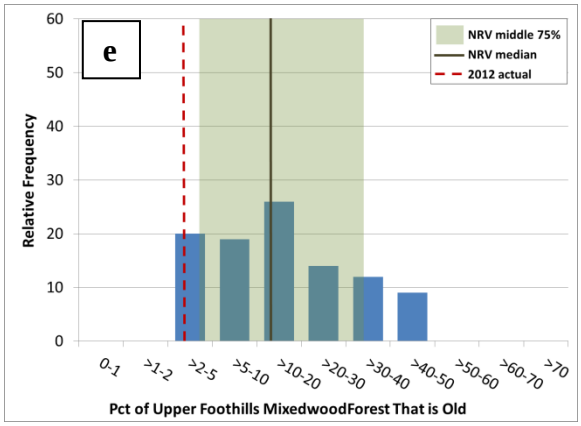
<u>FMA Upper Foothills aspen forest highlights:</u>

- The current condition of Old forest is below the lower boundary of NRV, and the current condition of the Late Mature forest is on the upper boundary of NRV.
- The current condition of remaining seral stages are with their respective 75% NRV ranges.









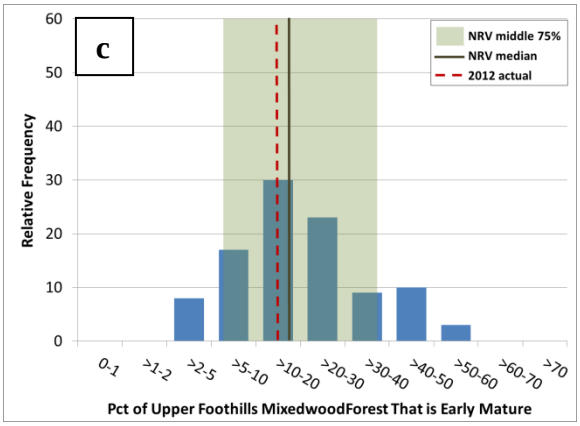


Figure A21. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the Upper Foothills NSR within the HWP FMA.

<u>FMA Upper Foothills mixedwood forest highlights:</u>

- The current condition of Old forest is below the lower boundary of NRV, and the current condition of the Late Mature forest is on the upper boundary of NRV.
- The current condition of remaining seral stages are with their respective 75% NRV ranges.

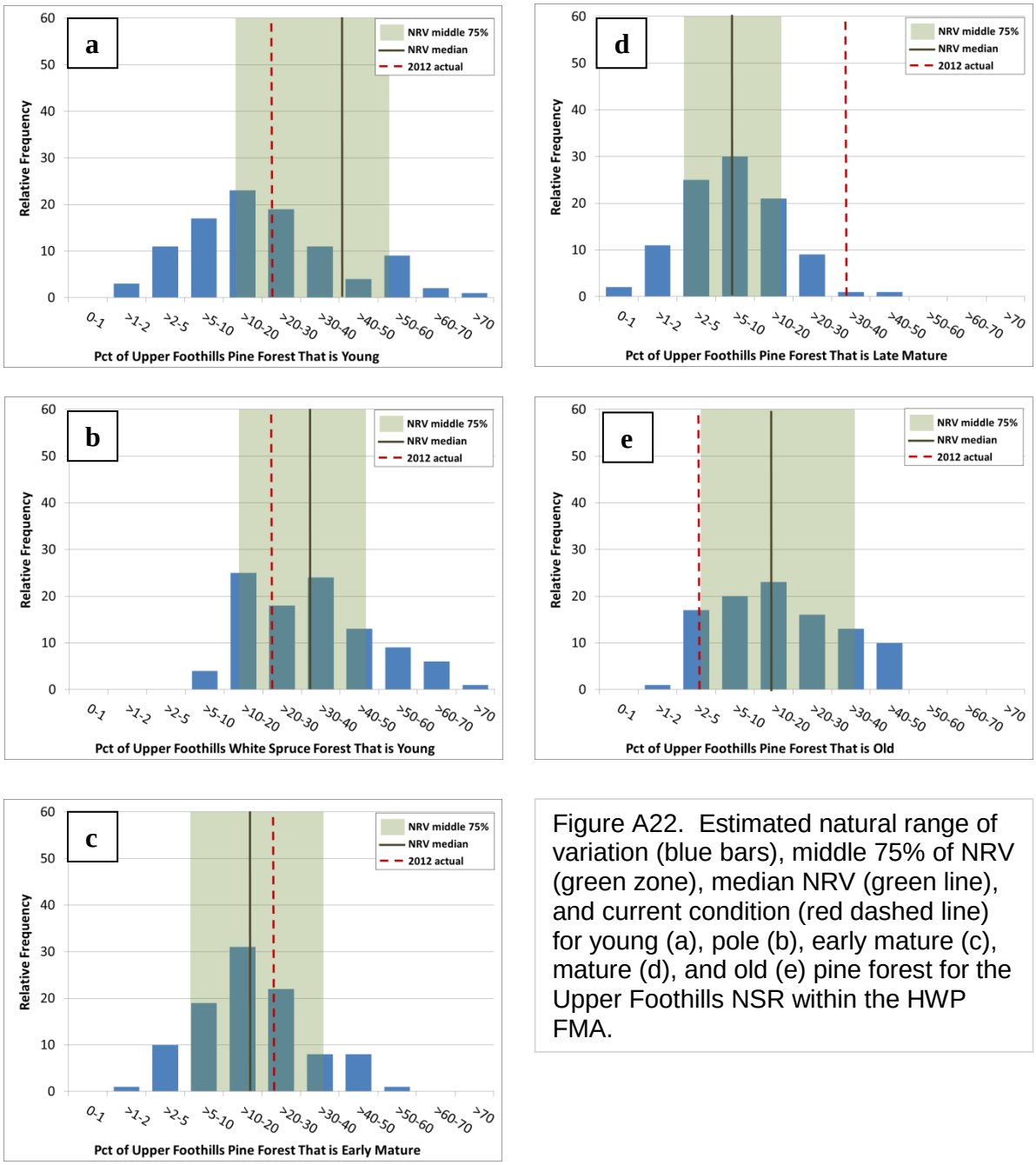
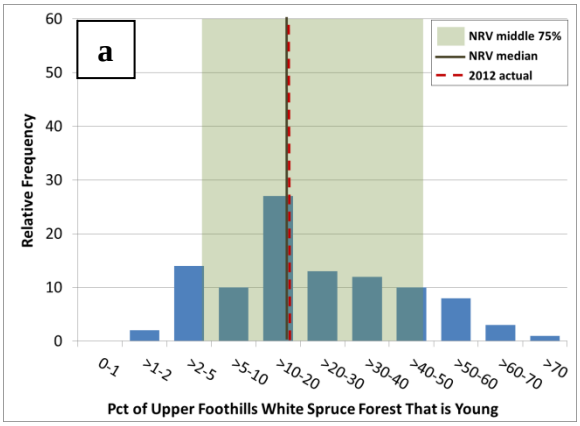
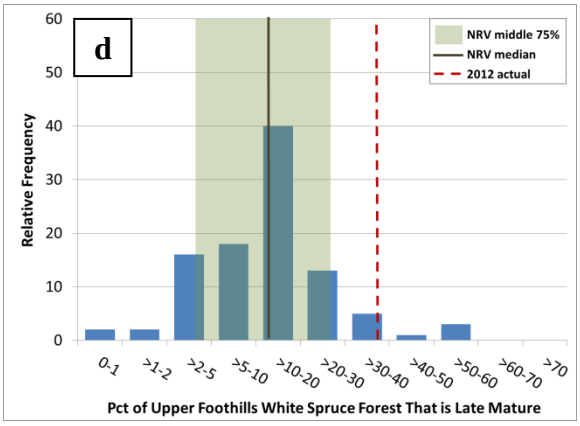


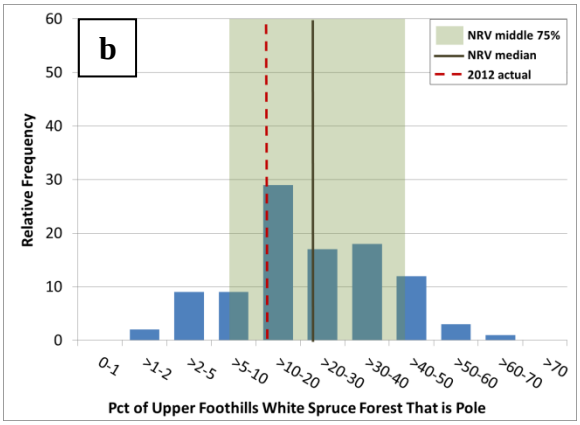
Figure A22. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the Upper Foothills NSR within the HWP FMA.

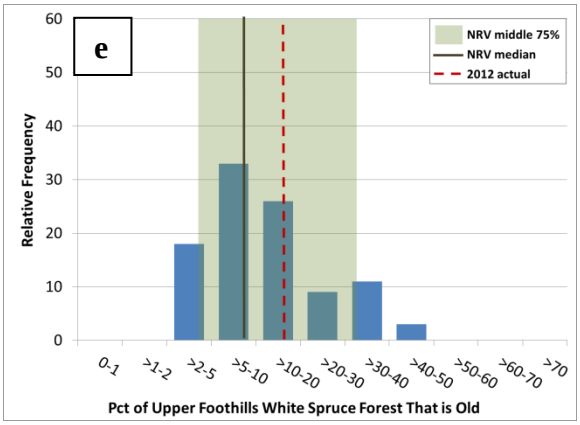
<u>FMA Upper Foothills pine forest highlights:</u>

- The current condition of Late Mature forest is on the upper boundary of NRV.
- The current condition of Old is slightly lower than the lower boundary of the 75% NRV range.









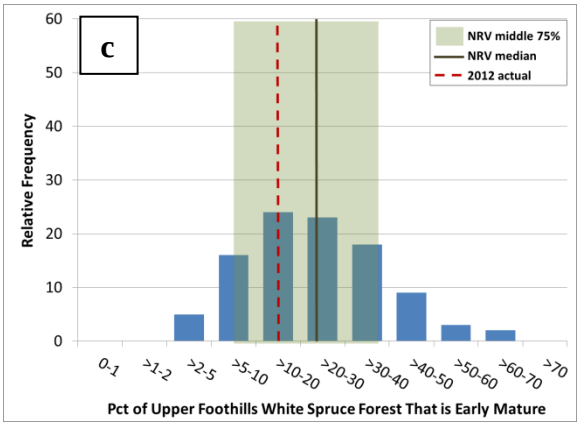


Figure A23. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the Upper Foothills NSR within the HWP FMA.

<u>FMA Upper Foothills white spruce forest highlights:</u>

- All current conditions are within NRV, although the Late Mature level is close to the upper boundary.
- All other seral stages are within the 75% NRV bounds.

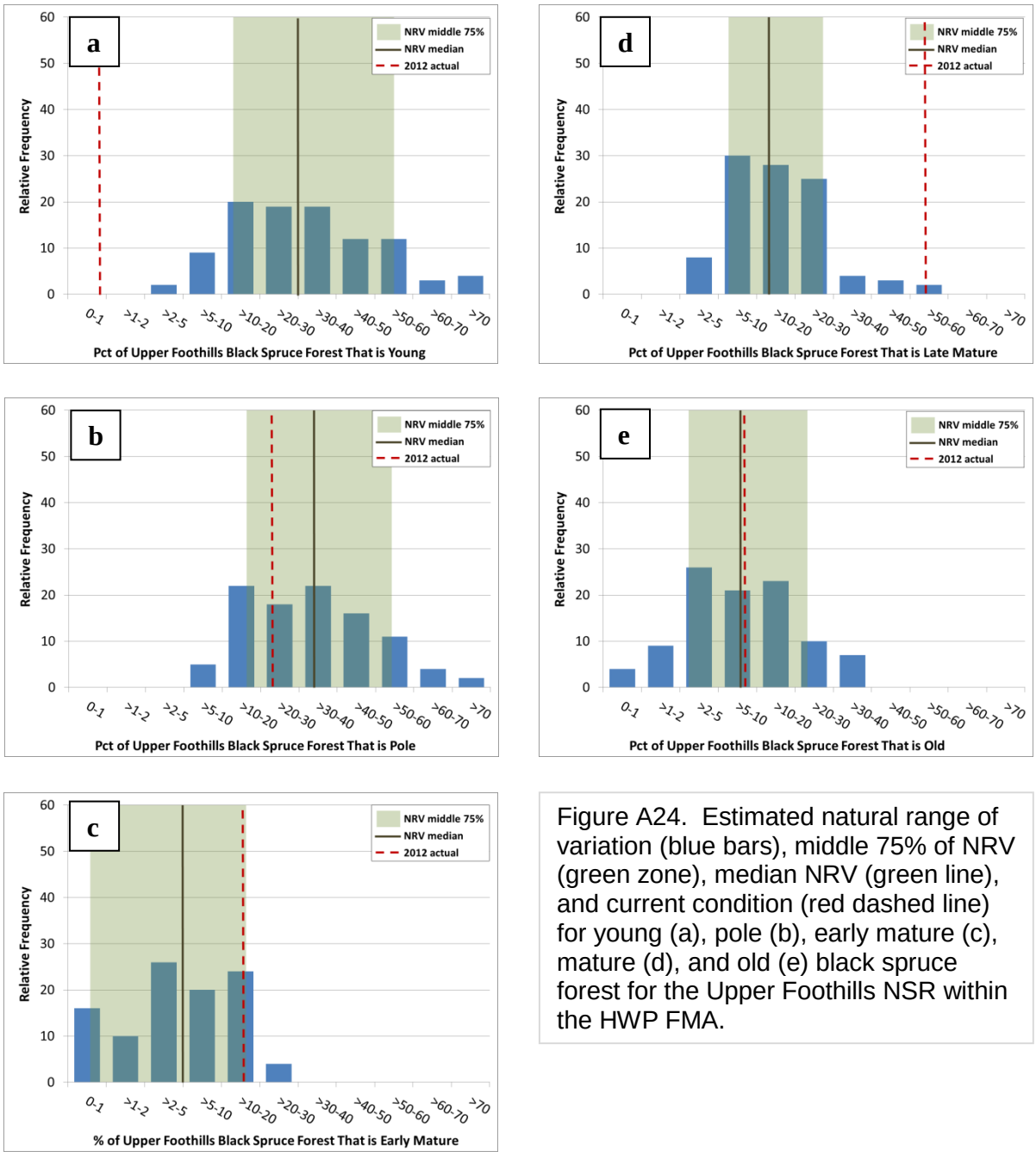
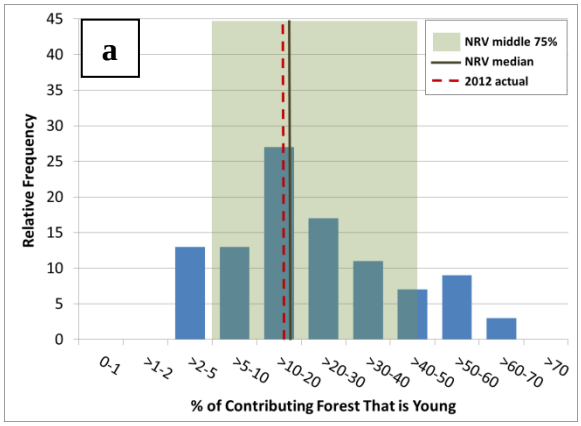
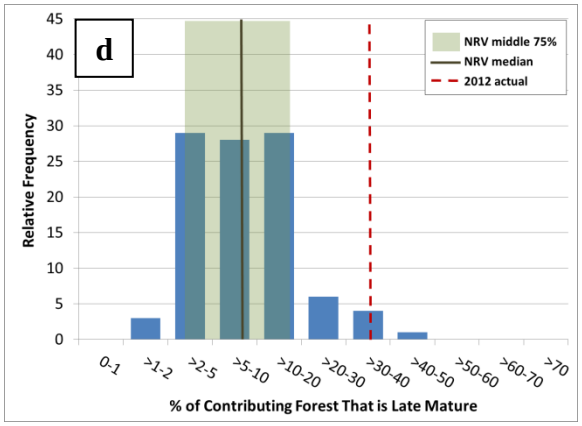


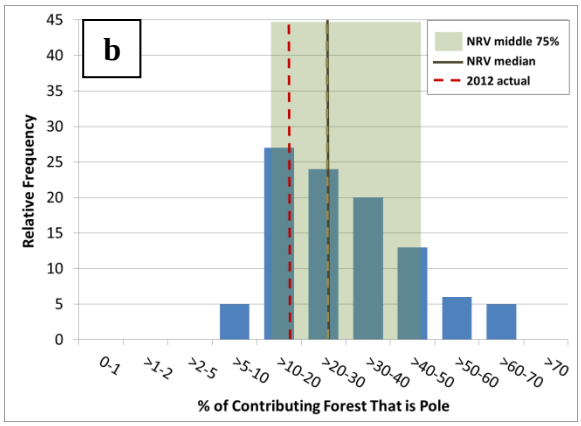
Figure A24. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the Upper Foothills NSR within the HWP FMA.

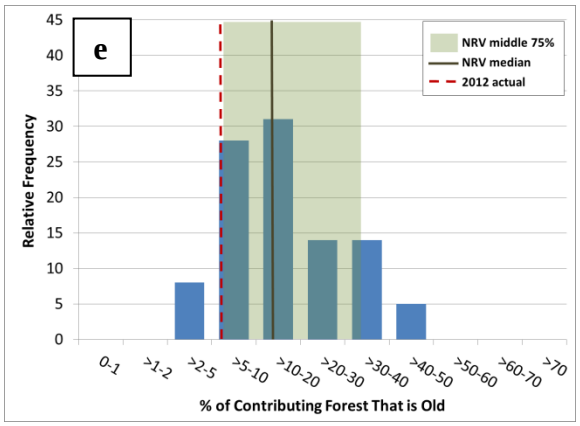
<u>FMA Upper Foothills black spruce forest highlights:</u>

- The current condition of Young is well beyond the lower bound of NRV, and the Late Mature level is close to the upper boundary of NRV.
- All other seral stages are within the 75% NRV bounds.









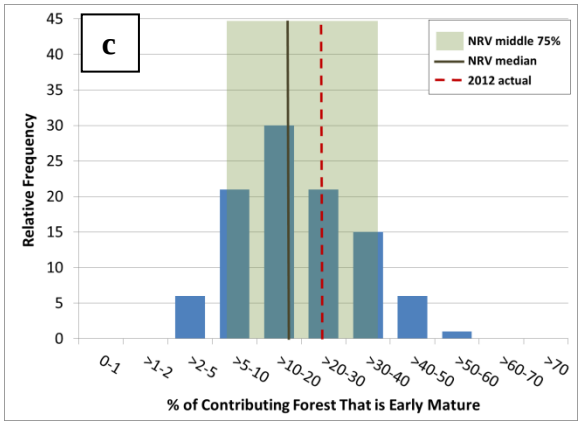
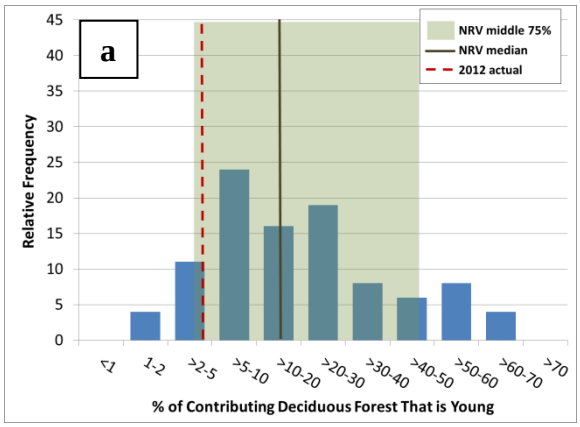
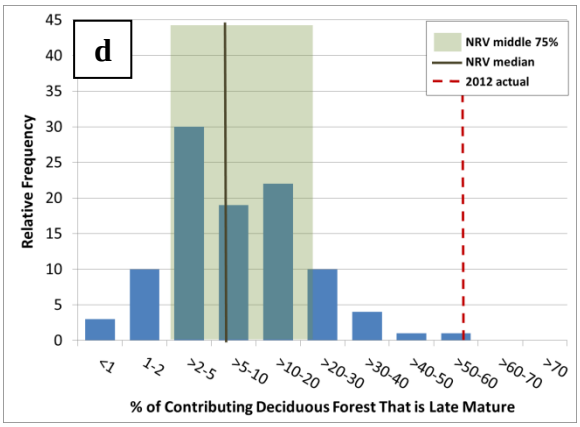


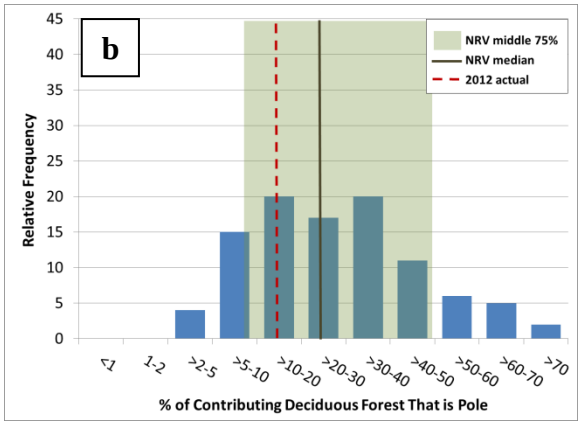
Figure A25. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the 'contributing' part of the HWP FMA.

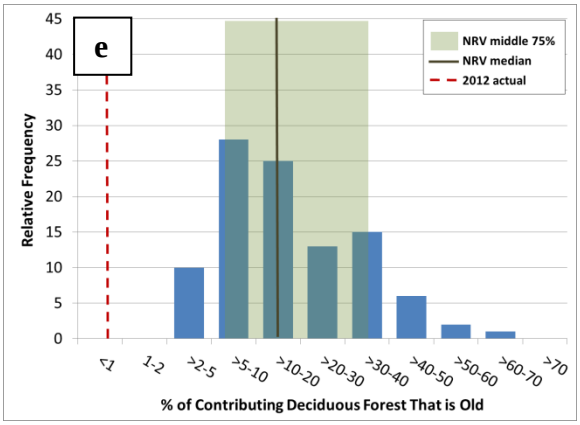
<u>HWP FMA contributing forest highlights:</u>

- All current conditions are within NRV.
- The current condition of the Late Mature is well beyond the upper bound of the 75% NRV range, and close to the upper bounds of NRV.
- The current condition of Old is on the lower bound of the 75% NRV range.









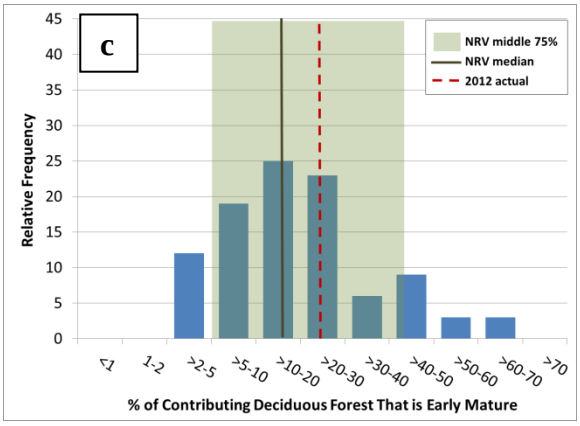
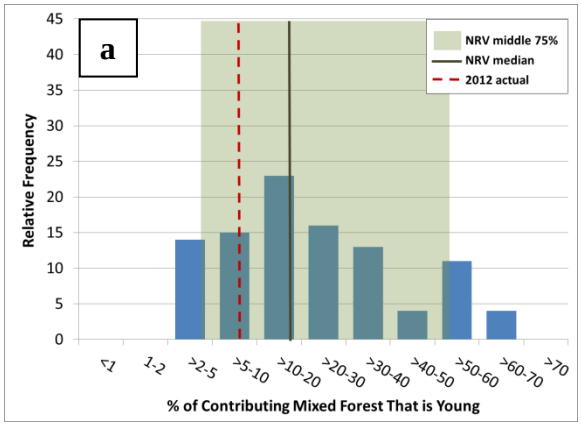
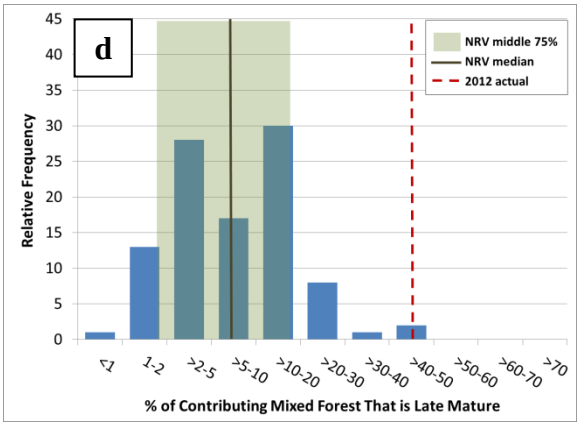


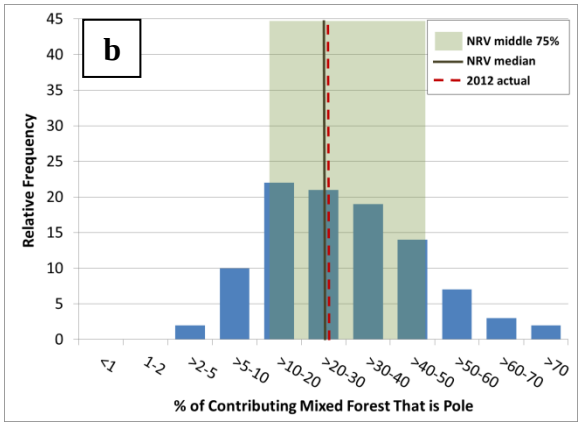
Figure A26. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) deciduous (aspen) forest for the 'contributing' part of the HWP FMA.

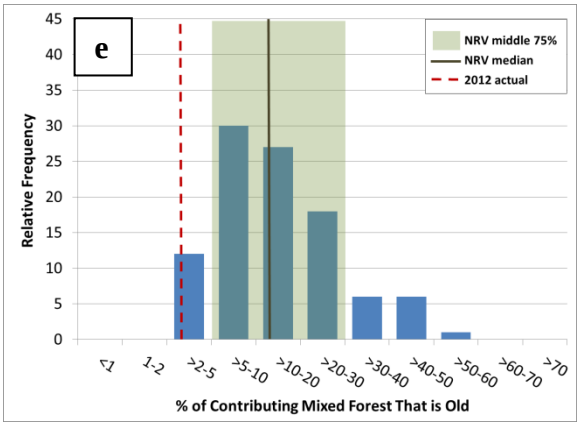
<u>HWP FMA contributing deciduous leading forest highlights:</u>

- The current condition of Late Mature is on the upper bound of NRV, and Old is well below the lower bounds of NRV.
- The current condition of Young is on the lower bounds of the 75% NRV range.









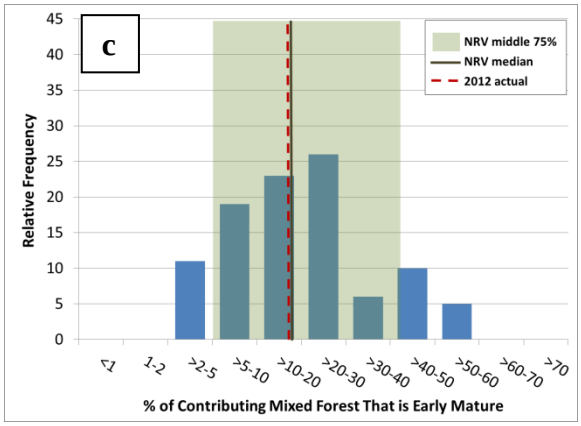


Figure A27. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the 'contributing' part of the HWP FMA.

<u>HWP FMA contributing mixedwood leading forest highlights:</u>

- All current conditions are within NRV, although current condition of Late Seral is very close to the upper boundary of NRV.
- The current condition of Old is beyond the lower boundary of the 75% NRV range.

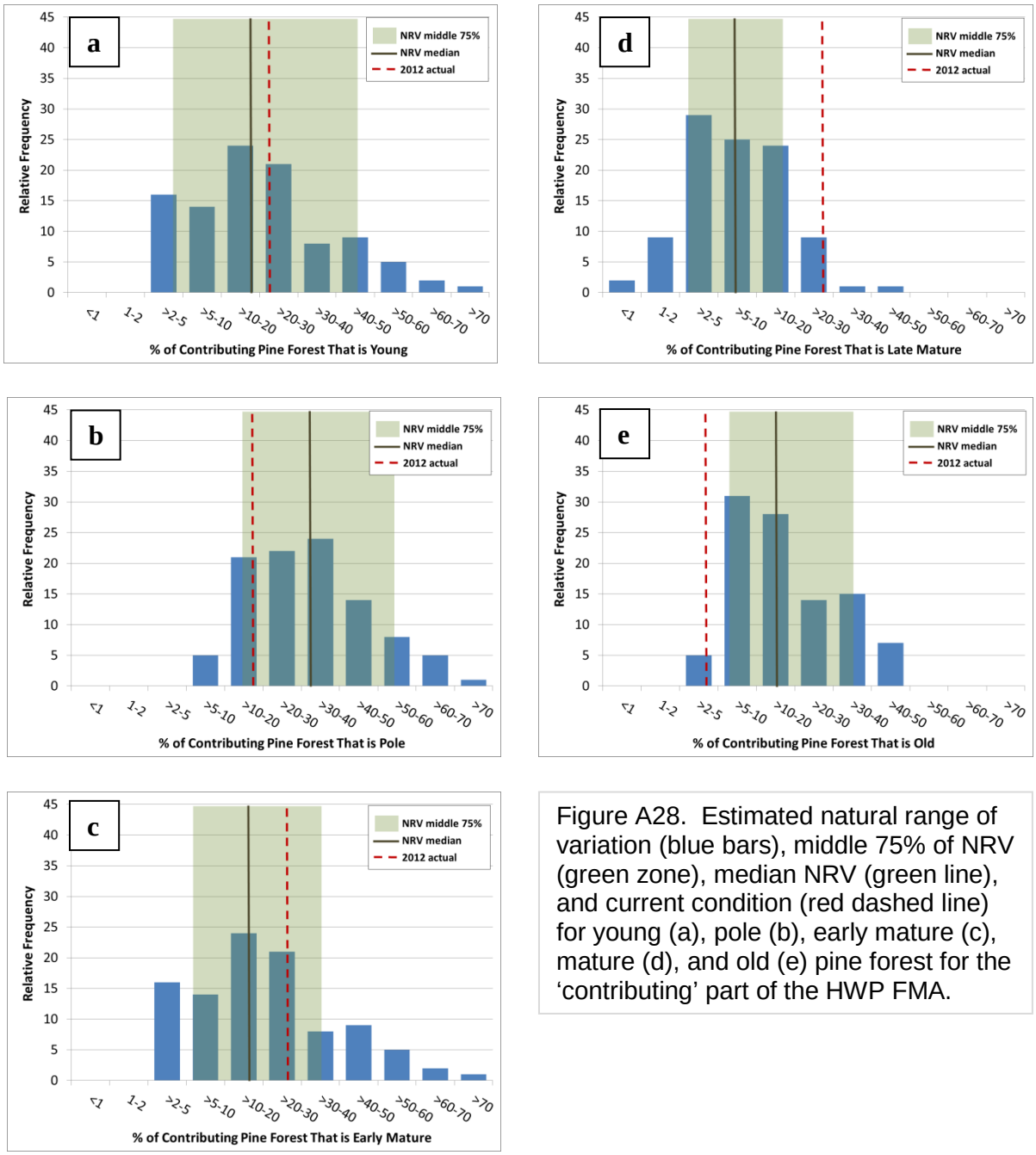
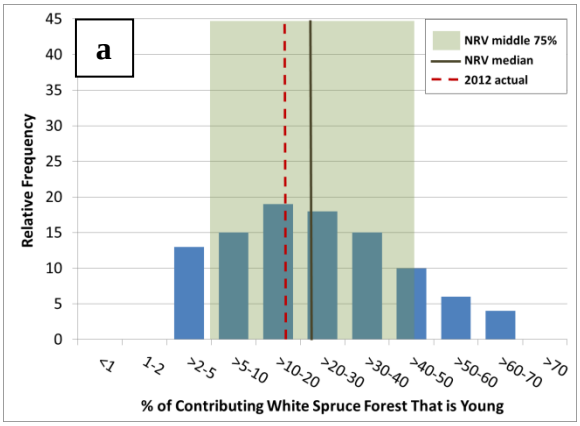
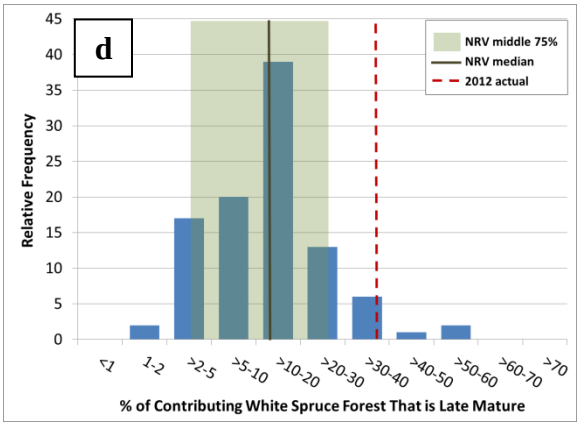


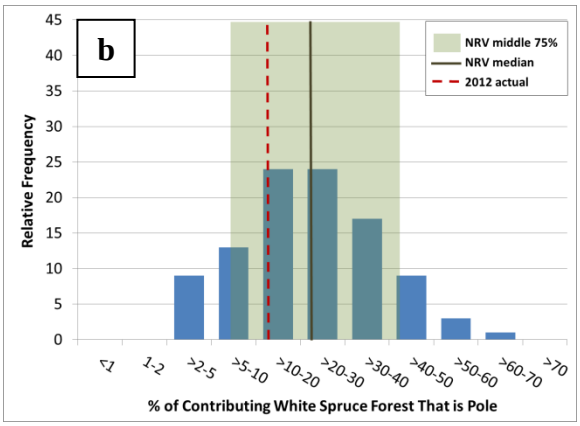
Figure A28. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the 'contributing' part of the HWP FMA.

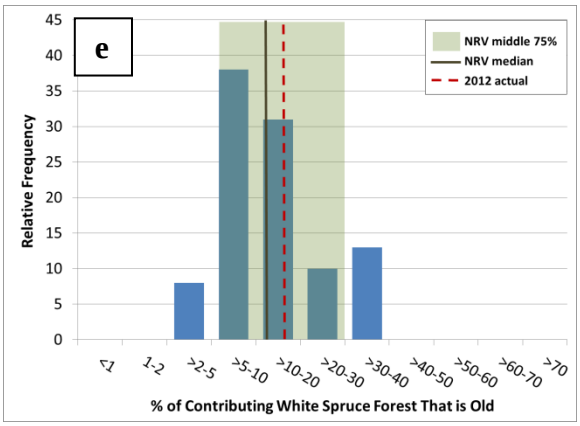
<u>HWP FMA contributing pine leading forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Old is beyond the lower boundary of the 75% NRV range, and the current condition of Late Mature is beyond the upper boundary of the 75% NRV range.









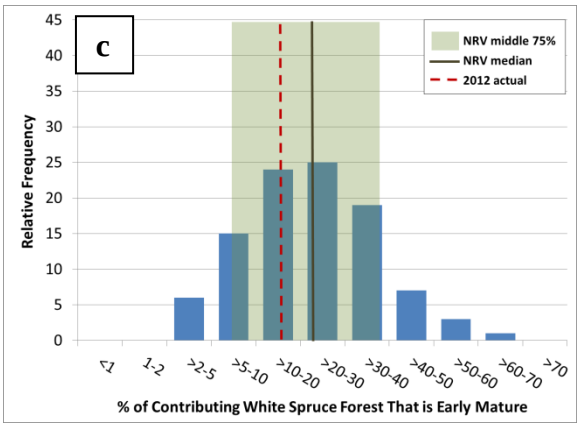
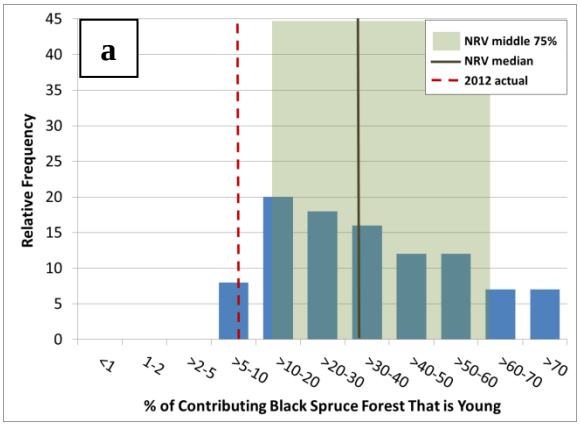
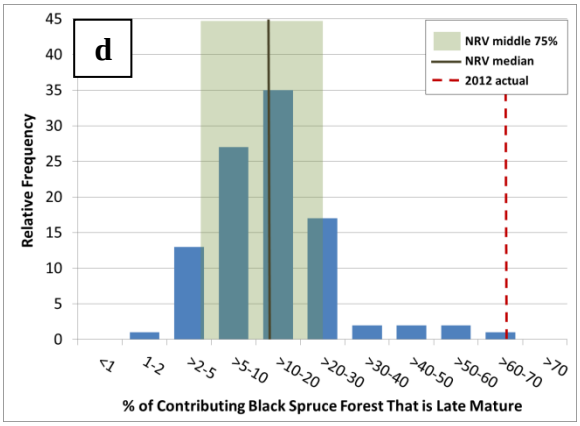


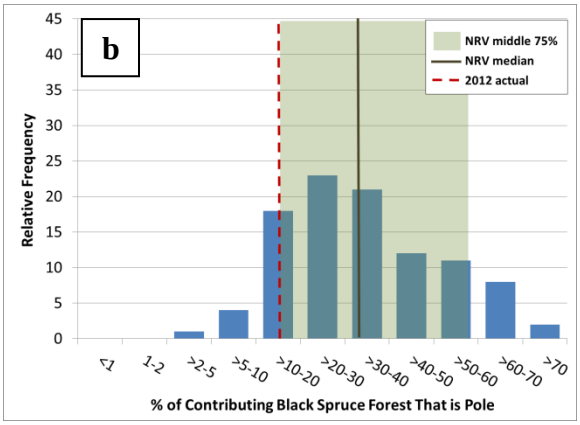
Figure A29. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the 'contributing' part of the HWP FMA.

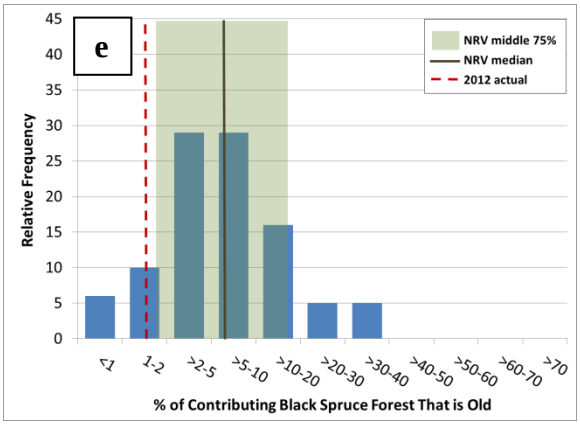
<u>HWP FMA contributing white spruce leading forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Late Mature is beyond the upper boundary of the 75% NRV range.









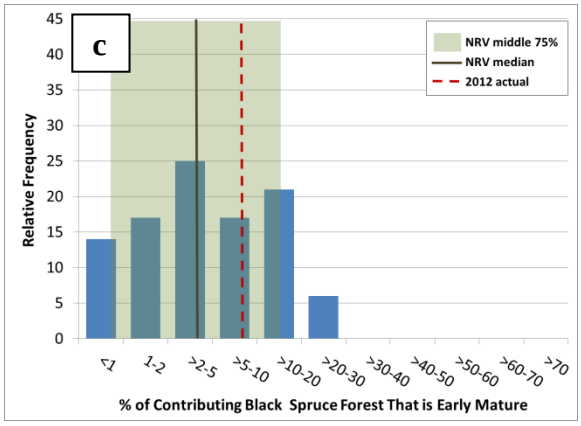


Figure A30. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the 'contributing' part of the HWP FMA.

<u>HWP FMA contributing black spruce leading forest highlights:</u>

- All current conditions are within NRV – although the Late Mature is on the upper boundary of NRV.
- The current conditions of Young, Pole, and Old are all below the lower boundaries of their respective 75% NRV ranges.

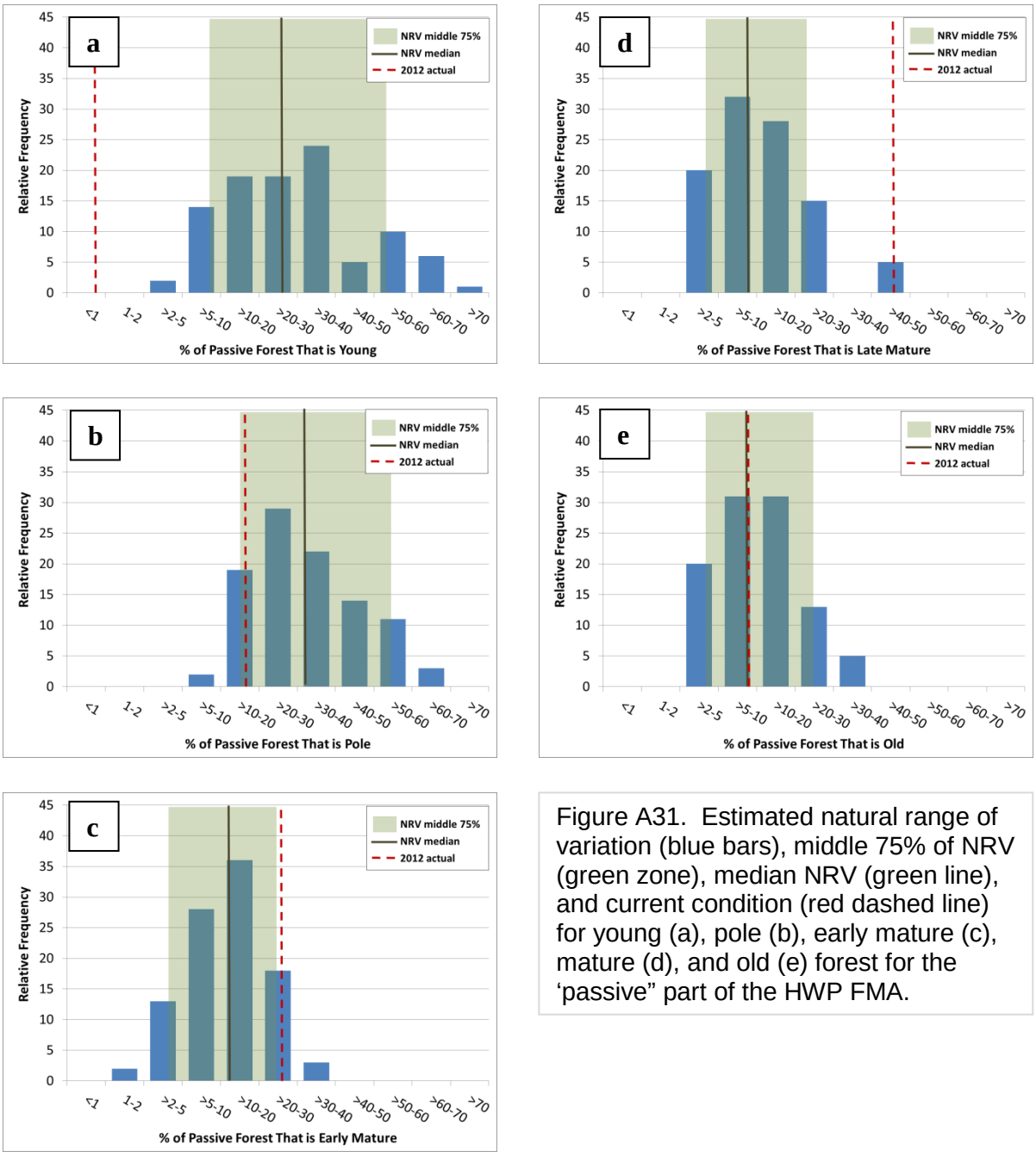


Figure A31. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) forest for the 'passive" part of the HWP FMA.

<u>HWP FMA passive forest highlights:</u>

- The current condition of Young is well below the lower bounds of NRV.
- The current condition of Late Mature is on the upper boundary of NRV.
- The current condition of Pole is on the lower bounds of the 75% NRV zone.
- The current condition of Early Mature is slightly beyond the upper bounds of the 75% NRV zone.

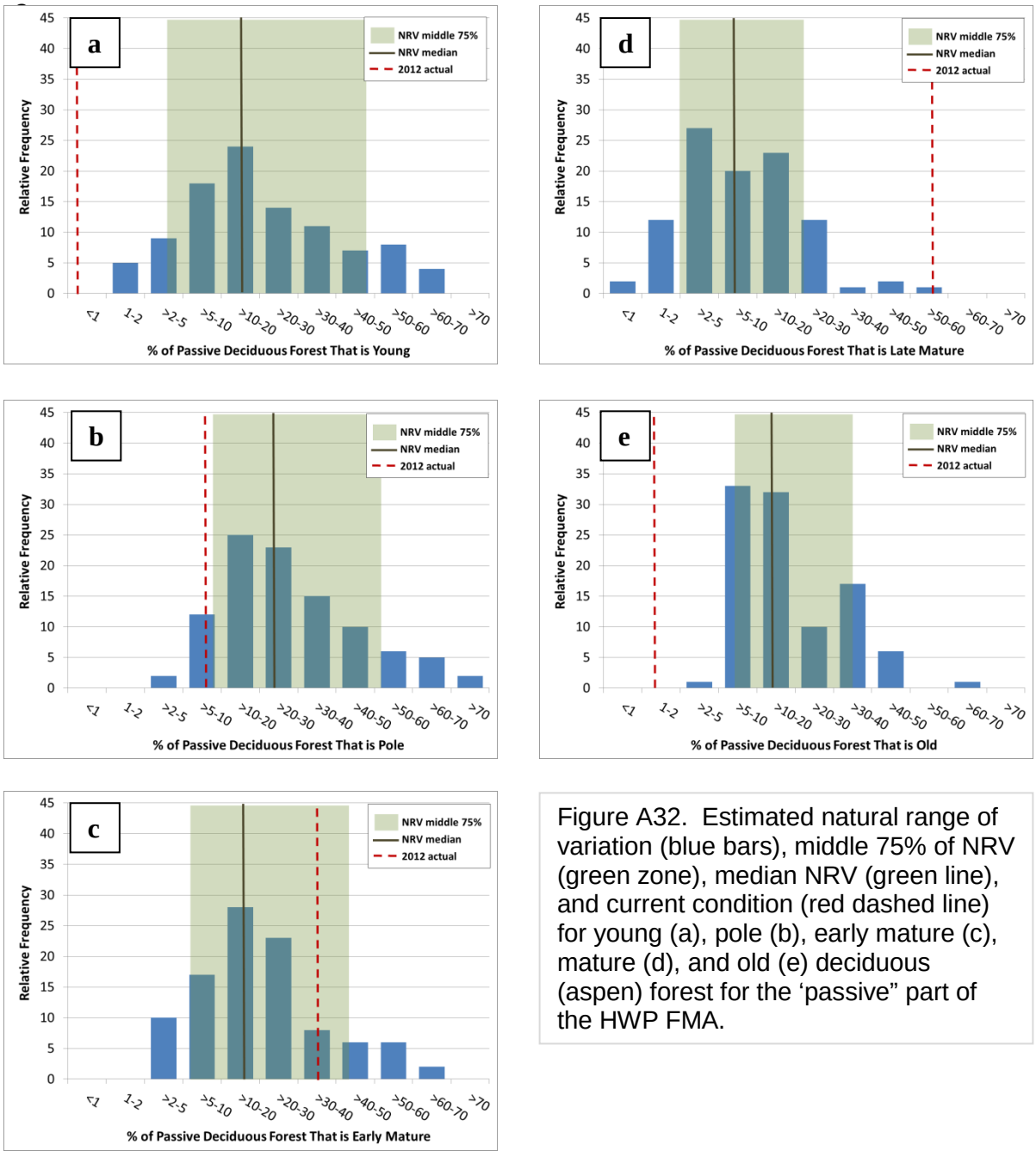
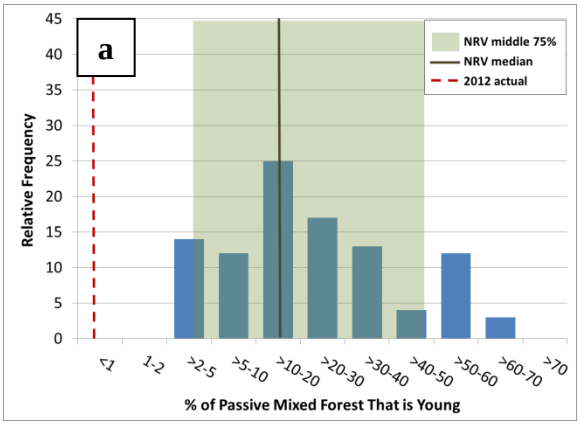
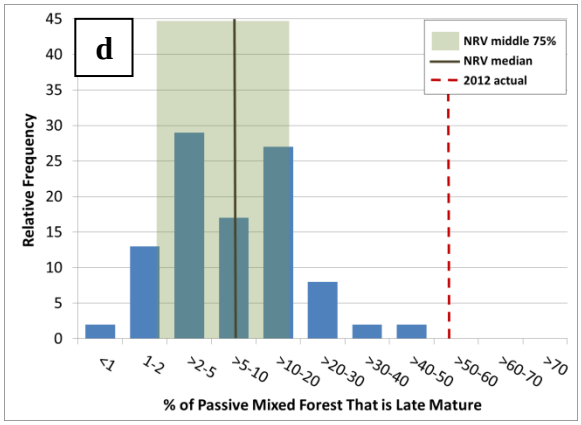


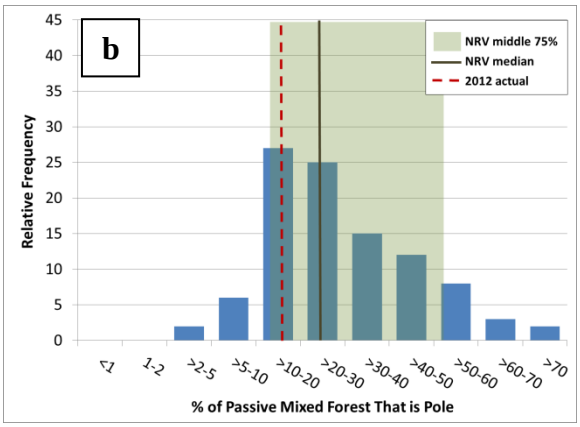
Figure A32. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) deciduous (aspen) forest for the 'passive" part of the HWP FMA.

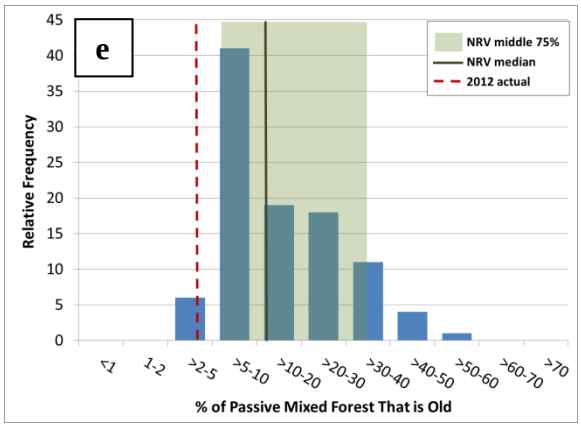
<u>HWP FMA passive deciduous leading forest highlights:</u>

- The current conditions of both Young and Old are well below the lower bounds of their respective NRVs.
- The current condition of Late Mature is on the upper boundary of NRV.
- The current condition of Pole is on the lower bounds of the 75% NRV zone.









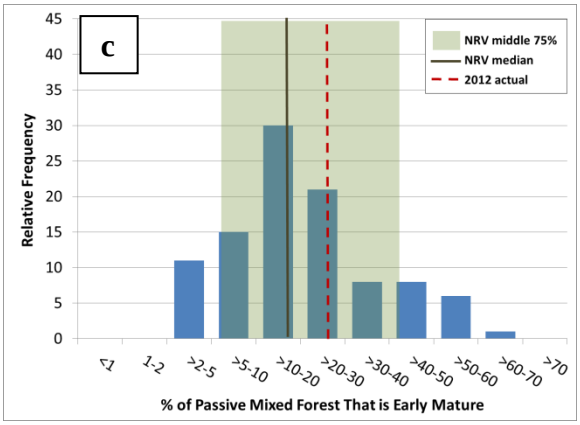
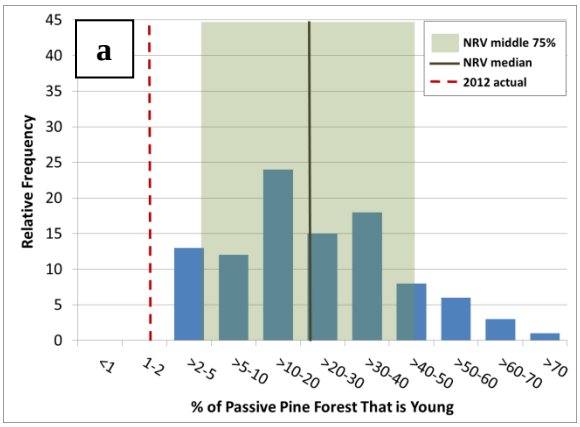
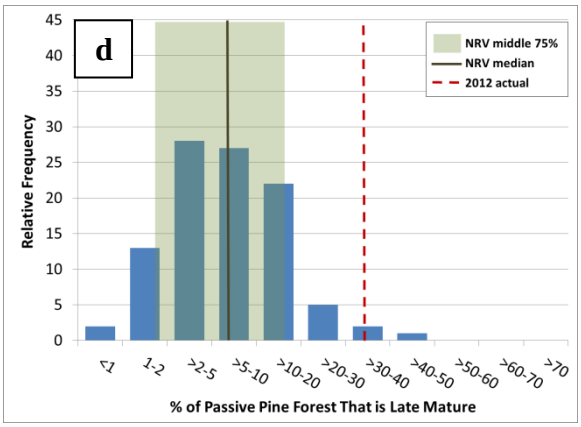


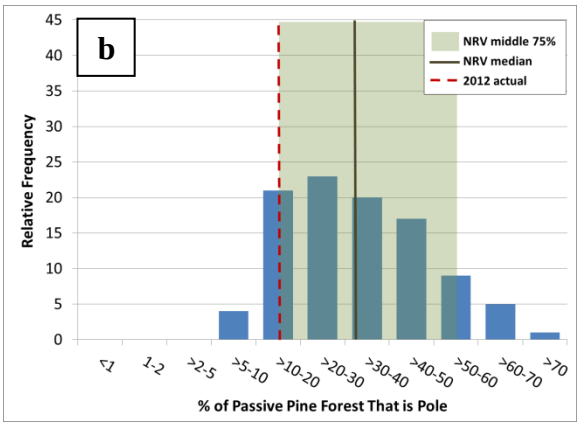
Figure A33. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) mixedwood forest for the 'passive" part of the HWP FMA.

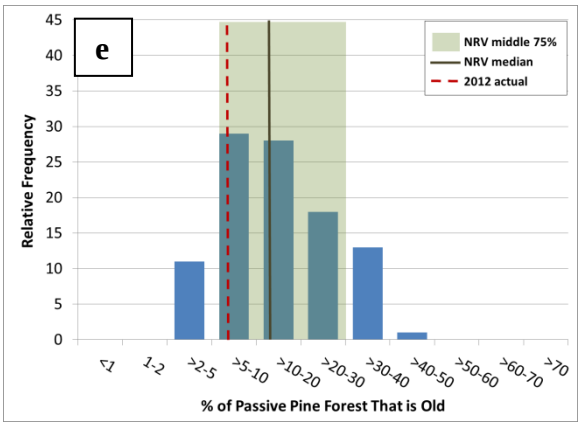
<u>HWP FMA passive mixedwood leading forest highlights:</u>

- The current condition of Young is below the lower bounds of NRVs.
- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Old is below the lower bound of the 75% NRV zone.









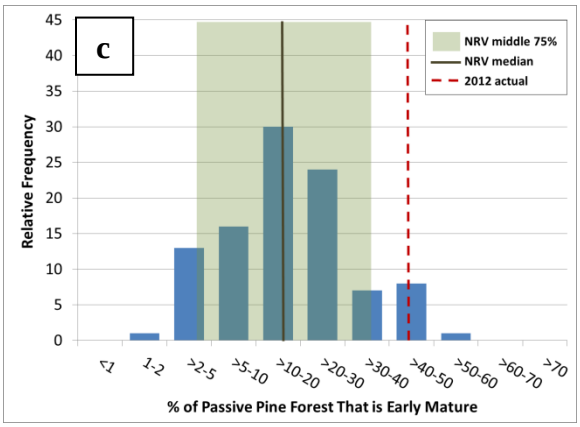
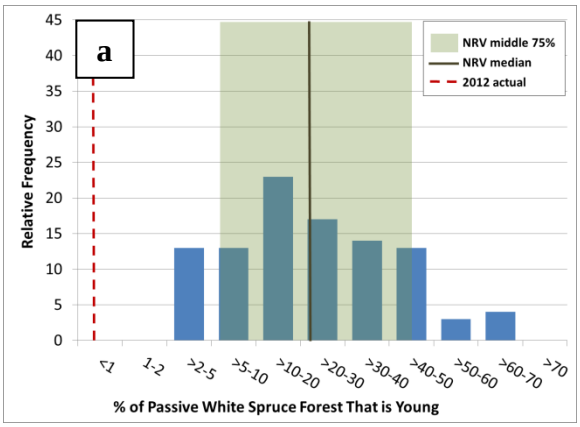
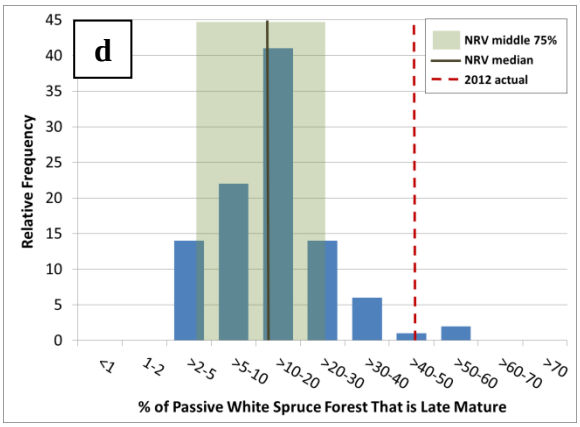


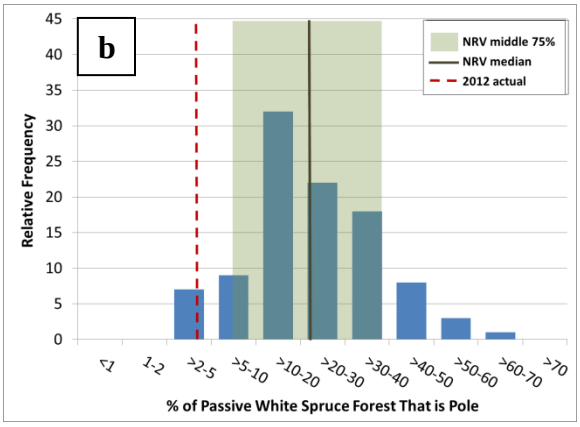
Figure A34. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) pine forest for the 'passive" part of the HWP FMA.

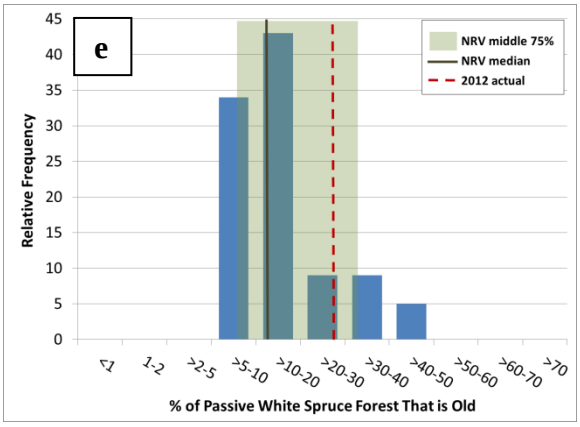
<u>HWP FMA passive pine leading forest highlights:</u>

- The current condition of Young is below the lower bounds of NRV.
- The current conditions of both Early Mature and Late Mature are beyond the upper boundaries of their respective NRV 75% zones, and close to the upper bounds of their respective NRVs.
- The current condition of Pole is on the lower boundary of its 75% NRV zone.









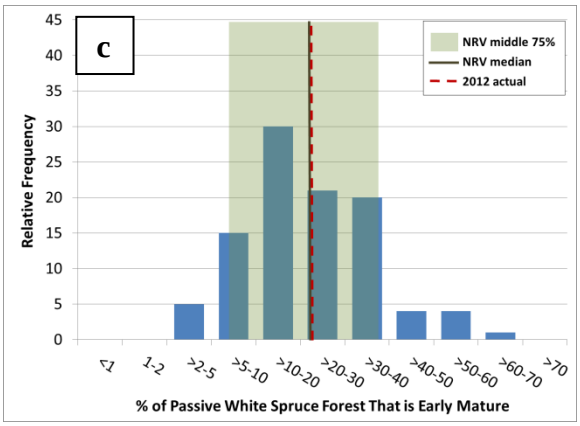
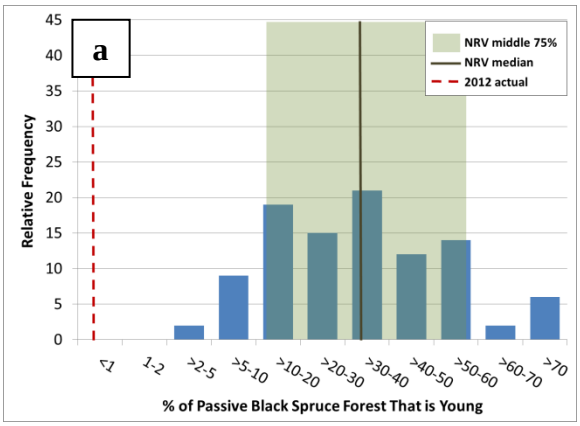
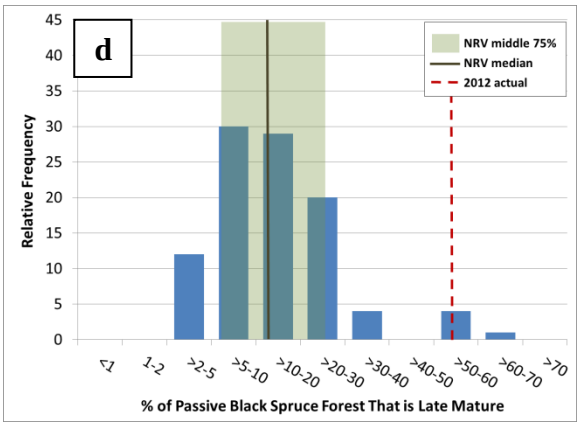


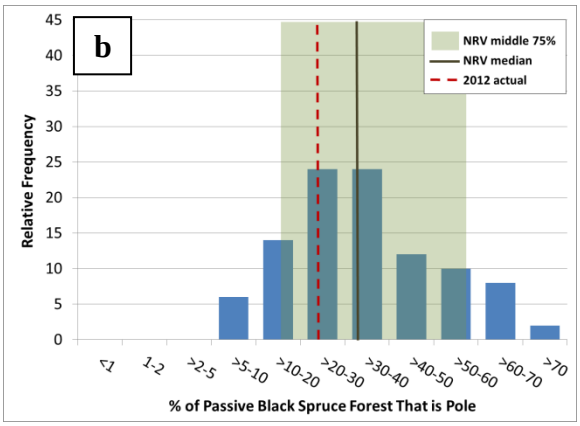
Figure A35. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) white spruce forest for the 'passive" part of the HWP FMA.

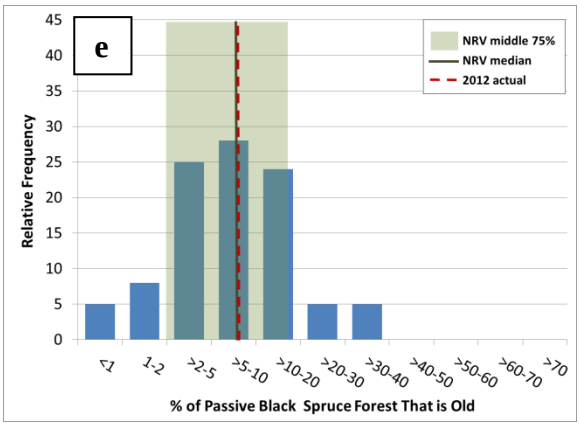
<u>HWP FMA passive white spruce leading forest highlights:</u>

- The current condition of Young is well below the lower bounds of NRV.
- The current condition of Pole is beyond the lower bound of the 75% NRV zone.
- The current condition of Late Mature is well beyond the upper bounds of the 75% NRV zone, and close to the upper limit of NRV.









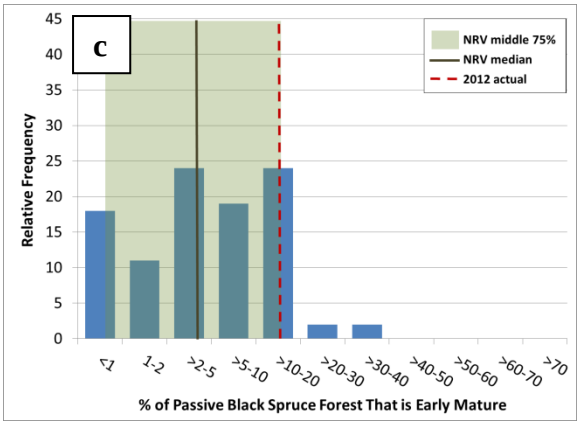
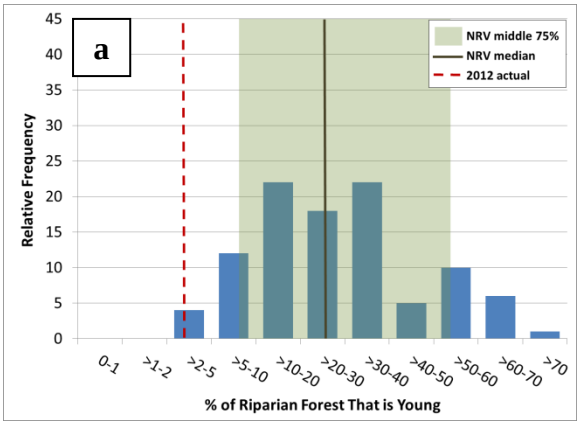
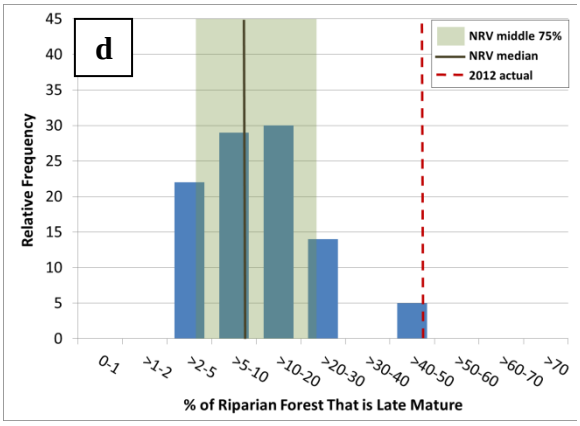


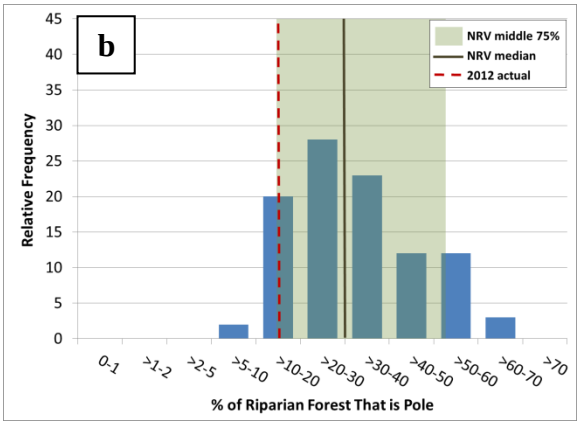
Figure A36. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) black spruce forest for the 'passive" part of the HWP FMA.

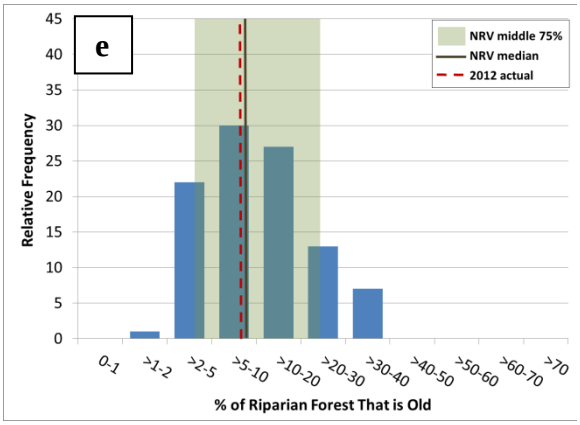
<u>HWP FMA passive black spruce leading forest highlights:</u>

- The current condition of Young is well below the lower bounds of NRV.
- The current condition of Early Mature is on the upper bounds of the 75% NRV zone.
- The current condition of Late Mature is well beyond the upper bounds of the 75% NRV zone, and close to the upper limit of NRV.









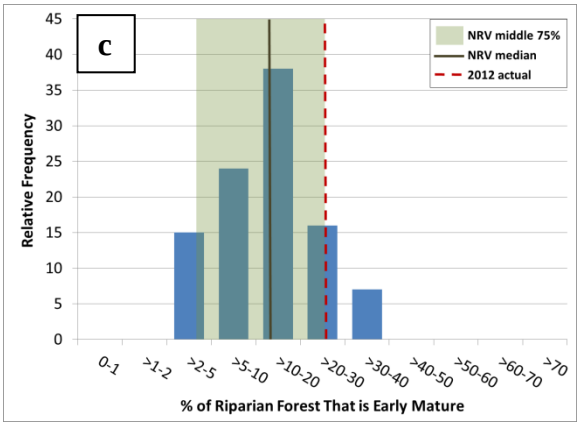


Figure A37. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian forest for the HWP FMA.

<u>HWP FMA riparian forest highlights:</u>

- The current condition of Young is on the lower bounds of NRV.
- The current condition of Late Mature is on the upper bounds of NRV.
- The current condition of Pole is on the lower bound of the 75% NRV zone.
- The current condition of Early Mature is on the upper bounds of the 75% NRV zone.

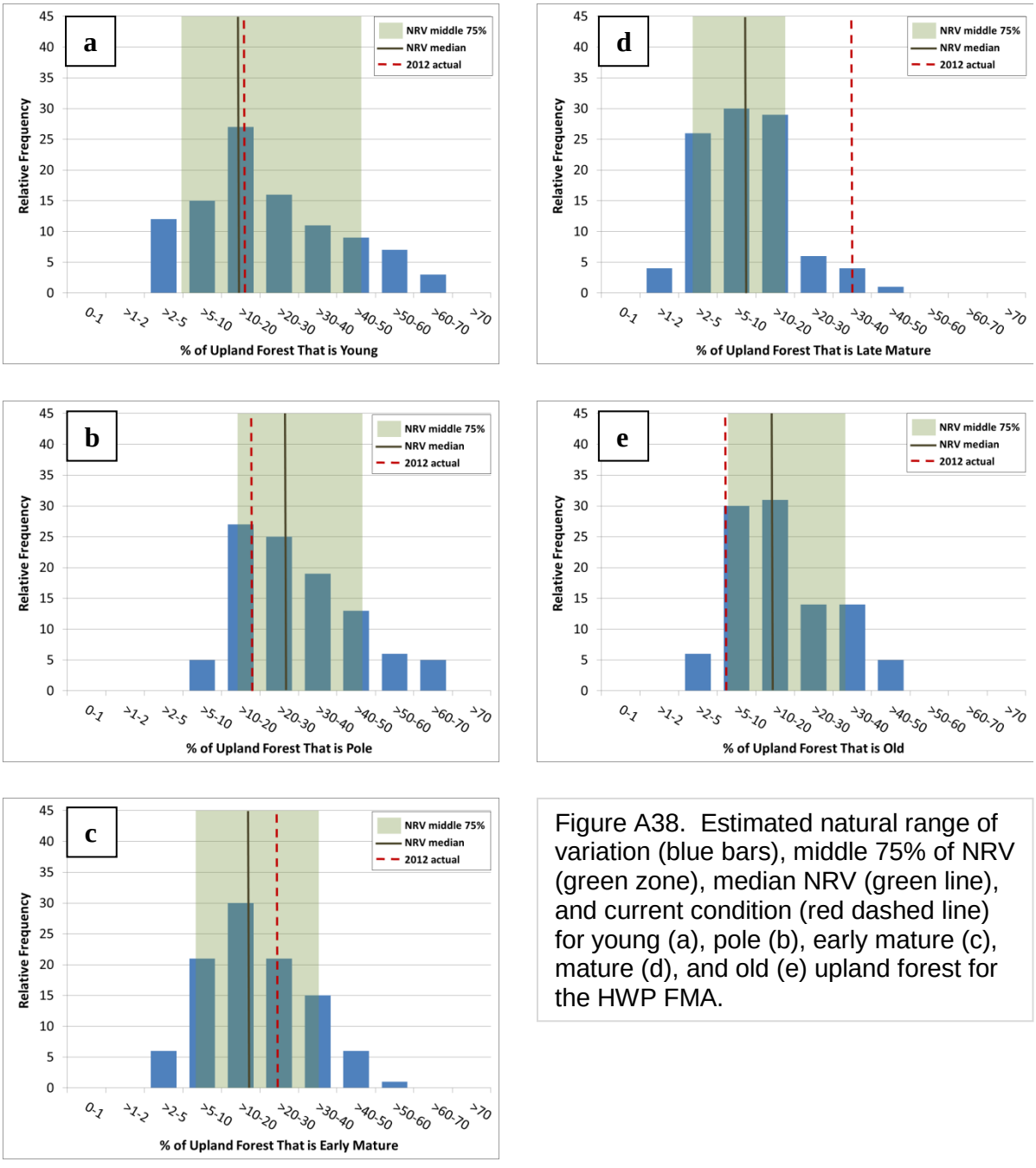


Figure A38. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland forest for the HWP FMA.

<u>HWP FMA upland forest highlights:</u>

- All current conditions are within NRV
- The current condition of Late Mature is beyond the upper bounds of the 75% NRV zone.
- The current condition of Old is on the lower bound of the 75% NRV zone.

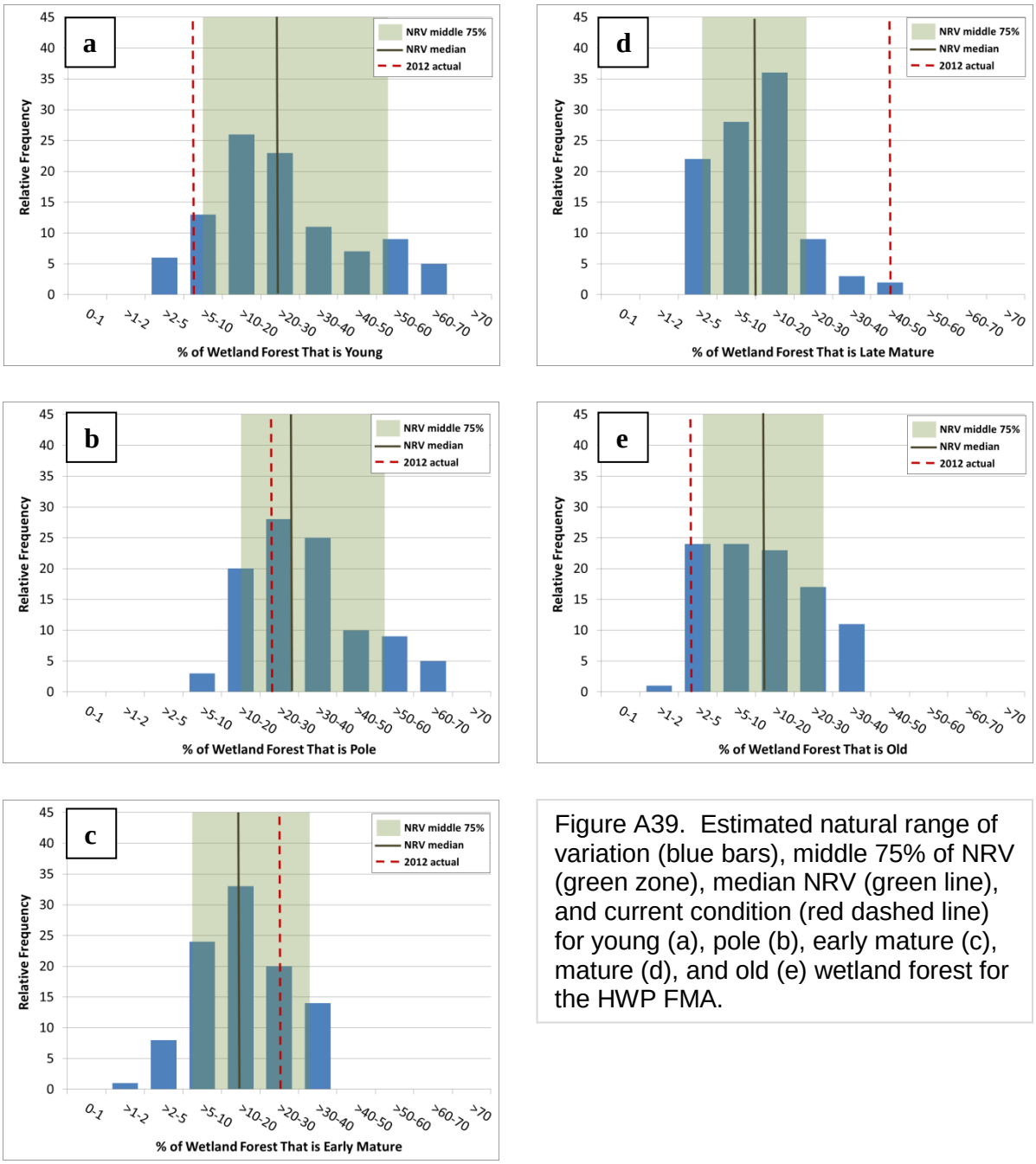
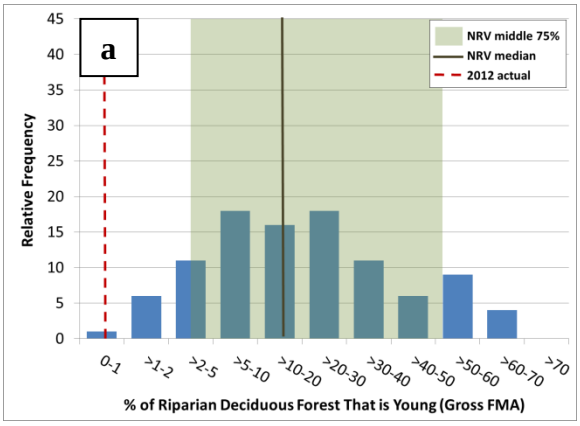
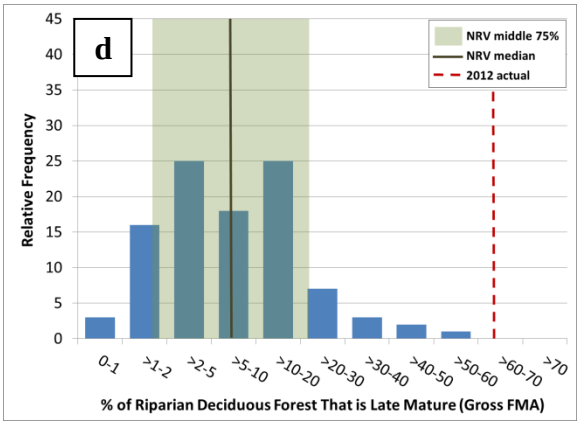


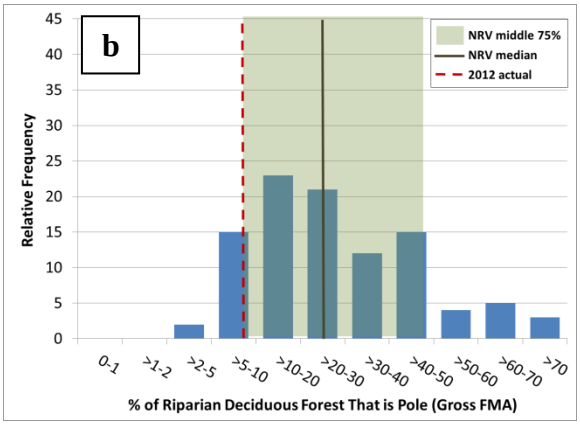
Figure A39. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland forest for the HWP FMA.

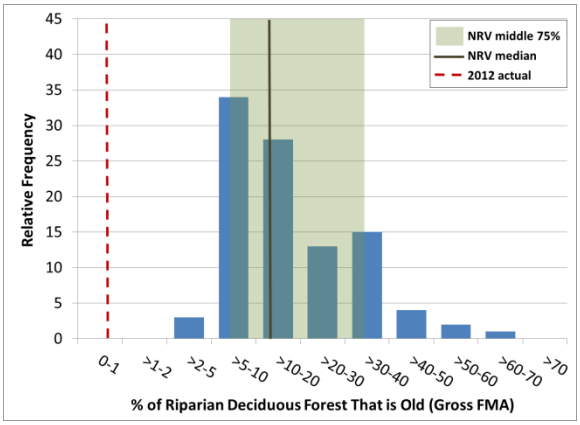
HWP FMA wetland forest highlights:

- The current condition of Late Mature forest is on the upper bound of NRV.
- The current condition of Young is below the lower bounds of the 75% NRV zone.
- The current condition of Old is below the lower bound of the 75% NRV zone.









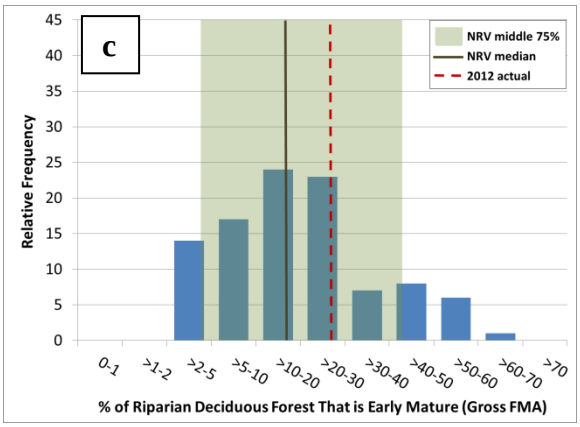
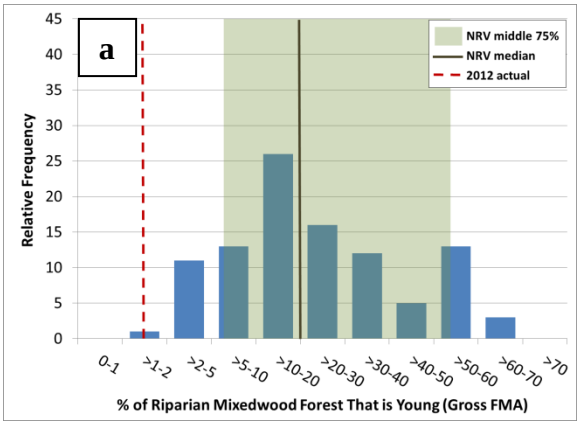
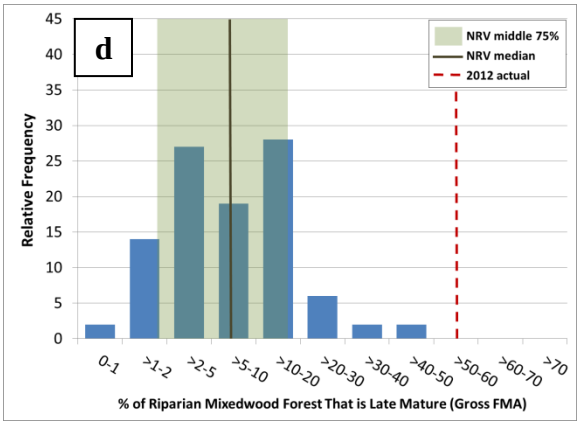


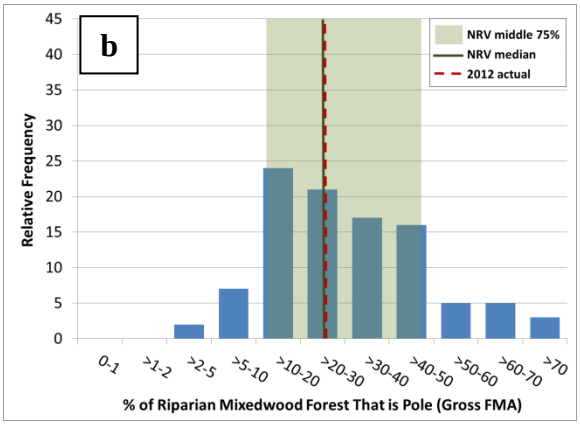
Figure A40. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian deciduous leading forest for the HWP FMA.

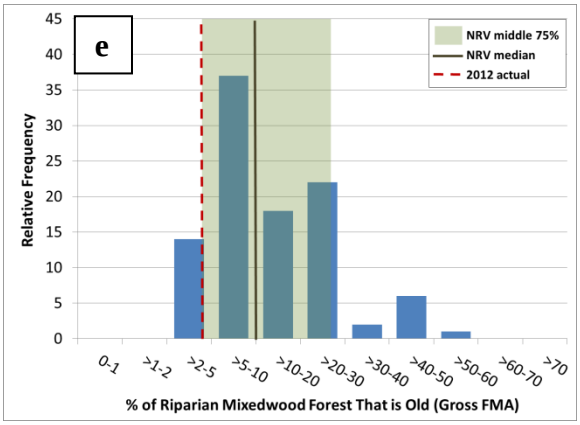
<u>HWP FMA riparian deciduous forest highlights:</u>

- The current condition of Young forest is on the lower boundary of NRV.
- The current condition of Late Mature forest is beyond the upper boundary of NRV.
- The current condition of Old forest is below the lower boundary of NRV.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.









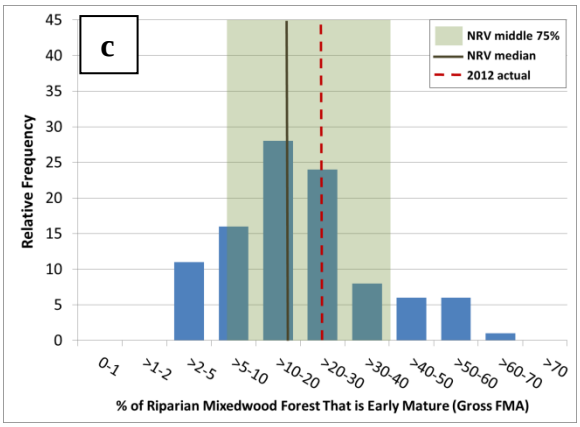
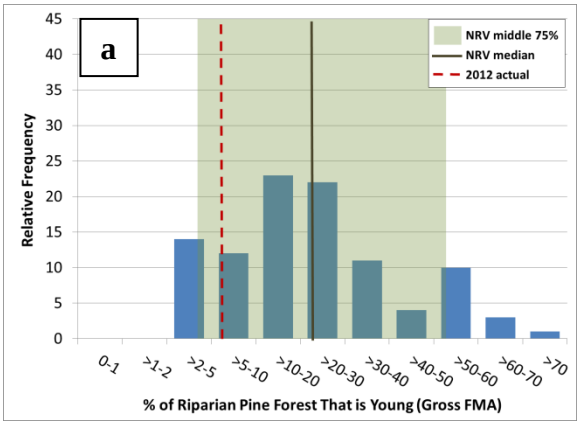
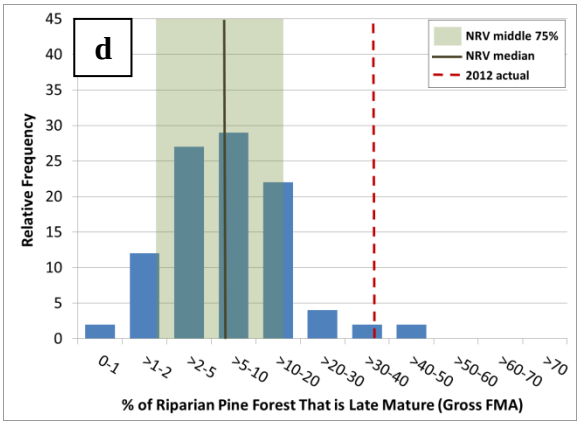


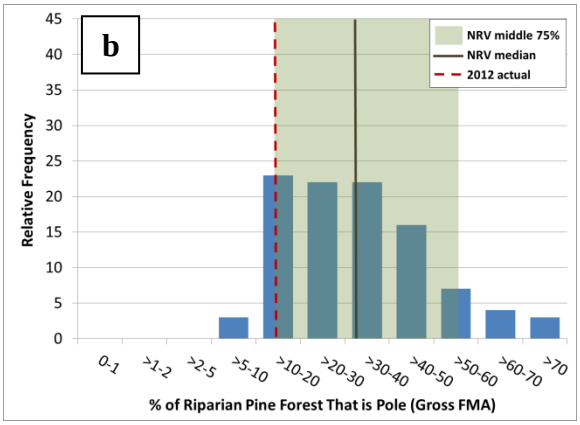
Figure A41. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian mixedwood leading forest for the HWP FMA.

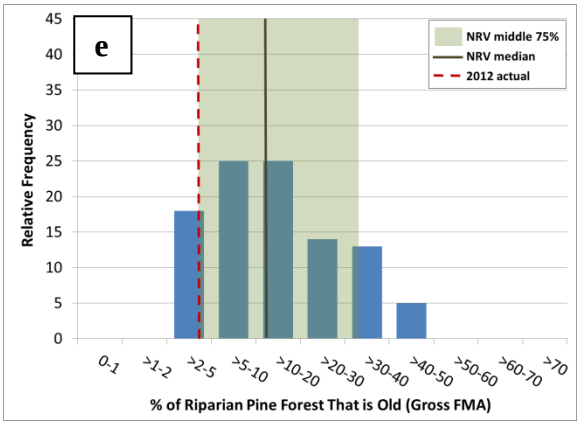
<u>HWP FMA riparian mixedwood forest highlights:</u>

- The current condition of Young forest is on the lower boundary of NRV.
- The current condition of Late Mature forest is beyond the upper boundary of NRV.
- The current condition of Old forest is below the lower boundary of the 75% NRV zone.









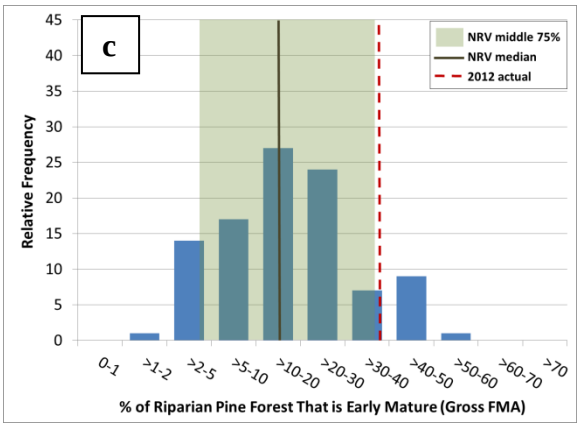
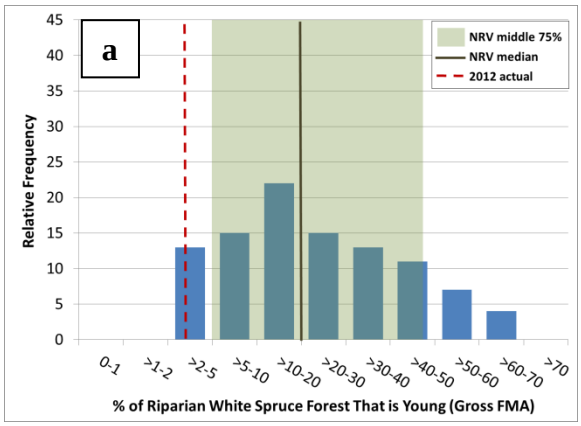
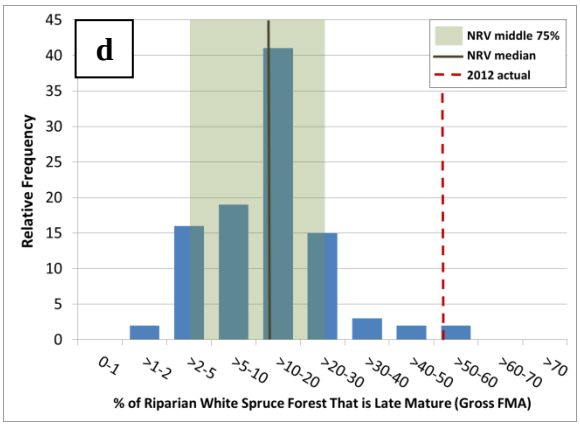


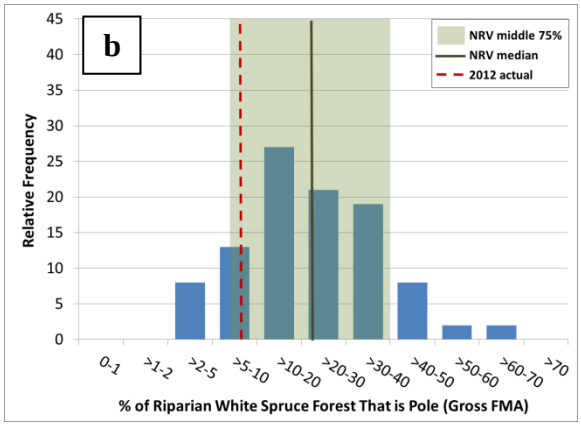
Figure A42. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian pine leading forest for the HWP FMA.

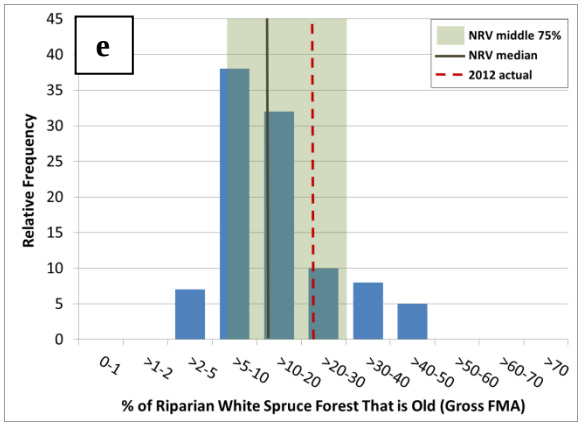
<u>HWP FMA riparian pine forest highlights:</u>

- The current condition of Late Mature forest is beyond the upper boundary of NRV.
- The current conditions of Pole and Old forest are on the lower boundaries of their respective 75% NRV zones.
- The current condition of Early Mature is slightly beyond the upper boundary of the 75% NRV zone.









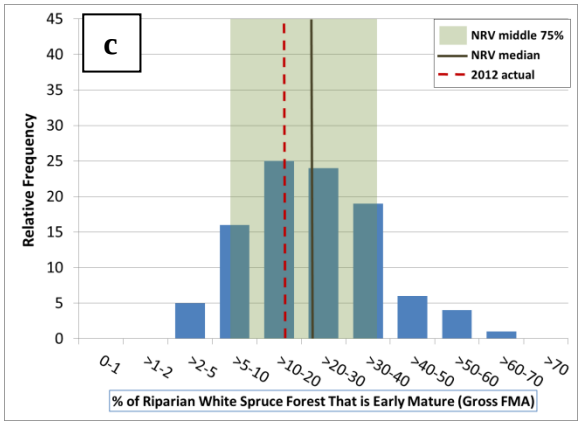
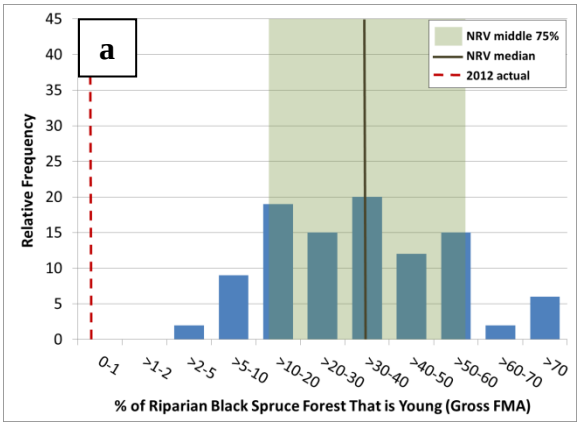
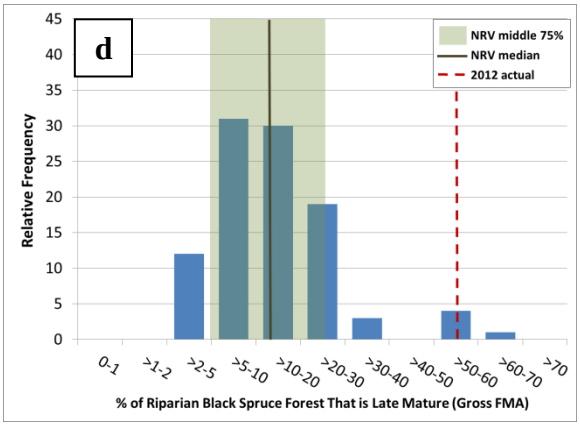


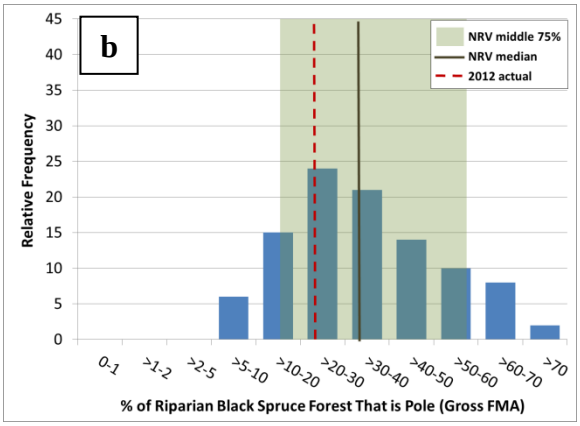
Figure A43. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian white spruce leading forest for the HWP FMA.

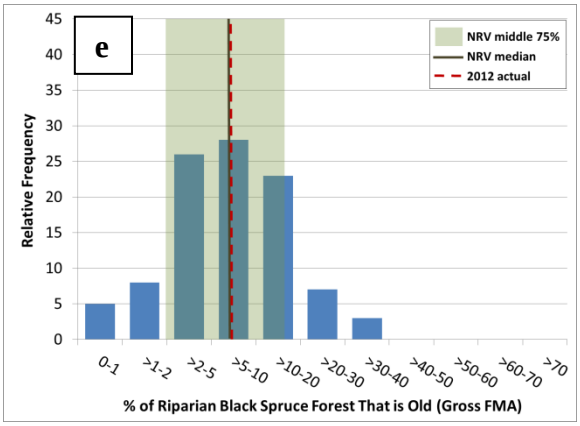
<u>HWP FMA riparian white spruce forest highlights:</u>

- The current condition of Young forest is on the lower boundary of NRV.
- The current condition of Late Mature forest is on the upper boundary of NRV.









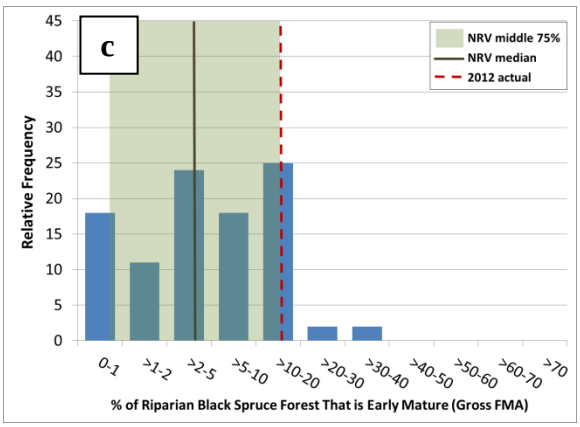
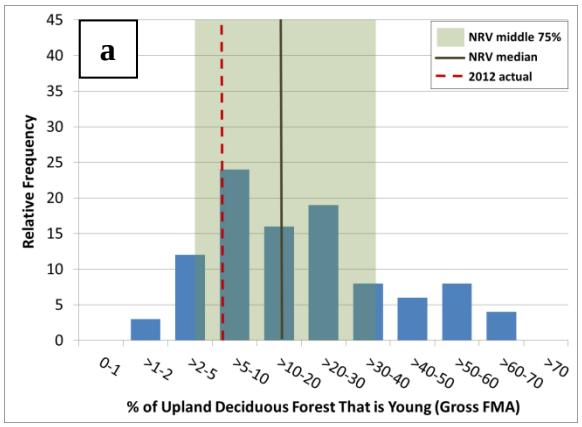
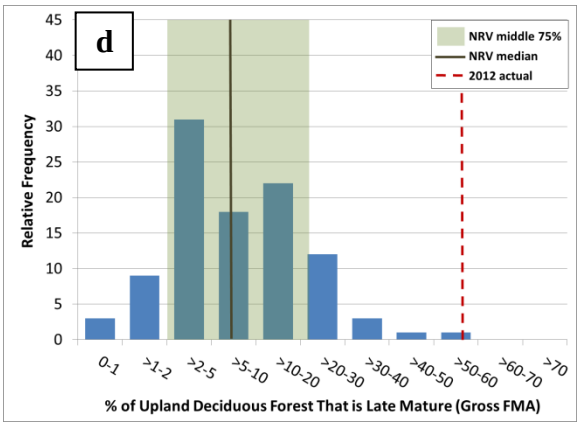


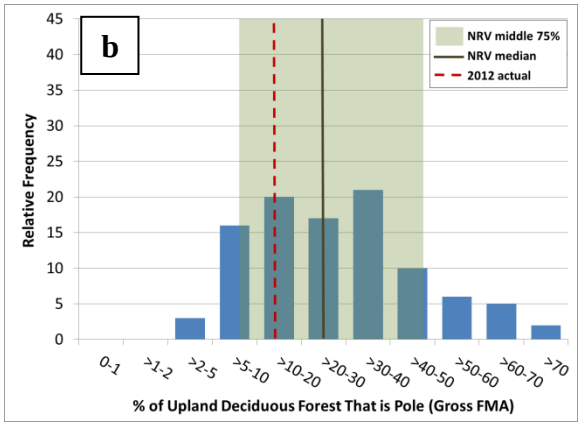
Figure A44. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) riparian black spruce leading forest for the HWP FMA.

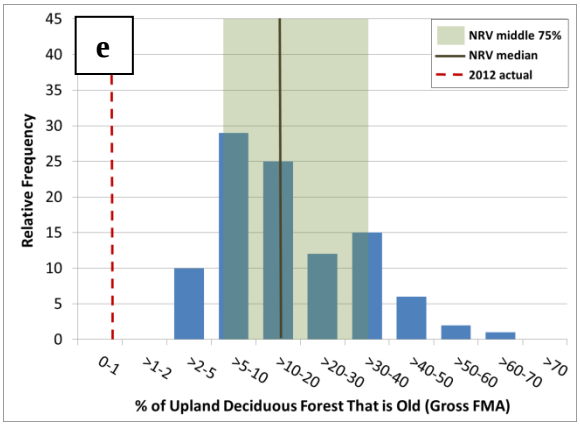
<u>HWP FMA riparian black spruce forest highlights:</u>

- The current condition of Young forest is well below the lower boundary of NRV.
- The current condition of Late Mature forest is well above the upper boundary of the 75% NRV zone.
- The current condition of Early Mature is on the upper boundary of the 75% NRV zone.









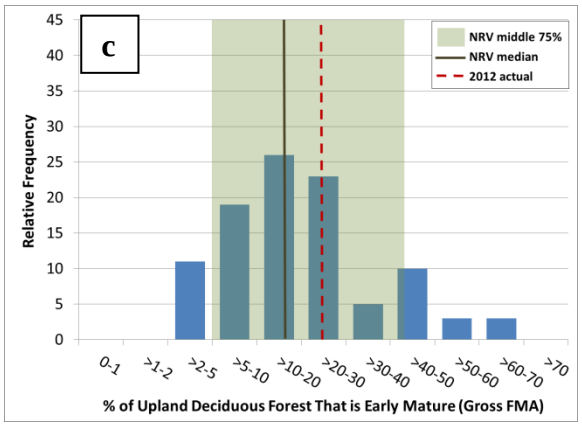
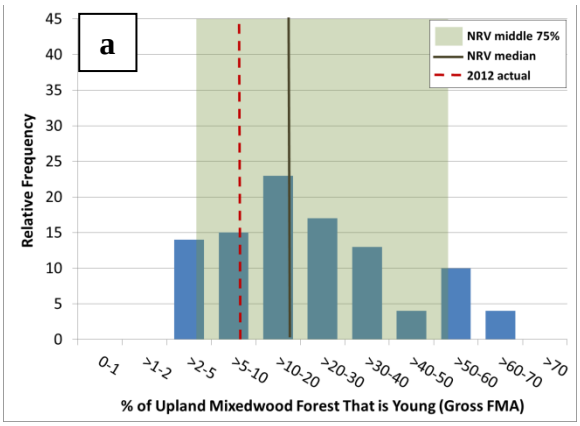
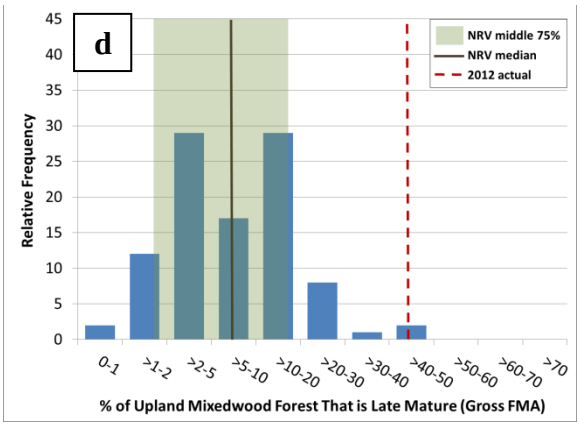


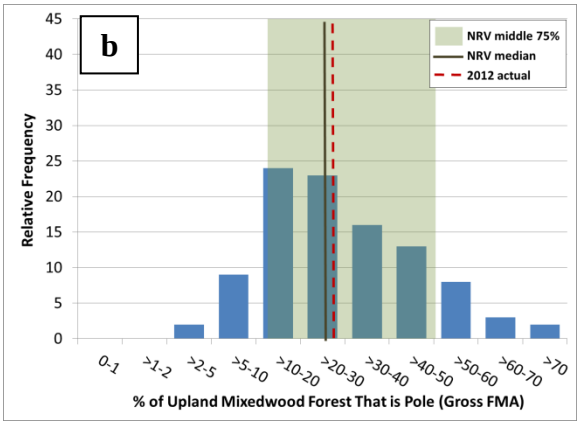
Figure A45. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland deciduous leading forest for the HWP FMA.

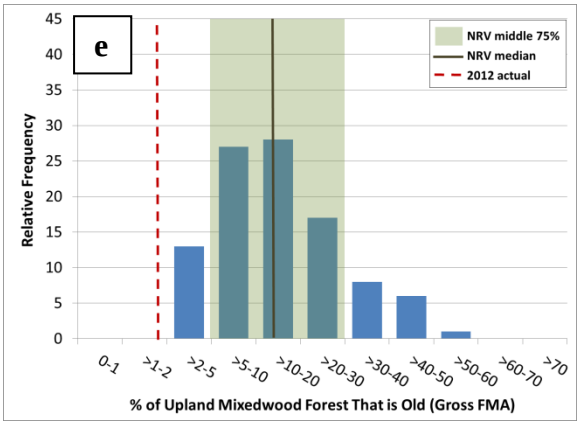
HWP FMA upland deciduous forest highlights:

- The current condition of Old forest is below the lower bounds of NRV.
- The current condition of Late Mature is on the upper bounds of NRV.









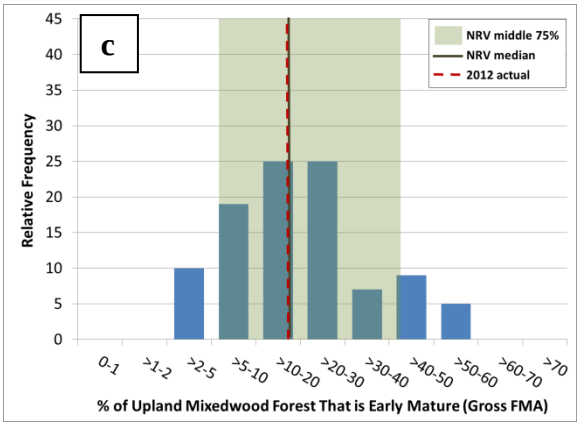
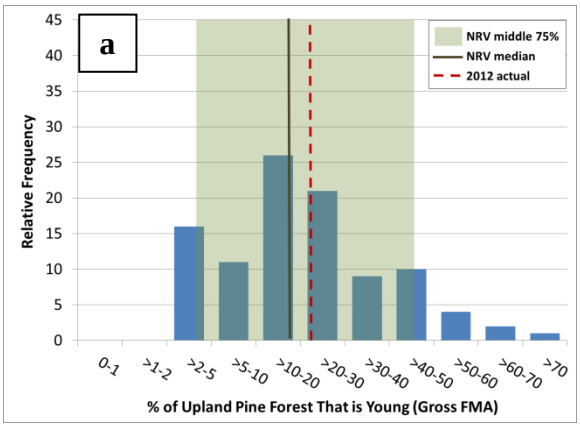
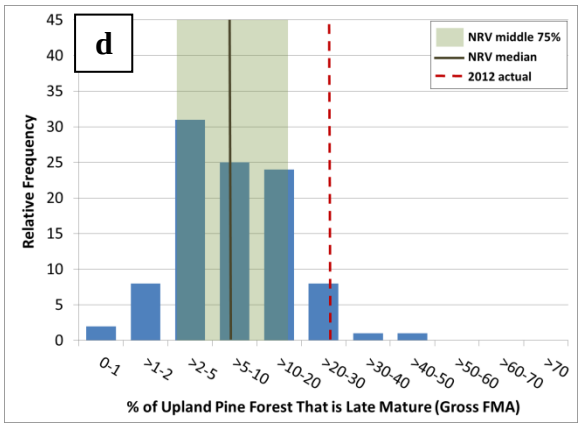


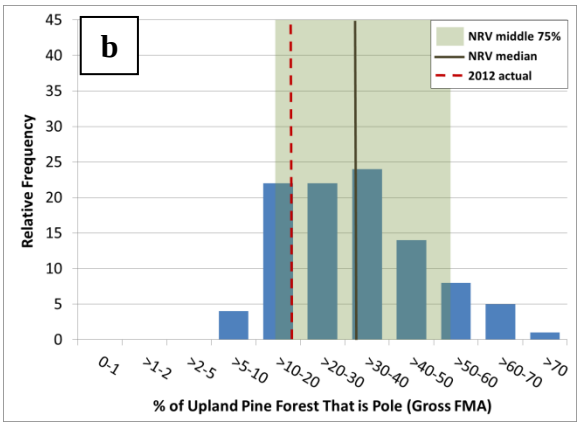
Figure A46. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland mixedwood leading forest for the HWP FMA.

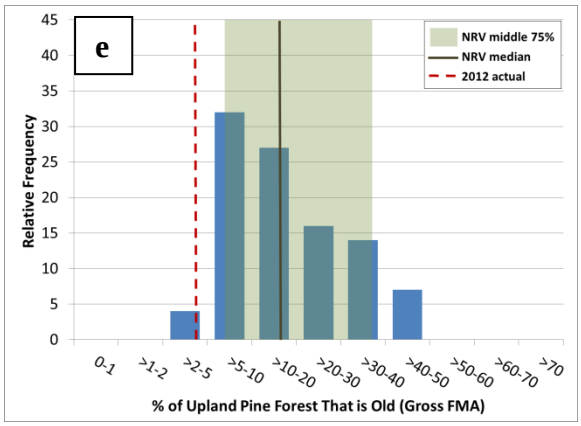
<u>HWP FMA upland mixedwood forest highlights:</u>

- The current condition of Old forest is below the lower bounds of NRV.
- The current condition of Late Mature is on the upper bounds of NRV.









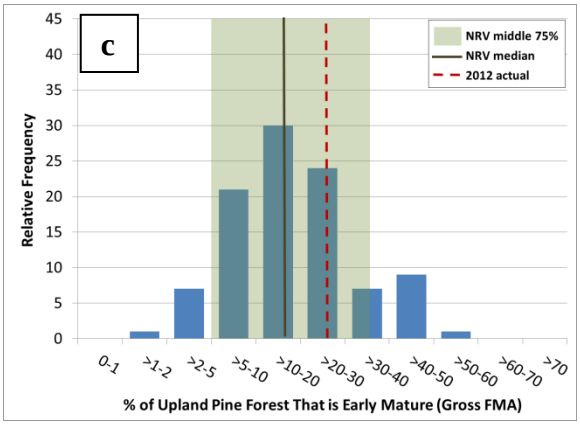
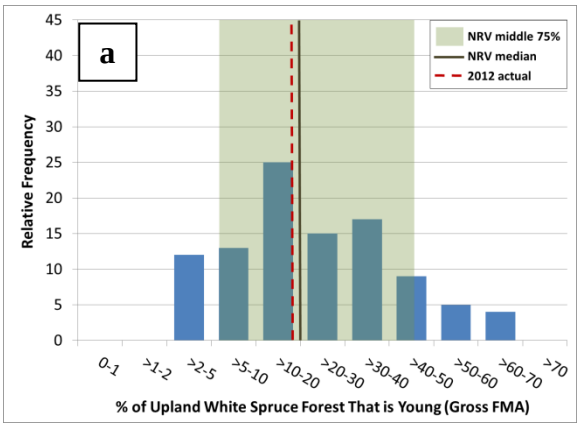
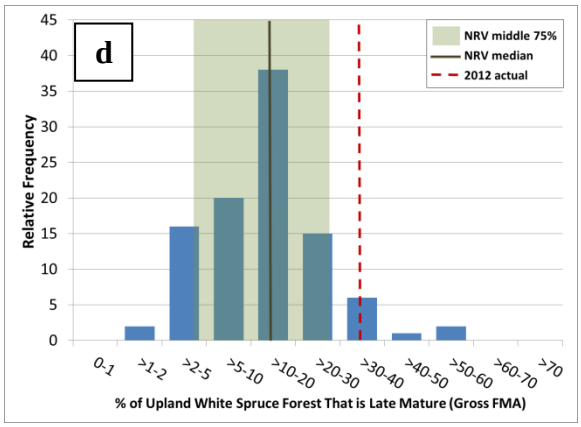


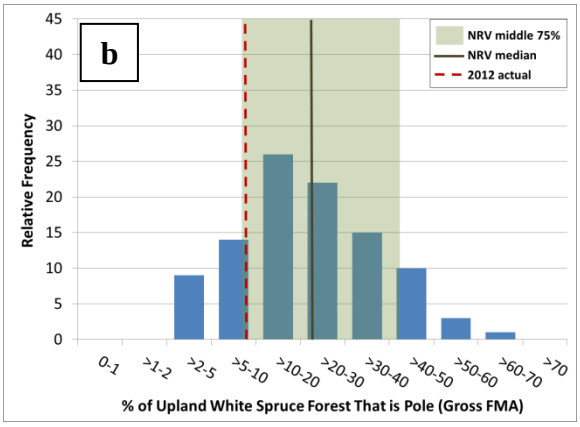
Figure A47. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland black pine leading forest for the HWP FMA.

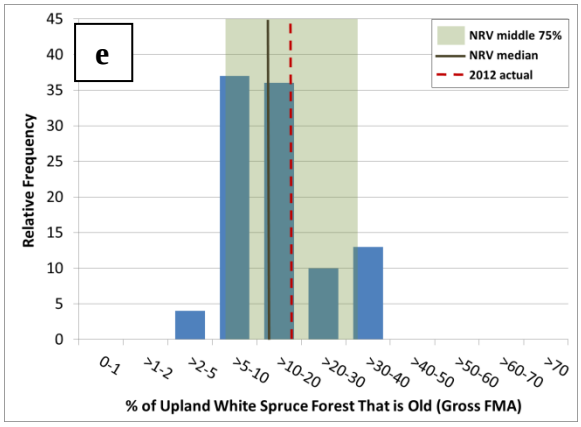
<u>HWP FMA upland pine forest highlights:</u>

- The current condition of Late Mature is beyond the upper bounds of the 75% NRV zone.
- The current condition of Old is below the lower bound of the 75% NRV zone.









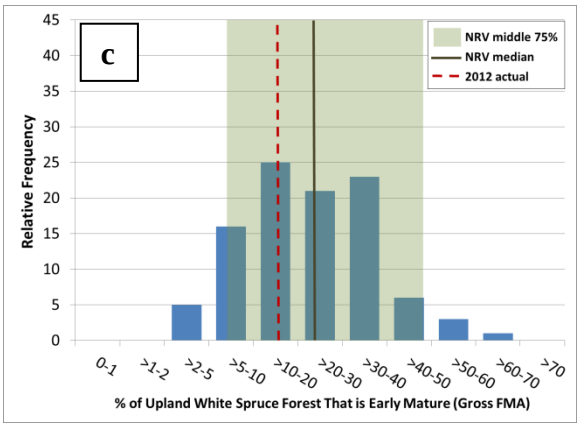
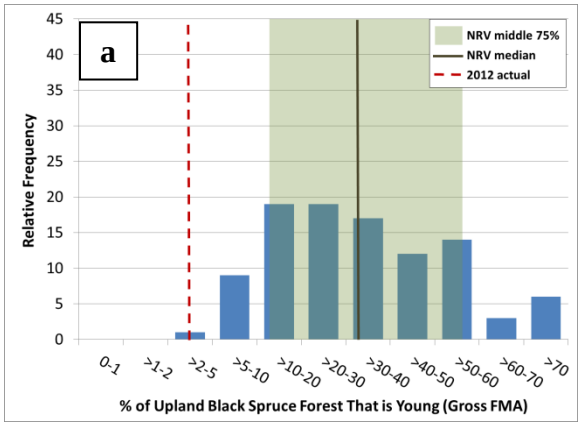
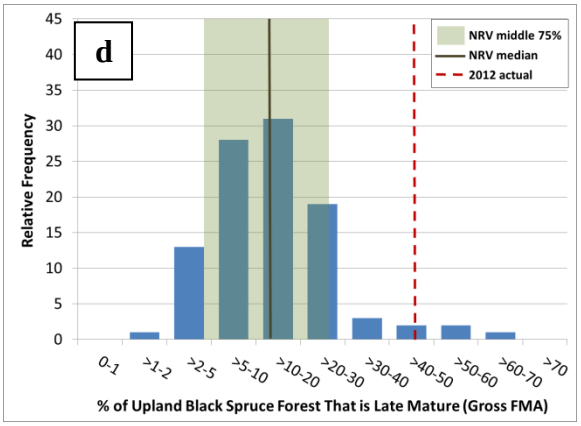


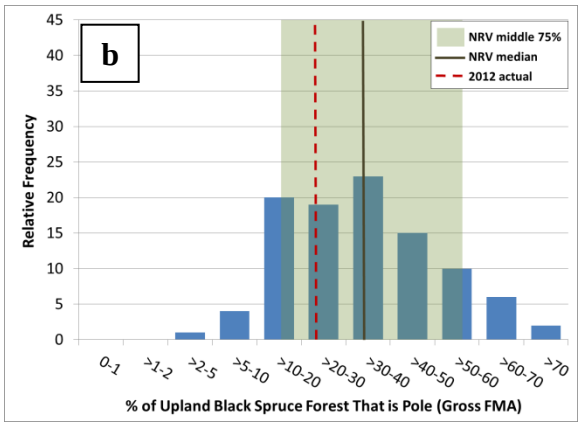
Figure A48. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland white spruce leading forest for the HWP FMA.

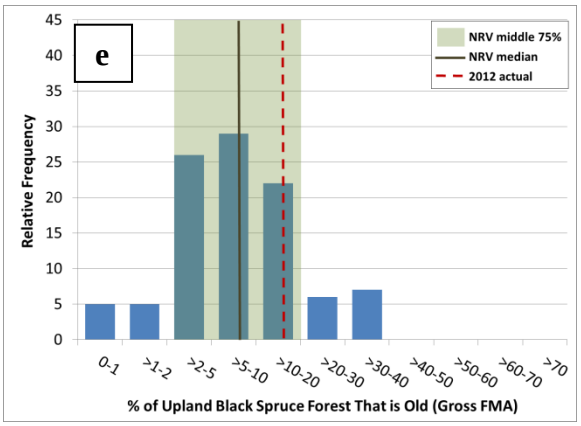
<u>HWP FMA upland white spruce forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Pole is on the lower bound of the 75% NRV zone.
- The current conditions of Late Mature is beyond the upper bound of the 75% NRV zone.









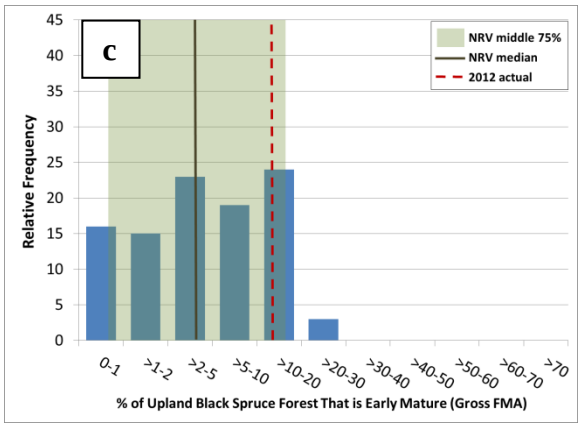
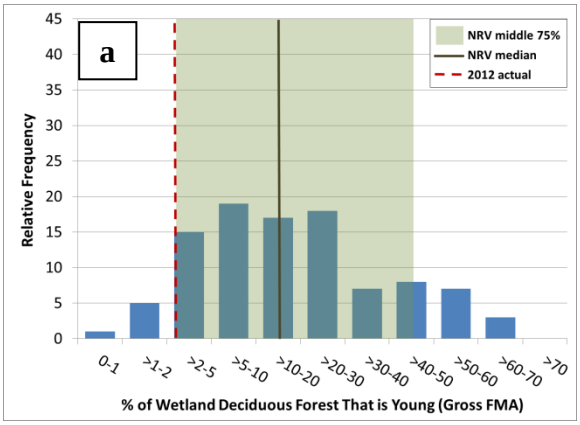
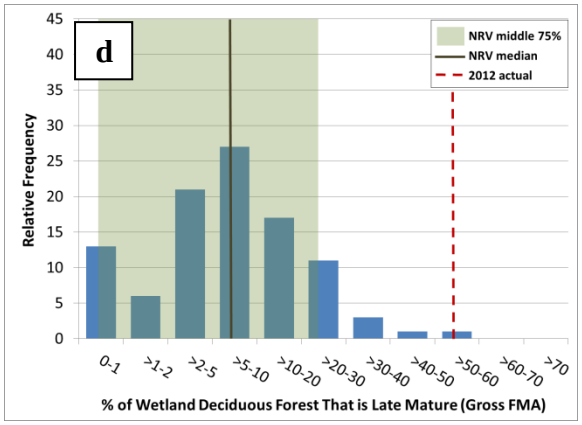


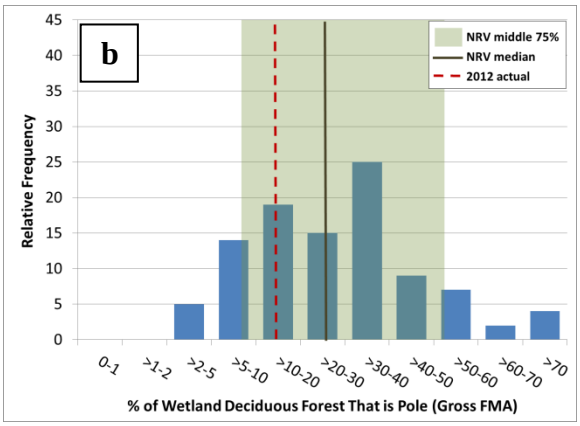
Figure A49. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) upland black spruce leading forest for the HWP FMA.

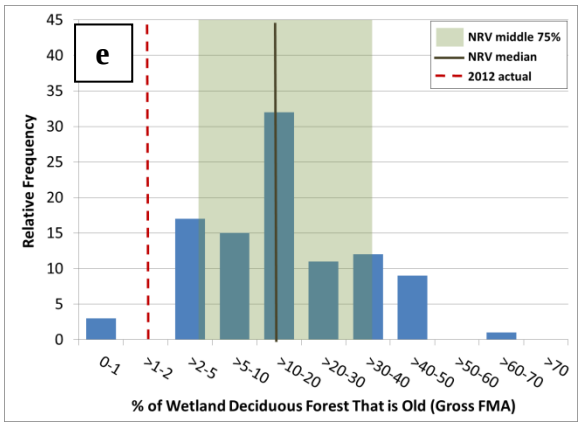
<u>HWP FMA upland black spruce forest highlights:</u>

- The current condition of Young is on the lower bounds of NRV.
- The current conditions of Late Mature is beyond the upper bound of the 75% NRV zone.









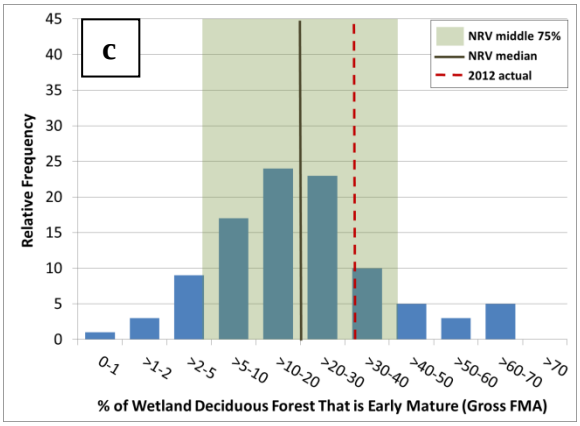
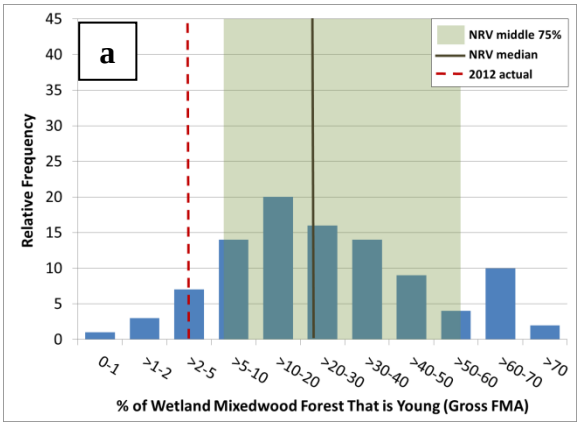
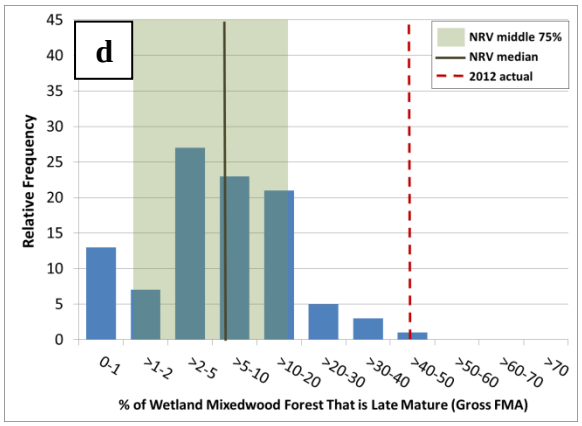


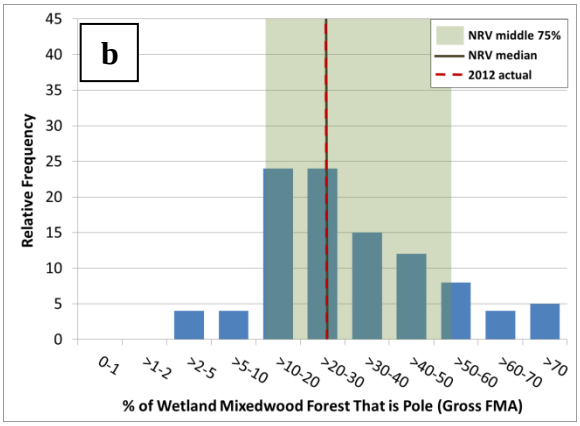
Figure A50. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland deciduous leading forest for the HWP FMA.

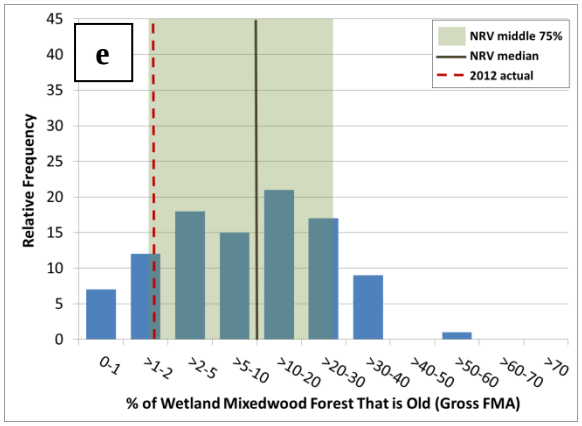
<u>HWP FMA wetland deciduous forest highlights:</u>

- The current condition of Late Mature is on the upper bounds of NRV.
- The current condition of Young is on the lower bound of the 75% NRV zone.
- The current condition of Old is below the lower bound of the 75% NRV zone.









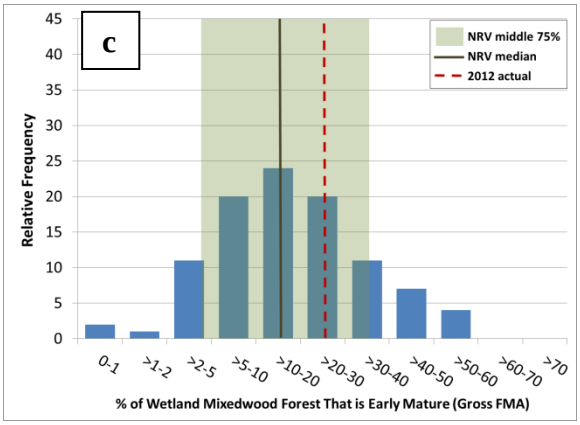
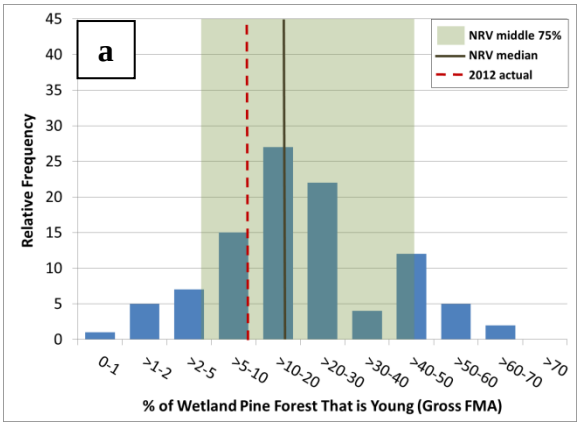
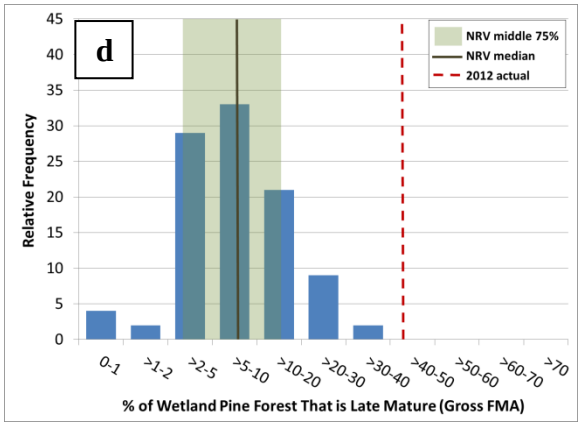


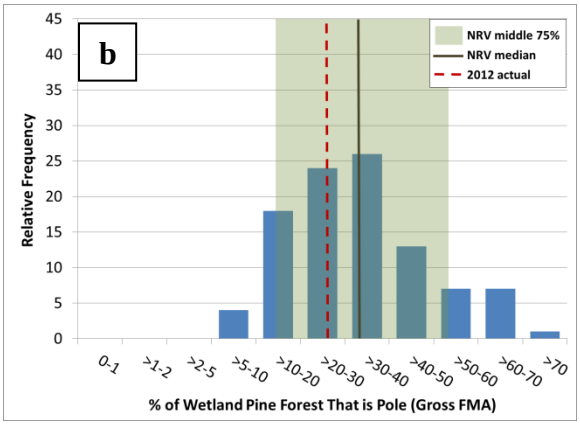
Figure A51. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland mixedwood leading forest for the HWP FMA.

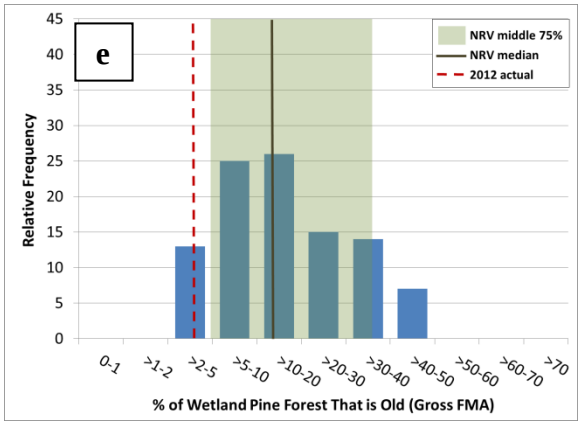
<u>HWP FMA wetland mixedwood forest highlights:</u>

- The current condition of Late Mature is on the upper bounds of NRV.
- The current condition of Young is below the 75% NRV zone.
- The current condition of Old is on the lower bound of the 75% NRV zone.









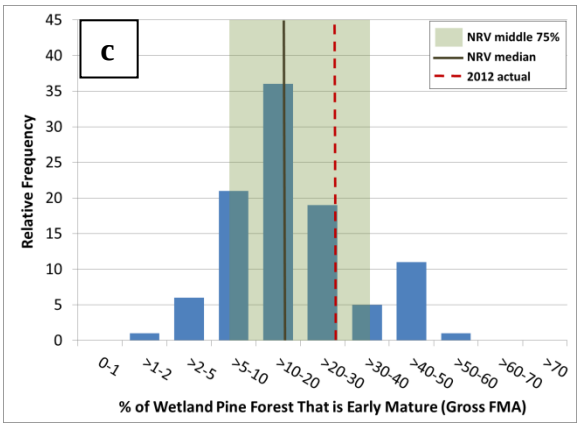
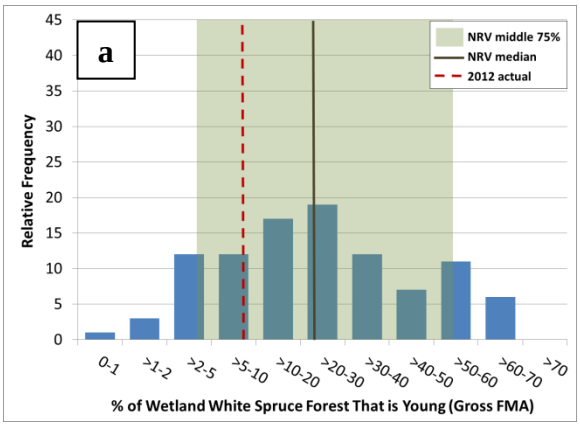
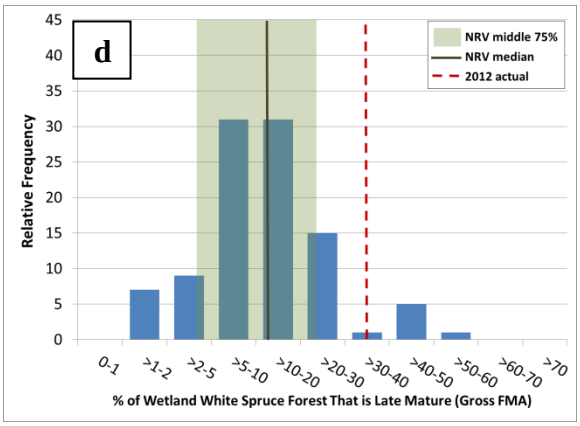


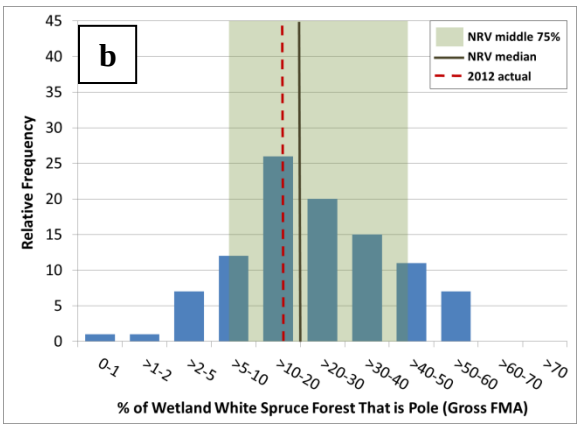
Figure A52. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland pine leading forest for the HWP FMA.

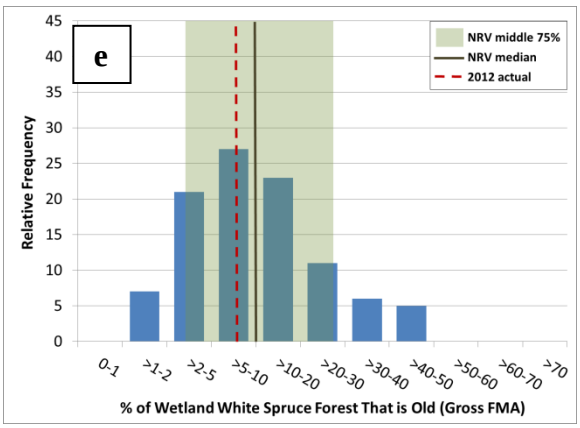
<u>HWP FMA wetland pine forest highlights:</u>

- The current condition of Late Mature is beyond the upper bounds of NRV.
- The current condition of Old is below the lower bound of the 75% NRV zone.









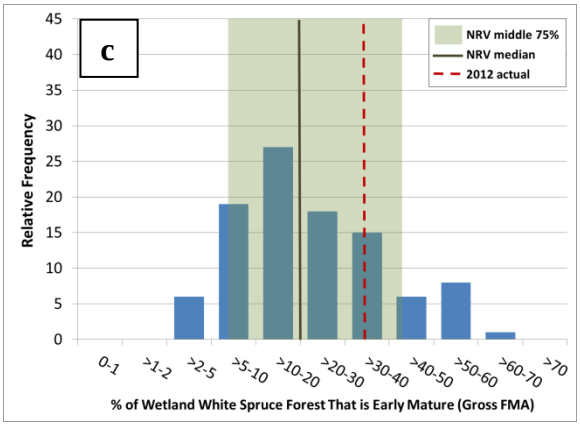
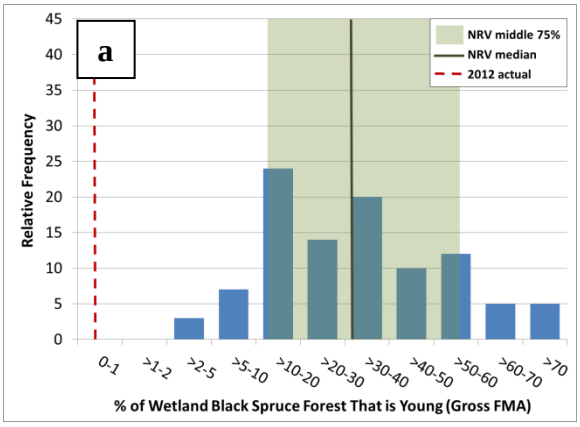
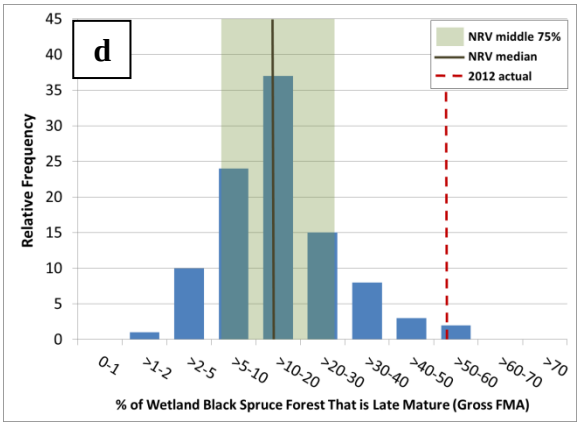


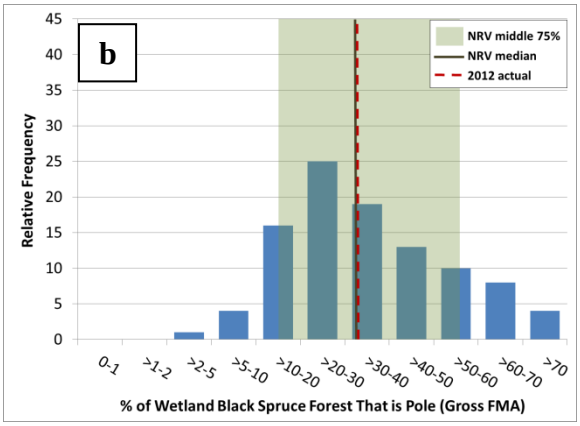
Figure A53. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland white spruce leading forest for the HWP FMA.

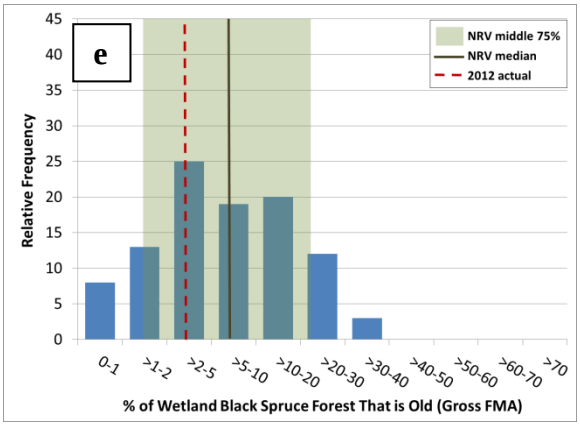
<u>HWP FMA wetland white spruce forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Late Mature is above the upper bound of the 75% NRV zone.









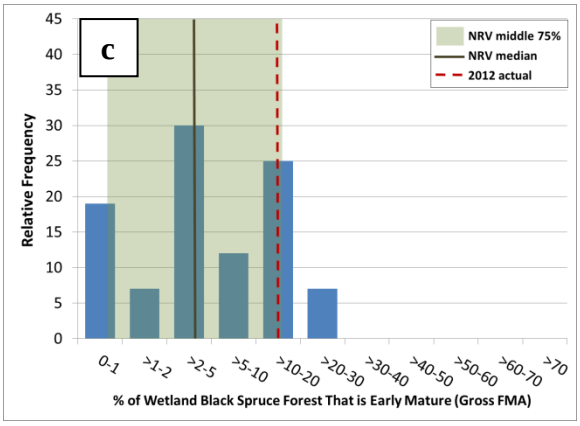
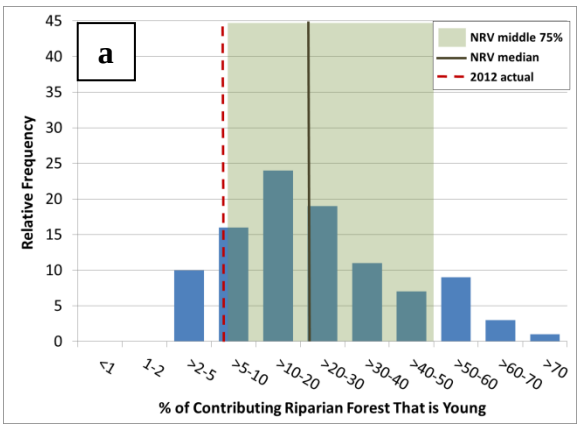
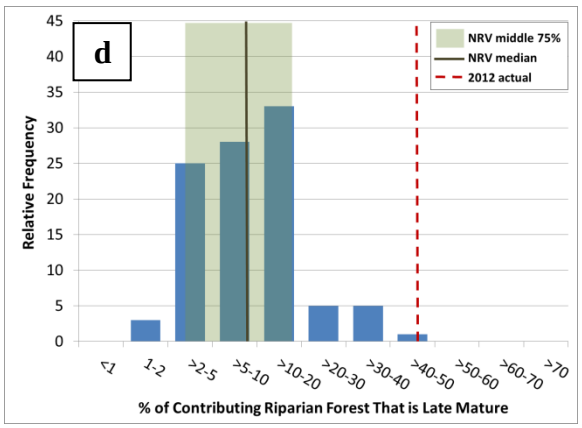


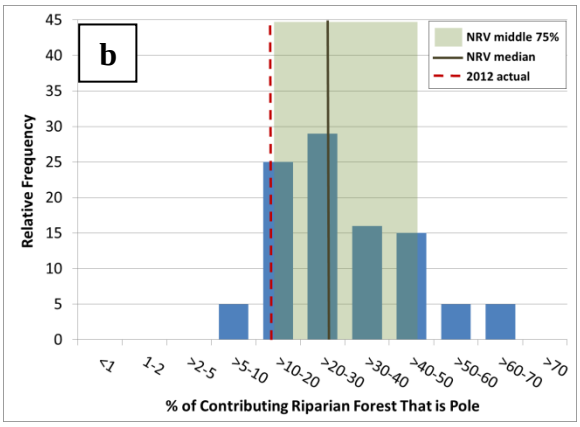
Figure A54. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) wetland black spruce leading forest for the HWP FMA.

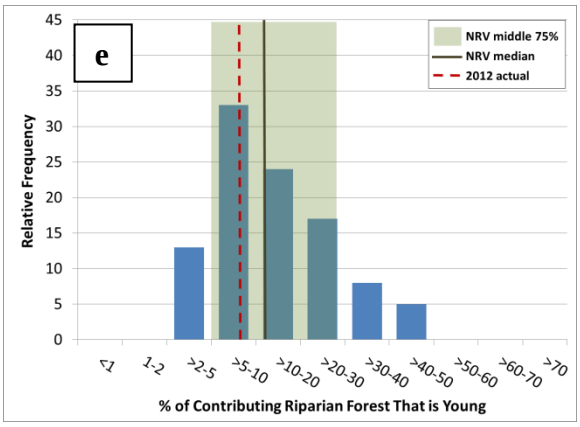
<u>HWP FMA wetland black spruce forest highlights:</u>

- The current condition of Young is below the lower boundary of NRV.
- The current condition of Late Mature is above the upper bound of the 75% NRV zone, and close to the upper boundary of NRV.









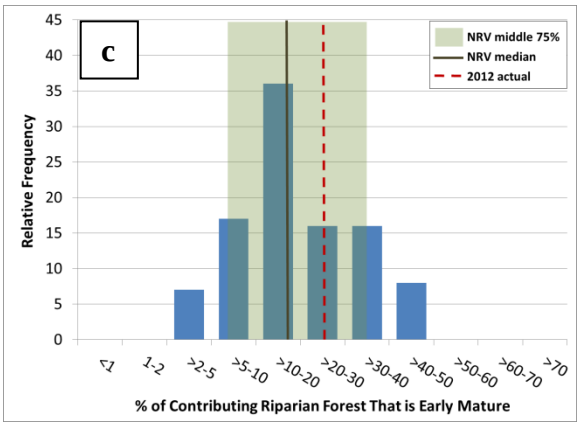
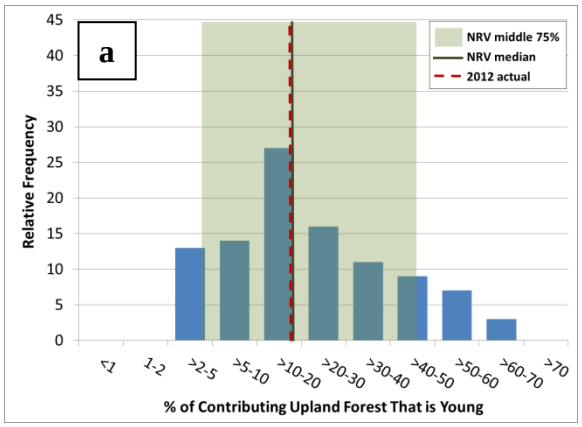
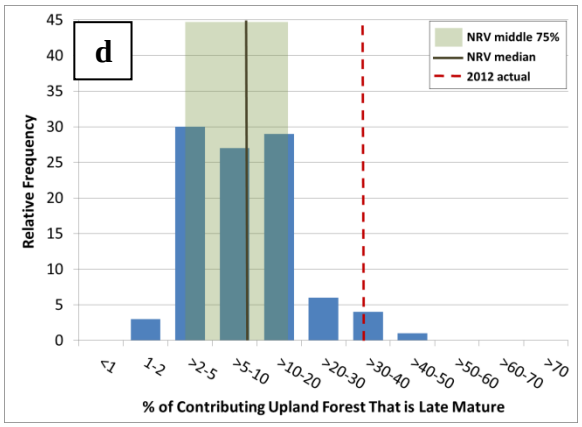


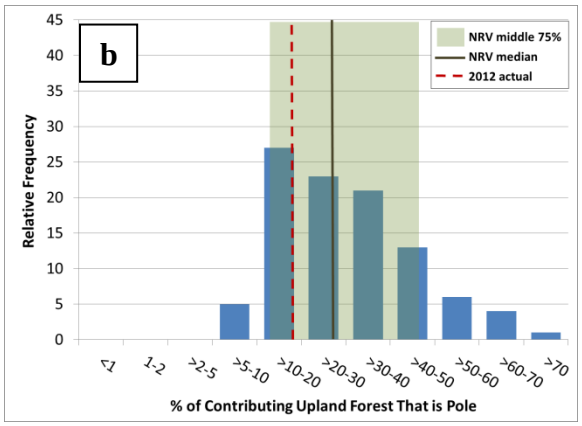
Figure A55. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian forest for the HWP FMA.

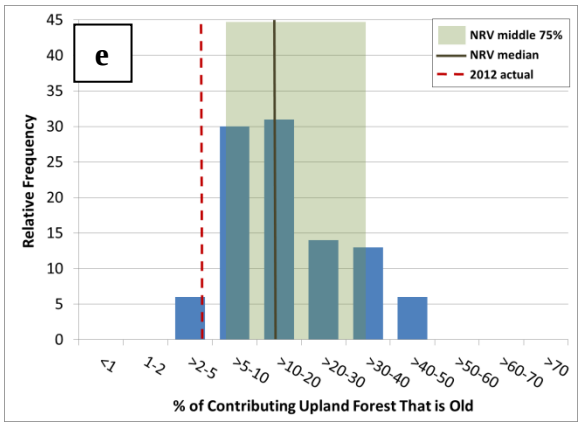
<u>HWP FMA contributing riparian forest highlights:</u>

- The current condition of Late Mature is on the upper boundary of NRV.
- The current conditions of Young and Pole are both on the lower boundary of the 75% NRV zone.









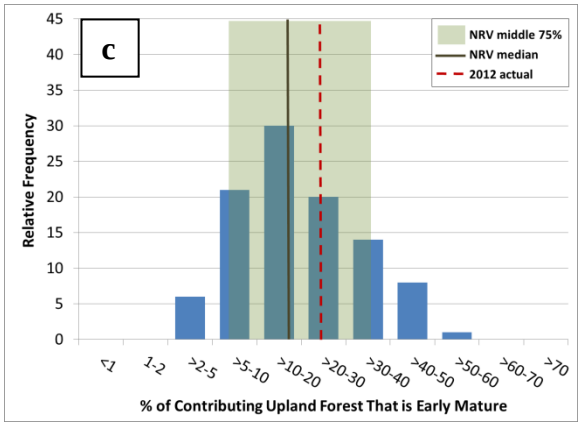


Figure A56. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, upland forest for the HWP FMA.

<u>HWP FMA contributing upland forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Late Mature is beyond the upper boundary of the 75% NRV zone.
- The current condition of Old is beyond the lower boundary of the 75% NRV zone.

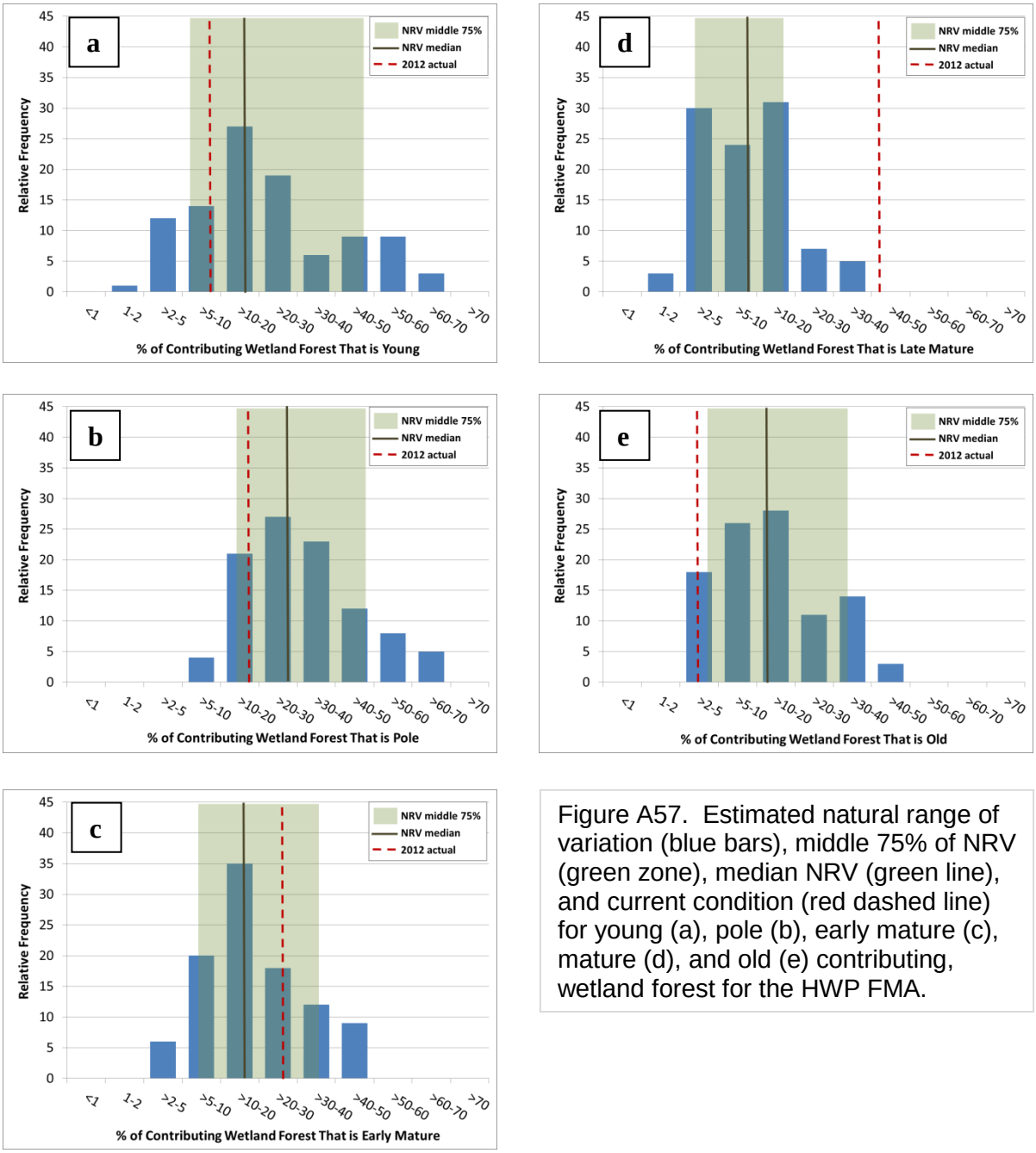


Figure A57. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, wetland forest for the HWP FMA.

<u>HWP FMA contributing wetland forest highlights:</u>

- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Old is beyond the lower boundary of the 75% NRV zone.

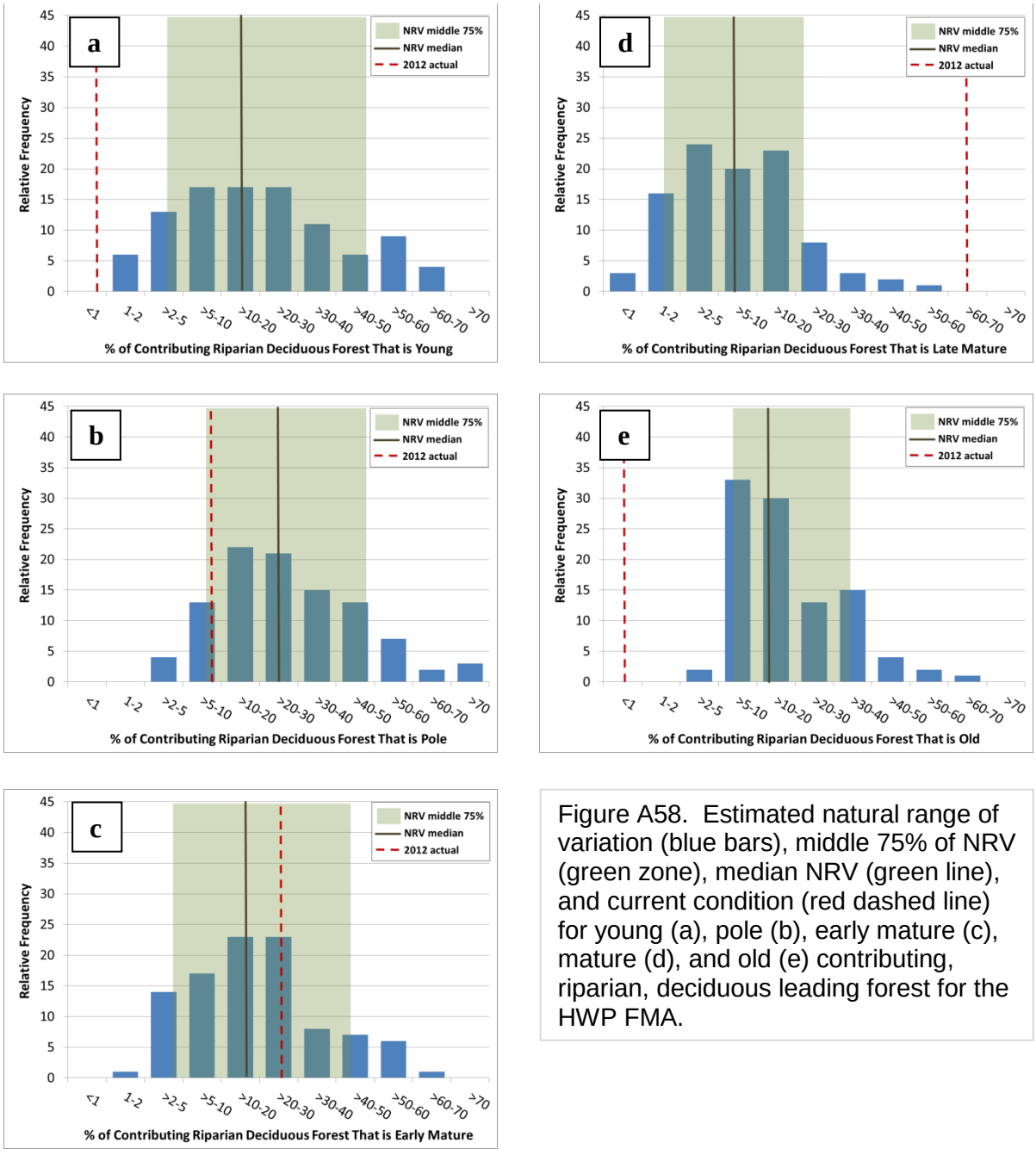
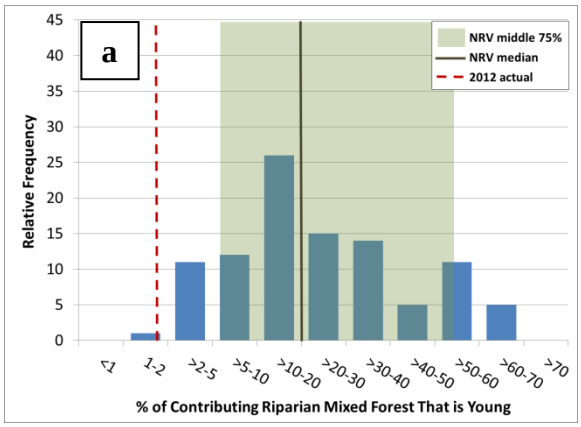
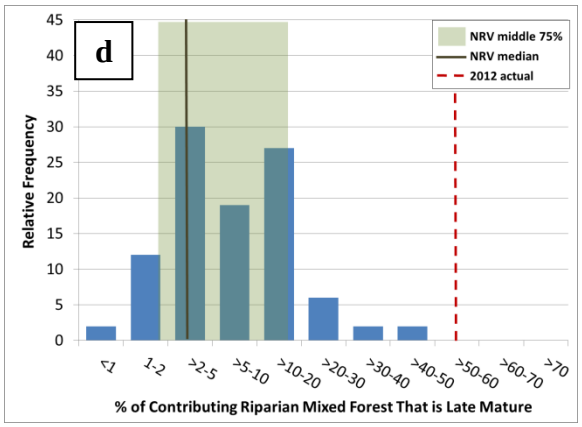


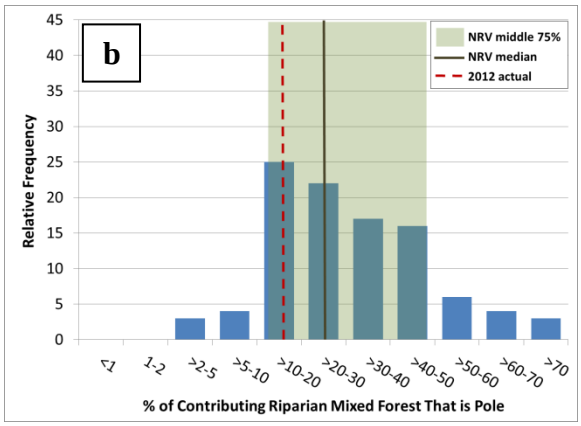
Figure A58. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian, deciduous leading forest for the HWP FMA.

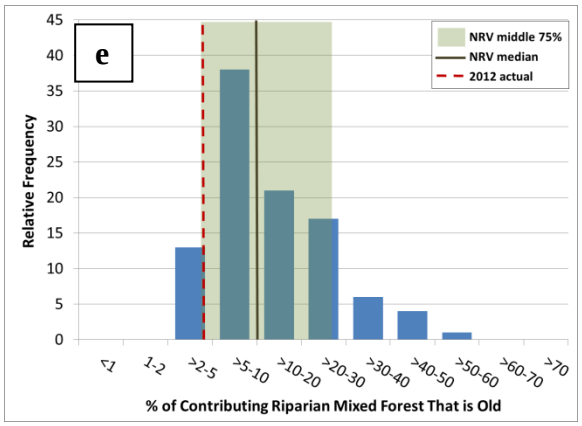
<u>HWP FMA contributing riparian deciduous forest highlights:</u>

- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current conditions of Young and Old are both beyond the lower boundary of NRV.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.









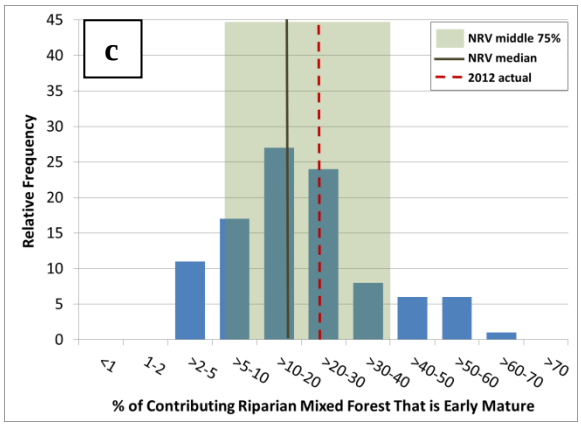
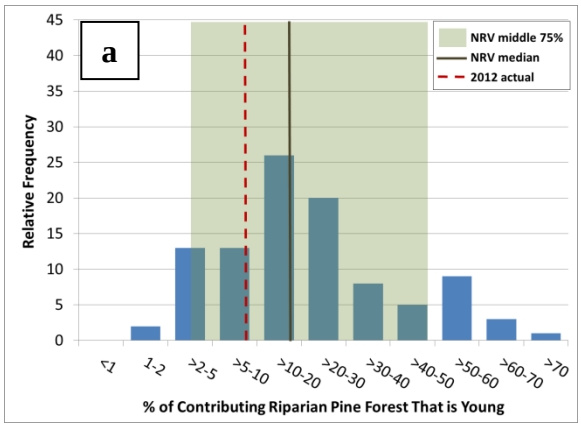
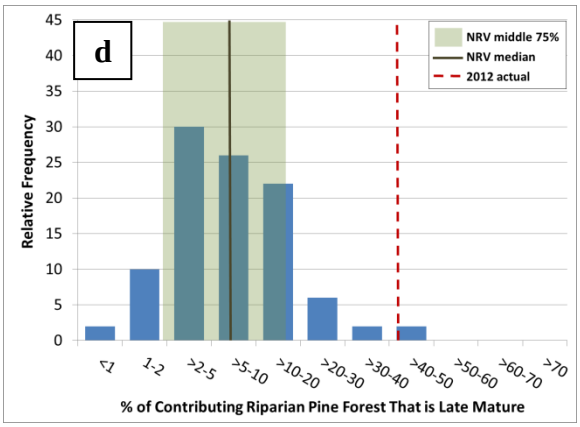


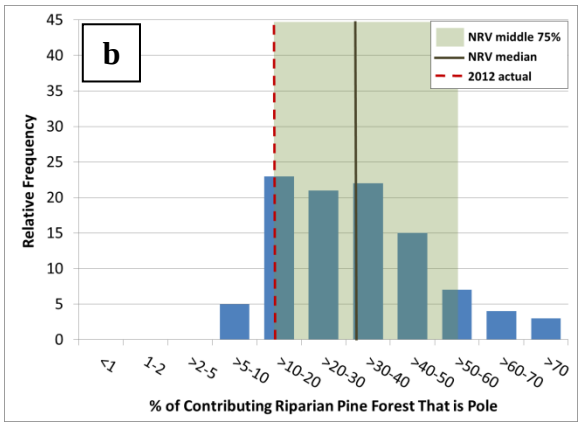
Figure A59. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian, mixedwood leading forest for the HWP FMA.

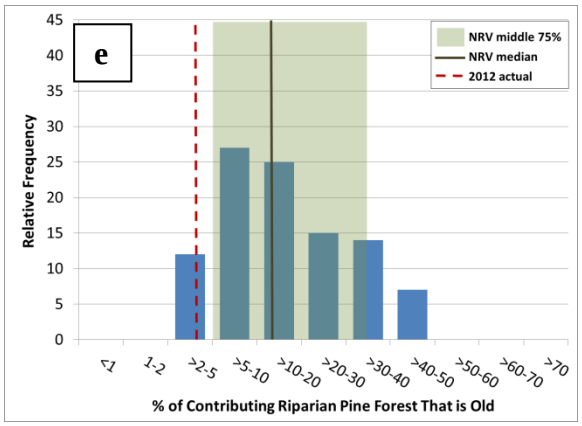
<u>HWP FMA contributing riparian mixedwood forest highlights:</u>

- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Young is beyond the lower boundary of the 75% NRV zone.
- The current condition of Old is on the lower boundary of the 75% NRV zone.









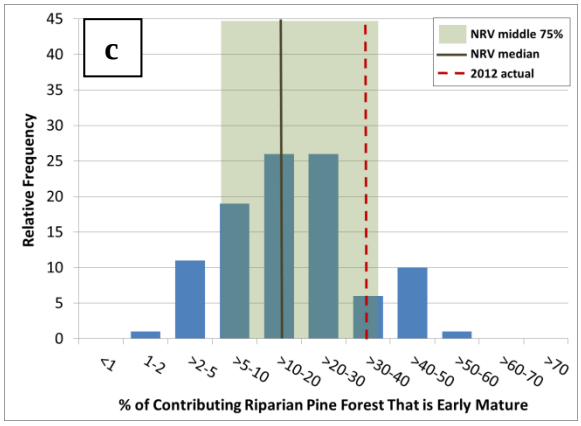
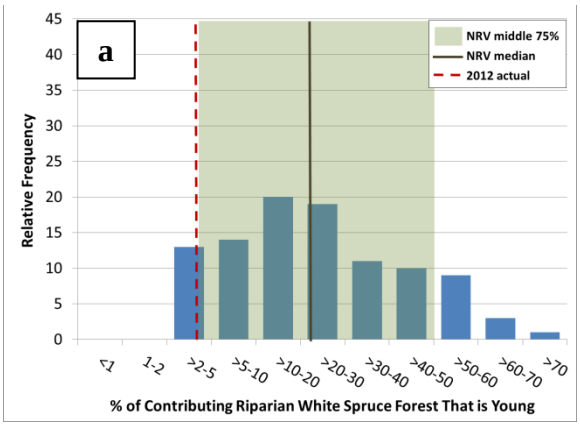
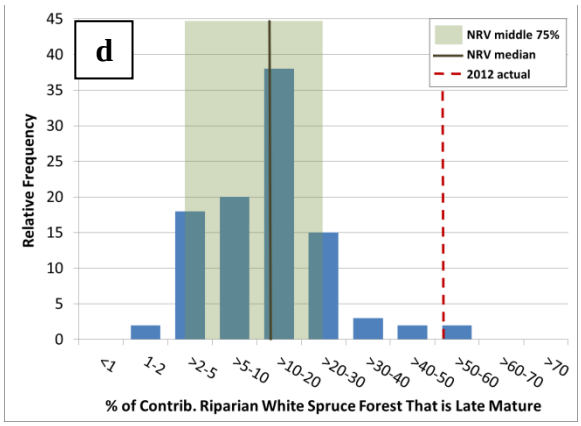


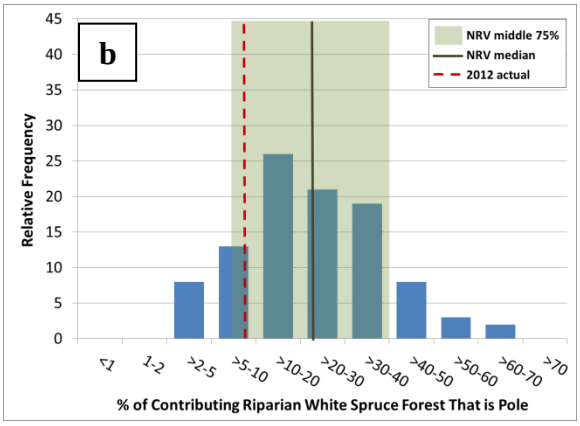
Figure A60. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian, pine leading forest for the HWP FMA.

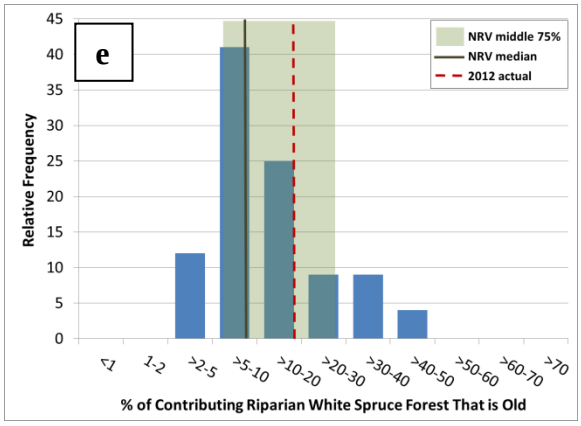
<u>HWP FMA contributing riparian pine forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Pole is beyond the lower boundary of the 75% NRV zone.
- The current condition of Late Mature is beyond the upper boundary of the 75% NRV zone.
- The current condition of Old is below the lower boundary of the 75% NRV zone.









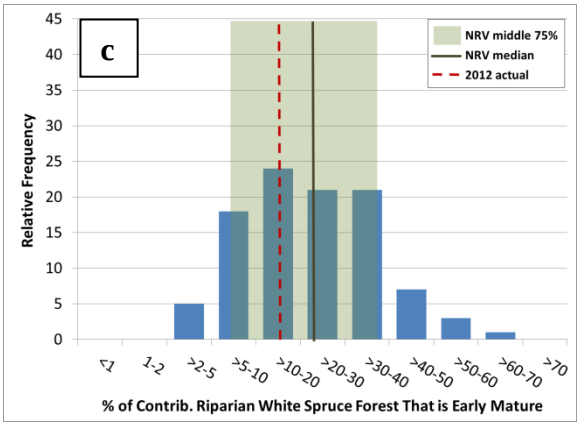
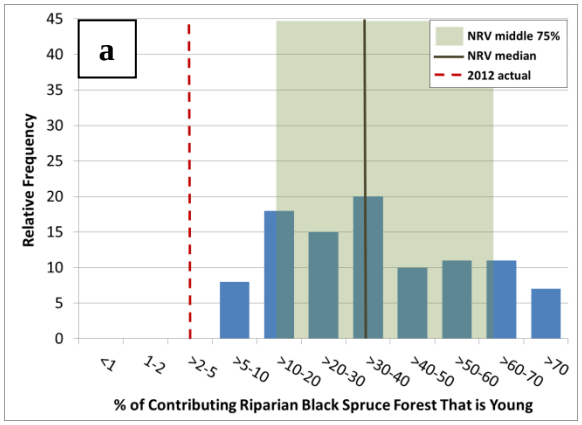
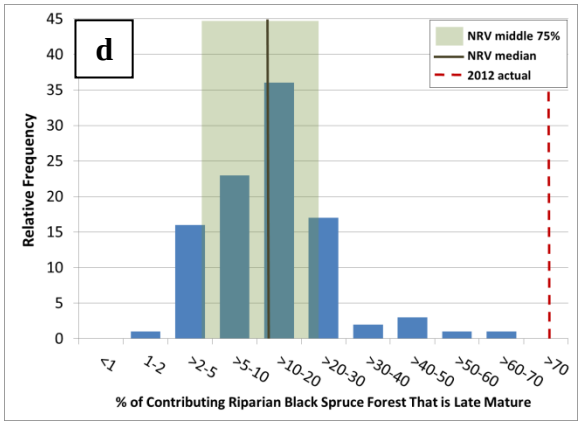


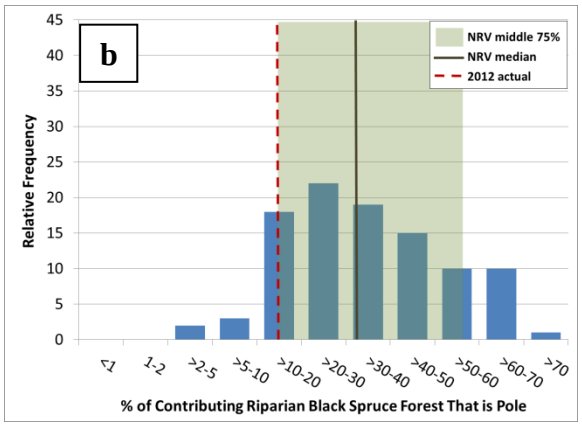
Figure A61. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian, white spruce leading forest for the HWP FMA.

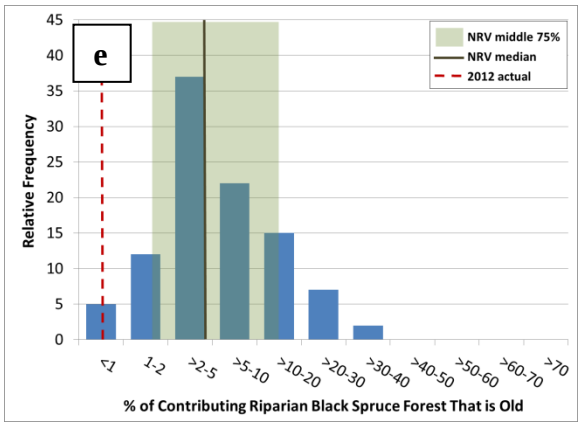
<u>HWP FMA contributing riparian white spruce forest highlights:</u>

- All current conditions are within NRV.
- The current condition of Young is on the lower boundary of the 75% NRV zone.
- The current condition of Late Mature is beyond the upper boundary of the 75% NRV zone.









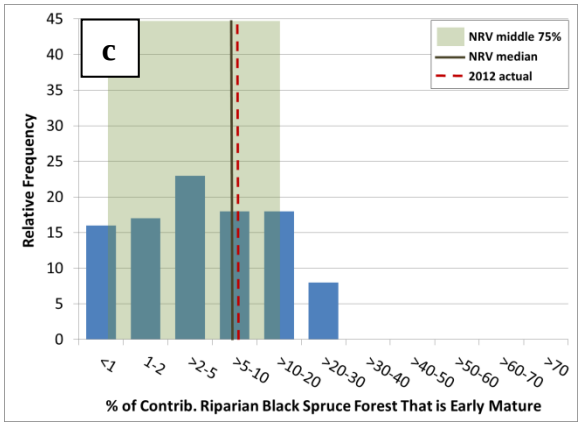


Figure A62. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) contributing, riparian, black spruce leading forest for the HWP FMA.

<u>HWP FMA contributing riparian black spruce forest highlights:</u>

- The current condition of Young is beyond the lower boundary of NRV.
- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.
- The current condition of Old is below the lower boundary of the 75% NRV zone.

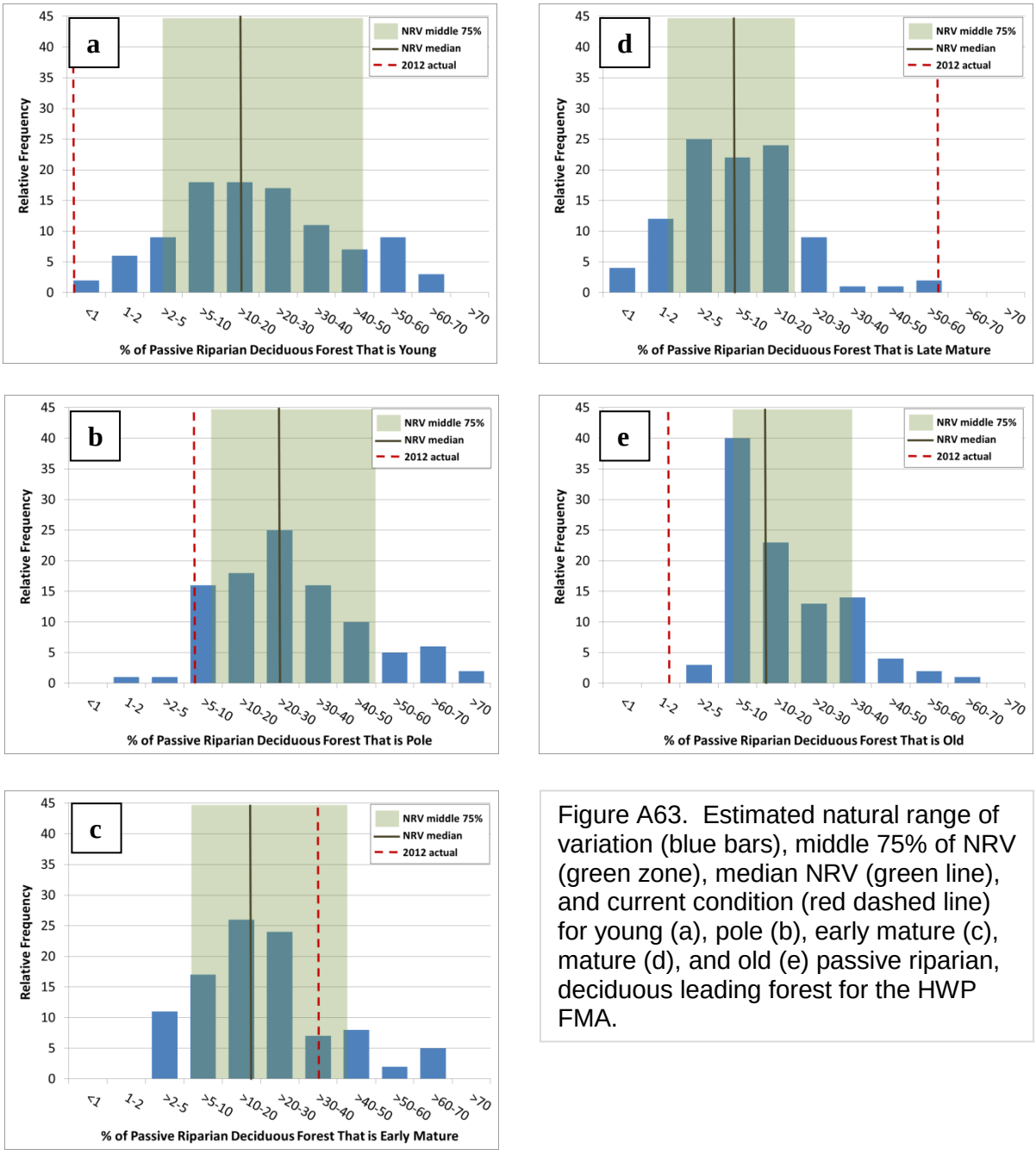
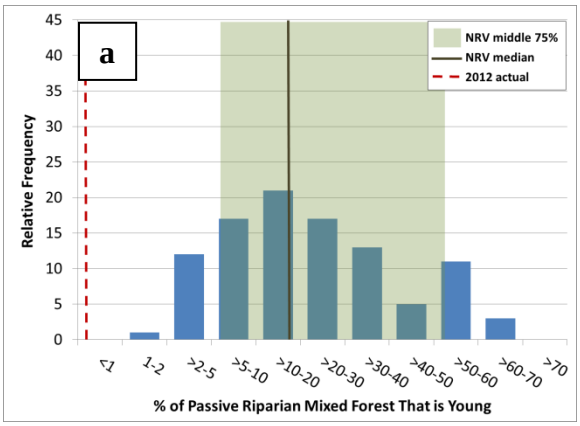
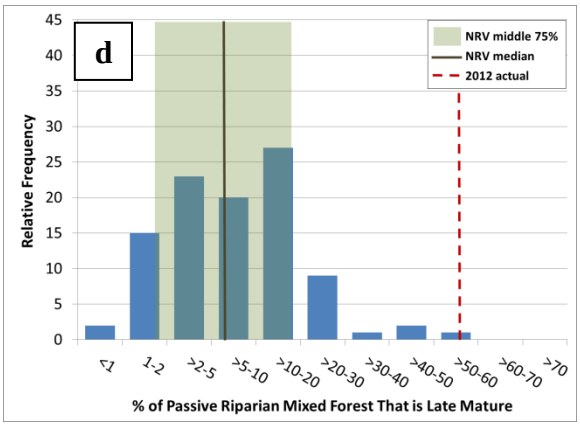


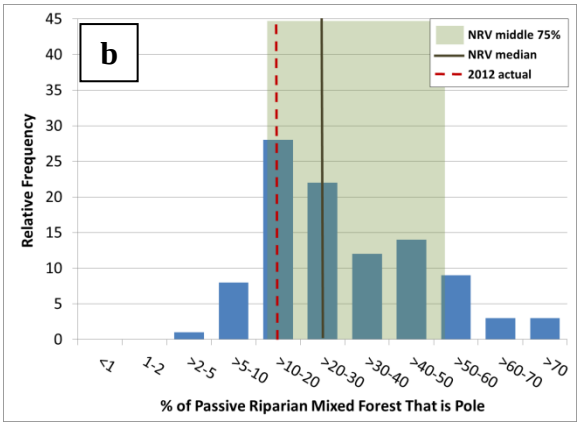
Figure A63. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive riparian, deciduous leading forest for the HWP FMA.

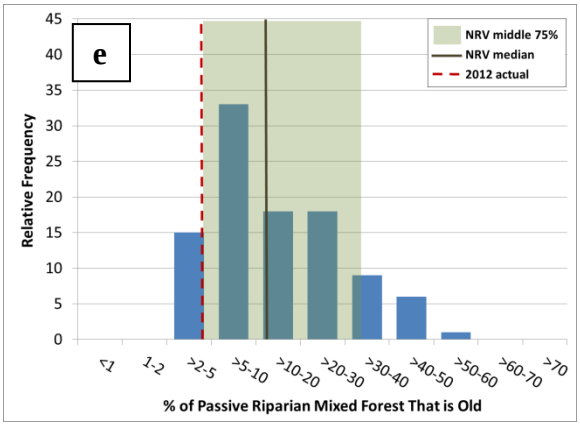
<u>HWP FMA passive riparian deciduous forest highlights:</u>

- The current condition of Young is beyond the lower boundary of NRV.
- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Pole is below the lower boundary of the 75% NRV zone.
- The current condition of Old is below the lower boundary of the 75% NRV zone.









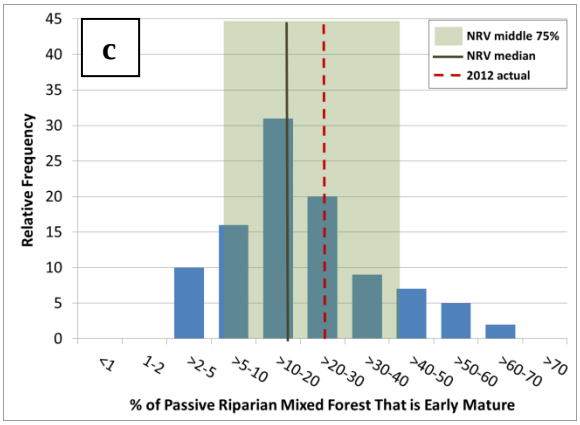
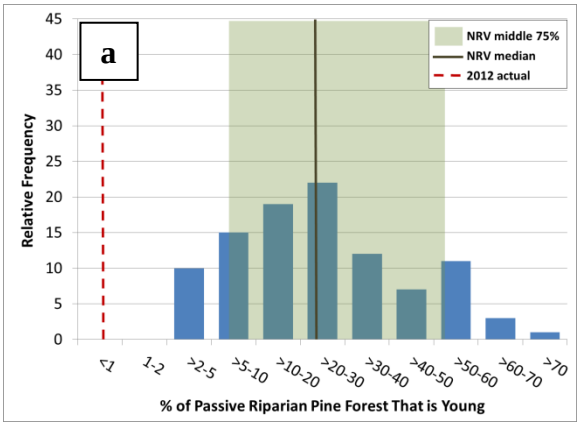
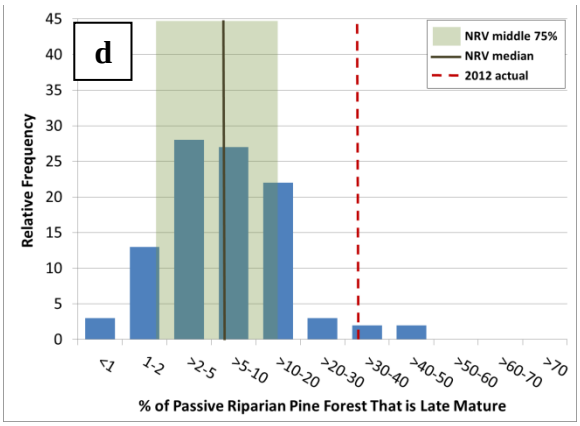


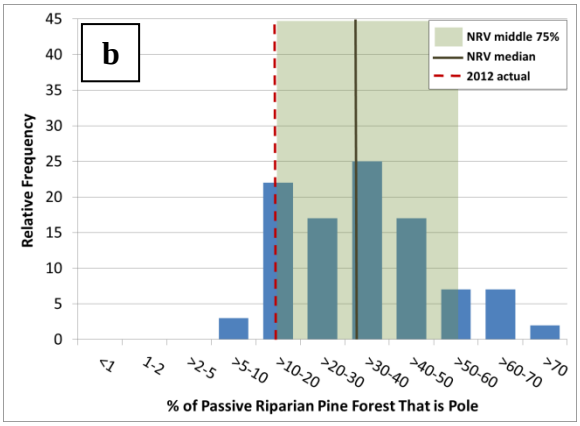
Figure A64. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive riparian, mixedwood leading forest for the HWP FMA.

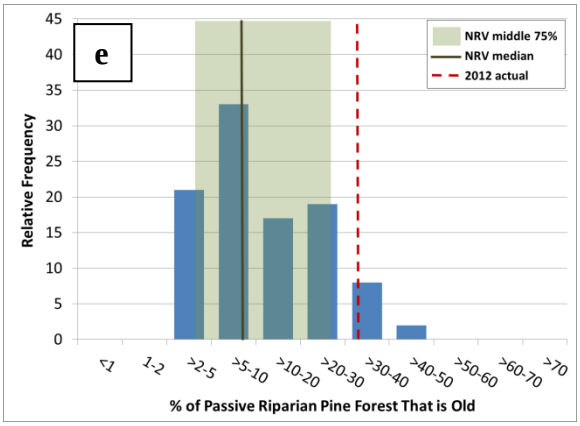
<u>HWP FMA passive riparian mixedwood forest highlights:</u>

- The current condition of Young is beyond the lower boundary of NRV.
- The current condition of Late Mature is beyond the upper boundary of NRV.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.
- The current condition of Old is on the lower boundary of the 75% NRV zone.









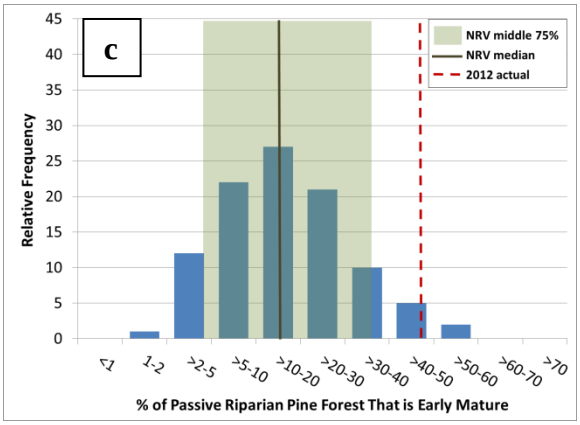
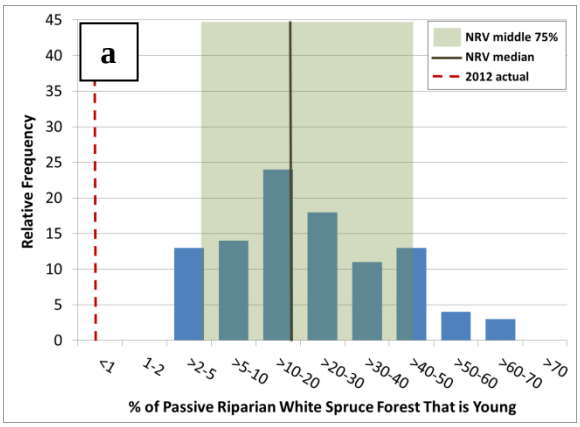
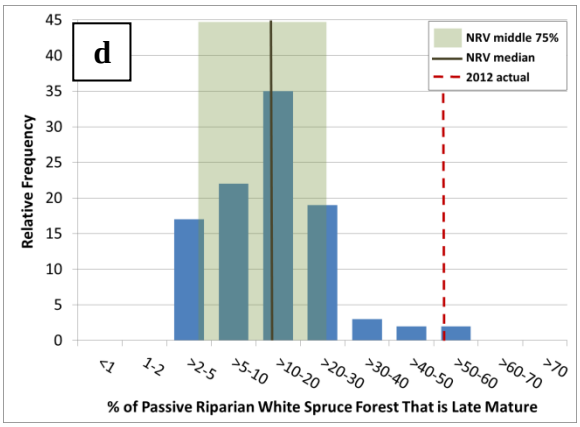


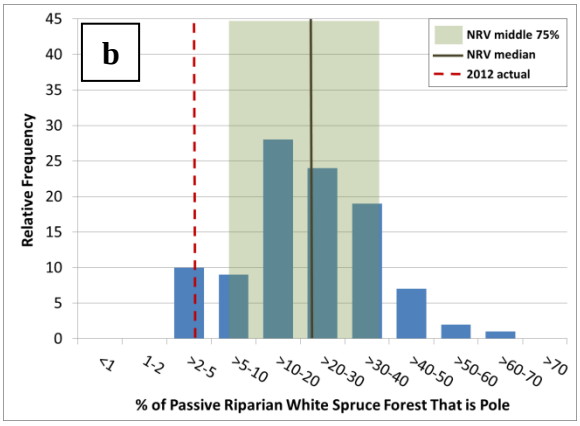
Figure A65. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive riparian, pine leading forest for the HWP FMA.

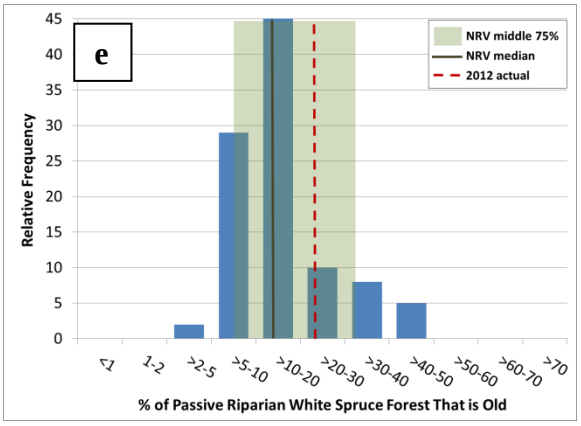
<u>HWP FMA passive riparian pine forest highlights:</u>

- The current condition of Young is beyond the lower boundary of NRV.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.
- The current condition of Early Mature is beyond the upper boundary of the 75% NRV zone.
- The current conditions of both Later Mature and Old are beyond the upper boundaries of their respective 75% NRV zones.









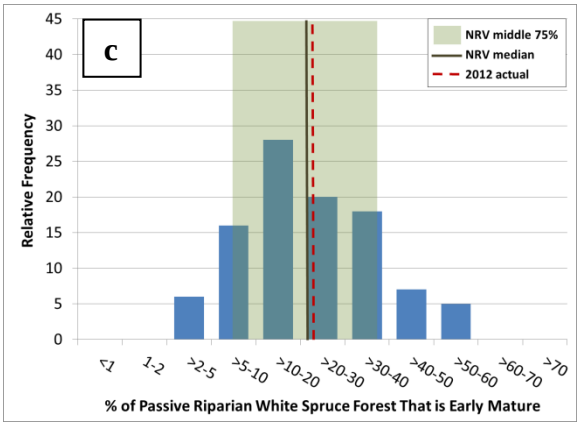


Figure A66. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive riparian, white spruce leading forest for the HWP FMA.

<u>HWP FMA passive riparian white spruce forest highlights:</u>

- The current condition of Young is beyond the lower boundary of NRV.
- The current condition of Pole is below the lower boundary of the 75% NRV zone.
- The current condition of Late Mature is well beyond the upper boundary of the 75% NRV zone.

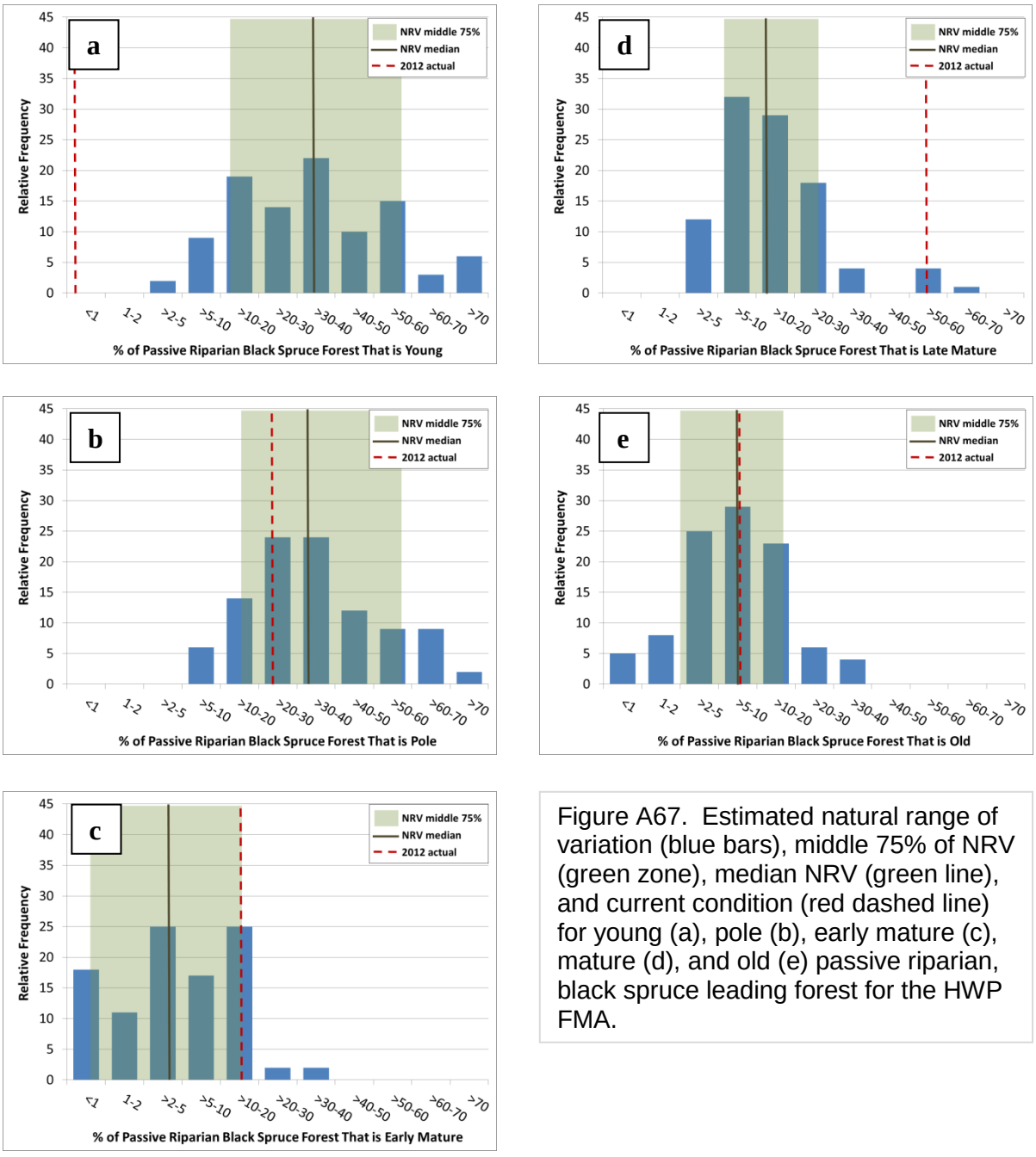


Figure A67. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive riparian, black spruce leading forest for the HWP FMA.

<u>HWP FMA passive riparian black spruce forest highlights:</u>

- The current condition of Young is well beyond the lower boundary of NRV.
- The current condition of Early Mature is on the upper boundary of the 75% NRV zone.
- The current condition of Late Mature is well beyond the upper boundary of the 75% NRV zone.

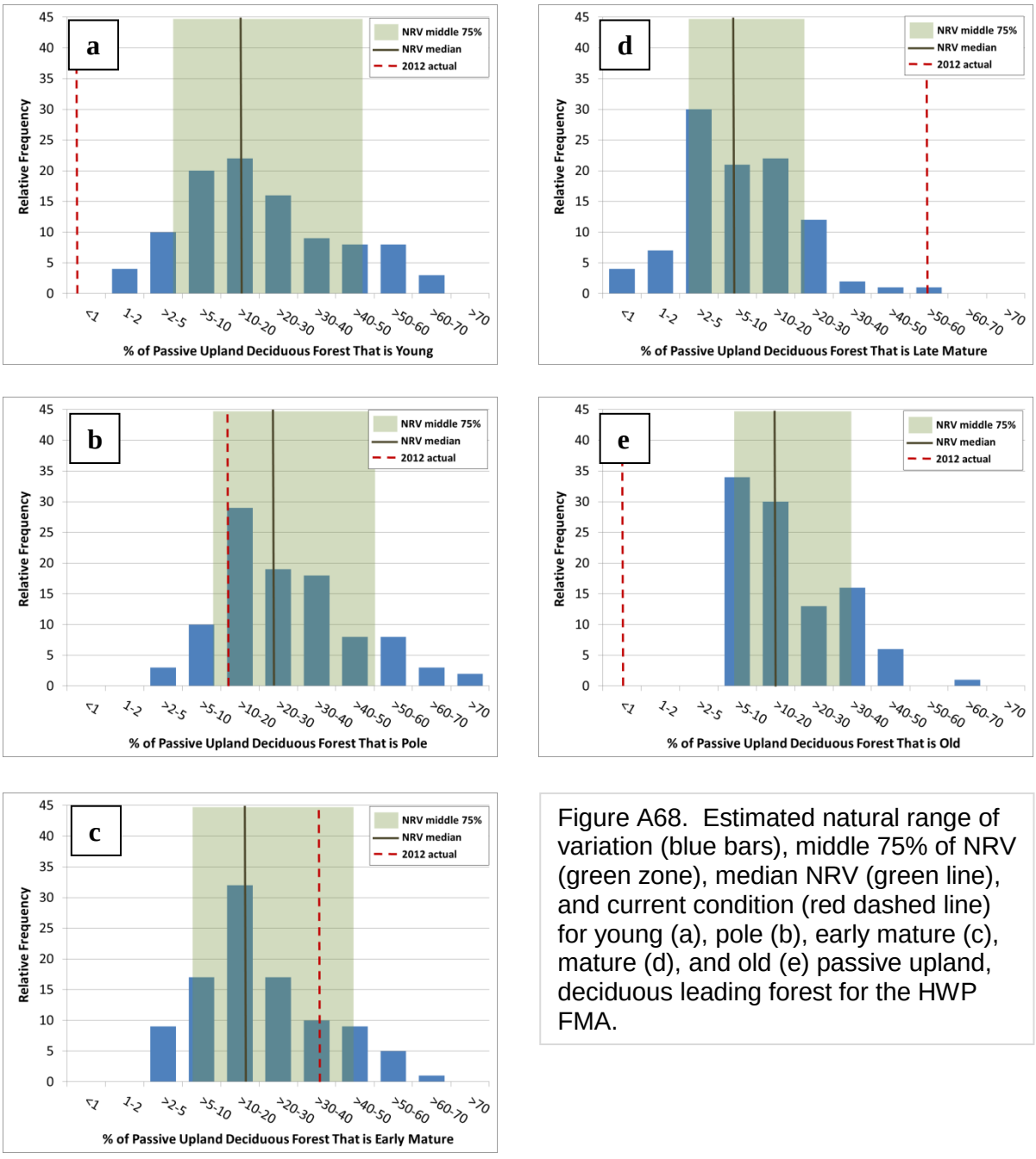
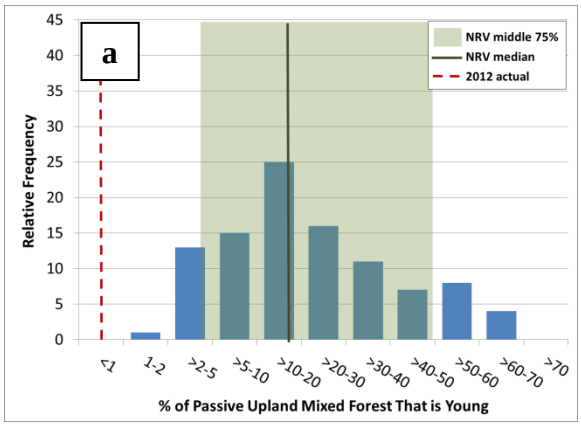
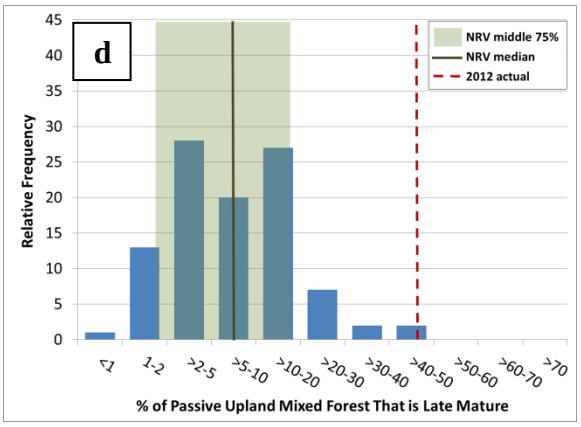


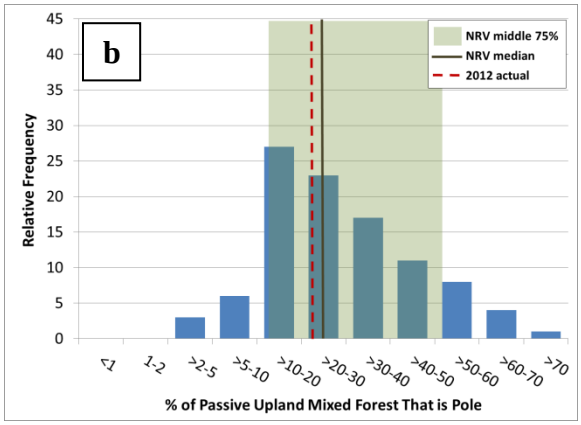
Figure A68. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive upland, deciduous leading forest for the HWP FMA.

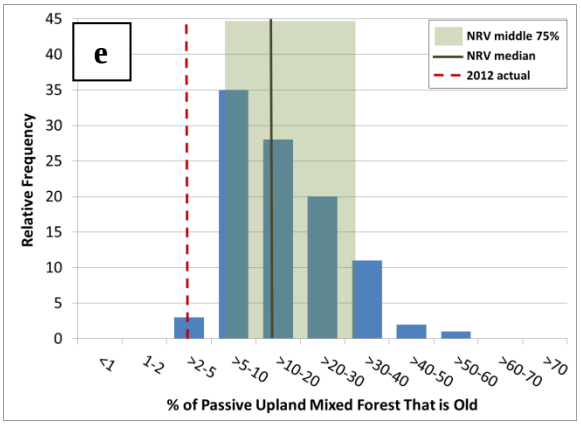
<u>HWP FMA passive upland deciduous forest highlights:</u>

- The current conditions of Young and Old are beyond the lower boundaries of their respective NRVs.
- The current condition of Late Mature is on the upper boundary of NRV.









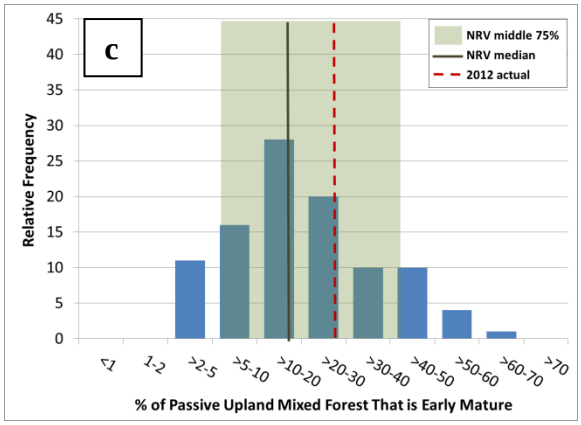
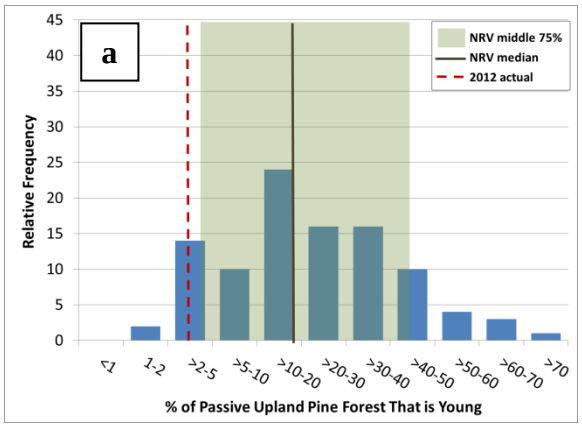
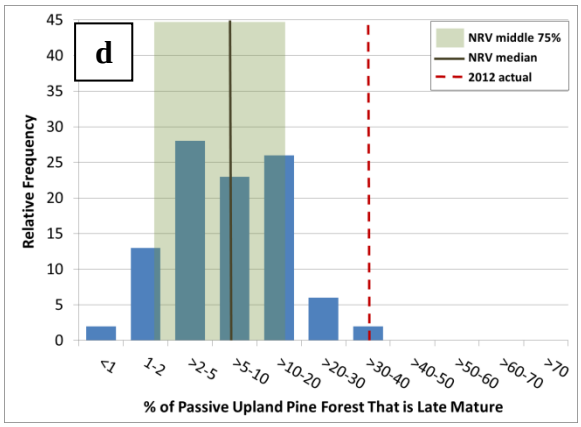


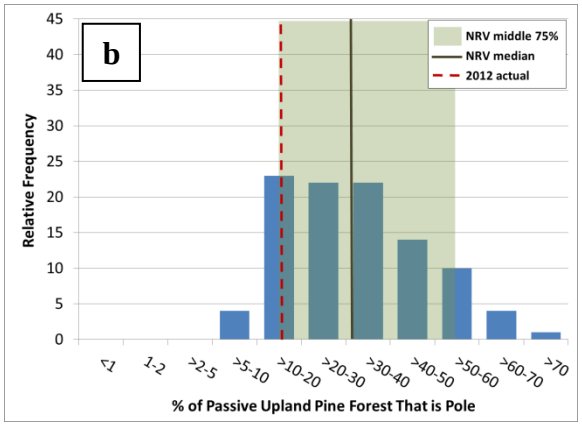
Figure A69. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive upland, mixedwood leading forest for the HWP FMA.

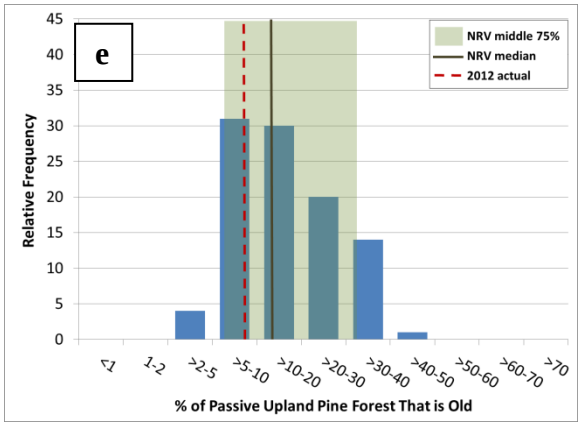
<u>HWP FMA passive upland mixedwood forest highlights:</u>

- The current condition of Young is beyond the lower boundaries of NRV.
- The current condition of Late Mature is on the upper boundary of NRV.
- The current condition of Old is beyond the lower boundary of the 75% NRV zone.









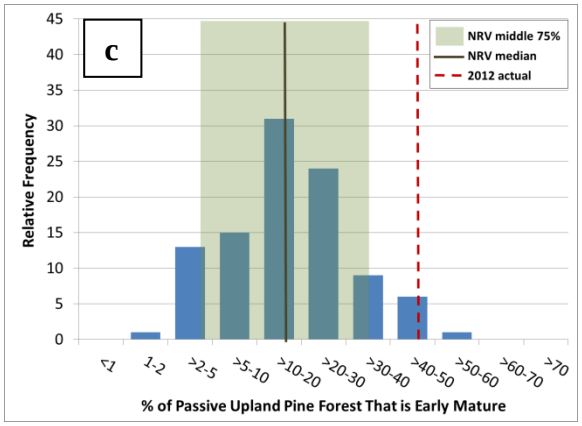
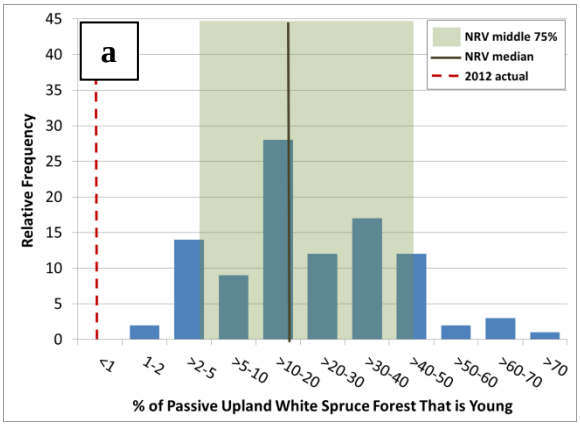
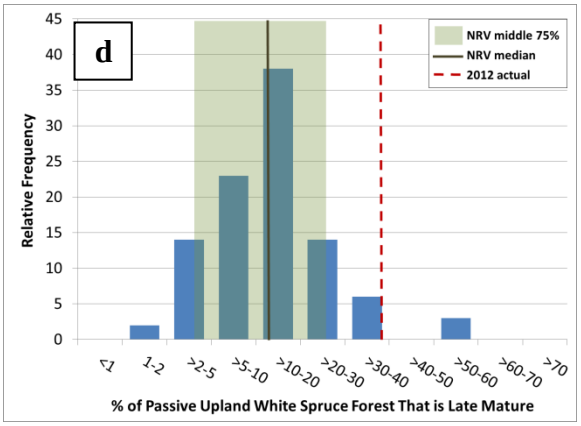


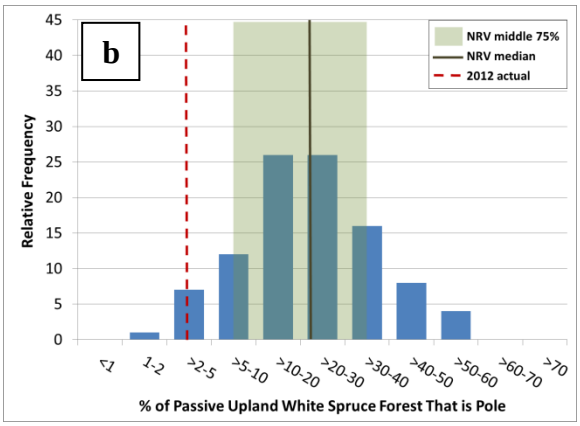
Figure A70. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive upland, pine leading forest for the HWP FMA.

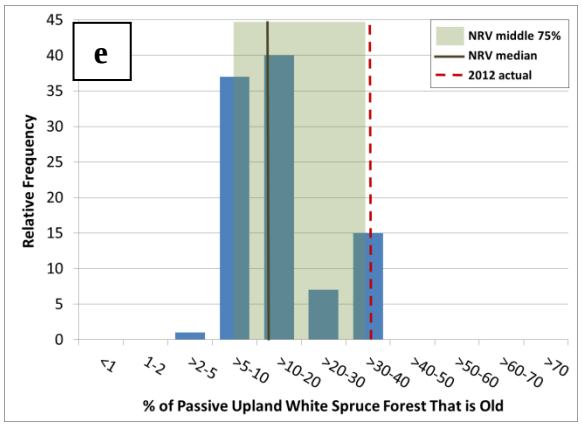
<u>HWP FMA passive upland pine forest highlights:</u>

- The current condition of Late Mature is on the upper boundary of NRV.
- The current condition of Young is below the lower boundary of the 75% NRV zone.
- The current condition of Pole is on the lower boundary of the 75% NRV zone.
- The current condition of Early Mature is beyond the upper boundary of the 75% NRV zone.









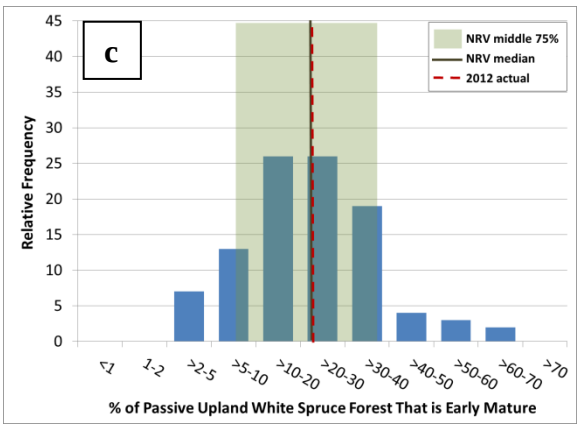
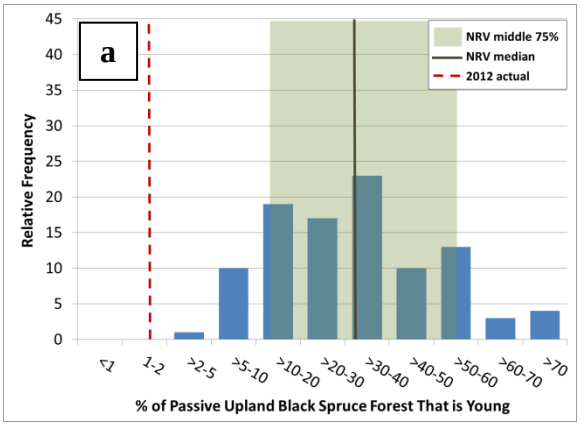
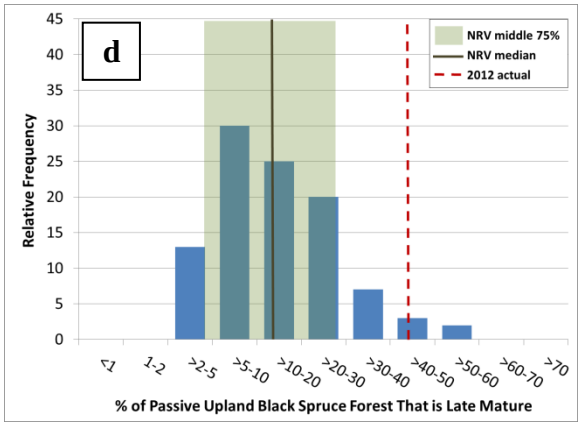


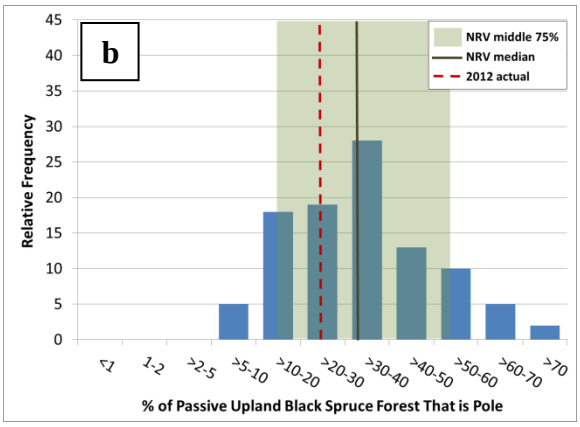
Figure A71. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive upland, white spruce leading forest for the HWP FMA.

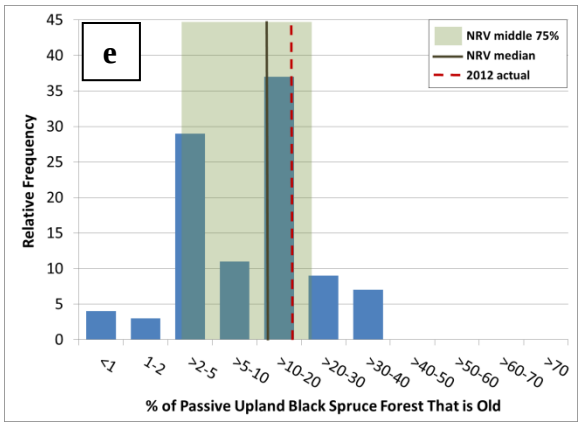
<u>HWP FMA passive upland white spruce forest highlights:</u>

- The current condition of Young is below the lower boundary of NRV.
- The current condition of Pole is below the lower boundary of the 75% NRV zone.
- The current condition of Early Mature is beyond the upper boundary of the 75% NRV zone.
- The current condition of Old is on the upper boundary of the 75% NRV zone.









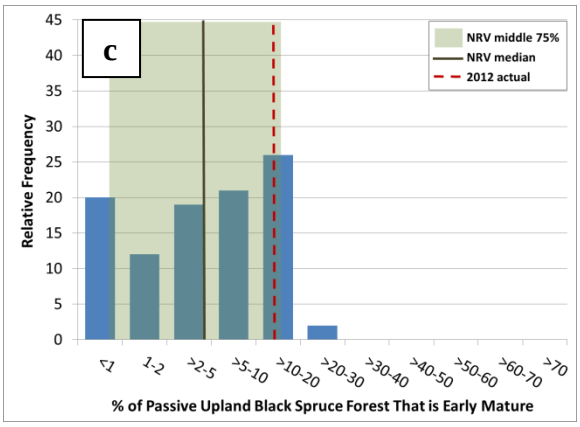


Figure A72. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), and current condition (red dashed line) for young (a), pole (b), early mature (c), mature (d), and old (e) passive upland, black spruce leading forest for the HWP FMA.

<u>HWP FMA passive upland black spruce forest highlights:</u>

- The current condition of Young is below the lower boundary of NRV.
- The current condition of Early Mature is on the upper boundary of the 75% NRV zone.
- The current condition of Late Mature is beyond the upper boundary of the 75% NRV zone.

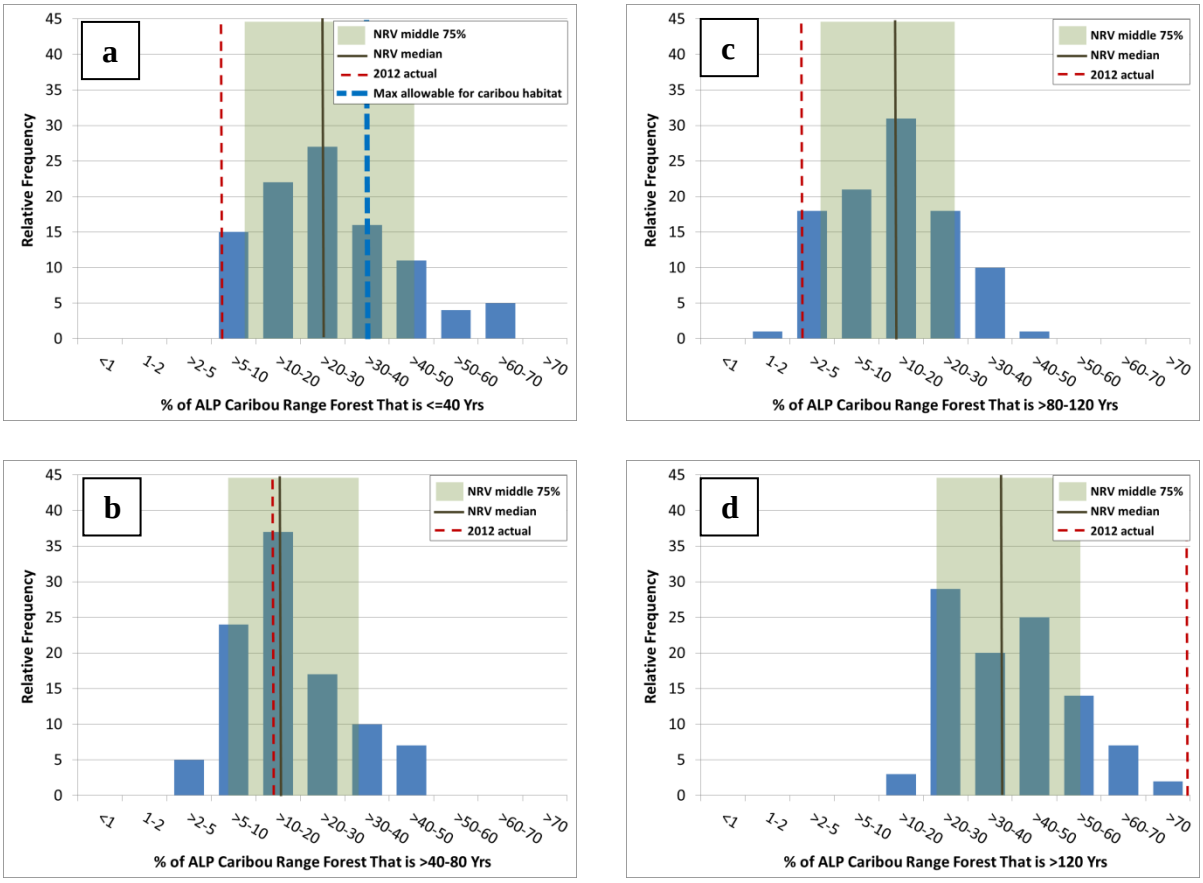


Figure A73. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), current condition (red dashed line) and the maximum threshold suggested by Environment Canada for woodland caribou (blue dashed line) for young (<=40 yrs) (a), pole (>40-80 yrs) (b), mature (>80-120 yrs) (c), and old (>120 yrs) (d) seral-stages using the provincial age-class definitions for the A la Peche woodland caribou range within the HWP FMA.

<u>HWP FMA A la Peche caribou range highlights:</u>

- The current condition of Old is beyond the upper boundary of NRV*
- The current condition of Young is on the lower boundary of NRV, and well below the 35% maximum suggested by Environment Canada.
- The current condition of Mature is below the lower boundary of the 75% NRV zone.

** Note that NRV was generated for the entire caribou range area, so this may not be true of the portion of the range within the HWP FMA.*

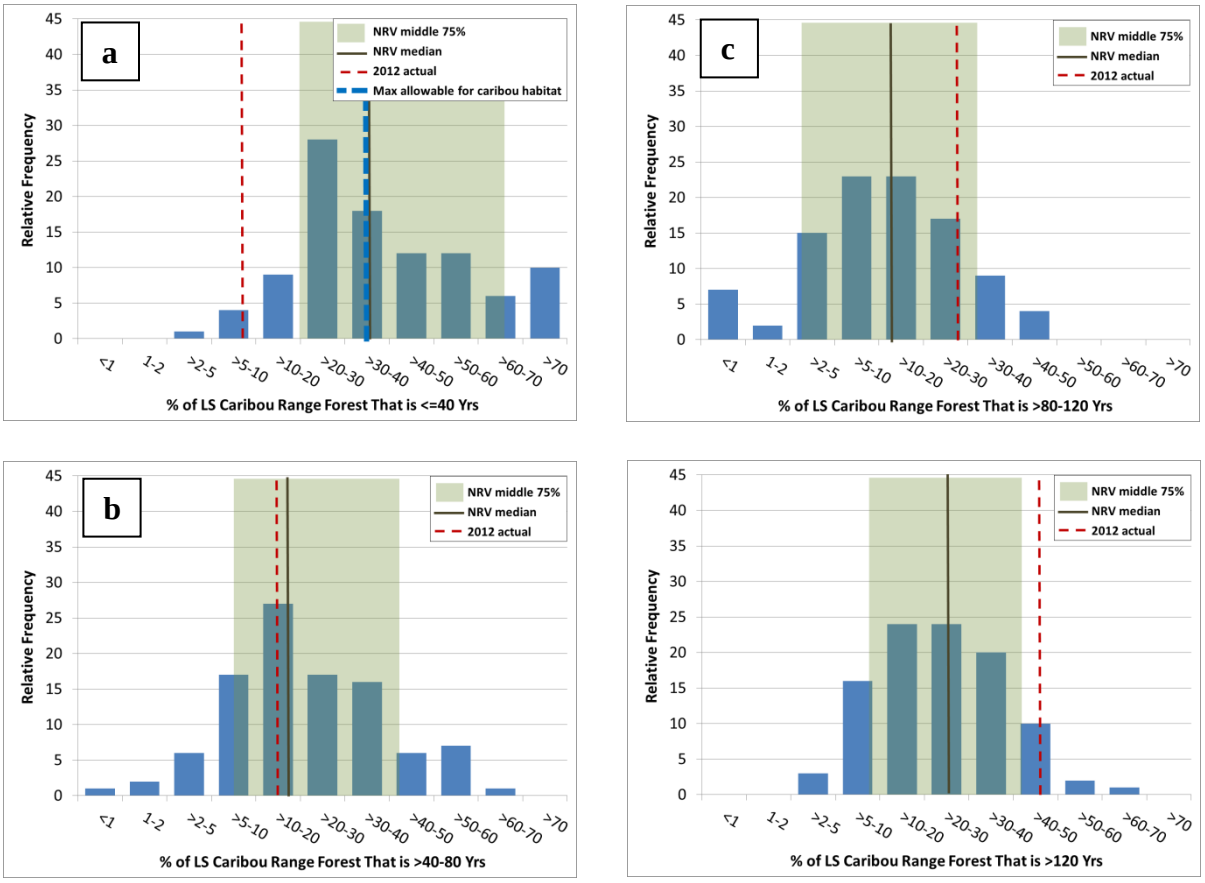


Figure A74. Estimated natural range of variation (blue bars), middle 75% of NRV (green zone), median NRV (green line), current condition (red dashed line) and the maximum threshold suggested by Environment Canada for woodland caribou (blue dashed line) for young (<=40 yrs) (a), pole (>40-80 yrs) (b), mature (>80-120 yrs) (c), and old (>120 yrs) (d) seral-stages using the provincial age-class definitions for the Little Smokey woodland caribou range within the HWP FMA.

<u>HWP FMA Little Smokey caribou range highlights:</u>

- All current conditions are within NRV.
- The current condition of Young is well below the lower boundary of NRV, and well below the 35% maximum suggested by Environment Canada.
- The current condition of Old is beyond the upper boundary of the 75% NRV zone.

Appendix B: Tabular Details of Patch Size Model Output

Table B1. NRV minimum and maximum and current condition for patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	78	2,331	390	11,655	13,473	100,703
	>100-500	12	109	2,796	25,397	77	12,634
	>500-1,000	3	25	2,001	16,675	-	-
	>1-2,000	2	19	2,666	25,327	-	-
	>2-5,000	0	17	0	51,000	-	-
	>5-10,000	0	8	0	53,336	-	-
	>10-50,000	0	7	0	163,331	-	-
	>50,000	0	4	0	654,824	-	-
Pole	<=100	493	2,454	2,465	12,270	50,402	118,496
	>100-500	26	113	6,058	26,329	175	33,003
	>500-1,000	3	25	2,001	16,675	14	9,239
	>1-2,000	1	20	1,333	26,660	4	5,288
	>2-5,000	0	14	0	42,000	1	3,098
	>5-10,000	0	7	0	46,669	-	-
	>10-50,000	0	9	0	209,997	-	-
	>50,000	0	3	0	583,048	-	-
Early Mature	<=100	664	3,121	3,320	15,605	33,224	138,837
	>100-500	32	166	7,456	38,678	211	37,645
	>500-1,000	3	29	2,001	19,343	26	17,713
	>1-2,000	1	19	1,333	25,327	7	9,162
	>2-5,000	0	16	0	48,000	-	-
	>5-10,000	0	10	0	66,670	1	7,918
	>10-50,000	0	9	0	209,997	1	12,267
	>50,000	0	2	0	288,721	-	-
Late Mature	<=100	608	3,019	3,040	15,095	58,616	267,866
	>100-500	16	126	3,728	29,358	355	64,319
	>500-1,000	0	26	0	17,342	13	9,018
	>1-2,000	1	16	1,333	21,328	8	10,714
	>2-5,000	0	14	0	42,000	1	4,154
	>5-10,000	0	7	0	46,669	-	-
	>10-50,000	0	6	0	139,998	-	-
	>50,000	0	2	0	253,404	-	-
Old	<=100	768	2,215	3,840	11,075	6,642	40,360
	>100-500	33	85	7,689	19,805	63	11,895
	>500-1,000	3	23	2,001	15,341	5	3,453
	>1-2,000	2	16	2,666	21,328	2	3,076
	>2-5,000	0	15	0	45,000	1	2,126
	>5-10,000	0	5	0	33,335	-	-
	>10-50,000	0	8	0	186,664	-	-
	>50,000	0	3	0	264,994	-	-

Table B2. NRV minimum and maximum and current condition for deciduous patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	69	1,764	345	8,820	258	2,481
	>100-500	1	95	233	22,135	0	0
	>500-1,000	0	17	0	11,339	0	0
	>1-2,000	0	4	0	5,332	0	0
	>2-5,000	0	2	0	6,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Pole	<=100	196	1,775	980	8,875	3,891	7,085
	>100-500	2	93	466	21,669	1	103
	>500-1,000	0	17	0	11,339	0	0
	>1-2,000	0	4	0	5,332	0	0
	>2-5,000	0	2	0	6,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Early Mature	<=100	163	1,694	815	8,470	2,812	11,602
	>100-500	0	86	0	20,038	18	2,563
	>500-1,000	0	12	0	8,004	0	0
	>1-2,000	0	3	0	3,999	0	0
	>2-5,000	0	1	0	3,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Late Mature	<=100	28	1,495	140	7,475	6,866	26,867
	>100-500	0	69	0	16,077	41	6,669
	>500-1,000	0	9	0	6,003	0	0
	>1-2,000	0	2	0	2,666	0	0
	>2-5,000	0	1	0	3,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Old	<=100	236	1,562	1,180	7,810	106	367
	>100-500	1	65	233	15,145	1	108
	>500-1,000	0	12	0	8,004	0	0
	>1-2,000	0	5	0	6,665	0	0
	>2-5,000	0	4	0	12,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0

Table B3. NRV minimum and maximum and current condition for mixedwood patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	139	2,820	695	14,100	1,344	8,460
	>100-500	0	86	0	20,038	0	0
	>500-1,000	0	6	0	4,002	0	0
	>1-2,000	0	1	0	1,333	0	0
	>2-5,000	0	0	0	0	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Pole	<=100	303	2,982	1,515	14,910	10,607	32,229
	>100-500	0	97	0	22,601	18	2,373
	>500-1,000	0	6	0	4,002	0	0
	>1-2,000	0	1	0	1,333	0	0
	>2-5,000	0	0	0	0	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Early Mature	<=100	197	2,599	985	12,995	6,949	26,916
	>100-500	0	88	0	20,504	2	259
	>500-1,000	0	4	0	2,668	0	0
	>1-2,000	0	1	0	1,333	0	0
	>2-5,000	0	0	0	0	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Late Mature	<=100	19	2,218	95	11,090	13,514	59,501
	>100-500	0	60	0	13,980	23	3,143
	>500-1,000	0	1	0	667	0	0
	>1-2,000	0	0	0	0	0	0
	>2-5,000	0	0	0	0	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Old	<=100	291	2,408	1,455	12,040	789	3,774
	>100-500	1	72	233	16,776	0	0
	>500-1,000	0	3	0	2,001	0	0
	>1-2,000	0	0	0	0	0	0
	>2-5,000	0	0	0	0	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0

Table B4. NRV minimum and maximum and current condition for pine patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	179	2,403	895	12,015	6,313	71,951
	>100-500	9	150	2,097	34,950	71	11,930
	>500-1,000	0	30	0	20,010	0	0
	>1-2,000	0	23	0	30,659	0	0
	>2-5,000	0	15	0	45,000	0	0
	>5-10,000	0	6	0	40,002	0	0
	>10-50,000	0	8	0	186,664	0	0
	>50,000	0	1	0	78,597	0	0
Pole	<=100	777	2,931	3,885	14,655	14,643	44,821
	>100-500	42	161	9,786	37,513	136	27,472
	>500-1,000	4	32	2,668	21,344	13	8,700
	>1-2,000	1	20	1,333	26,660	3	4,286
	>2-5,000	0	16	0	48,000	1	3,098
	>5-10,000	0	8	0	53,336	0	0
	>10-50,000	0	7	0	163,331	0	0
	>50,000	0	1	0	135,927	0	0
Early Mature	<=100	374	2,637	1,870	13,185	12,772	64,279
	>100-500	16	149	3,728	34,717	168	31,209
	>500-1,000	1	31	667	20,677	23	15,841
	>1-2,000	0	19	0	25,327	7	9,162
	>2-5,000	0	18	0	54,000	0	0
	>5-10,000	0	9	0	60,003	1	7,918
	>10-50,000	0	5	0	116,665	1	12,267
	>50,000	0	0	0	0	0	0
Late Mature	<=100	51	2,500	255	12,500	22,384	88,584
	>100-500	3	133	699	30,989	180	35,243
	>500-1,000	0	26	0	17,342	8	5,636
	>1-2,000	0	14	0	18,662	6	8,146
	>2-5,000	0	12	0	36,000	1	4,154
	>5-10,000	0	7	0	46,669	0	0
	>10-50,000	0	2	0	46,666	0	0
	>50,000	0	0	0	0	0	0
Old	<=100	584	2,398	2,920	11,990	2,231	13,209
	>100-500	14	102	3,262	23,766	26	5,059
	>500-1,000	1	19	667	12,673	2	1,530
	>1-2,000	0	15	0	19,995	1	1,307
	>2-5,000	0	11	0	33,000	0	0
	>5-10,000	0	8	0	53,336	0	0
	>10-50,000	0	6	0	139,998	0	0
	>50,000	0	0	0	0	0	0

Table B5. NRV minimum and maximum and current condition for white spruce patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	126	2,897	630	14,485	1,742	17,072
	>100-500	2	105	466	24,465	6	704
	>500-1,000	0	11	0	7,337	0	0
	>1-2,000	0	9	0	11,997	0	0
	>2-5,000	0	6	0	18,000	0	0
	>5-10,000	0	2	0	13,334	0	0
	>10-50,000	0	1	0	23,333	0	0
	>50,000	0	0	0	0	0	0
Pole	<=100	169	2,974	845	14,870	9,732	9,648
	>100-500	3	103	699	23,999	6	829
	>500-1,000	0	12	0	8,004	1	539
	>1-2,000	0	9	0	11,997	1	1,002
	>2-5,000	0	4	0	12,000	0	0
	>5-10,000	0	2	0	13,334	0	0
	>10-50,000	0	1	0	23,333	0	0
	>50,000	0	0	0	0	0	0
Early Mature	<=100	341	2,786	1,705	13,930	8,004	18,875
	>100-500	5	97	1,165	22,601	12	1,947
	>500-1,000	0	10	0	6,670	3	1,871
	>1-2,000	0	6	0	7,998	0	0
	>2-5,000	0	4	0	12,000	0	0
	>5-10,000	0	1	0	6,667	0	0
	>10-50,000	0	1	0	23,333	0	0
	>50,000	0	0	0	0	0	0
Late Mature	<=100	176	2,528	880	12,640	6,831	38,716
	>100-500	1	87	233	20,271	47	8,805
	>500-1,000	0	8	0	5,336	4	2,868
	>1-2,000	0	4	0	5,332	2	2,568
	>2-5,000	0	3	0	9,000	0	0
	>5-10,000	0	2	0	13,334	0	0
	>10-50,000	0	1	0	23,333	0	0
	>50,000	0	0	0	0	0	0
Old	<=100	344	2,257	1,720	11,285	2,388	15,604
	>100-500	5	70	1,165	16,310	27	5,128
	>500-1,000	0	9	0	6,003	2	1,255
	>1-2,000	0	3	0	3,999	1	1,769
	>2-5,000	0	4	0	12,000	1	2,126
	>5-10,000	0	1	0	6,667	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0

Table B6. NRV minimum and maximum and current condition for black spruce patch sizes on the gross HWP FMA area

Seral Stage	Size Class (ha)	Patch Density (#)		Patch Area (ha)		Current status (2012)	
		NRV min.	NRV max	NRV min.	NRV max	Patch #	Patch Area
Young	<=100	271	3,687	1,355	18,435	3,816	739
	>100-500	13	149	3,029	34,717	0	0
	>500-1,000	0	25	0	16,675	0	0
	>1-2,000	0	13	0	17,329	0	0
	>2-5,000	0	11	0	33,000	0	0
	>5-10,000	0	3	0	20,001	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Pole	<=100	621	3,665	3,105	18,325	11,529	24,713
	>100-500	12	155	2,796	36,115	14	2,226
	>500-1,000	0	25	0	16,675	0	0
	>1-2,000	0	14	0	18,662	0	0
	>2-5,000	0	8	0	24,000	0	0
	>5-10,000	0	3	0	20,001	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Early Mature	<=100	5	1,975	25	9,875	2,687	17,165
	>100-500	0	78	0	18,174	11	1,667
	>500-1,000	0	12	0	8,004	0	0
	>1-2,000	0	8	0	10,664	0	0
	>2-5,000	0	2	0	6,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Late Mature	<=100	350	3,347	1,750	16,735	9,021	54,198
	>100-500	4	120	932	27,960	64	10,460
	>500-1,000	0	22	0	14,674	1	514
	>1-2,000	0	10	0	13,330	0	0
	>2-5,000	0	5	0	15,000	0	0
	>5-10,000	0	2	0	13,334	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0
Old	<=100	97	2,316	485	11,580	1,128	7,404
	>100-500	0	75	0	17,475	9	1,599
	>500-1,000	0	10	0	6,670	1	669
	>1-2,000	0	4	0	5,332	0	0
	>2-5,000	0	2	0	6,000	0	0
	>5-10,000	0	0	0	0	0	0
	>10-50,000	0	0	0	0	0	0
	>50,000	0	0	0	0	0	0

Appendix C: Model inputs

The relative influence of wildfire as a source of change varies significantly across the study area. By definition, in Alpine areas, there is no significant continuous vegetation, and wildfire ignition and spread are not possible. To the east and west of the Alpine zone, the Subalpine is the lowest elevation area of continuous (conifer) vegetation. Wildfire is very infrequent and highly selective in these areas due to a combination of infrequent lightning, short growing/fire seasons, and strong topographic controls. The fire season in the Upper Foothills zone to the east is only moderately in length, but the Upper Foothills also has some of the densest and most highly flammable fuel-types in the boreal combined with moderate levels of lighting density. Further to the east, both the Lower Foothills and Central Mixedwood zones have the highest density of lightning strikes and the longest fire season, but fire activity here is moderated by higher proportions of vegetation with lower flammability (e.g., hardwoods and wetlands). LANDMINE was calibrated to accommodate these natural differences in a number of ways.

C.1 Fire frequency

Fire frequency is defined here as the proportion of the landscape of interest that burns per time period, which in this case is every 10 years. Averaged over extended periods (i.e., hundreds of years), the fire frequency is the equivalent of a *fire cycle*, which is the average number of years required to burn the area equivalent to the landscape size. However, these measures are not necessarily the same thing as regards natural landscape dynamics.

This is a critical point worth further explanation*:* Over, 500 years, an average annual fire frequency of 1% equates to an average decadal fire frequency of 10%, both of which are the equivalent of a fire cycle of 100 years. However, the variation in decadal fire levels within those same 500 years may be 2-40%, and the variation in annual fire levels even greater, perhaps 0-70%. Given the nature of the objectives of this modelling initiative, one could argue that the natural *range* is as meaningful to capture as the natural *average*. In this version of LANDMINE, we chose to use a 10-year range based on the ability of forest harvesting activities to create disturbance events over space and time. Modelling landscape conditions based on an annual (or finer) level of resolution would be more precise, but of no practical value. At the other end of the spectrum, although the long-term fire cycle (LTFC) is not a LANDMINE input, it is a valuable calibration metric (see ahead).

C.1.1 Historical fire cycles

LANDMINE requires one or more equations that describe the natural range of (pre-industrial) decadal fire levels. In the absence of observed data over the last 1-500 years, the simplest way of creating pre-industrial decadal fire frequency estimates is to *roll back* landscapes a-spatially. The idea is that the area underneath the most recent age-class on a given landscape was previously proportional to the age of the

remaining age-classes. Again – it is important to understand that this is not a (location or fire) specific reconstruction technique, but rather a general one.

We were fortunate in this case to have access to extensive historical records of previous landscape conditions, which allowed us to reconstruct some likely decadal levels of fire activity. The existing forest areas in the decades since 1960 are shown in Table B1. Any data past 1960 was assumed to be of the industrial era either because of forest harvesting or fire control. In any case, the area was minimal (5.7%).

To create a historical range of wildfire activity, an estimate of the original area burned by decade was made for different parts of the study area. Previous work on the HWP study area demonstrated that inventory ages are only moderately successful surrogates for the number of years since the last fire (Andison 1999b). However, this same study suggested that the differences were mostly precision errors, as opposed to accuracy. In other words, over vast areas (such as the study area), the existing percentages of forest in each decade are a reasonable estimate of the time since the last fire.

Assuming this to be the case, the original amount of area disturbed in each decade can be estimated by assigning the area of more current ages proportionally to the remaining forest age-classes. The only decades used for this calculation were those for which there was a relatively high level of confidence that they represent "natural" conditions, which in this case was pre-1960. The results are shown in Table C1.

Table C1. Existing and estimated original percent of forest area burned by decade by natural sub-region for the study area.

Period (years)	Existing and Estimated Original % of Forest Area Burned							
	Lower Foothills		Upper Foothills		Subalipne		Landscape	
	Existing	Estimated Original	Existing	Estimated Original	Existing	Estimated Original	Existing	Estimated Original
1950-59	1.3	1.4	1.5	1.6	0.4	0.4	1.3	1.4
1940-49	6.2	6.7	2	2.1	9.3	9.5	4.0	4.2
1930-39	3.8	4.4	5.6	6.1	3.9	4.3	4.9	5.4
1920-29	3	3.6	0.8	0.9	5.3	6.1	1.9	2.2
1910-19	9.2	11.4	18	20.7	25.1	30.5	16.2	19.2
1900-09	30.1	41.5	27.7	39.2	16.9	28.7	27.3	38.8
1890-99	5.1	11.7	3.9	8.8	2	4.7	4.0	9.2
1880-89	18.5	47.9	10.7	26.5	0.1	0.2	11.8	29.6
Average		**16.1**		**13.2**		**10.5**		**13.8**
LT Fire Cycle (yrs)		62		76		95		73

The results from Table B1 were used for the HWP modelling exercise in three ways. First, the long term (LT) fire cycles calculated here are consistent with pre-industrial fire cycle estimates in the Alberta foothills made by others. In fact, if anything, more

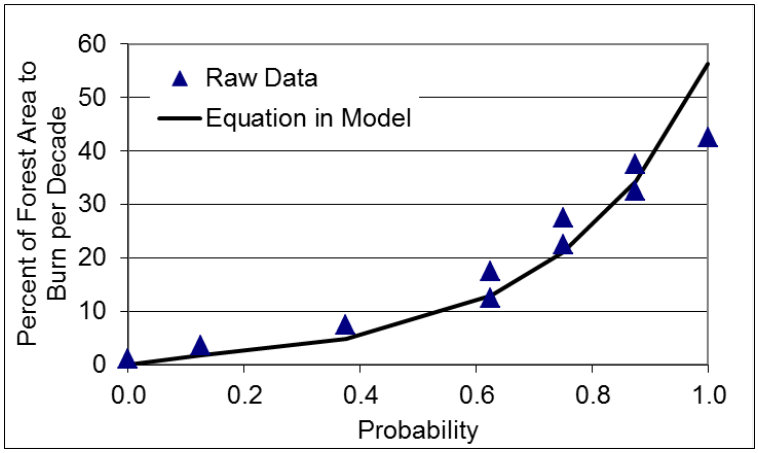
recent evidence suggests that historical fire cycles may even be lower (*e.g*. Amoroso et al. 2011). In any case, this provides a measure of confidence that – *details aside* - the ranges of decadal estimates presented here, if anything, err on the high side.

The second use of the results of Table C1 is the data in the last column (the estimated original area burned in eight pre-industrial decades over the whole landscape). From these data, a cumulative distribution function was defined from which random number draws can be made (Figure C1).

$$Historical\ Area\ Burned\ per\ Decade = 10^{(0.04+1.71P)}$$

n=8, SEE = 0.05, R^2 =0.99

Figure C1. Cumulative probability distribution function (and raw data) for pre-industrial decadal area burned for the study area – *used in LANDMINE*.



The application of this equation equally to all parts of the study area would create relatively stable long-term fire cycles in all parts of the landscape. Since we know this not to be true, then we need a way to apportion fire activity accordingly. Thus, the third value of the data in Table C1 is to help validate regional fire activity levels. Ideally, we want the long-run fire cycles from the model output to be reasonably close to 62 years, 76, and 95 years. (note that with stochastic spatial models, it is extremely unlikely to match long-term targets exactly).

C.2 Fire ignitions

Once the model knows how much area to burn in each time-step, it begins to light and burn fires. The probability of ignition varies significantly across this particular study area. Differential ignition probability was estimated in two ways. First, the available historical lightning data for the HWP FMA for a 10 year period showed the highest lighting activity in the Lower Foothills (56 strikes / 1,000 ha) followed by the Upper Foothills (44 hits / 1,000 ha) and the HWP FMA Subalpine (34 hits / 1,000 ha). The higher elevation Subalpine within Jasper Park recorded only 11 hits / 1,000 ha, and the Montane 29 / 1,000 ha.

The important information here is the relative level of fire activity. For example, if we use the high elevation Subalpine as the baseline, then the Montane has 2.6 times more lighting, the HWP Subalpine 3.4 times more, and the Upper and Lower

Foothills 4.0 and 5.1 times more lighting respectively. These ratios can be applied directly within LANDMINE to each zone. The assumption with this technique is that it assumes every lighting strike has an equal probability of lighting a fire, which given the vegetation and climatic complexity on this landscape is not true.

The second way of estimating ignition probabilities is using the relative long-term *burn fractions* (i.e. the annual percent of area burned) from each zone in the study area. This will create higher levels of fire activity in zones with higher burn fractions (Table C2). For example, an LTFC of 70 corresponds to a landscape scale burn fraction of (100/70=) 1.4% per year. The resulting burn fractions for each ecological zone were then weighted by the proportional area within each zone. So although the burn fractions of the Lower Foothills / Montane area are identical to that of the Central Mixedwood (1.4), the BF-area scores were very different because of the relative area in each zone (Table C2). The "Standardized Probability" column just adjusts the BF-area numbers to add up to 100, which is more convenient to use as model input.

Table C2. Two ways of estimating ignition probability on a landscape with complex fire history patterns.

Ecological Zone	% Area	Burn-Fraction Based Ignition				Lightning Based Ignition		
		LTFC	LT Burn Fraction	BF-area	Standardized Probability	Lightning density	Lightning area	Standardized Probability
LF / Montane	32	70	1.4	45.7	43	56	1792.0	44
SA	22	100	1.0	22.0	21	34	748.0	18
UF	28	85	1.2	32.9	31	44	1232.0	30
Central	2	70	1.4	2.9	3	56	112.0	3
Other	16	1000	0.1	1.6	2	10	160.0	4

The similarities between the two standardized probabilities in C2 resulting from these two methods is reassuring. The lighting-based probabilities were used as initial seeds in the model. As part of the model calibration process, these numbers were changed iteratively in order to achieve the targeted fire frequency averages defined in the previous section. The final probabilities used were: LF/Montane 48, SA 17, UF 23, Central 3, and other 3.

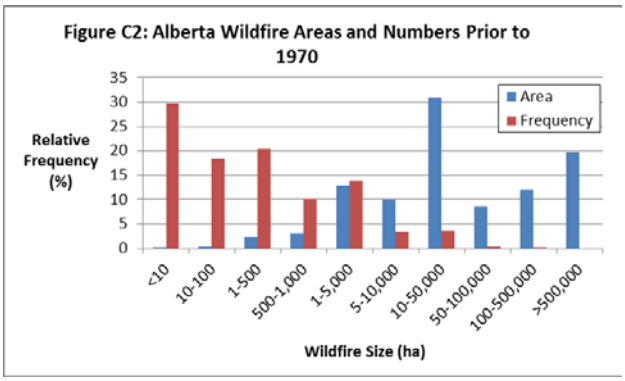
C.3 Fire size

Landmine requires an empirical estimate of the historical fire size distribution as one of its inputs. Historical fire sizes were approxim ated using available historical fire records for Alberta (http://wildfire.alberta.ca/wildfire-maps/historical-wildfire-information/historical-wildfire-database).

However, clearly the historical data could not be used "as is" to represent pre-industrial conditions. Given the well documented intersecting biases associated with both fire control (which would tend to underestimate the impact of larger fires) and the quality of fire reporting (which would tend to underestimate the impact of smaller fires), I chose to use the data from fires that were reported prior to 1970. Prior to this time, detection and mapping technologies (via satellite imagery for example)

were unavailable, so it is likely that many smaller fires were missed. But it is also likely that after 1970, initial attack fire control activities were having a significantly negative influence on fire sizes. In the absence of incontrovertible evidence either way, the pre-1970 baseline was thought to be the best option.

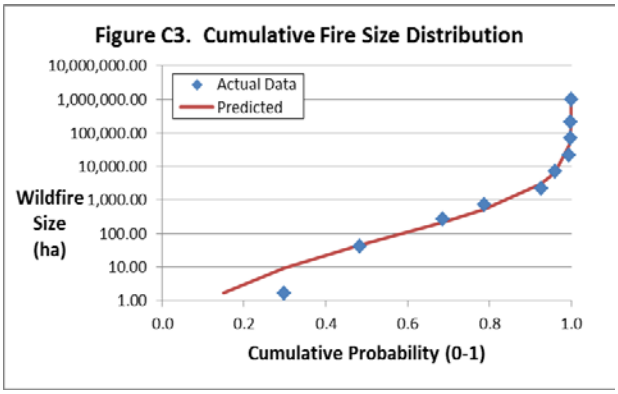
A total of 6.8 million hectares of forest burned in Alberta from circa 1930 to 1970. Over that period, 36% of the burned area was accounted for by just 0.5% of the fires that were larger than 50,000 ha (Figure C2). This fire size pattern is typical of the boreal forest (Ward and Tithecott 1993).



These observed historical data were transformed into a cumulative distribution function (Figure C3) that allowed the model to choose fire sizes according to the appropriate historic probabilities. The best-fit equation (n=12, r=0.99) is:

$$Fire\ Size(ha) = 10^{(-4.2+6.3(-\ln(1-p)^{0.2}}$$

Where (p) is a random number (with at least six significant digits) between 0 and 1.



For example, if a random draw between 0 and 1 yielded a value of 0.4, then the fire will be 23 ha. If the random value were 0.9, the associated fire would be 1,996 ha, and if the random number were 0.992, the fire size would be 30,970 ha. Note the relatively small chance of very large fires. For example, only 8 out of every 10,000 fires will be larger than 30,970 ha.

To make the model more efficient, fires less than 12 ha in size were not allowed to start. Small fires account for 32% of the fires, but only 0.03% of the area burned, and thus not likely to create a bias given the broad objectives.