Geologic and Genetic Implications of Restoring Whitebark Pine Under Climate Change: Suitable Substrate, Blister Rust Resistance and Drought Tolerance

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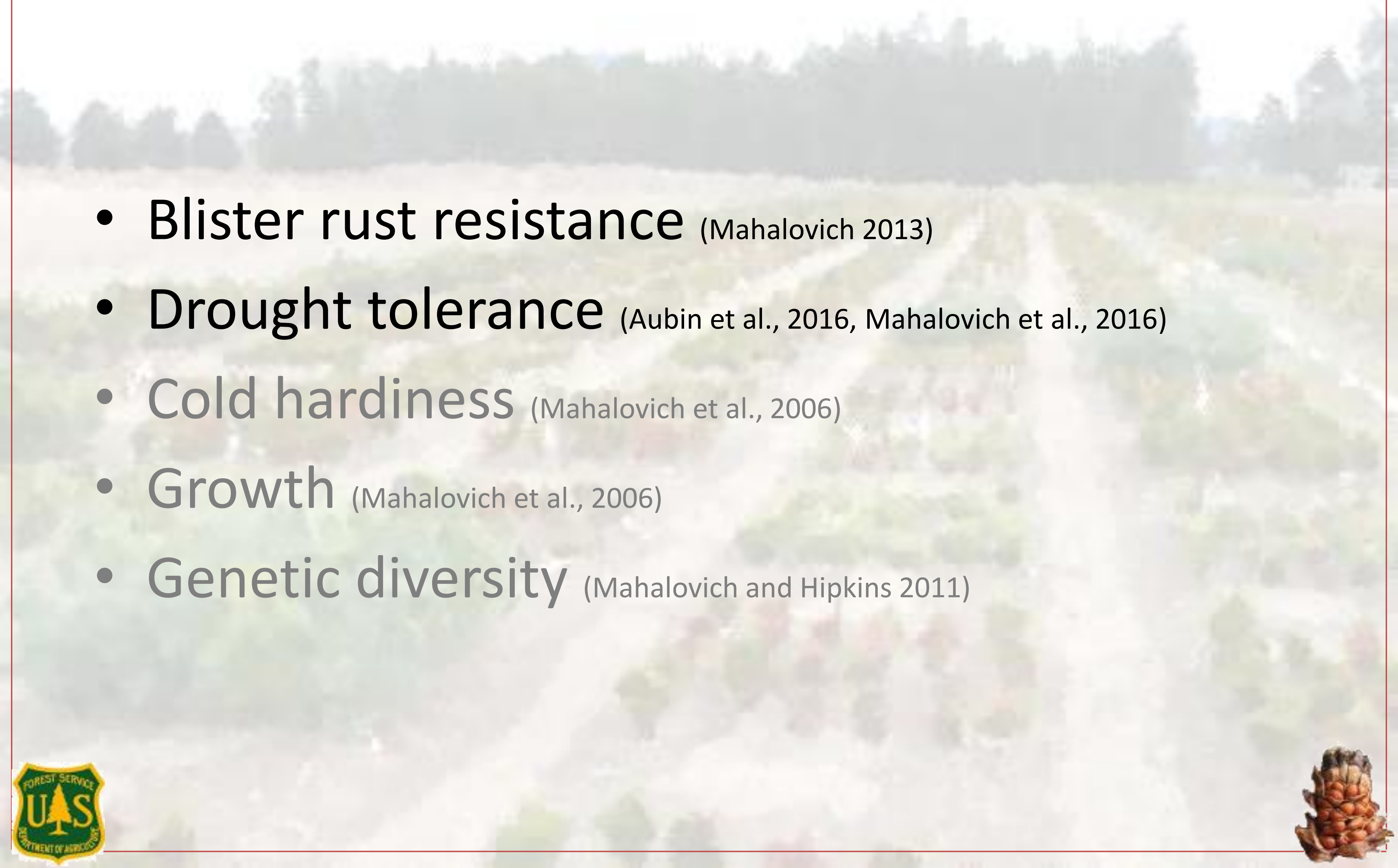
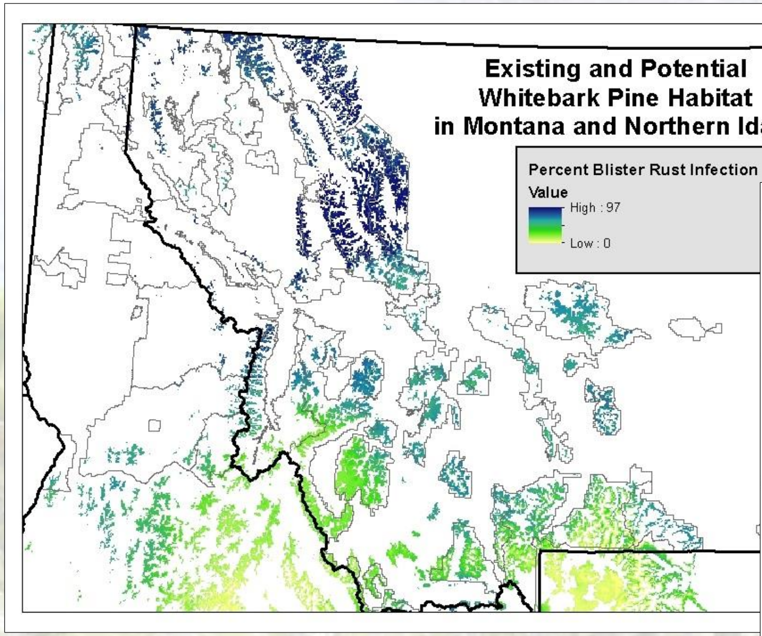
Adaptive capacity and climate change

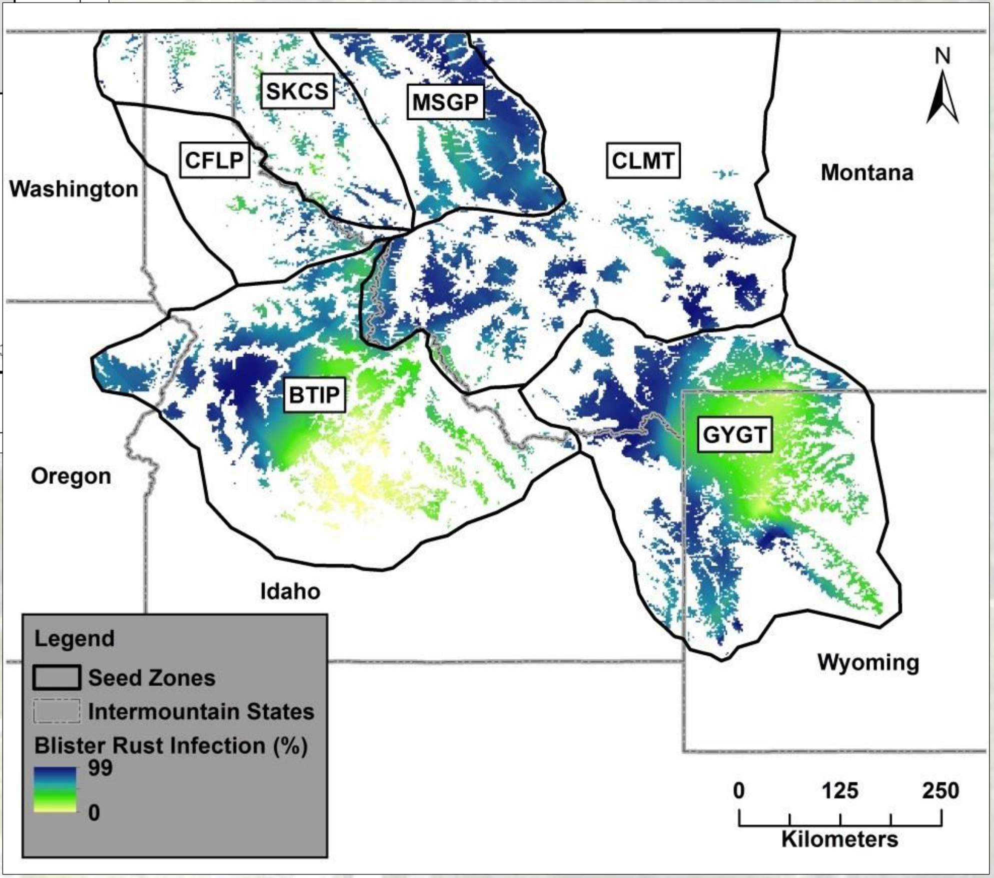


- Blister rust resistance (Mahalovich 2013)
- Drought tolerance (Aubin et al., 2016, Mahalovich et al., 2016)
- Cold hardiness (Mahalovich et al., 2006)
- Growth (Mahalovich et al., 2006)
- Genetic diversity (Mahalovich and Hipkins 2011)

Blister rust infection



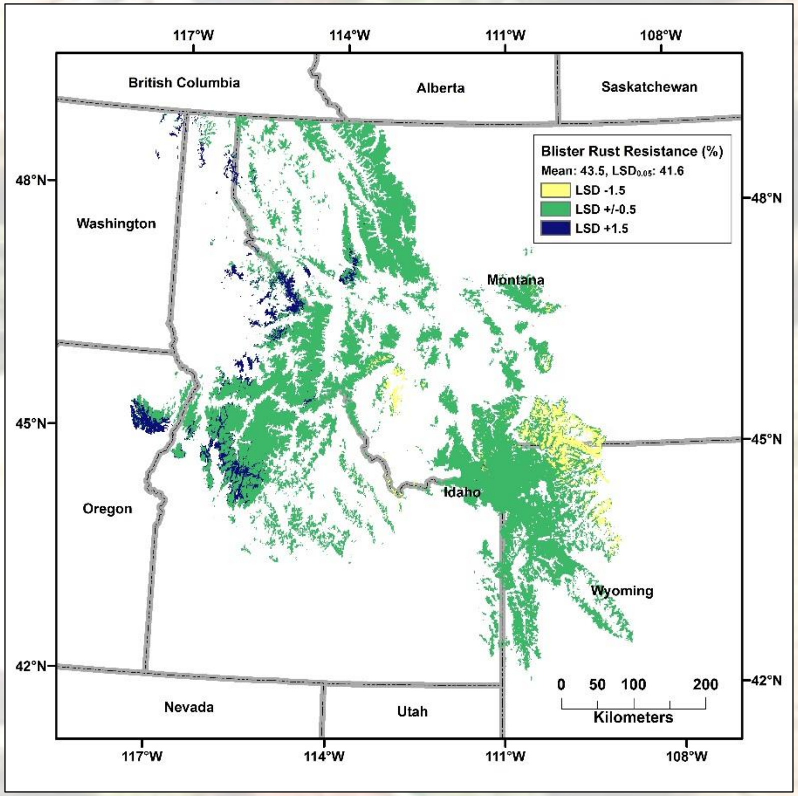
2000-2006 (Helmbrecht et al., 2007)



2001-2014

Blister rust resistance

- Percent resistance (no-spot+needle shed+short shoot+bark reaction)
- Resistance at low spore density; baseline data 110 seed source study
- Areas with high infection and longer length of exposure = high rust resistance
- Generalist adaptive strategy



%Resistance = -0.52 -0.05*Latitude +0.03*Longitude – 0.003*Elevation + 0.003*PAS, $R^2 = 0.49$, $p < 0.001$

Adaptive capacity and climate change

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Intrinsic water-use efficiency $\Delta^{13}C$ (‰)

- Drought resistance; pines exhibit drought avoidance (Leavitt 1980)
- Shorter needles, slower growth, ability to colonize drier, exposed sites
- $\Delta^{13}C = (\delta_a - \delta_p) / (1 + \delta_p)$ (Farquhar et al., 1989); useful proxy for drought tolerance (Piñol and Sala 2000, Sala et al. 2001, 2012)
- Recognition of multiple source pools for C assimilation

Seed Zone	n	$\Delta^{13}C$ (‰)
BTIP	17	13.8 (0.9) b
CLMT	20	13.7 (1.1) b
GYGT	38	13.1 (1.0) a
CFLP	20	14.0 (0.8) b
MSGP	25	13.8 (1.1) b
SKCS	25	13.9 (1.0) b
$F_{5,139}$		3.5
p		0.01
Northern Rockies	145	13.6 (1.0)

$\Delta^{13}C$ = **17.38 - 0.001*Elevation - 1.01*Ca-Sedimentary - 0.80*Sedimentary - 0.22*Summer mean temperature + 0.01*Frost-free period - 0.001*Mean annual precipitation,**
$R^2 = 0.31$, $p < 0.01$ (Mahalovich et al., 2016)

Drought tolerance ($\Delta^{13}C$)

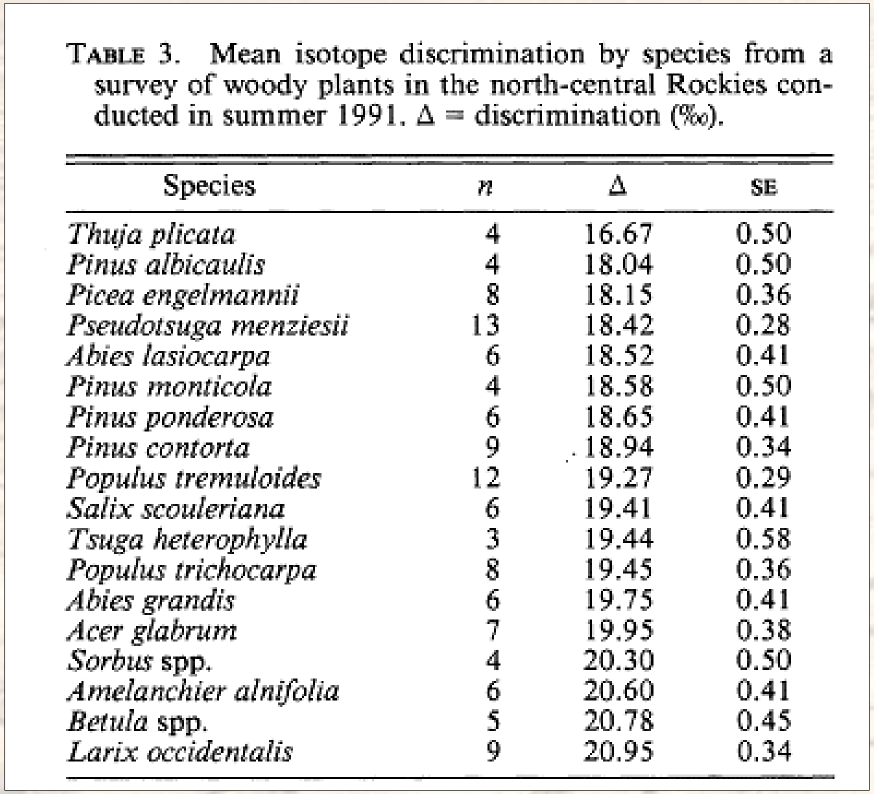
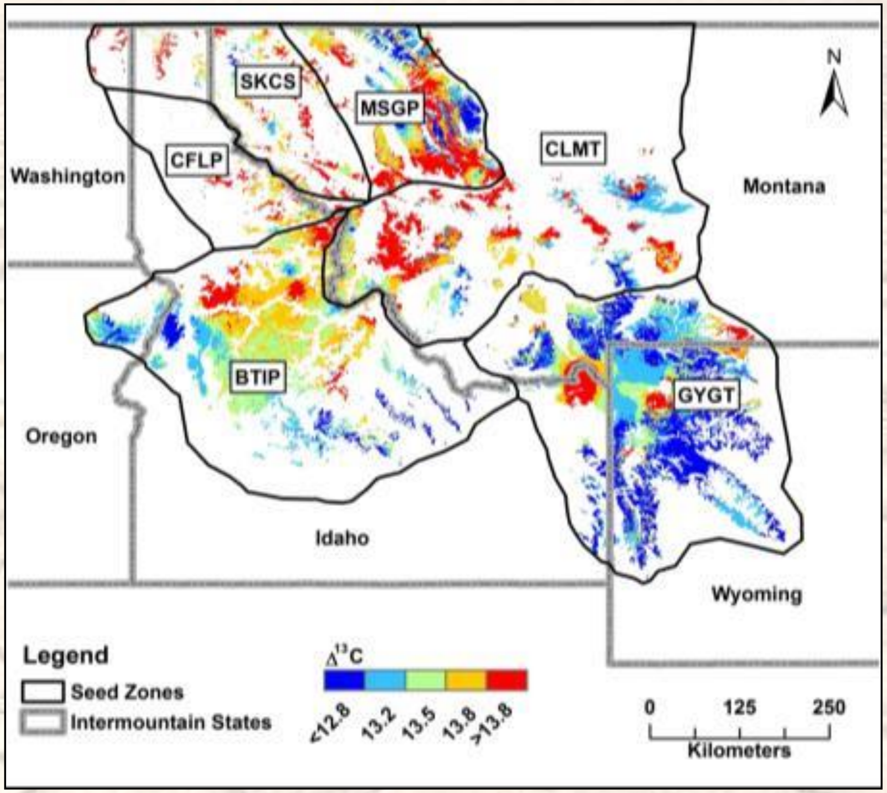


TABLE 3. Mean isotope discrimination by species from a survey of woody plants in the north-central Rockies conducted in summer 1991. Δ = discrimination (‰).

Species	*n*	Δ	SE
Thuja plicata	4	16.67	0.50
Pinus albicaulis	4	18.04	0.50
Picea engelmannii	8	18.15	0.36
Pseudotsuga menziesii	13	18.42	0.28
Abies lasiocarpa	6	18.52	0.41
Pinus monticola	4	18.58	0.50
Pinus ponderosa	6	18.65	0.41
Pinus contorta	9	18.94	0.34
Populus tremuloides	12	19.27	0.29
Salix scouleriana	6	19.41	0.41
Tsuga heterophylla	3	19.44	0.58
Populus trichocarpa	8	19.45	0.36
Abies grandis	6	19.75	0.41
Acer glabrum	7	19.95	0.38
Sorbus spp.	4	20.30	0.50
Amelanchier alnifolia	6	20.60	0.41
Betula spp.	5	20.78	0.45
Larix occidentalis	9	20.95	0.34

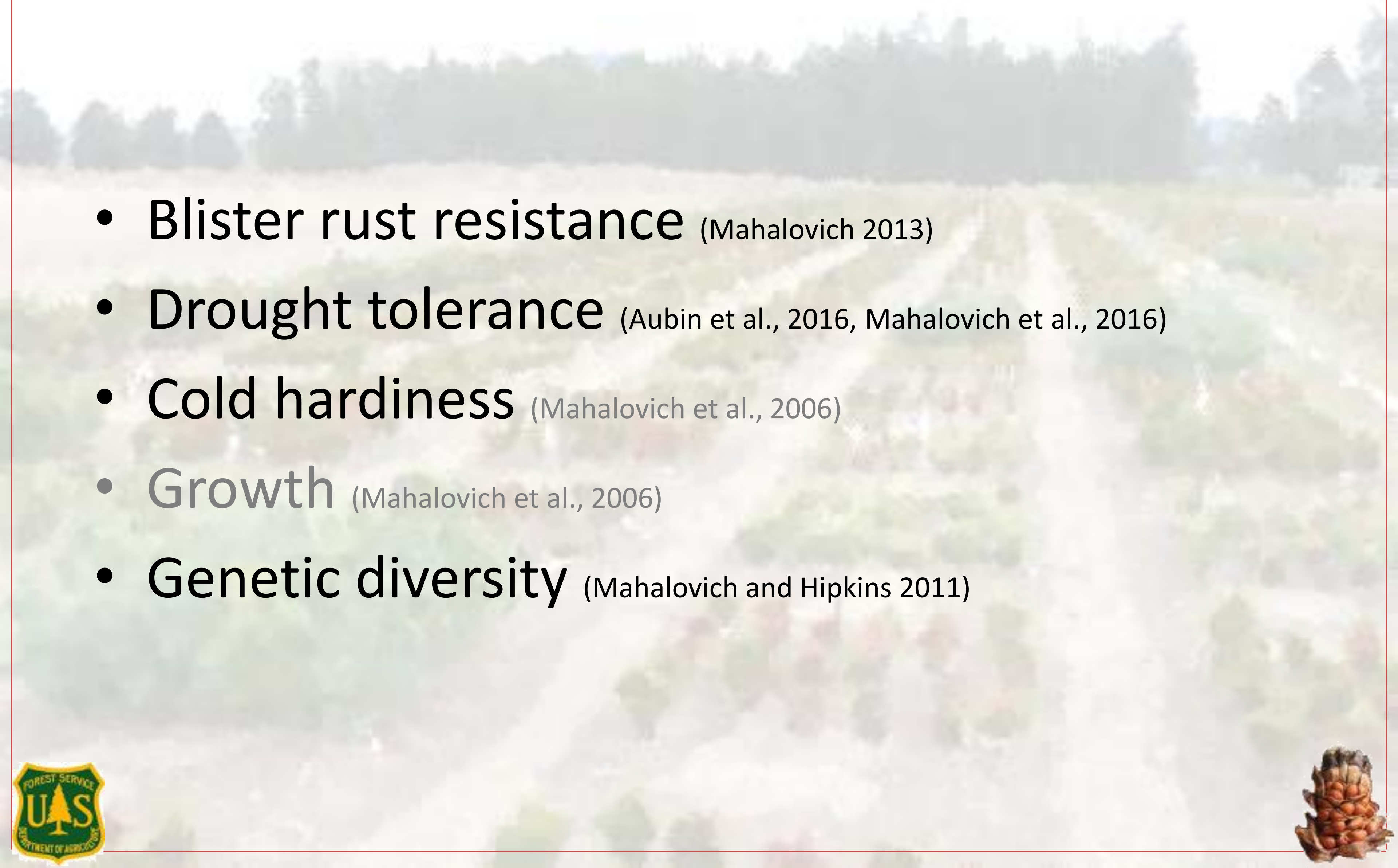
(Marshall and Zhang 1994)



(Mahalovich et al., 2016)

Whitebark pine is one of the most drought tolerant trees

Adaptive capacity and climate change



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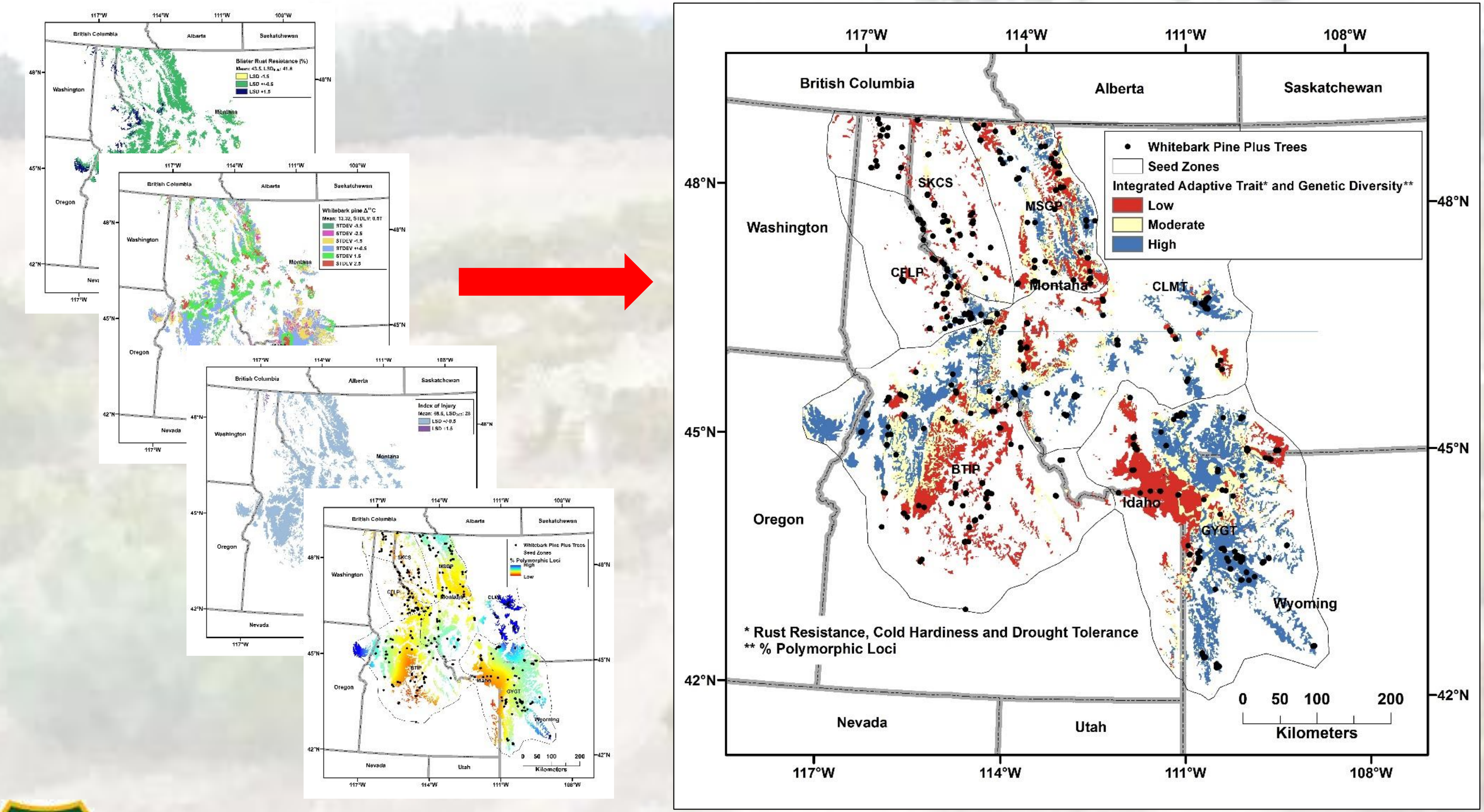
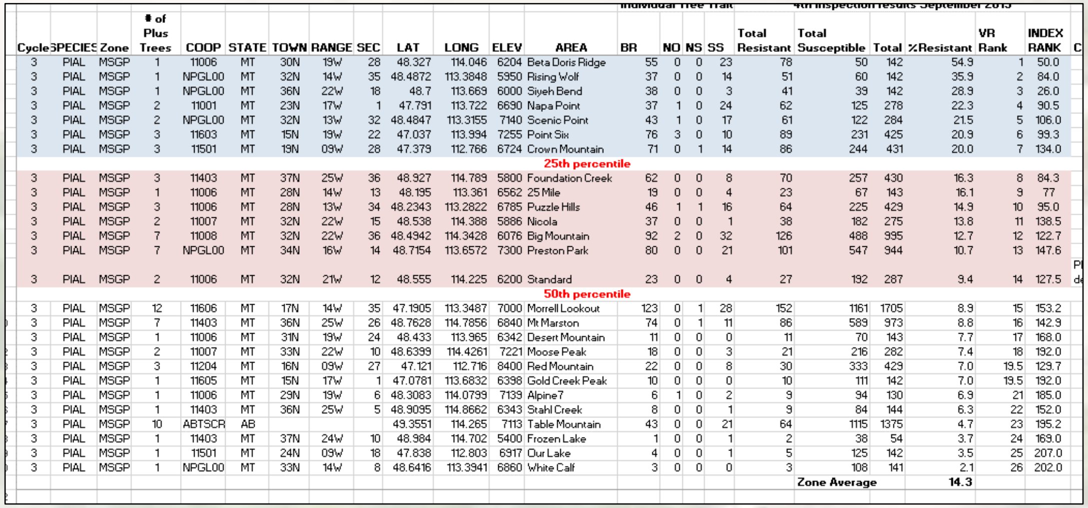
Adaptive capacity/gap analysis

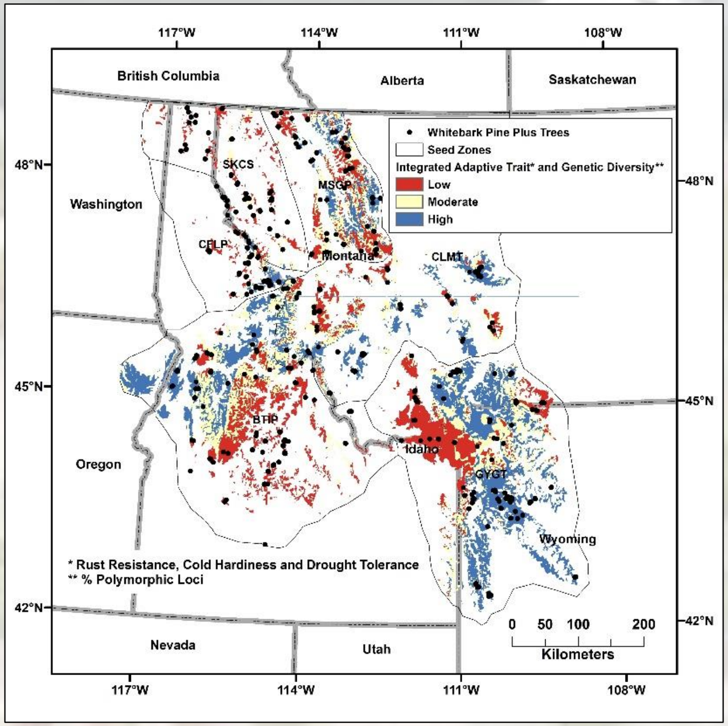


Areas highlighted in blue indicate high levels of blister rust resistance, drought tolerance, cold hardiness and genetic diversity

Good cone collections are the basis for successful reforestation



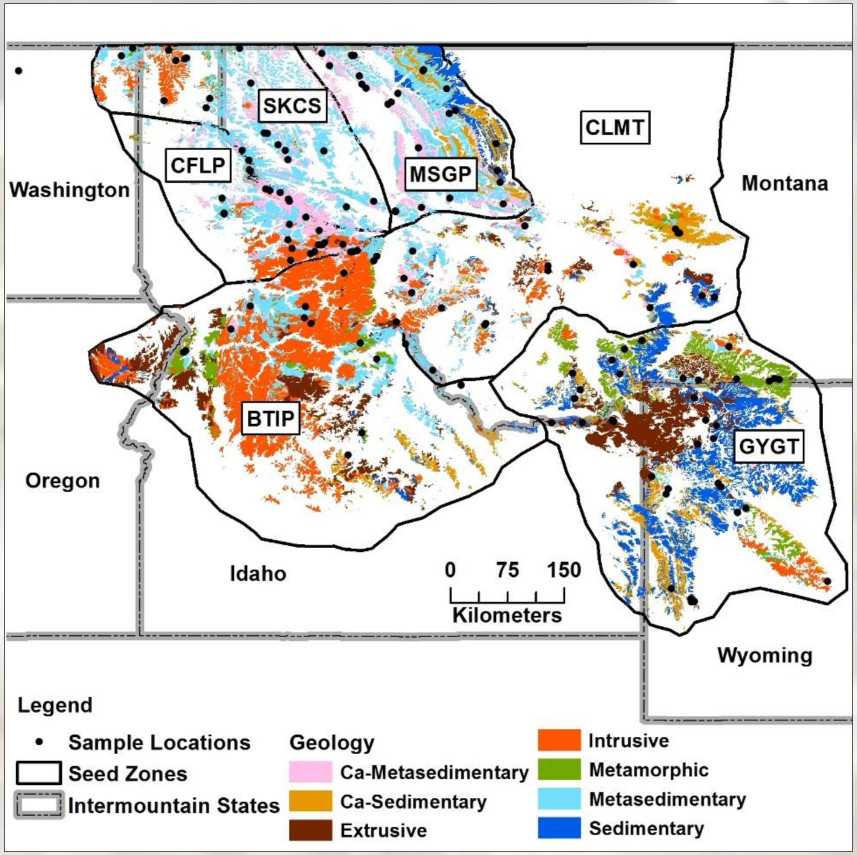
Cycle	SPECIES	Zone	# of Plus Trees	COOP	STATE	TOWN	RANGE	SEC	LAT	LONG	ELEV	AREA	BR	NO	NS	SS	Total Resistant	Total Susceptible	Total	%Resistant	VR Rank	INDEX RANK
3	PIAL	MSGP	1	11006	MT	30N	19W	28	48.327	114.046	6204	Beta Doris Ridge	55	0	0	23	78	50	142	54.9	1	50.0
3	PIAL	MSGP	1	NPGL00	MT	32N	14W	35	48.4872	113.3848	5950	Rising Wolf	37	0	0	14	51	60	142	35.9	2	84.0
3	PIAL	MSGP	1	NPGL00	MT	36N	22W	18	48.7	113.669	6000	Siyeh Bend	38	0	0	3	41	39	142	28.9	3	26.0
3	PIAL	MSGP	2	11001	MT	23N	17W	1	47.791	113.722	6690	Napa Point	37	1	0	24	62	125	278	22.3	4	90.5
3	PIAL	MSGP	2	NPGL00	MT	32N	13W	32	48.4847	113.3155	7140	Scenic Point	43	1	0	17	61	122	284	21.5	5	106.0
3	PIAL	MSGP	3	11603	MT	15N	19W	22	47.037	113.994	7255	Point Six	76	3	0	10	89	231	425	20.9	6	99.3
3	PIAL	MSGP	3	11501	MT	19N	09W	28	47.379	112.766	6724	Crown Mountain	71	0	1	14	86	244	431	20.0	7	134.0
												25th percentile										
3	PIAL	MSGP	3	11403	MT	37N	25W	36	48.927	114.789	5800	Foundation Creek	62	0	0	8	70	257	430	16.3	8	84.3
3	PIAL	MSGP	1	11006	MT	28N	14W	13	48.195	113.361	6562	25 Mile	19	0	0	4	23	67	143	16.1	9	77
3	PIAL	MSGP	3	11006	MT	28N	13W	34	48.2343	113.2822	6785	Puzzle Hills	46	1	1	16	64	225	429	14.9	10	95.0
3	PIAL	MSGP	2	11007	MT	32N	22W	15	48.538	114.388	5886	Nicola	37	0	0	1	38	182	275	13.8	11	138.5
3	PIAL	MSGP	7	11008	MT	32N	22W	36	48.4942	114.3428	6076	Big Mountain	92	2	0	32	126	488	995	12.7	12	122.7
3	PIAL	MSGP	7	NPGL00	MT	34N	16W	14	48.7154	113.6572	7300	Preston Park	80	0	0	21	101	547	944	10.7	13	147.6
3	PIAL	MSGP	2	11006	MT	32N	21W	12	48.555	114.225	6200	Standard	23	0	0	4	27	192	287	9.4	14	127.5
												50th percentile										
3	PIAL	MSGP	12	11606	MT	17N	14W	35	47.1905	113.3487	7000	Morrell Lookout	123	0	1	28	152	1161	1705	8.9	15	153.2
3	PIAL	MSGP	7	11403	MT	36N	25W	26	48.7628	114.7856	6840	Mt Marston	74	0	1	11	86	589	973	8.8	16	142.9
3	PIAL	MSGP	1	11006	MT	31N	19W	24	48.433	113.965	6342	Desert Mountain	11	0	0	0	11	70	143	7.7	17	168.0
3	PIAL	MSGP	2	11007	MT	33N	22W	10	48.6399	114.4261	7221	Moose Peak	18	0	0	3	21	216	282	7.4	18	192.0
3	PIAL	MSGP	3	11204	MT	16N	09W	27	47.121	112.716	8400	Red Mountain	22	0	0	8	30	333	429	7.0	19.5	129.7
3	PIAL	MSGP	1	11605	MT	15N	17W	1	47.0781	113.6832	6398	Gold Creek Peak	10	0	0	0	10	111	142	7.0	19.5	192.0
3	PIAL	MSGP	1	11006	MT	29N	19W	6	48.3083	114.0799	7139	Alpine7	6	1	0	2	9	94	130	6.9	21	185.0
3	PIAL	MSGP	1	11403	MT	36N	25W	5	48.9095	114.8662	6343	Stahl Creek	8	0	0	1	9	84	144	6.3	22	152.0
3	PIAL	MSGP	10	ABTSCR	AB				49.3551	114.265	7113	Table Mountain	43	0	0	21	64	1115	1375	4.7	23	195.2
3	PIAL	MSGP	1	11403	MT	37N	24W	10	48.984	114.702	5400	Frozen Lake	1	0	0	1	2	38	54	3.7	24	169.0
3	PIAL	MSGP	1	11501	MT	24N	09W	18	47.838	112.803	6917	Our Lake	4	0	0	1	5	125	142	3.5	25	207.0
3	PIAL	MSGP	1	NPGL00	MT	33N	14W	8	48.6416	113.3941	6860	White Calf	3	0	0	0	3	108	141	2.1	26	202.0
																		Zone Average		**14.3**		



- 10-year seed procurement planning window
- Opportunity to capture new material in a more focused manner to maintain genetic diversity in our genetics and reforestation programs

Soil parent material

- Conifers typically exhibit clinal variation
- Stable isotope analysis was the first indication whitebark pine also exhibits ecotypic variation
- Range limits controlled by competition at lower elevations and temperature at higher elevations (Keane et al. 2012)
- Current distribution as well as future range shifts may be modulated by edaphic variation



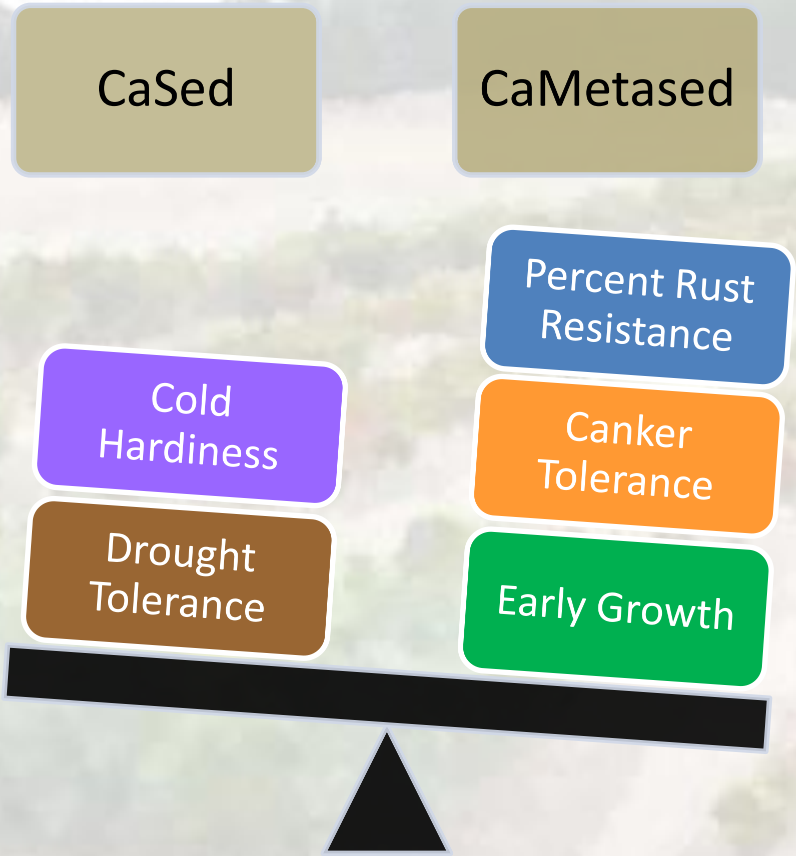
M. Kimsey

Matching species to site
Suitable climate *and* soil substrates

NRCS orders of soil taxonomy

Whitebark grows on inceptisols, limber on entisols and western white on andisols

Importance of edaphic variation



CaSed

CaMetased

Cold Hardiness

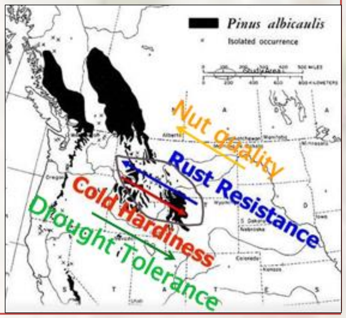
Drought Tolerance

Percent Rust Resistance

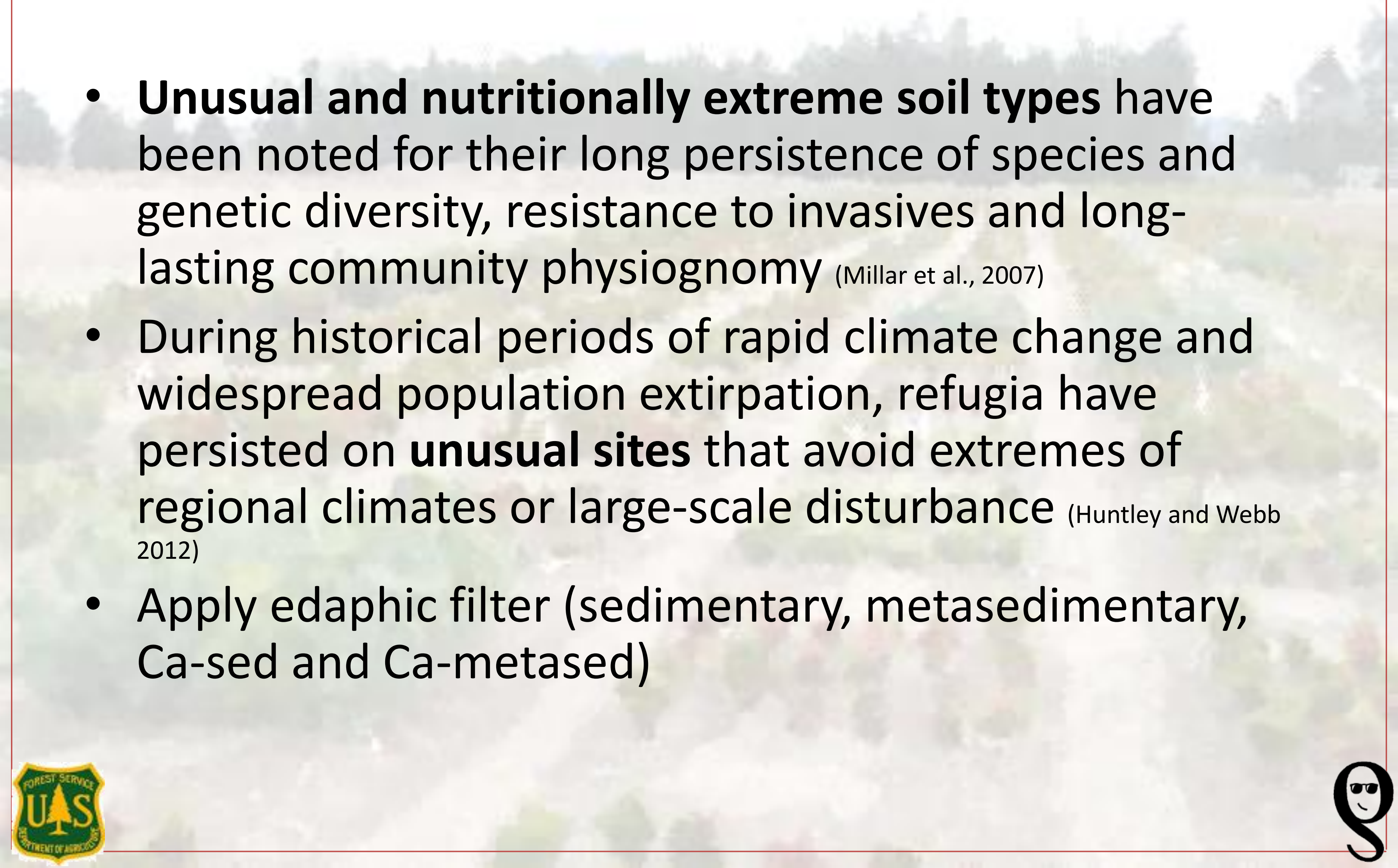
Canker Tolerance

Early Growth

- Impacts how and where we deploy seedlings
- Enhances predictive capability of species distribution models
- Refines where we look for climate refugia

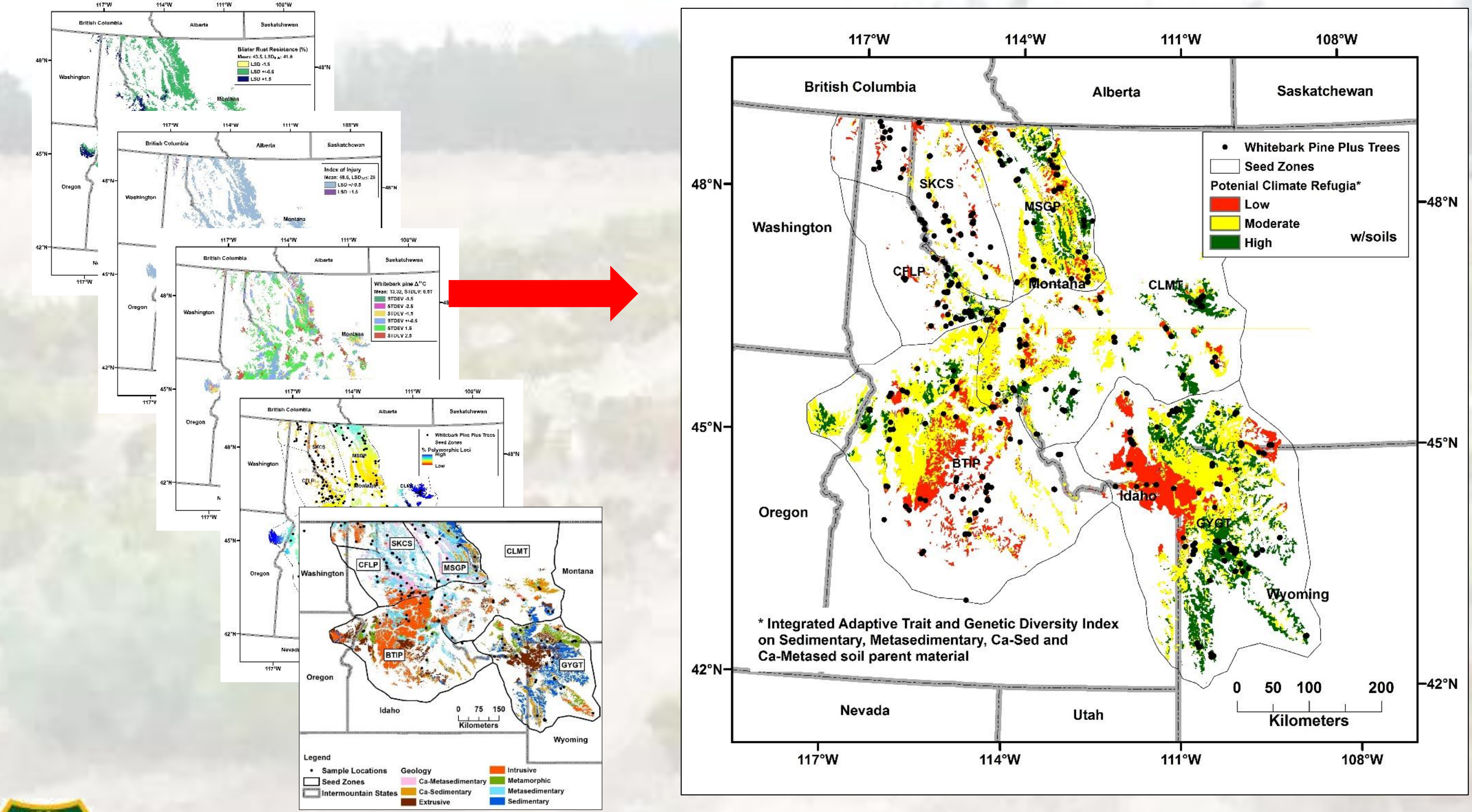


Geologic perspective of climate refugia



- **Unusual and nutritionally extreme soil types** have been noted for their long persistence of species and genetic diversity, resistance to invasives and long-lasting community physiognomy (Millar et al., 2007)
- During historical periods of rapid climate change and widespread population extirpation, refugia have persisted on **unusual sites** that avoid extremes of regional climates or large-scale disturbance (Huntley and Webb 2012)
- Apply edaphic filter (sedimentary, metasedimentary, Ca-sed and Ca-metased)

Potential climate refugia



* Integrated Adaptive Trait and Genetic Diversity Index on Sedimentary, Metasedimentary, Ca-Sed and Ca-Metased soil parent material

Incorporating soil substrates, areas highlighted in green are potential climate refugia

Low density and Allee effects*

(Courchamp et al. 2008)

- Genetic drift and inbreeding depression
- Ineffective pollen clouds for seed set
- Retention of Clarks nutcracker for seed caching (McKinney et al. 2007, Barringer et al. 2012)
- Decline in natural regeneration
- Local population extinction

* Positive correlation between population density and individual fitness; negative population growth observed at low population densities

Implications

- Low to moderate resolution models for blister rust resistance and drought tolerance supports whitebark pine as having a generalist adaptive strategy
- Restoration strategies need to consider both clinal and ecotypic (edaphic) variation in the context of tree density
- Isoscapes and spatial maps of adaptive traits provide invaluable reference (legacy) data relative to key geo-climatic and edaphic factors
- Knowledge of regional patterns will be important for prioritizing areas for conservation (climate refugia)
- Predictive outcome of species distribution models can be enhanced with adaptive capacity measures *and* suitable substrate

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