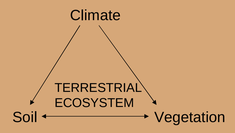
Gradient Analysis of Soil, Vegetation and Climate on the Tonto National Forest

George T. Robertson[1] Elizabeth Makings[2]

[1] Supervisory Soil Scientist, USDA Forest Service, Southwestern Region

[2] Botanist, USDA Forest Service, Southwestern Region



Abstract:

Gradient analysis is used to integrate soil and vegetation with climate on the Tonto National Forest. Soil moisture and temperature regimes, defined by Soil Taxonomy and supported by recent soil climate studies conducted within the Region and on the Forest, form the basis for the initial division of the climate gradient into uniform segments.

The gradient is further divided into life zones by correlating elevation, air temperature, precipitation and indicator plants with soil moisture and temperature regimes. This is accomplished through a robust ordering program known as Non-parametric Multivariate Analysis (NMS) in PC-ORD (version 4.0). It arranges or ordinates ecological site description plot data (approximately 150 soil and vegetation data elements per plot) and plant data and climate data from NOAA weather stations into life zones. In part, this is accomplished by using standard gradient analysis techniques developed for complex, multivariate ecological data. Ordination output is not by itself definitive, but evaluates the arrangement of vegetation and soils along a climate gradient.

The final step consists of integrating soil categories (Soil Taxonomy) to form individual terrestrial ecosystems. The final gradient is a combination of both field knowledge and ordination results. The resultant organized alignment of terrestrial ecosystems is a continuum of plant communities and their associated soils along a climate gradient ranging from the low elevation, hot, dry Sonoran Desert to the high elevation, cool, moist coniferous forests.

Figure 1. Bartlett Dam NOAA Weather Station. Each station is evaluated to ensure climate data reflects the natural environment and not artificial influences from nearby buildings, pavement, etc.

Figure 2. Landscape view of the plant community associated with the Bartlett Dam NOAA Weather Station.

NOAA Weather Station/Plant Community			
NOAA Station: Bartlett Dam, AZ (020632)		**Plant Community:** CAGI7/OLTE/LATRT/AMDE4	
MAAT (deg. C): 21.3		**Climax Class:** Edaphic	
MMXAAT (deg C): 29.2	**MMXSAT** (J_J_A) (deg C): 39.4	**Climate Class:** LSM 2, -1	
MMNAAT (deg C): 13.3	**MMNWAT** (D_J_F) (deg C): 5.1	**Gradient** (%): 05	
MAP (cm): 36.5		**Aspect** (deg.): 62	
MLSP (O_N_D_J_F_M) (cm): 22.7		**Elevation** (m): 500	
MLSP (%): 62		**Air Temperature Sensor:** Yes	
By: DD, GR	**Date:** 07/18/03	**Precipitation Guage:** Yes	

Trees		Shrubs				Forbs				Graminoids	
Species	%CC	Species	%CC	Species	%CC	Species	%CC	Species	%CC	Species	%CC
OLTE	6.3	LATRT	8.0			LEPID	0.1			POBI	0.1
CAGI7	1.0	AMDE4	7.0			CRYPT	T			VUOC	0.1
PAMI5	5.0	OPAC	10.0			PERE	1.0			SCHIS	5.0
PRVE	P	OPEN3	4.0			ERCI6	T			BRRU	T
		OPFU	5.0			LIBI2	T			BRAR4	P
		KRGR	P			PLANT	0.1				
		ENFA	5.0			CHBR	T				
		CEPA8	0.7			DAPU3	T				
		LYCIUM	0.8			AMMEI2	T				
		MAGR9	P			PHACE	T				
		JUCA8	P			EUCH	T				
		FECY	P			ERIAS	T				
		BEJUA	P			URLI5	T				
		AMAM2	P			GULA4	T				
						SIAN2	T				
						BRTO	T				
Totals	12.3	**********			40.5	**********			1.2	********	5.2

Notes:
Soil Temperature Study Site located at this plot. Established 07/18/2003.

Figure 3. Example of data sheet used to describe the plant community and selected physical attributes of the Bartlett Dam NOAA Weather Station.

Ordination of Plant Species For Each Soil Temperature Study Site Along a Climate Gradient															
Study Site		**A-2_VI**	**A-1_IV**	**A-2_V**	**A-1_II**	**A-2_X**	**A-1_I**	**A-2_XI**	**A-2_VIII**	**B-1_6**	**B-3_3**	**B-4_7**	**B-4_8**	**B-1_4**
Life Zone		**2**			**3**			**4**				**5**		**6**
Elevation (m)		597	764	985	1000	1142	1094	1297	1403	1780	1679	1826	1806	2134
Precipitation (cm)		33	38	45	40	47	53	55	48	58	74	76	71	84
SMR		Aridic	Aridic	Ustic	Ustic	Ustic	Ustic	Ustic	Ustic	Ustic	Ustic	Ustic	Ustic	Udic
MAST (C°)		20.6 - 21.7	18.9 - 20.6	18.3 - 20.0	17.8 - 18.3	15.0 - 17.2	16.1 - 17.8	16.1 - 16.7	17.2 - 17.8	13.3	11.1	12.2	12.8	08.9
STR		Thermic	Thermic	Thermic	Thermic	Thermic	Thermic	Thermic	Thermic	Mesic	Mesic	Mesic	Mesic	Mesic
Plant Community		CAGI7	CAGI7	PRVE	PRVE	PRVE	QUTU2	JUCO11	JUCO11	JUDE2	PIPOS	PIPOS	PIPOS	ABCO
Plant Species	**LF**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**
CAGI7	T	0.4	0.8	P										
PAMI5	T	4.5	1.5											
AMDE4	S	4	P											
CAER	S	5.5	0.6	P										
FOSP2	S	0.5	0.4											
LYCIUM	S	0.5		0.4										
ALDO	S		0.2	T										
SPAM2	S		2.5	P										
PAFL6	T			1										
PRVE	T			3	50	5		7						
KRER	S			T		0.1								
JUCO11	T				P	T	3	1.5	15					
MCAB	S				1	10	45	T	0.5	1				
OPPH	S				1	2								
ARPU8	G				T		1							
NOMI	S					0.1	T		1	T				
ARPU5	S						P			2				
QUTU2	S						15	0.4	2					
BOCU	G						T		0.8	1	0.2	1	3	
HIBE	G							0.3	T					
BOHI2	G								0.3	0.1				
JUDE2	T								T	20	10	8	10	2
PIMOF	T									3				
PIPOS	T									4	35	15	20	25
QUEM	T									5	3			
QUGR3	T									3	4	4	4	
GAWR3	S									1			0.1	
BOGR2	G									1	0.1	0.5	0.5	
QUGA	T										T	1		1
ARPR	S										T	0.5		
CEFE	S											0.1	0.1	
ABCO	T													20
PSMEG	T													10
RONE	S													0.5
TOTAL		**8 (2)**		**13 (3)**			**17 (4)**			**10 (3)**				**6 (1)**

Figure 4. Soil temperature data is collected to determine soil temperature regimes. Indicator plants identified through the ordination process are correlated with soil temperature and soil moisture regimes along a climate gradient.

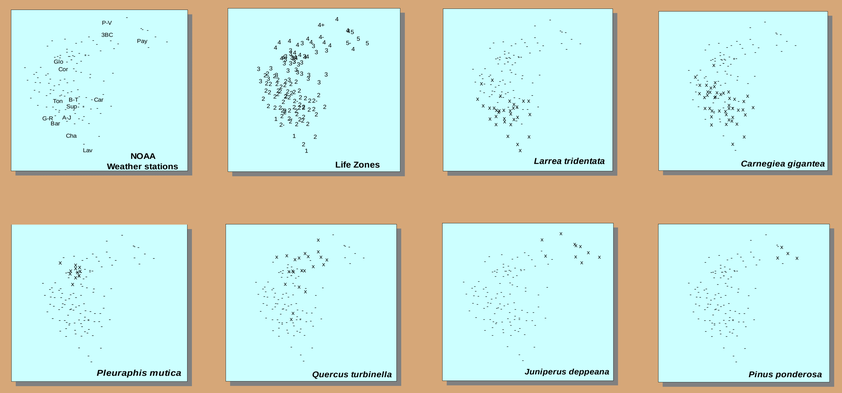


Figure 5. Using Non-parametric Multivariate Analysis (NMS) in PC-ORD, individual plant species (based on presence/absence) are ordinated along a climate gradient. Their position in the ordination is based upon elevation, mean annual air temperature, and mean annual precipitation as determined by NOAA Weather Stations. Lower portions of each chart represent hot, dry desert climates. Upper portions represent high elevation, cool, moist climates.

NOAA Weather Station Plant Species Ordinated Along A Climate Gradient							
NOAA Weather Station	Granite Reef	Bartlett Dam	Globe R.S.	Cordes Junction	Pleasant Valley	Crown King	Tonto Creek
Elevation (m)	405	500	1106	1158	1539	1804	1948
MAP (cm)	22	37	47	39	53	73	84
MAAT (C°)	20.6	21.3	16.2	16.1	12	11.9	---
Life Zone	1	2	3	3	4	5	6
Plant Community	LATRT	CAGI	PRVE	PLMU6	JUDE2	PIPOS	PSMEG
Plant Species	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**	**% cc**
Ambrosia deltoidea	5	7					
Larrea tridentata var. tridentata	25	8					
Mammillaria grahamii		P					
Encelia farinosa	T	5					
Olneya tesota		6.3					
Krameria grayi		P					
Ferocactus cylindraceus		P					
Parkinsonia microphylla		5					
Carnegia gigantea		1					
Ericameria laricifolia			0.1				
Dasilyrion wheeleri			P				
Krameria erecta			0.1				
Prosopis velutina			5	0.3			
Acacia greggii			1	2			
Ziziphus obtusifolia			T	P			
Senna bauhinioides			P	0.2			
Acacia constricta			T				
Muhlenbergia porteri				0.2			
Hilari belangeri				5			
Pleuraphis mutica				15			
Bacharis pteronioides			0.1		0.4		
Escobaria vivipara var. arizonica			P		T		
Bouteloua curtipendula				0.3	2		
Elymus elymoides					1.5		
Rhus trilobata var. pilosissima					3		
Calliandra humilus reticulata					0.5		
Bouteloua gracilis					10	0.2	
Juniperus deppeana					2	T	
Artemisia carruthii						1	
Cercocarpus montanus						3	
Garrya wrighti						0.5	
Arctostaphylos pungens						0.5	
Nolina microcarpa						P	0.1
Arctostaphylos pringlei						0.5	2
Quercus gambelii						T	T
Ceanothus fendleri						3	5
Quercus grisea						3	2
Quercus emoryi						5	5
Pinus ponderosa						35	5
Poa fendleriana						0.3	1
Pteridium aquilinum							T
Muhlenbergia virescens							0.1
Muhlenbergia longiligula							1
Pseudotsuga menziesii var. glauca							50
Total Plant Species By Life Zone	**3 (1)**	**9 (1)**	**19 (2)**	**8 (1)**	**14 (1)**	**12 (1)**	

Figure 6. Illustrates how life zones are defined by elevation, plant species, plant communities, precipitation, and air temperature along a climate gradient that ranges from low elevation, hot, dry deserts to high elevation, cool, moist coniferous forests.

Life Zones
1 - Lower Sonoran Desert
2 - Upper Sonoran Desert
3 - Grassland
4 - Woodland/Chaparral
5 - Coniferous Forest
6 - Mixed Coniferous Forest

Climate Gradient - Tonto National Forest						
Life Zones						Climate Descriptors
1	**2**	**3**	**4**	**5**	**6***	
Lower Sonoran Desert	**Upper Sonoran Desert**	**Grassland**	**Woodland/Chaparral**	**Coniferous Forest**	**Mixed Conifer**	
Granite Reef Dam			Pleasant Valley R. S.			**NOAA Weather Station**
---	---	Globe R. S.	---	Crown King	---	
---	Bartlett Dam	---	---	---	Tonto Creek	
1893 - 1979	---	---	1964 - 2004	---	---	**Period of Record**
---	---	1981 - 2003	---	1914 - 1995	---	
---	1939 - 2004	---	---	---	1971 - 2000	
405	---	---	1539	---	---	**ME**
---	---	1113	---	1804	---	
---	503	---	---	---	1948	
22	---	---	53	---	---	**MAP**
---	---	47	---	73	---	
---	37	---	---	---	84	
14 (64%)	---	---	29 (55%)	---	---	**MLSP**
---	---	25 (52%)	---	43 (59%)	---	
---	23 (62%)	---	---	---	49 (59%)	
20	---	---	12	---	---	**MAAT**
---	---	16	---	12	---	
---	21	---	---	---	10*	
---	---	16.1 - 18.9 (2)	11.1 - 13.3 (2)	---	---	**MAST**
---	18.9 - 23.9 (2)	15.0 - 18.3 (2)	---	7.8 - 13.3 (6)	8.9	
---	20.6 - 22.2 (2)	18.3 - 20.0 (1)	15.6 - 17.8 (5)	12.2 - 12.8 (1)	---	
---	---	23.3 - 29.4 (2)	18.9 - 23.3 (2)	---	---	**MSST**
---	29.4 - 32.8 (2)	25.6 - 28.9 (2)	---	12.2 - 21.7 (6)	11.7	
---	30.0 - 34.4 (2)	28.9 - 30.0 (1)	22.2 - 29.4 (5)	18.3 - 20.0 (1)	---	
---	---	8.3 - 12.8 (2)	2.8 - 7.8 (2)	---	---	**MWST**
---	8.9 - 12.2 (2)	2.8 - 11.1 (2)	---	- .6 - 7.2 (6)	7.2	
---	8.3 - 19.9 (2)	8.9 - 11.7 (1)	4.4 - 11.7 (5)	5.0 - 8.9 (1)	---	
Aridic	Aridic	Ustic	Ustic	Ustic	Udic	**SMR**
[Hyperthermic]	Thermic	Thermic	Mesic	Mesic	Mesic	**STR**
---	Thermic	Thermic	Mesic	Mesic	Mesic	
---	Thermic	Thermic	Thermic	Mesic	Mesic	
Typic	Ustic	Aridic	Typic	Ustic	Typic	**Soil Subgroup**
Haplargids	Haplargids	Argiustolls	Haplustalfs	Haplustalfs	Hapludalfs	**Soil Great Group**
LATRT	CAGI7	BOER4	QUTU2	PIPOS	PSMEG	**Veg. Series Name**

Life Zone Ecotones - Within each life zone, climate variability (hot/dry, cool/moist) influences plant species composition and soils. The central concept (typical) of climate that characterizes a life zone is indicated by 0. Variation in climate due to a shift to warm/dry is coded as -1, and a shift to cool/moist is coded as +1.

MAST - MSST - MWST - Parenthesis ( ) - Number of soil temperature study sites.

STR - [Hyperthermic] - Predicted soil temperature regime for the Lower Sonoran Desert.

* MAAT is estimated. Tonto Creek Weather Station collects only precipitation data.

Figure 7. The unique combination of soil moisture and temperature regimes, indicator plants, and climate provide the basis for dividing the gradient into life zones. The final result of the analysis is an organized alignment of plant communities and their associated soils along a climate gradient.

Gradient Abbreviations - Tonto National Forest				
Abbreviation	**Definition**	**Unit of Measure**	**Data Source**	**Information Source**
NOAA Weather Station	**National Oceanic and Atmospheric Administration Weather Station.** The weather station from which climate data is observed.	NOAA Weather Station Name	WRCC	Western Regional Climate Center (WRCC) http://www.wrcc.dri.edu/climsum.html
Period of Record	**Period of Record** The actual period in years that climate data is observed and reported.	The time period that climate data is observed	O	WRCC - Period of Record Data Tables Monthly Tabular Data Period of Record Monthly Climate Summary
ME	**Mean Elevation**	Meters	---	WRCC - Period of Record Station Meta Data Terra Geospatial Toolkit
MAP	**Mean Annual Precipitation**	Centimeters	C	WRCC - 1961 to 1990 Monthly Tabular Data Monthly Climate Summaries
MLSP	**Mean Low Sun Period** Amount of precipitation received during the period of October 01 through March 31.	Centimeters and as a percent of the annual precipitation.	C	WRCC - 1961 to 1990 Monthly Tabular Data Monthly Climate Summaries
MAAT	**Mean Annual Air Temperature**	Degree Celsius	C	WRCC - 1961 to 1990 Monthly Tabular Data Monthly Climate Summaries
MAST	**Mean Annual Soil Temperature**	Degree Celsius	O	Tonto National Forest Soil Temperature - Moisture Studies (1969 - 1979)
MSST	**Mean Summer Soil Temperature** Average soil temperature during the period of June, July and August.	Degree Celcius	O	Tonto National Forest Soil Temperature - Moisture Studies (1969 - 1979)
MWST	**Mean Winter Soil Temperature** Average soil temperature during the period of December, January and February.	Degree Celcius	O	Tonto National Forest Soil Temperature - Moisture Studies (1969 - 1979)
SMR	**Soil Moisture Regime** (Aquic, Aridic, Torric, Udic, Ustic)	Class Name	---	Keys to Soil Taxonomy, Ninth Edition 2003
STR	**Soil Temperature Regime** (Hyperthermic, Thermic, Mesic, Frigid)	Class Name	---	Keys to Soil Taxonomy, Ninth Edition 2003
Data Source:	O	Climate data is from observations. Soil temperature data collected from thermistors at 50 centimeters or at bedrock, whichever is shallower.		
	C	Unofficial values based on averages/sums of smoothed daily data. Information is computed from available daily data during the period of 1961-1990. Smoothing, missing data and observation-time changes may cause these 1961-1990 values to differ from official NCDC values.		
	WRCC	Western Regional Climate Center		

Figure 8. Definition of terms and abbreviations used in gradient analysis. Other climate descriptors include SP (snow period), MASF (mean annual snow fall), and FFP (freeze free period).

Figure 9. Life Zone 1 - **Lower Sonoran Desert.** Dominant species: *Larrea tridentata*.

Figure 10. Life Zone 2 - **Upper Sonoran Desert.** Common species include *Carnegiea gigantea, Prosopis velutina, Parkinsonia microphylla, P. florida, Larrea tridentata, Simmondsia chinensis, Fouquieria splendens, Opuntia* spp. *and Ferocactus* spp.

Figure 11. Life Zone 3 - **Grassland.** Common grasses include *Hilari belangeri, Pleuraphis mutica, Bouteloua eriopoda, B. hirsuta, B. gracilis, B. curtipendula,* and *Panicum obtusum.*

Figure 12. Life Zone 4 - **Woodland.** Common tree species include *Pinus monophylla, Juniperus coahuilensis, J. deppeana and J. osteosperma.* Common understory species include *Quercus turbinella, Arctostaphylos pungens, Mahonia haematocarpa, Nolina microcarpa* and *Agave* spp.

Figure 13. Life Zone 4 - **Chaparral.** (Fire Climax). Co-dominant species include *Quercus turbinella, Arctostaphylos pungens,* and *A. pringlei. Ceanothus greggii, Cercocarpus montanus,* and *Rhus trilobata* are also common.

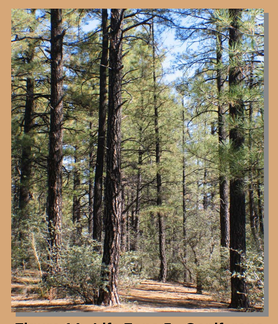


Figure 14. Life Zone 5 - **Coniferous Forest.** *Pinus ponderosa* var. *scopulorum* is the dominant tree species with an understory of *Quercus emoryi, Q. grisea,* and *Juniperus deppeana.*

Figure 15. Life Zone 6 - **Mixed Coniferous Forest.** Dominant tree species are *Abies concolor, Pseudotsuga menzeisii* var. *glauca,* and *Pinus ponderosa* var.*scopulorum.* Understory species include *Quercus emoryi, Q. grisea* and *Q. gambelii.*