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A GIS to Select Plant Species for Erosion Control Along California Highways

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Abstract

Through road construction and maintenance activities, the California Department of Transportation (Caltrans) actively manages roadside rights-of-way that transect California's 41 million hectares (101 million acres), spanning over 3,000 meters of elevational change from seashore to subalpine. State and federal highways are grouped into 12 districts, each encompassing from one to 11 of the state's 58 counties. District personnel are typically responsible for implementing site-specific adaptations of general statewide guidelines for short- to long-term erosion control following construction or storm damage. Many erosion control projects involve reestablishing vegetation through seeding where the precarious life stages of germination and establishment are controlled by both unpredictable short-term weather events and often physically inappropriate seedbeds. Many revegetation failures result from improperly siting species such that individual plants are expected to germinate, grow, and persist in locations or on topographic aspects that present physical extremes in solar radiation, temperature, precipitation, surface water flow, or wind beyond their genetically-determined physical tolerances. Each district includes enough environmental heterogeneity that revegetation using a few, district-wide seed mixes will not adequately meet the need for erosion control among diverse project sites. Consequently, a geographic information system (GIS) is being developed which allows employees to rapidly access lists of plant species for revegetation that are both ecologically appropriate for the project site and potentially useful in minimizing erosion from roadcuts and roadsides. This GIS uses hydrologic units of CALWATER at 1:24000 as a means to link physiographic and climatalogical data together with presence or absence of selected plant species in each hydrologic unit. Plantclimate classifications follow the 19 general plantclimates

depicted on the California Plantclimates map devised by the University of California Cooperative Extension Service in 1967, and revised in 1979. These 19 general plantclimates are being refined using elevation contours and topographic aspects derived from digital elevation models to allow assignment of different plantclimates to portions of hydrologic units that exhibit steep elevational gains or considerable landform diversity. Through the overlay of other data depicting county boundaries, roads, and places, users are able to locate project sites, query the plant species climate matrix, and export data tables to spreadsheets or reports. Guidebooks that index the same plant species climate matrix through a standard *route+county+mile/km* georeferencing system make these data available to district personnel in another format as well.

Key Words: Revegetation Specifications, Plants, Climates, Geographic Information Systems, Caltrans

Biographical Sketches

Michael Curto

Michael Curto earned a BS in Ecology & Systematic Biology from Cal Poly State University. His interests and experience center around plant biogeography, ecology, and systematics, especially of Western North American grasses. As a consultant to the Utah Department of Transportation (UDOT), he designed and constructed RoadVeg, their statewide database inventory of roadside vegetation (now a GIS), and performed field inventories on over 2,500 miles of Utah roadways.

Brent G. Hallock, Ph.D., CPSS, CPESC

Brent Hallock has been a professor at California Polytechnic, San Luis Obispo, since 1979. He teaches an undergraduate course in Soil and Water Conservation, an upper division course in Rangeland Resources, and a graduate course in Soil Erosion and Sediment Control. Brent earned Cal Poly's highest award of Distinguished Teacher in 2000. He has taught over 30 seminars and short courses in site analysis, erosion control, and selecting management measures. Dr. Hallock's research grants with Caltrans, RWQCB, and EPA on the use of vegetation in erosion control and water quality total over two million dollars in the past six years.

Misty Scharff, APSSc

Ms. Misty Scharff has been involved with California State University, Sacramento, performing research on erosion and sediment control for Caltrans since 2000. Misty was educated in soil science at California Polytechnic State University, San Luis Obispo, were she assisted in numerous erosion control research studies. Misty has been a member of IECA since 1996.

Introduction

Through road construction and maintenance activities, the California Department of Transportation (Caltrans) actively manages roadside rights-of-way that transect California's 41M ha (101M ac), spanning over 3,000 meters of elevational change from seashore to subalpine. Interactions among diverse climates, landforms, substrates, and floristic species "pools" produce a diversity of plant species in California that ranks among the highest of any comparably sized temperate region of the world, with about 4,900 native, and over 1,000 naturalized alien, vascular plant species known to occur within the state (Dallman 1998; Hickman 1993; Raven and Axelrod 1978).

State and federal highways are grouped into 12 districts varying in size from 207K ha (511K ac) to 7.3M ha (18M ac), each encompassing from one to 11 of California's 58 counties. District personnel are typically responsible for implementing site-specific adaptations of general statewide guidelines for short- to long-term erosion control following construction or storm damage. Many erosion control projects involve reestablishing vegetation through seeding where the precarious life-stages of germination and establishment are controlled by both unpredictable short-term weather events and often physically inappropriate seedbeds.

When such revegetation projects produce poor results, or fail altogether, a search for remediation ensues. Some revegetation failures likely result from the improper siting of species such that individual plants are expected to germinate, grow, and persist in locations or on topographic aspects that present physical extremes in solar radiation, temperature, precipitation, surface water flow, or wind beyond their genetically-determined physical tolerances. Other revegetation failures are due to poorly executed seeding or installation procedures even when the correct species are properly sited. Undoubtedly, many project failures result from a combination of both fundamental problems. Each district includes environmental heterogeneity such that revegetation using a few, district-wide seed mixes will not adequately meet the need for erosion control among diverse project sites.

Proper siting of plant species or ecological races in locations that promote their establishment and persistence is fundamental to any successful revegetation effort. Where individual plant species grow and reproduce today, and have done so within the recent past, are places conducive to their establishment and persistence.

If geographical distributions of all plant species used in roadside revegetation were overlaid, and upon these distributions a road layer was superimposed, the presence or absence of individual species could be ascertained along a given route, and through a geographic information system (GIS), a site-specific species list for a revegetation project could be obtained. Thus, a solution to the problem of site-specific species delineation is seemingly simple in both the initial identification of data requirements, and in the finished presentation of processed data. However, the middle tasks of acquiring, processing, and synthesizing data have presented great obstacles to easy solutions.

Data are readily available for features such as hypsography (elevation) or road routes, but biogeographical data depicting the spatial extent and area-of-occupancy for individual plant species are largely unavailable owing to the high cost to produce such data layers from accurately identified herbarium specimens and field surveys. Consequently, surrogate distributions for individual species must be derived instead through the scoring of presence or absence within some reasonably sized, landscape-level polygons formed either by natural boundaries or by overlay of coordinate grids.

Such multi-species distribution layers are typically complex in the patterns depicted by the aggregate distributions of different species subsets. Thus, a common objective is further analysis to ascertain distributional patterns held in common by subsets. Generally, climate is the predominant factor controlling the presence or absence of plant species. The overall global distributions of solar radiation and precipitation determined by latitude result in climate zones commonly referred to as tropical, subtropical, temperate, and polar (Köppen and Geiger 1936; Trewartha and Horn 1983). Moving from global and continental to subcontinental and regional scales, these zonal climates are further modified by interactions among other major influences including *continentality* (distance from an ocean body), and landform size, shape, altitude, and orientation. Effects from these interactions are experienced at subcontinental scales as regional climates (see Bailey 1996 for a detailed discussion).

For example, much of California experiences a subtropical, summer-dry (Mediterranean) climate modified from place to place by the degree of continentality and topographic elevation (Bailey 1996; Brenzel 2001; Hornbeck et al. 1983; James 1966; Kesseli 1942; Kimball and Brooks 1959; Patton 1962; Russell 1926, 1931; Trewartha and Horn 1983; Yahr 1961). At increasingly local scales, topography and directional aspects combine to exacerbate or ameliorate zonal conditions and render *topoclimates*. Further modifications, such as the presence of overstory vegetation, produce *microclimates* at the scale of stands or individual plants. Topoclimates are typically paramount design factors in revegetation projects. Greater intensity and duration of solar radiation combined with lesser soil moisture and ambient humidity make south-facing slopes in the Northern Hemisphere especially difficult sites for the establishment and persistence of many plant species, especially in the more arid areas of interior California. Hence, site aspect figures prominently in the prescription of plant species for revegetation. Individuals of species improperly sited on aspects that will expose them to inadequate or extreme solar radiation, temperature, precipitation, surface water flow, or wind beyond their genetically-determined physical tolerances are destined to fail.

Project Objective

In an attempt to improve the process of specifying plant species for erosion control, a geographic information system (GIS) is being developed that combines state and district-level climatalogical, geological, topographical, and plant biogeographical data to define ecologically meaningful sub-district Plant Climate Zones. These climate zones form the foundation for rapid access to lists of plant species for revegetation that are both ecologically appropriate for the project site and useful in minimizing erosion.

Needs Expressed by Highway Personnel

The development of this GIS was shaped by the following parameters outlined during initial project planning meetings with highway personnel:

- Keep species selection process as simple as possible
- Use the University of California plant climate zone approach of the Sunset Western Garden Book
- Use previous site specific criteria to create a master species list for each district
- Create species lists for seeding only, not for container stock planting

- Include only those species presently commercially available as seed
- Include assumed general site conditions, caveats, qualifiers about zones and potential variability that may affect intended results.

Intended Usage

This GIS is considered an *advisory* resource in the specification of plant species and is in no way intended to supplant knowledge of local areas held by district personnel, nor does use of this GIS obviate any need for site visits to proposed project locations before specifications of plant materials are made. The species lists provided are intended as recommendations, not as fixed prescriptions because general species lists, even tailored to climate zones, will not always meet special needs of specific projects, especially when sites present azonal conditions, especially with regard to wetlands.

Conceptual Foundation & Approach

The approach involves three basic processes:

1. Refine an existing statewide climate map (at ca 1:1,500,000) to a more local scale (ca 1:50,000);
2. Create a layer for plant species used in revegetation that scores individual presence or absence within landscape-level polygons that overlay California completely;
3. Intersect the climate and plant species distribution layers to obtain a plant/climate layer and data matrix from which plantclimate zones are delineated.

Local Climate Refinements

The 19 general climate zones were digitized and depicted on the California Plantclimates Map (UCCE 1989; ca 1:1,500,000), evolved from a map of 16 zones devised by the University of California Cooperative Extension Service in 1959 (Kimball and Brooks 1959), and revised by the UCCE to 19 zones in 1967. Recent revisions of mountain and northcoastal California climates expanded the zone number to 23 in the latest edition of the Sunset Western Garden Book (Brenzel 2001). While these latest revisions to mountain and north coast climate zones were generally reasonable and needed, the nearly complete elimination of mountain climates from the Peninsular Range in Southern California is untenable given the presence there of mixed conifer forests and ample snowfall. Therefore, the 1989 version was used as the base map.

The 1989 map classifies over 54 percent of California to just three climate zones: Zone 1 (Highlands), Zone 11(Desert Lowlands), and Zone 7 (Interior Foothills and Valleys). More local refinements of these general climate zones are necessary because these zone delineations are disproportionately broad, encompassing areas with pronounced differences in seasonal temperatures and precipitation. This is especially true for Zone 7, a broad ring around California's Central Valley that includes coastal highland areas of the Santa Lucia Mountains that receive over 1,400mm (55in) of annual precipitation and experience cool, humid summers, together with interior valley areas of the Carrizo Plain and Cuyama River Valley that receive 125mm (5in) of annual precipitation and experience very hot, arid summers.

These 19 general climate zones statewide are now being refined using elevation contours and topographic aspects derived from digital elevation models, along with interpolated isohyets developed from annual precipitation data recorded at local weather stations, to allow assignment of different climates or subclimates to portions of landform units that exhibit steep elevational gains or considerable topographic diversity. Further local refinements use presence and type of tree cover as an indicator of long-term climate trends where weather station data are poor or nonexistent. This is especially necessary for the more arid areas where fewer people reside and few, if any, weather stations exist. For example, the presence of Blue Oak (*Quercus douglasii* H. & A.) typically indicates average annual precipitation of at least 250mm (10in), and Black Oak (*Quercus kelloggii* Newb.) at least 890mm (35in). For tree cover polygons, landcover data provided with the California Gap Analysis Project CD-ROM was used (Davis et al.1998).

Plant Species Distributions

As a means to link plant species distributions to landscape-level polygons hydrologic units of CALWATER 2.2 (CDFF 1999), a statewide polygon coverage digitized from 1:24000 scale U. S. Geological Survey (USGS) quads, were used to score presence or absence of selected plant species in each hydrologic unit.

For example, the Master Species List for District 5 (Santa Cruz, San Benito, Monterey, San Luis Obispo, and Santa Barbara counties) includes 47 readily available species used for erosion control on projects within the district during the past five years (Caltrans 1996, 1998, 1999, 2000a, 2000b, and other erosion specifications excerpted from past bid packages). Presence or absence decisions were made using herbarium specimens housed in the Hoover Herbarium at California Polytechnic State University, San Luis Obispo, and floras and floristic guides (too numerous to cite here but included in the GIS metadata) that pertain to varying portions, or the whole, of the five counties of interest, or adjacent areas. On-line floristic resources of the Jepson Herbarium at the University of California, Berkeley (http://ucjeps.herb.berkeley.edu/jeps-list.html), and of the multi-agency CalFlora project (http://www.calflora.org/), were queried as well. Working knowledge of plant distributions in the region gained through past fieldwork also aided these decisions because even the most recent floral manual for California (Hickman 1993) contains many acknowledged errors of omission and commission in the distributional statements for both native and alien species (see http://ucjeps.berkeley.edu/all_corr2.html).

Plant Species Nomenclature and Other Attributes

For each species of a district master list, the following nomenclatural, life form, establishment, and seed attribute data are provided:

Nomenclatural Attributes

- full scientific name
- synonymous scientific names of regional importance
- the most frequently used vernacular (common) name
- plant family membership.

Taxonomy conforms largely to the latest statewide flora for California (Hickman 1993) and updates at http://ucjeps.herb.berkeley.edu/jeps-list.html.

Life-Form and Life-Cycle Attributes

- legume or non-legume (Fabaceae)
- shrub, forb, or grass
- perennial or annual

Establishment Attributes

Eleven fields of the database present a specially devised Erosion Control Index that ranks species with regard to the following attributes:

- germination rates
- growth rates
- competitive abilities
- overall establishment
- surface soil erosion reduction
- visual presence, and

- persistence.

This specially devised index is modeled after the Competitive Suitability Index developed for reestablishing native species on Utah rangelands (Plummer et al. 1968), and the ecological tolerance rankings for species recommended for revegetation along highways in Utah (Hansen et al. 1991). Although the rankings provided by the Erosion Control Index are based largely on pertinent ecological literature, and on observations of past performance within a district, users of this GIS should regard these rankings as general indicators of expected performance, not as absolute values, as individual plant performance is principally site-specific, being highly dependent upon short-term weather events.

Seed Attributes
Fifteen fields furnish data for each species regarding typical seed sample purity:

- seed germination rates
- typical percent pure live seed (PLS)
- number of seeds per pound
- seeding rates per acre
- number of PLS and potential plants per square foot at recommended seeding rate
- recent low and high prices per pound.

These data are also calculated in metric equivalents to eliminate unnecessary repetitive conversion.

Plantclimate Zone Delineations
Overlay and intersection of the plant species distribution layer upon the revised climate layer, along with subsequent modifications to delineate "best-fit" boundaries, results in a secondary combined Plantclimate layer.

For District 5, this process resulted in the delineation of 24 Plantclimate Zones rather than the 10 Plantclimate Zones of the 1989 version of the University of California Map for the same spatial extent. Owing to reasons stated above, Zone 7 was split into six zones based largely on increasing continentality and aridity. Labeling of these 24 Plantclimate Zones follows the UC/Sunset System with the addition of an alphabetical suffix, e.g., 7a, 7b, 7c, 7d, 7e, and 7f.

GIS Query and Output
Through the overlay of other data depicting district and county boundaries, roads, and places, users are able to locate project sites, query the plant species climate matrix, and export data tables to spreadsheets or reports (see Figure 1 for example of interface). Guidebooks that index the same plant species climate matrix through a standard *route+county+mile/km* georeferencing system make these data available to district personnel in another format as well (see Figure 2).

Future Developments
An expansion of this GIS is anticipated to include a statewide inventory of existing roadside and context-landscape vegetation much like the RoadVeg GIS developed for the Utah Department of Transportation (Bickford et al. 1998). Field inventories of species presence or absence would then provide the basic data for GIS layers of plant distribution.

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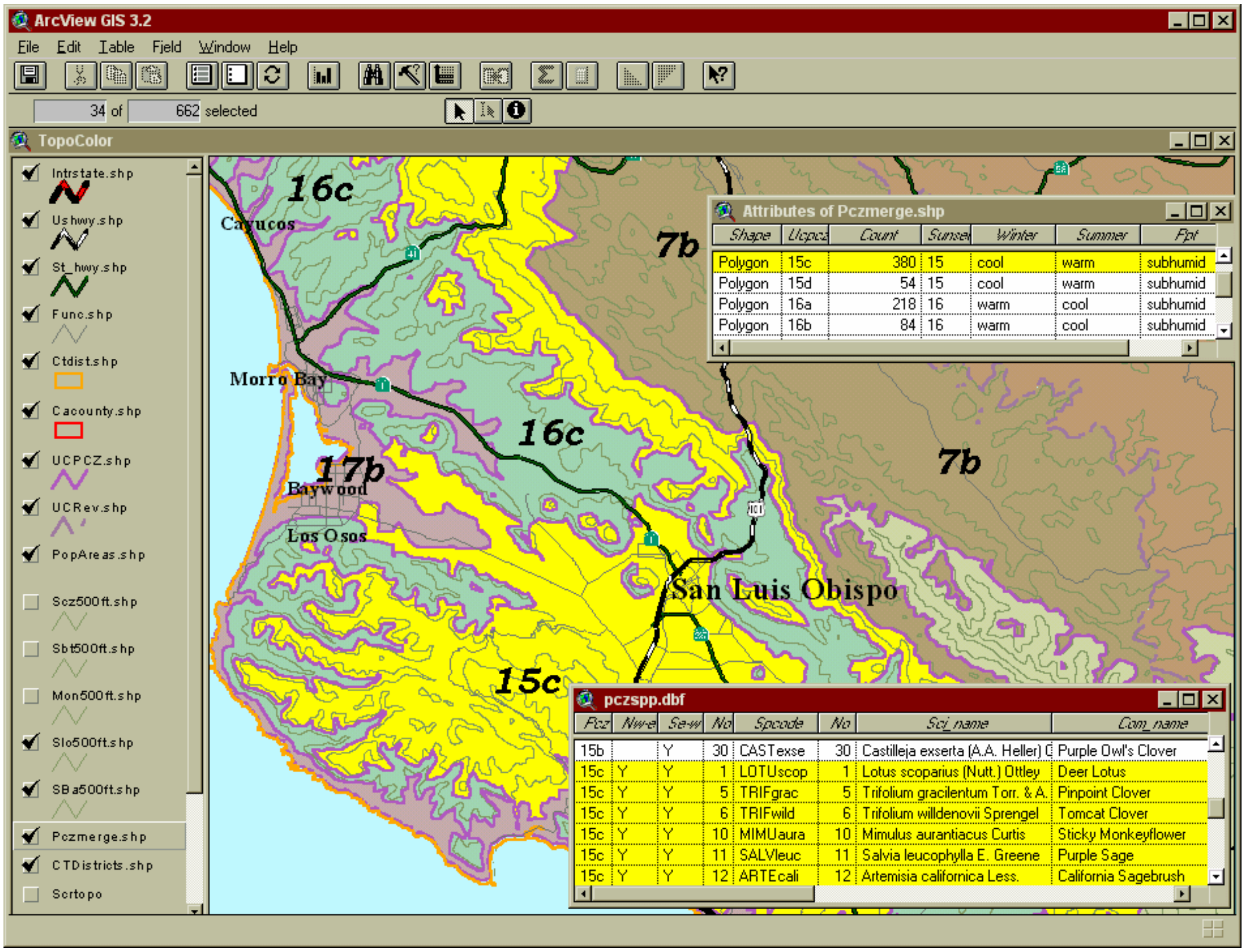

Figure 1. Example of GIS Interface

How to Use This Guide

Where is the project site located?

1. Use the Index to Climate Zones to find the Climate Zone for a project site

- Turn to the **Index to Climate Zones** starting on page **3-1;**
- Select the appropriate **County** table;
- Read down the **Route** column and across either the **From_Mile** and **To_Mile**, or the **From_Km** and **To_Km**, columns to find the route segment that includes the project site of interest;
- The **Climate Zone** appropriate for that route segment is indicated in the rightmost column by a number and letter code.

For example, if a project site is in San Luis Obispo County along **SR 1 (001)** at mile **5.5**, this occurs between mile **3.7** and **6.9**, so **Climate Zone 15c** is the appropriate selection.

San Luis Obispo County

County	Route	From_Mile	To_Mile	From_Km	To_Km	Climate Zone
SLO	001	0.0	3.0	0.0	4.8	17b
SLO	001	3.0	3.5	4.8	5.6	15c
SLO	001	3.5	3.7	5.6	6.0	17b
SLO	001	3.7	6.9	6.0	11.1	15c
SLO	001	6.9	7.9	11.1	12.7	17b
SLO	001	7.9	10.4	12.7	16.7	15c

What is the general topographic aspect ?

2. Find the Species List for the indicated Climate Zone

- Find the two species lists for the **Climate Zone** indicated in step 1 above;
- Select the list appropriate for the general topographic aspect of the site, either ***northwest to east*** (NW to E), or ***southeast to west*** (SE to W);
- Use the list of shrub, forb, and grass species recommended as a guide in developing mixes for hydroseeding.

Zone 15c · Aspect NW

No	Scientific Name	Common Name	ECIndex/50	%PLS	lbsPLS/ac	PLS/ft2	PP/ft2	Low$/lb	High$/lb
	LEGUMES								
	Shrubs								
1	**Lotus scoparius**	Deer Lotus	35	54	8	83	50	7	15
	Annual Forbs								
5	**Trifolium gracilentum**	Pinpoint Clover	25	64	15	172	138	9	18
	NON — LEGUMES								
	Shrubs								
10	**Mimulus aurantiacus**	Sticky Monkeyflower	32	4	4	918	643	35	50
11	**Salvia leucophylla**	Purple Sage	32	49	4	39	27	35	50
12	**Artemisia californica**	California Sagebrush	31	8	4	505	253	20	25
17	**Baccharis pilularis**	Chaparral Broom	31	1	2	230	69	8	22
18	**Eriogonum fasciculatum var. fasciculatum**	Coastal California Buckwheat	31	7	4	41	27	10	20
21	**Salvia mellifera**	Black Sage	31	35	4	57	29	15	40
	Perennnial Forbs								
23	**Achillea millefolium**	Common Yarrow	39	69	1	62	43	15	20
	Annual Forbs								
25	**Collinsia heterophylla**	Chinese Houses	37	88	6	55	50	16	24
26	**Clarkia unguiculata**	Mountain Garland	35	74	2	73	54	18	25
	Perennial Grasses								
31	**Bromus carinatus**	California Brome	42	95	25	57	56	8	15
32	**Elymus glaucus**	Blue Wild Rye	38	93	20	46	44	8	12
33	**Deschampsia elongata**	Slender Hairgrass	37	93	20	826	785	25	30
35	**Nassella lepida**	Foothill Needlegrass	35	90	20	147	135	75	95
36	**Nassella pulchra**	Purple Needlegrass	35	93	20	69	65	35	50
38	**Elymus elymoides**	Squirreltail	33	88	20	46	41	50	60
39	**Hordeum brachyantherum**	Meadow Barley	33	93	20	46	44	15	20
40	**Hordeum californicum**	California Barley	33	93	20	46	44	15	20
41	**Leymus triticoides**	Creeping Wildrye	32	49	10	25	13	15	35
42	**Leymus condensatus**	Giant Wildrye	29	49	10	23	11	80	95
43	**Melica californica**	California Melic	29	49	20	149	75	18	25
44	**Melica imperfecta**	Coast Range Melic	29	49	20	230	115	80	95
	Annual Grasses								
46	**Vulpia microstachys**	Small Fescue	40	90	20	367	349	20	40

Figure 2. Sample Pages from District Guidebooks to Plant Specifications