Baylands Vegetation Mapping Protocol

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For
San Francisco Bay Area Wetlands Restoration Program

Purpose

This protocol has been produced for the Bay Area Wetlands Restoration Program (WRP) to help standardize maps of wetland vegetation within the San Francisco Bay Area and between this region and other regions of California. A standard approach is needed to compare one place to another and to track changes over time. The protocol is intended to meet the usual needs of environmental scientist and managers for empirical information about the distribution and abundance of dominant plant species, assemblages, and associations within and among wetlands. A separate, complementary protocol has been developed to assess vegetation in tidal wetlands based on field transects. This protocol and other protocols for intensive monitoring of wetlands surrounding the San Franco Estuary are available through the Monitoring Group of the WRP.

Protocol Development

The USEPA provided CWA Section 104(b) funding to the San Francisco Estuary Institute (SFEI) for developing a regional wetland monitoring and assessment program. SFEI established an inter-agency and multi-disciplinary steering committee to guide program development. The steering committee is now referred to as the Monitoring Group of the WRP. It recommended the development of regional protocols for wetland monitoring, including a protocol for mapping wetland vegetation using orthogonal imagery. SFEI acted on this recommendation by partnering with the Point Reyes Bird Observatory Conservation Science (PRBO) to plan and hold a technical workshop on vegetation mapping. SFEI also coordinated with the leadership of related mapping ventures, including the State and National Wetlands Inventory, the California Riparian Habitat Joint Venture, the California Vegetation Map, and the South Bay salt marsh conversion studies to optimize the relevance of the protocol to these and other wetland conservation efforts within the region and State.

A workshop was convened by SFEI and PRBO on February 23, 2004 to discuss appropriate mapping standards and protocols. The workshop focused primarily on tidal marsh and diked marsh vegetation mapping. The workshop was attended by a range of professionals representing regulatory and land management agencies, local governments, environmental consulting firms, and academic researchers (see Appendix A). Examples of vegetation mapping and classification were presented by representatives from UC Berkeley, HT Harvey and Associates (under contract with the City of San Jose), and the California Department of Fish and Game. Geomorphic mapping examples were presented by Wetlands and Water Resources, SFEI, PRBO, and the Elkhorn Slough Preserve. The discussion centered around three primary topics: (1) Image standards for vegetation mapping; (2) Vegetation mapping methods; and (3) Vegetation classification.

With respect to each of these major topics, the group discussed the priority objectives for mapping and the related appropriate standards. During the course of the discussion, it became apparent that a wide~~r~~ range of protocols covering a broader set of circumstances would eventually need to be developed, given the variety of mapping objectives and data uses, as well as limitations on data availability, budgets, staff time, field access, and mapping technologies. In addition, the group discussed the possibility of developing standards and protocols based on imagery specifications and limitations. Participants also agreed that any protocol for vegetation mapping should be consistent with the Manual of California Vegetation (MCV) and should also compliment the protocol for field-based assessment of plant community composition and structure already developed by the Monitoring Group of the WRP.

Drafts of the proceedings of the workshop were reviewed by the attendees and comments were incorporated into this protocol. Coordination with the Wildlife and Habitat Data Analysis Branch of the Department of Fish and Game for vegetation mapping was emphasized. Members of the Monitoring Group of the WRP were also invited to review the draft protocol. This version of the protocol captures the topics of discussion and recommendations from these reviews.

Technical Recommendations

Image Standards

Image standards focus on traditional analog aerial imagery because it is the most widely available and accessible image format at this time. However, the availability of high-resolution (i.e., 0.6m-4m) multi-spectral satellite imagery (e.g., IKONOS or QuickBird), as well as airborne multi-spectral (e.g., DAIS) and hyperspectral (e.g., CASI, SASI) digital sensor data is increasing. Workshop participants noted that the use of standard digital imagery (from satellite or airborne sensors) throughout the Bay Area would greatly benefit the wetland science and management community. However, there is still no current substitute for the value of stereo pairs of analog images for detailed work that requires estimating subtleties of vegetation structure.

Image capture scale / resolution

For digital mapping, a guideline for pixel resolution might be more appropriate than image capture scale, given that smaller-scale photos can be scanned at a higher resolution to achieve better image quality. In order to achieve a balance between file size and level of detail, a 0.5-ft (0.15-m) pixel resolution for photographing individual sites under standard conditions is recommended. For airborne analog imagery, a capture scale of 1:6,000 (1" = 500') or higher is preferred, and the minimum recommended capture scale is 1:12,000 (1" = 1,000'). For mapping efforts that use imagery consistent with these guidelines for capture scale and pixel resolution, the quality of the final product probably depends on the quality and of ground-truthing rather than the quality of the imagery.

The multi-spectral properties (i.e., near-infrared and visual spectral bands) and wide spatial (13.8-km tiles) and temporal (~every 3 days) coverage of currently available satellite imagery (e.g., 1-m panchromatic and 4-m multispectral from *IKONOS*) can compensate for its low resolution. However, it is still important to use imagery that more or less matches the minimal patch sizes of vegetation that are assessed on the ground. For example, one would not want to use imagery of 1-m or 2-m pixel resolution to map vegetation with the fine scale patterning that is typical of tidal salt marsh; sub-meter pixel resolution would be necessary.

Timing of image capture

Tidal stage. Low-tide imagery is generally preferable for vegetation mapping, so that vegetation is not submerged and spectral signatures are not confused by standing water. For certain projects, however, images that correspond to high tides may be preferable. For example, tidal channels and pannes are more easily distinguished from the vegetated plain of tidal marshes during high tide, especially if macroalgae or aquatic vegetation is present on exposed channel banks or mudflats. Again, for the purpose of mapping vegetation, the imagery should indicate conditions during low tide.

Season. The imagery should generally be taken during early summer when vegetation growth is maximal and plant species are most easily distinguishable. However, for mapping invasive *Spartina*, imagery taken during late summer to early fall may be preferable, since the non-native species and hybrids of *Spartina* grow for a longer time and later in the year than the native species.

Time of day / solar angle. For most purposes, the sun should not be so low as to cast shadows across plant patches, or so high as to cause reflective glare in the orthogonal imagery. There is generally a need to balance the benefits of high tide timing against the likelihood of sunlight glare from exposed water surfaces. In general, lower angles are better, and the direction of flight should be chosen to minimize the risk of glare.

Image spectral properties. The expected amount of ground-truthing and the level of experience of the photo interpreters should be considered when selecting the spectral properties of the imagery. With minimal ground-truthing, multi-spectral (or at least color infrared imagery in the red, green, and near infrared bands) is probably preferable. The near-infrared band is particularly useful for capturing differences in photosynthetic activity, while the Normalized Difference Vegetation Index (***NDVI***) can help differentiate vegetation from water or bare ground. Other vegetation indices (VIs), e.g., soil-enhanced VIs, can be used to enhance different aspects of vegetation characteristics. With ample ground-truthing, highly experienced technicians can use natural color imagery to produce maps that meet most requirements.

Image matching and balancing. Changes in flight direction, solar angle, and ambient light characteristics can cause differences in spectral characteristics across a single image and between images. Some of these problems can be corrected using brightness adjustment and radiometric correction techniques, as well as manual delineation/correction of classified "problem" pixels.

Vegetation classification

Plant patches should be classified according the latest version of the California Department of Fish and Game's ***Manual of California Vegetation*** (***MCV***), published by the California Native Plant Society (CNPS). The MCV has been standardized to the ***National Vegetation Classification Standard***, and has been adopted by the state for vegetation mapping. The higher, more general levels of the MCV (i.e., system, class, group, and formation) are based on growth form, hydrology, and environment, and the lower, more specific levels (alliance and association) are based on floristics. Although the MCV has been verified for many of the higher levels of the classification system, it is still being developed. The MCV is not adequate for mapping all vegetation systems or classes at his time. New mapping efforts can be used to help further develop the classification system using ***MCV procedures***. For further information about the MCV and updates, contact the ***Wildlife and Habitat Data Analysis Branch*** of the California Department of Fish and Game at ***tkwolf@dfg.ca.gov***, or ***dhickson@dfg.ca.gov***. A description of coastal wetland vegetation alliances and associations has been developed (see Appendix B).

Minimum mapping units

It is generally better to favor detail. For most restoration projects, the vegetation should be mapped at the association level. For very large projects, and for ambient regional assessment, the vegetation might be mapped at the alliance level. A nested approach might also be used, whereby the map of alliances is augmented with polygons for species or associations of special interest. This nested approach to mapping allows different levels of detail for different purposes (e.g., the alliance level often works well for historic change mapping, whereas associations may work well for restoration assessment).

Even relatively detailed maps do not usually have a 1:1 relationship between the mapping units and all plant associations or alliances, unless there is an extremely high proportion of polygons is verified in the field and the imaging has very high resolution. The plant ecologists should decide on the target level of vegetation classification base on field reconnaissance before the actually mapping effort is begun. Most projects are small enough that unique patches of vegetation that have high conservation value, even if they are rare across the landscape, should be included in the map. Very small patches of special interest can be mapped as lines or dots, rather than polygons. Decisions about lumping field-based, species-specific patches into associations, or lumping associations into alliances should be based on fieldwork and well documented. If mapping will be used to detect changes over time, then the patches must be based on differences that are clearly discernable from the imagery, and not necessarily dependent on comprehensive resurveys in the field. This puts a premium on identifying patch types, whether at the level of species, associations, or alliances that are most likely to change and can be readily mapped from the imagery.

Map attributes

Standardized attributes for vegetation are provided by the MCV (see Appendix C), and should be adhered to if possible, at least in the absence of specific project-specific attributes. In addition to vegetation classification, the standardized attributes include plant height, structural diversity, and percent cover. Using these standardized attributes may help reduce a potential bias towards upper canopy vegetation mapping as well as the possibility of overlooking rare species.

Vegetation crosswalks

Maps based on classification systems other than the MCV should be "crosswalked" to the MCV system if possible. Crosswalks from the MCV to other classification systems are also possible, if *a priori* rules are determined. It may be useful, for example, to crosswalk from the MCV to certain other classification system in use in California, including especially the systems of the National and State Wetlands Inventories, and the California Wildlife Habitat Relationships System. The crosswalks need to be developed before the start of actual mapping.

Vegetation mapping methods

Manual vs. automated methods. The choice between automated and manual methods is largely determined by the project purpose, funding, availability of classification tools, as well as site accessibility, size, and shape. Automated methods are improving, but are not yet able to consistently achieve the level of accuracy and repeatability expected for tracking vegetation changes within and among wetland projects. Manual methods remain preferable for such applications at this time. Automated classification can be useful to quickly map large areas of relatively few plant classes, especially if multiple spectral bands are available. A Normalized Vegetation Difference Index (NVDI) can be particularly useful for distinguishing vegetation from water or bare ground, while a combination of near infrared (NIR), red, and green bands can help differentiate vegetation classes. Texture analysis and incorporation of topographic data can also be useful. However, the spectral signatures of wetland vegetation change seasonally due to plant maturation and also in relation to several more ephemeral factors, such as wind and water levels. Object-oriented classification (e.g., eCognition software), can improve the accuracy of automated classification by recognizing shapes and patterns as well as spectral signatures, but such tools are not well enough developed to be used broadly at this time.

Manual mapping methods are useful for creating smooth boundaries between vegetation community types and for capturing differences between patch types and reconciling spectral differences that automated methods cannot recognize at this time. The recommended approach to manual vegetation mapping is as follows**.**

1. Use scanned (digital) orthorectified aerial photos of the scale, timing, and spectra recommended herein, plus heads-up (on-screen) digitizing to draw most vegetation polygons, preferably by vegetation association, as defined in the current versions of the Manual of California Vegetation (MCV and see Appendix B). Patches of individual species can also be mapped as required.

2. Use stereo pair photo prints of the imagery to determine the vertical structure and subtle variations in plant patchiness that is not visible with a single image.

3. Verify the patch polygon boundaries and classifications based on field work (see section on ground-truth below for more details).

4. Revise the map based on the verification procedures.

Ground-truthing / verification

The purpose of ground-truthing or field verification is to empirically determine the boundaries of mapped patches and their species composition. The required amount of ground-truthing depends partly on the resolution of the imagery used for mapping. That is, a lack of pixel resolution can be compensated somewhat by increasing the amount of ground-truthing. However, ground-truthing is one of the more costly aspects of mapping, making high-resolution imagery cost-effective. The imagery resolution recommended herein is based on expected tradeoffs between costs for imagery and costs for ground-truthing, assuming that plant associations are the target level of vegetation classification. For manual vegetation mapping, two approaches to ground-truthing are recommended:

1. For most restoration projects in which it is desirable to map and track individual marsh plant association, association patches digitized in the office can be classified in the field, assuming that the observer can see or access the entire project area. The vegetation maps for the South Bay salt marsh conversion studies by H.T. Harvey and Associates for the City of San Jose are an example of this approach.

2. For larger projects, and for ambient regional assessment, initial polygon maps based on the imagery should be randomly verified in the field, based on a stratified random sampling design. The polygons (produced at either the alliance or association levels) are used as the sample strata. The sample size will depend on budget and time considerations, but at least three polygons of each stratum should be randomly selected. Using an aerial photo print overlaid with the boundaries of the sample population of polygons, verify the polygon boundaries and classifications in the field.

Change detection

The following guidelines are provided to help determine what constitutes a significant change in patchiness of vegetation.

- 20% change in size of an existing small (< 1 acre) polygon; or
- 10% change in size of a mid-sized (1-5 acre) polygon; or
- 5% change in size of a large (>5 acre) polygon; or
- type conversion of a vegetation polygon dominated by perennial species.

These guidelines only pertain to comparisons between maps that are based on comparable imagery that meet the specifications of this protocol. For comparisons between maps that are based on different kinds of imagery, (i.e., historical aerial photos with different characteristics than modern imagery), the minimum amount of detectable change will be determined by the limits of the lowest quality imagery.

Appendix A. List of workshop attendees

Name	Organization	Email Address
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Appendix B. CNPS Natural Vegetation Community Classification for Coastal Marsh Vegetation Communities

Code	Alliance	Association	Scientific Name
52.100.00	Fresh - Brackish Water Marsh		
52.100.01	Fresh - Brackish Water Marsh	Coastal and Valley Freshwater Marsh	
52.100.02	Fresh - Brackish Water Marsh	Coastal Brackish Marsh	
52.100.04	Fresh - Brackish Water Marsh	Vernal Marsh	
52.101.00	Bulrush		*Scirpus* spp.
52.101.01	Bulrush	California Bulrush Wetland	*Scirpus californicus*
52.101.06	Bulrush	California Bulrush / Tule	*Scirpus californicus/S. acutus*
52.101.07	Bulrush	Small-fruited Bulrush	*Scirpus microcarpus*
52.102.00	Bulrush - Cattail Wetland		*Scirpus spp. - Typha* spp.
52.102.01	Bulrush - Cattail Wetland	Bulrush - Cattail	*Scirpus spp. - Typha spp.*
52.102.02	Bulrush - Cattail Wetland	Common Tule - Southern Cattail	*Scirpus acutus - Typha domingensis*
52.102.04	Bulrush - Cattail Wetland	Brackish Bulrush - Cattail	*Scirpus spp. - Typha spp.*
52.103.00	Cattail Wetland		*Typha spp.*
52.103.01	Cattail Wetland	Brackish Cattail	*Typha spp.*
52.103.02	Cattail Wetland	Broad-leafed Cattail	*Typha latifolia*
52.104.00	Bur-reed Wetland		*Sparganium* spp.
52.104.01	Bur-reed Wetland	Narrowleaf Bur-reed	*Sparganium angustifolium*
52.105.00	Duckweed Wetland		*Lemma* spp.
52.106.00	Mosquito Fern Wetland		*Azolla filiculoides*
52.107.00	Pondweeds with floating		
52.108.00	leaves Wetland		*Potamogeton* spp.
52.109.00	Quillwort Wetland		*Isoetes* spp.
52.109.01	Quillwort Wetland	Western Spikerush	*Isoetes occidentalis*
52.110.00	Yellow Pond-lily Wetland		*Nuphar luteum*
52.111.00	Common Three-square		*Scirpus americanus*

Code	Association	Alliance	Scientific Name
52.111.01	Common Three-square	Common Three-square - Cooper Rush - Yerba Mansa	*Scirpus americanus - Juncus cooperi - Anemopsis californica*
52.111.02	Common Three-square	Common Three-square / Silverleaf Cinqufoil	*Scirpus americanus / Potentilla anserine*
52.111.03	Common Three-square	Common Three-square / Perennial Pepperweed	*Scirpus americanus / Lepidium latifolium*
52.111.04	Common Three-square	Common Three-square	*Scripus americanus*
52.112.00	Alkali Bulrush		*Scirpus maritimus*
52.112.01	Alkali Bulrush	Alkali Bulrush / Pickleweed	*Scirpus maritimus / Salicornia spp.*
52.112.02	Alkali Bulrush	Alkali Bulrush - Cattail	*Scirpus maritima. - Typha spp.*
52.120.00	Beaked Sedge Wetland		*Carex utriculata*
52.120.01	Beaked Sedge Wetland	Beaked Sedge	*Carex utriculata*
52.200.00	Salt - Alkali Marsh		
52.201.00	Pickleweed Wetland		*Salicornia spp.*
52.201.01	Pickleweed Wetland	Common Pickleweed	*Salicornia virginica*
52.201.02	Pickleweed Wetland	Common Pickleweed - Gumplant	*Salicornia virginica - Grindelia stricta*
52.201.03	Pickleweed Wetland	Common Pickleweed - Saltgrass	*Salicornia virginica - Distichlis spicata*
52.201.04	Pickleweed Wetland	Common Pickleweed - Jaumea - Saltgrass	*Salicornia virginica - Jaumea carnosa*
52.201.05	Pickleweed Wetland	Bigelow Pickleweed	*Salicornia bigelovii*
52.201.06	Pickleweed Wetland	Northern Coastal Salt Marsh	
52.201.07	Pickleweed Wetland	South Coastal Pickleweed Salt Marsh	
52.201.08	Pickleweed Wetland	Alkali Pickleweed	
52.201.09	Pickleweed Wetland	Southern Coastal Salt Marsh	
52.201.10	Pickleweed Wetland	Common Pickleweed - Bigelow Pickleweed / Western Sea Purslane	*Salicornia virginica - Salicornia bigelovii / Sesuvium verrucosum*
52.201.11	Pickleweed Wetland	Common Pickleweed - Bigelow Pickleweed / Saltbush	*Salicornia virginica - Salicornia bigelovii / Atriplex* spp.
52.201.12	Pickleweed Wetland	Common Pickleweed - Bigelow Pickleweed / Saltgrass	*Salicornia virginica - Salicornia bigelovii / Distichlis spicata*
52.201.13	Pickleweed Wetland	Common Pickleweed - Bigelow Pickleweed / Beardgrass	*Salicornia virginica - Salicornia bigelovii / Polypogon* spp.

Code	Association	Alliance	Scientific Name
52.201.14	Pickleweed Wetland	Common Pickleweed - Saltgrass - Jaumea	*Salicornia virginica - Distichlis spicata - Jaumea carnosa*
52.202.00	Ditch-grass Wetland		*Ruppia* spp.
52.203.00	Cismontane Alkali Marsh		
52.204.00	Transmontane Alkali Marsh		
52.205.00	Perennial Pepperweed		*Lepidium latifolium*
52.205.01	Perennial Pepperweed	Pepperweed - Saltgrass	*Lepidium latifolium - Distichlis* spp.
52.206.00	Gumplant		*Grindelia stricta stricta*
52.208.00	Birdfoot Trefoil		*Lotus corniculatus*
52.209.00	Brass Buttons		*Cotula coronopifolia*
52.210.00	Western Sea Purslane		*Sesuvium verrucosum*
52.211.00	Spearscale		*Atriplex triangularis*
52.500.00	Alkali Heath Dwarf Scrub		*Frankenia salina*

Appendix C. Standardized Mapping Attributes for Vegetation used by California Interagency Vegetation Mapping Team

Interagency Vegetation MOU Group

Map Unit Design Attributes

3/26/2003 version

Range of mapping scales	*1:7,500,000 to 1:250,000*	*1:250,000 to 1:24,000*	*1:24,000 to 1:6,000*
Typical polygon size	*10 to 1000 sq miles (6,400 to 64,000 acres)*	*1000 to 10,000 acres*	*< 1000 acres*
MMU	*50-250 acres*	*5-10 acres*	*1-5 acre*
Attribute	**Broad-scale**	**Medium-Scale**	**Fine-Scale**
A. Core Attributes at All Scales			
Life Form (Cover Type)	core	core	core
Ecological Unit	core	core	core
MCV Hierarchy (derived from other fields) - this consists of multiple fields, one for each hierarchical level	core	core	core
CalVeg Hierarchy (derived from other fields) - this consists of multiple fields, one for each hierarchical level	core	core	core
Land Use - Anderson Level 1	core	core	core
Birdseye Total Cover (max value 100%)	core	core	core
% of Birdseye Total Cover by trees (canopy closure - sum of conifers and hardwoods % cover)	core	core	core
% of Birdseye Total Cover by conifers	core	core	core
% of Birdseye Total Cover covered by hardwoods (and not covered by overstory trees)	core	core	core
% of Birdseye Total Cover covered by shrubs (and not covered by trees)	core	core	core
% of Birdseye Total Cover covered by herbaceous (and not covered by trees or shrubs)	core	core	core
Map Unit Aggregation Type (changed name from Internal Diversity)	core	core	core
Attribution Method (field-based, modeled, etc)	core	core	core
Cause and Date of Record Change (fire, error correction, etc.)	core	core	core
B. Core Attributes at Some Scales			
Dominant Species (visible from above, usually 1 to 3 species) by Layer	n/a	Core - *to species for trees, to genus level for other lifeforms*	Core - *to species level*
Size Class (DBH)	n/a	core	core
Height class and/or Vertical Structure	Optional - *see lifeform*	Optional - *use structural classes for trees (1, 2, or multiple layer)*	Core
WHR Type (derived from other fields) - this consists of multiple fields, one for each hierarchical level	optional	core	core
C. Optional Attributes			
Shrub Structural Diversity (includes Live/Dead Fuel Ratio)	optional	optional	optional
Disturbance Index (roads, exotics, erosion, other impacts)	Optional - *derived from other data - coarse (low) level of detail*	Optional - *derived from other data or remotely sensed- medium level of detail*	Optional - *observed or derived from other data - high level of detail*
Land Use - Anderson Level 2	optional	optional	optional
Groundlevel Total Vegetation Cover (max value 400% - a sum of all cover values from up to four different structural layers)	optional	optional	optional
Groundlevel Total Conifer Cover (max value 100%)	optional	optional	optional
Groundlevel Total Hardwood Cover (max value 100% - all hardwood cover, whether covered by overstory trees or not)	optional	optional	optional
Groundlevel Total Shrub Cover (max value 100% - all shrub cover, whether covered by trees or not)	optional	optional	optional
Groundlevel Total Herbaceous Cover (max value 100% - all herbaceous cover, whether covered by trees/shrubs or not)	optional	optional	optional
Percent Mortality	Optional - *coarse level*	Optional - *by type of tree*	optional
Special Habitat Elements (related to vegetation only - snags, downed logs, etc; not caves, cliffs, etc.) - Observed	n/a	n/a	optional
Age Class (difficult to capture using remote sensing)	n/a	optional	optional