Generalized Conceptual Models
Wetlands Regional Monitoring Program
2002

Compiled for the PEEIR

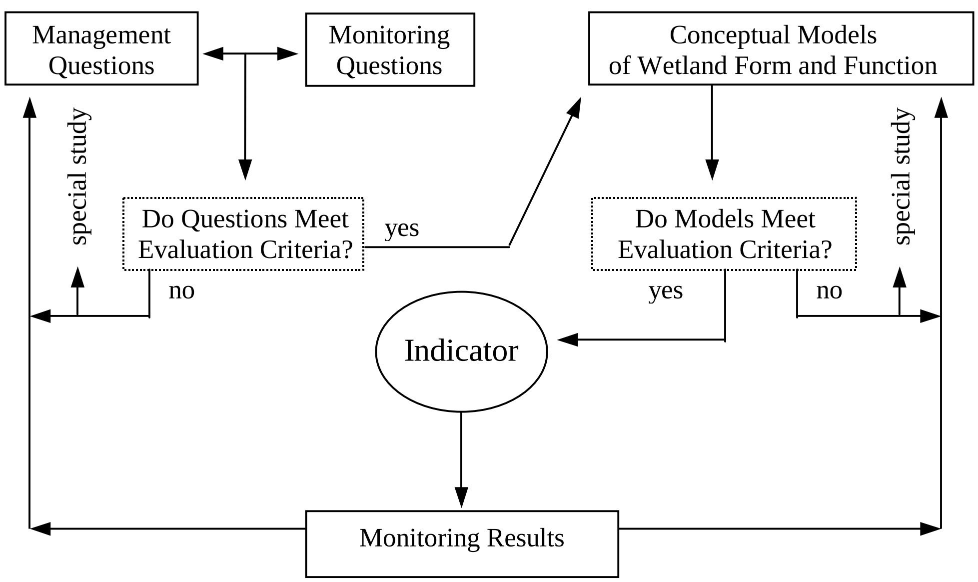
1. MANAGEMENT QUESTIONS DRIVE INDICATOR DEVELOPMENT

The overarching wetland management questions are: what is the status and trends in the conditions of wetlands, how are wetlands restoration and mitigation projects performing, and what are the effects of wetland management actions on the ecosystem?

These overarching management questions lead to more specific questions that relate to particular programs and projects. Scientists translate the management questions into monitoring questions. This leads to the selection of indicators and data collection, based upon conceptual models for how the target systems work. The data are interpreted as answers to the management questions, which then inform management actions. The actions can include revision of the management questions and revision of the conceptual models. This adaptive framework is commonly invoked for monitoring programs.

Not all of the management questions can be addressed at this time. Some questions are so difficult to address but so important that they warrant special studies to develop approaches to the answers. For example, scientists and managers commonly want to rely on natural sedimentation to restore tidal marshes. But this raises questions about the adequacy of the regional sediment supply. Studies are needed to learn how to answer these questions. As the Program matures, patterns in the data will emerge, and hypotheses will be formulated to explain these patterns. Special studies will be designed to test the hypotheses.

Diagram of Indicator Development Procedure



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2. TIDAL WETLANDS ARE TRANSITIONAL ENVIRONMENTS BETWEEN LOCAL WATERSHEDS AND BAYS

Tidal wetlands link bays and watersheds together. They are therefore strongly influenced by fluvial as well as estuarine processes.

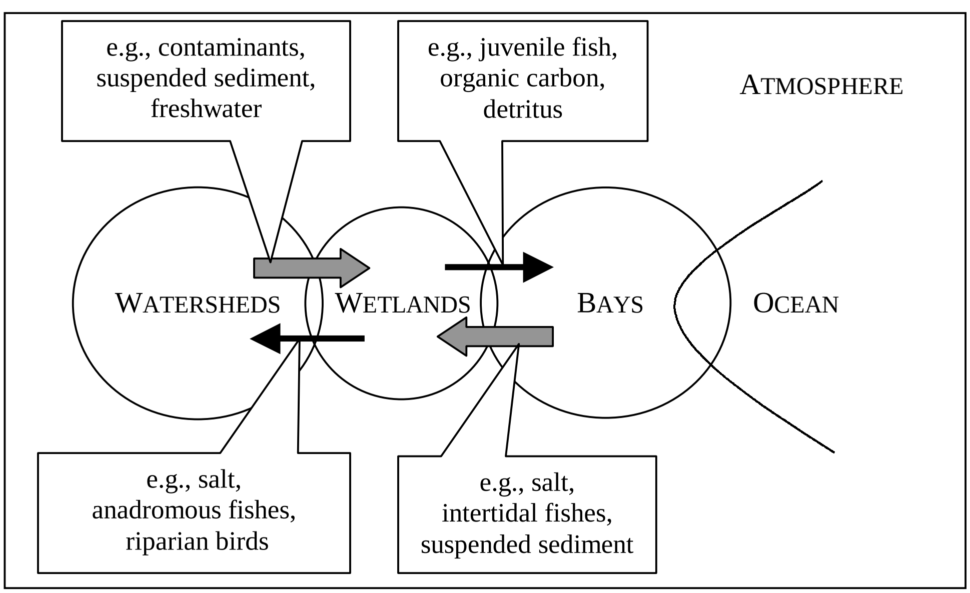
Tidal wetlands and tidal flats represent a net landward direction of estuarine sediment transport from the open bays (Postma 1967). This transport is punctuated seasonally due to re-suspension of tidal flat sediments by wind-generated waves (Krone 1979, Schoellhamer and Burau 1998). Most of the sediment that enters the marsh is eventually trapped within the channels or on the marsh plain.

Tidal wetlands influence watershed outputs. For example, some of the sediment from local watersheds is stored within mudflats and trapped within tidal wetlands before reaching the bays. Tidal marshes can temporarily store riverine flood waters and increase the mixing of bay water and river water.

Tidal wetlands have outputs from their own processes that influence bays and watersheds. For example, tidal wetlands are expected to provide carbon to local streams and to the Estuary. They are also expected to serve as nurseries for wildlife, such as fish and waterfowl that disperse to other environments or even to other regions.

Tidal and fluvial processes the affect tidal wetlands vary on six or more time scales. Fluvial processes vary seasonally, annually, and in relation to the irregular schedules el niño or la niña climatic episodes. Tidal processes also vary monthly, bi-weekly (i.e., on the neap-spring tidal cycle), and hourly (i.e., on the mixed-diurnal cycle of the daily tides).

Diagram of Tidal Wetlands as Transitional Environments
(larger arrows represent larger fluxes of materials or energy)



3. INTERACTIONS BETWEEN PHYSICAL PROCESSES AND VEGETATION CONTROL TIDAL WETLAND ECOLOGY

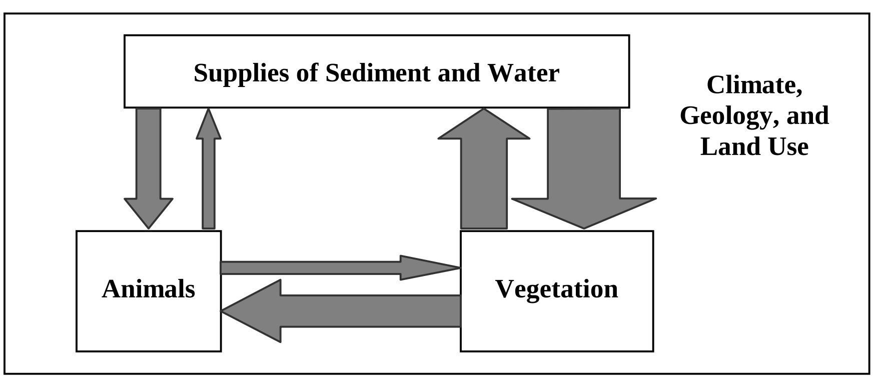
The evolution and natural maintenance of tidal wetlands depend upon supplies of water and sediment, the former to submerge the land, and the latter to prevent the land from being too deeply submerged.

Tidal marshes develop where the accumulation of sediment is equal to or greater than the rate of sea level rise (relative to changing land heights), and there is adequate protection from destructive waves. The supplies of water and sediment are largely controlled by climate, geology, and land use, and therefore they vary throughout the Estuary. The physical conditions conducive to the formation of tidal wetland are unusual enough that they rarely persist for geologically long time periods, at least not in the same location.

The effects of sediment and water supplies on tidal marsh evolution are mediated by vegetation. Plants significantly influence sediment availability, sediment deposition, sediment re-suspension, and shoreline erosion due to wave action. Wetlands with peat soils that are produced by plants are subject to subsidence if the peats desiccate and oxidize, and plants can protect wetlands from erosion due to wind. In the San Francisco Estuary, animals are expected to be less important that plants in shaping tidal wetlands. However, burrowing animals can weaken tidal channel banks, and shellfish communities may be important sources of friction that reduces the erosiveness of tidal currents in marsh channels.

The typology of tidal wetlands is primarily based on physical factors. The most important factors for predicting the ecological character of tidal wetlands are tidal elevation and aqueous salinity regime. Many attributes of plant and animal communities vary predictably along gradients of these two factors. Aqueous salinity and tidal elevation are the primary factors for stratifying the tidal marsh ecosystem as a sampling universe.

Diagram of primary factors that control tidal wetland form and function
(larger arrows represent larger interactions)



4. SITE CLASSIFICATION CAN CONTROL SAMPLE VARIANCE AMONG SITES

Major environmental gradients that strongly affect the local conditions of tidal wetlands are evident within and between subregions and landscapes.

There are five conventional subregions of the Estuary: South Bay, Central Bay, North Bay, Suisun, and the Delta. These subregions together comprise the region as a whole. The subregions generally separate the main surface water salinity gradient of the Estuary into five segments. Surface salinity is important because surface waters tend to move between the bays and the tidal wetlands.

Two landscape types are recognized at this time. A watershed landscape consists of all the tidal wetlands and related habitat types that are directly affected by the drainage from a perennial watershed. For example, the tidal wetlands along the Napa River represent one watershed landscape. A bayshore landscape consists of all the tidal wetlands and related habitat types between two local watershed landscapes. For example, all the tidal wetlands surrounding Suisun Bay between Suisun Slough, Alhambra Creek, and the Delta represent one large bayshore landscape for tidal wetlands.

The watershed landscapes greatly complicated the ecology of the Estuary. The local rivers and streams and the major effluent outfalls create their own estuarine gradients that affect estuarine conditions at sub-regional and local scales. These secondary or subordinate gradients are superimposed upon the primary gradient. The ecological variability among the tidal wetlands is affected by all of these gradients.

The size and shape of the Estuary as a whole varies naturally. Measures of shoreline change suggest that some shorelines alternately wax and wane. The tidal prism of local streams and marshes helps maintain the hydraulic geometry of the larger tidal channels that connect the marshlands to the tidal flats and open bays. A change in tidal prism due to changes in stream courses or changes in the rate of sea level rise can cause channels to widen or deepen, if sea level rise accelerates, or to shoal and narrow, if sea level rise slows.

Tidal phenomena and the supplies of freshwater and suspended sediment vary across orders of magnitude of time. Sediment re-suspension due to wave action can happen in seconds. The semi-diurnal tides cause the exposure of intertidal habitats to vary throughout each day. The neap-spring cycles of the tides can cause tidal pumping of saline water into large tidal wetlands during consecutive months. Major ENSO events increase water levels and increase the supplies of suspended sediment and freshwater on 3-7 year intervals. Major droughts have occurred at least once each century. The daily timing of higher high tides relative to the lower low tides varies on a 350 year cycle. And episodes of glaciation that lower sea levels are separated by many thousands of years.

The WRMP must monitor wetlands across a number of spatial scales, especially with regard to the effects of wetland restoration. For example, the effects of tidal wetland restoration can be anticipated at four spatial scales (sites, landscapes, subregions, and the Estuary as a whole), depending on the magnitude of the restoration efforts.

Restoration effects will be evident at the local site and its adjacent environs. For the purposes of the WRMP, a site is defined as a single study site or a wetland restoration project. Anticipated local effects include changes in plant and animal communities, increased flooding, enhanced shoreline protection, and changes in local sedimentary regimes.

Cumulative effects of restoration will emerge in landscapes, subregions, and the whole Estuary. Cumulative effects might include changes in habitat mosaics, tidal prism, shoreline length, status of endangered species, and sediment or chemical budgets.

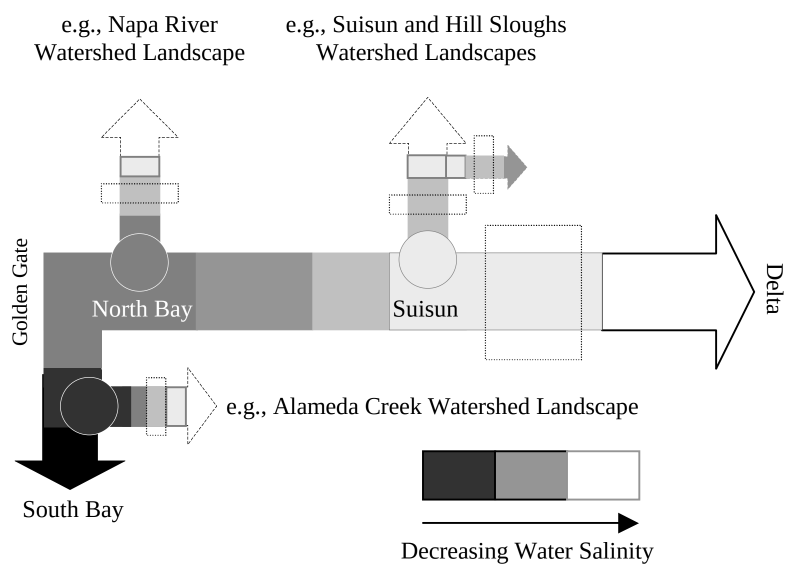
Diagram of Primary and Secondary Estuarine Gradients that Define Bayshore Landscapes and Watershed Landscapes of the San Francisco Estuary

The broad horizontal arrow leading from the Golden Gate toward the Delta indicates the primary upstream gradient of decreasing salinity and tidal range, increasing height of high tide datums, decreasing elevation of tidal baylands, increasing tidal hydroperiod for tidal baylands, decreasing channel density for tidal baylands, decreasing amount of tidal flat, and lower intertidal distribution of vascular vegetation.

The dark arrow leading from the Golden Gate to South Bay indicates increasing salinity and tidal range as part of the primary estuarine gradient.

The white-tipped arrows leading away from the primary gradient indicate secondary gradients into local watershed landscapes. Secondary gradients are steepest in South Bay where watersheds drain into the very saline bay.

The dashed rectangles indicate zones of maximum turbidity, and the circles represent amplification of the tidal range due to standing waves near the mouths of local rivers and streams.



There are natural similarities between bayshore landscapes and watershed landscapes, regardless of subregion. Both types of landscapes consist of local mosaics of tidal and non-tidal baylands, shallow and deep subtidal habitats, and upland habitats. The lower reaches of seasonal and perennial streams tend to involve narrow riparian corridors that lead to patches of diked and/or tidal baylands and tidal flats. The transition zone between the baylands and the uplands usually includes poorly drained, very fine-grain soils with seasonal wetlands and sometimes there are stands of willow trees. Each mosaic represents a complex history of land uses that interact with the natural gradients of water supply, suspended sediment supply, and salinity. If the extent and intensity of land use declines, and if the climate and topography do not significantly change, then the natural habitat mosaics tend to be restored.

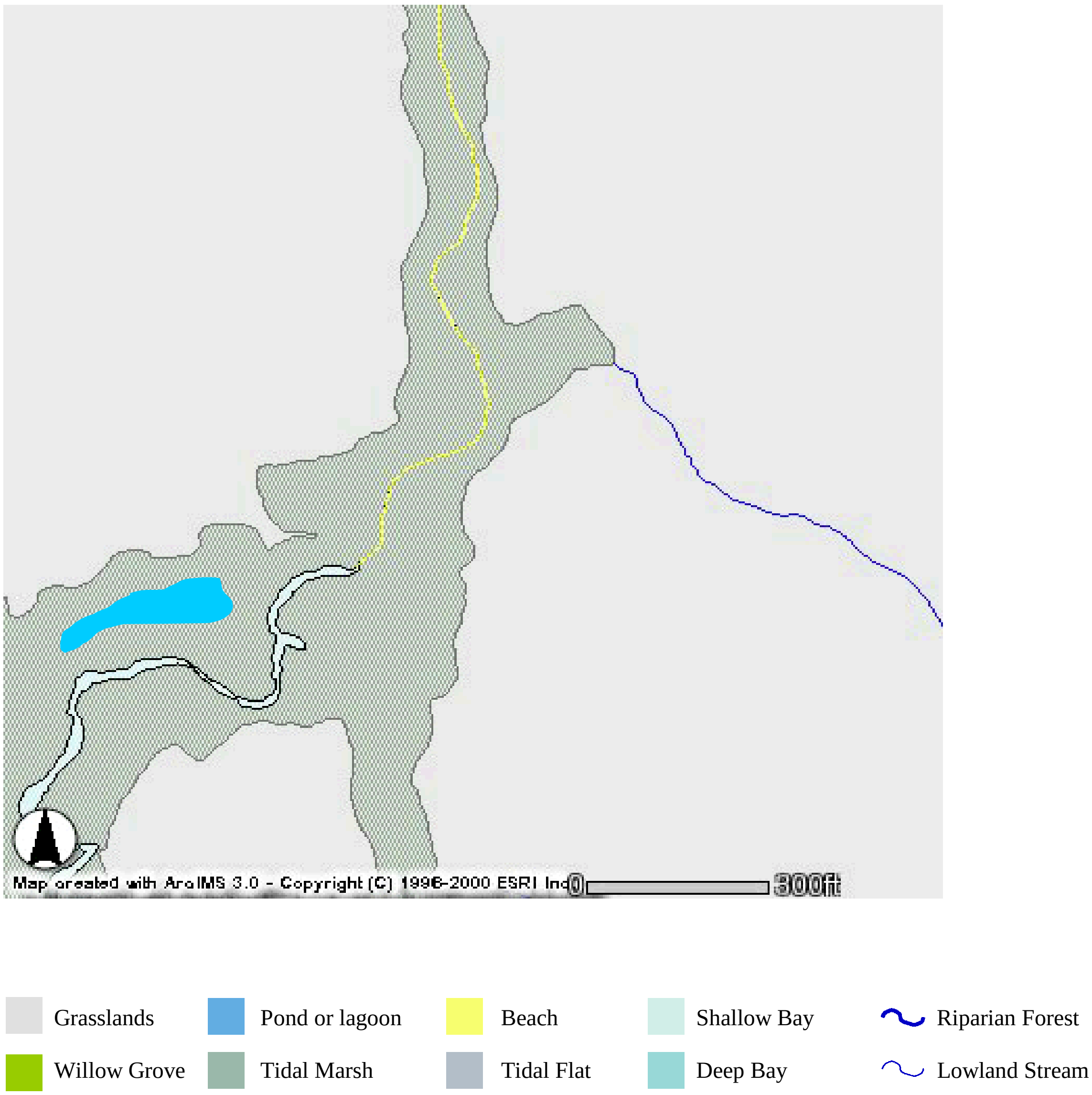
For either bayshore landscapes or watershed landscapes, there are differences within subregions. For example, within any subregion, watershed landscapes that have large sediment yields and moderate discharges through shallow channels have more tidal flats than larger watersheds with deeper channels that are directly connected to subtidal bays. And bayshore landscapes that are downwind from long fetches are more susceptible to shoreline erosion by wind-generated waves than bayshore landscapes that are protected from long fetches.

However, bayshore landscapes and watershed landscapes tend to be more similar within a subregion than between subregions. This suggests that the subregions are significantly different with regard to sediment supply and/or salinity, as mediated by climate, physiography, and land use.

Some of the subregional differences between landscapes are controlled by the main gradient of the Estuary. For example, the salinity of bayshore landscapes in North Bay, Suisun, and the Delta are dominated by Delta throughput from the Sacramento-San Joaquin drainage. Sediment supply for bayshore landscapes in the Delta and Suisun is also controlled by this drainage.

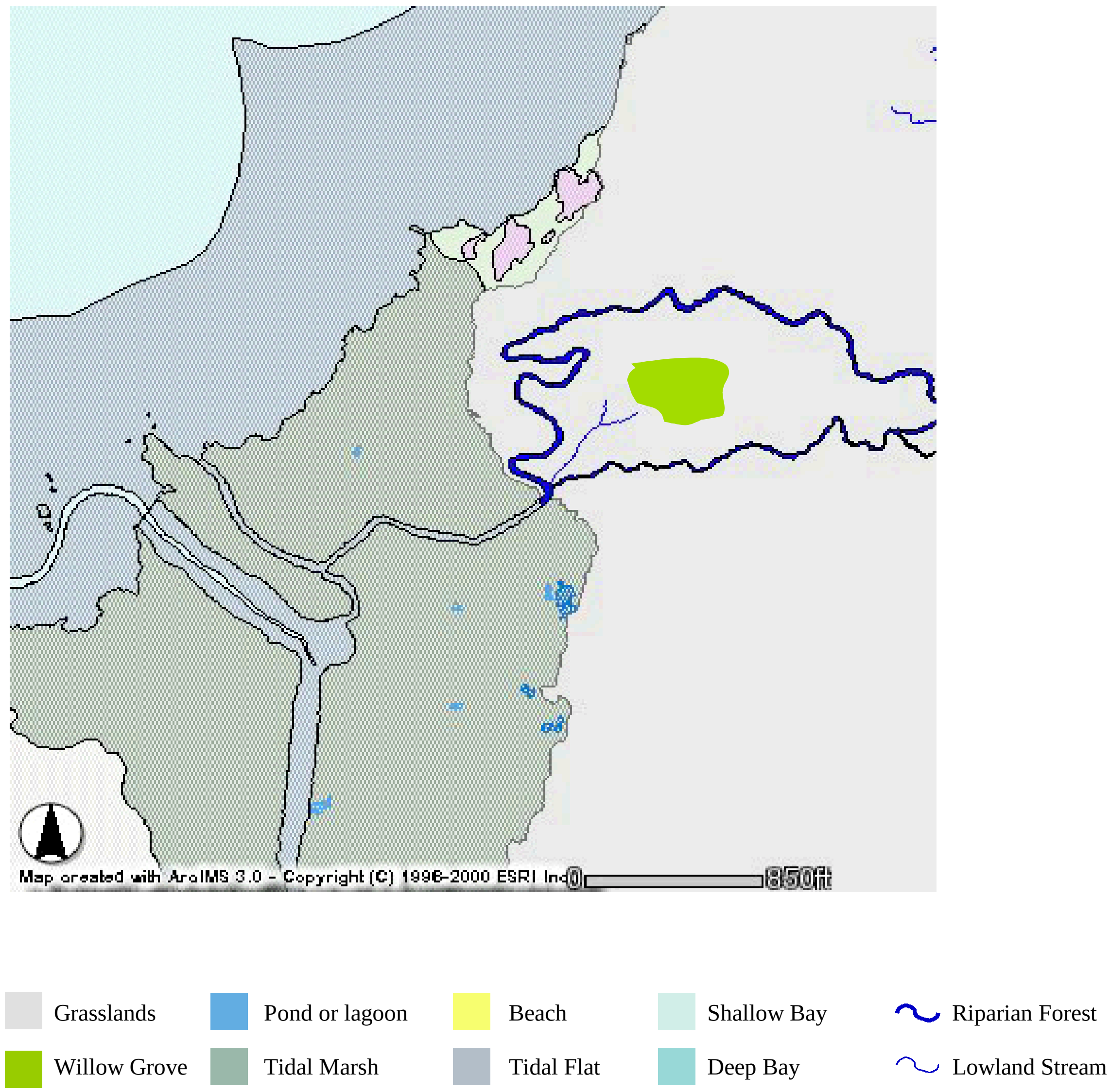
Many local indicators of tidal marsh condition vary in relation to these subregional differences in salinity. Vascular vegetation grows lower in the intertidal zone under fresher conditions. The density of tidal channels, the number of intertidal pannes, and the amount of tidal flats decrease with distance upstream along the main gradient. Conversely, vegetation that cannot tolerate high salinity does not grow as high in the intertidal zone. The brackish and freshwater tidal wetlands are therefore lower in elevation than the saline wetlands. Mean sea level and low tidal datums (i.e., Mean Lower Low Water and Mean Low Water) tend to increase toward the Delta, while tidal range tends to decrease. However, tidal range tends to be amplified at the tidal mouths of local rivers and streams (see previous diagram on p.12). The temporal variability in salinity and suspended sediment may become less regular upstream along local estuarine gradients, due to the rapid response of small watersheds to changes in weather.

Suisun Subregion Historical Landscape Mosaic



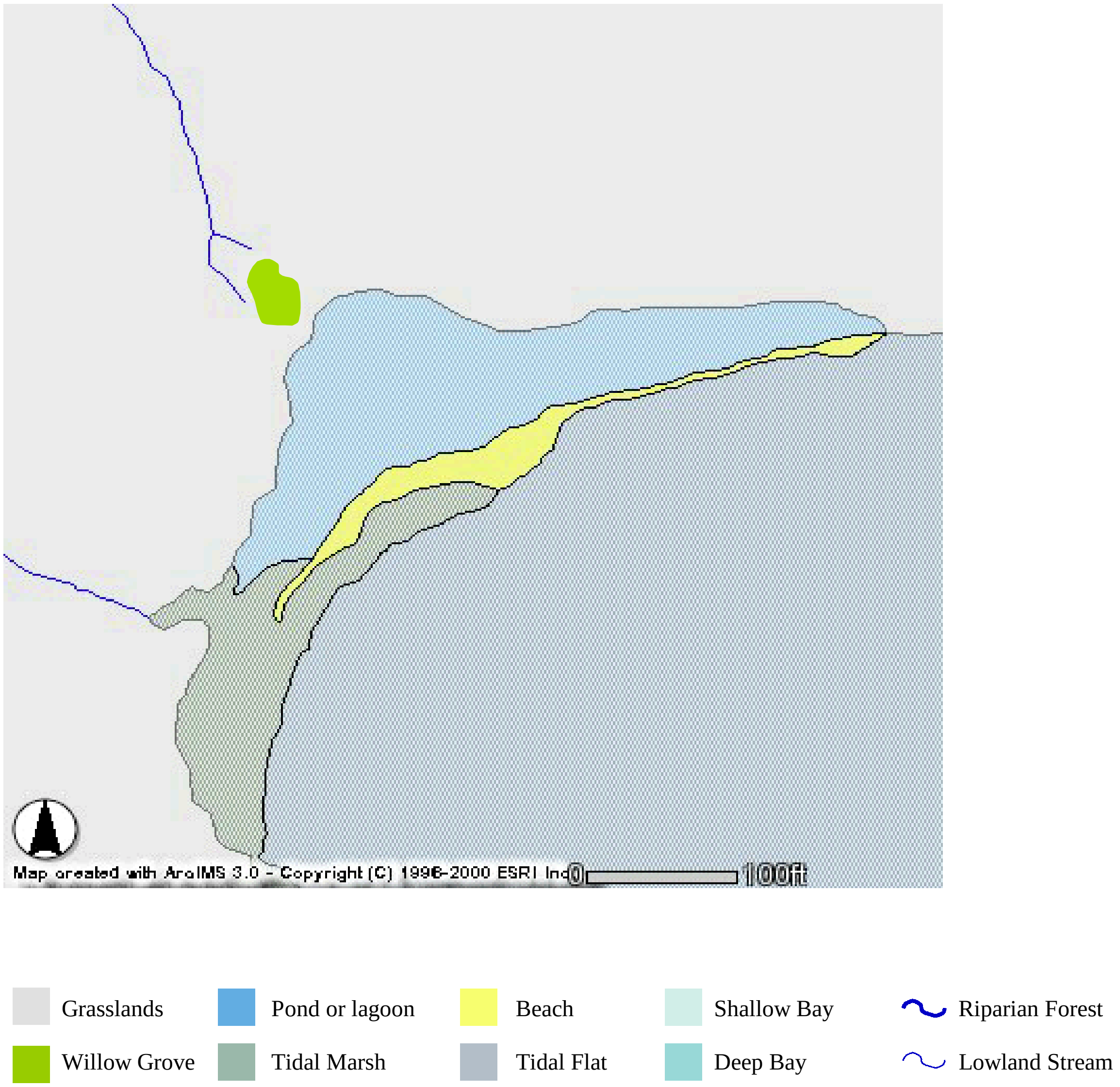
The historical landscape mosaic of Suisun typically consisted of very low-gradient seasonal streams that lacked riparian forests and that crossed very fine-grain and poorly drained alluvium that supported seasonal wetlands. These streams led to brackish tidal marsh with a broad backshore transition zone and a few large tidal marsh pannes. The marsh drainage networks were low-order although the main channels were very long. The tidal flats were narrow and the bays were mostly shallow.

North Bay Sub-Region Historical Landscape Mosaic



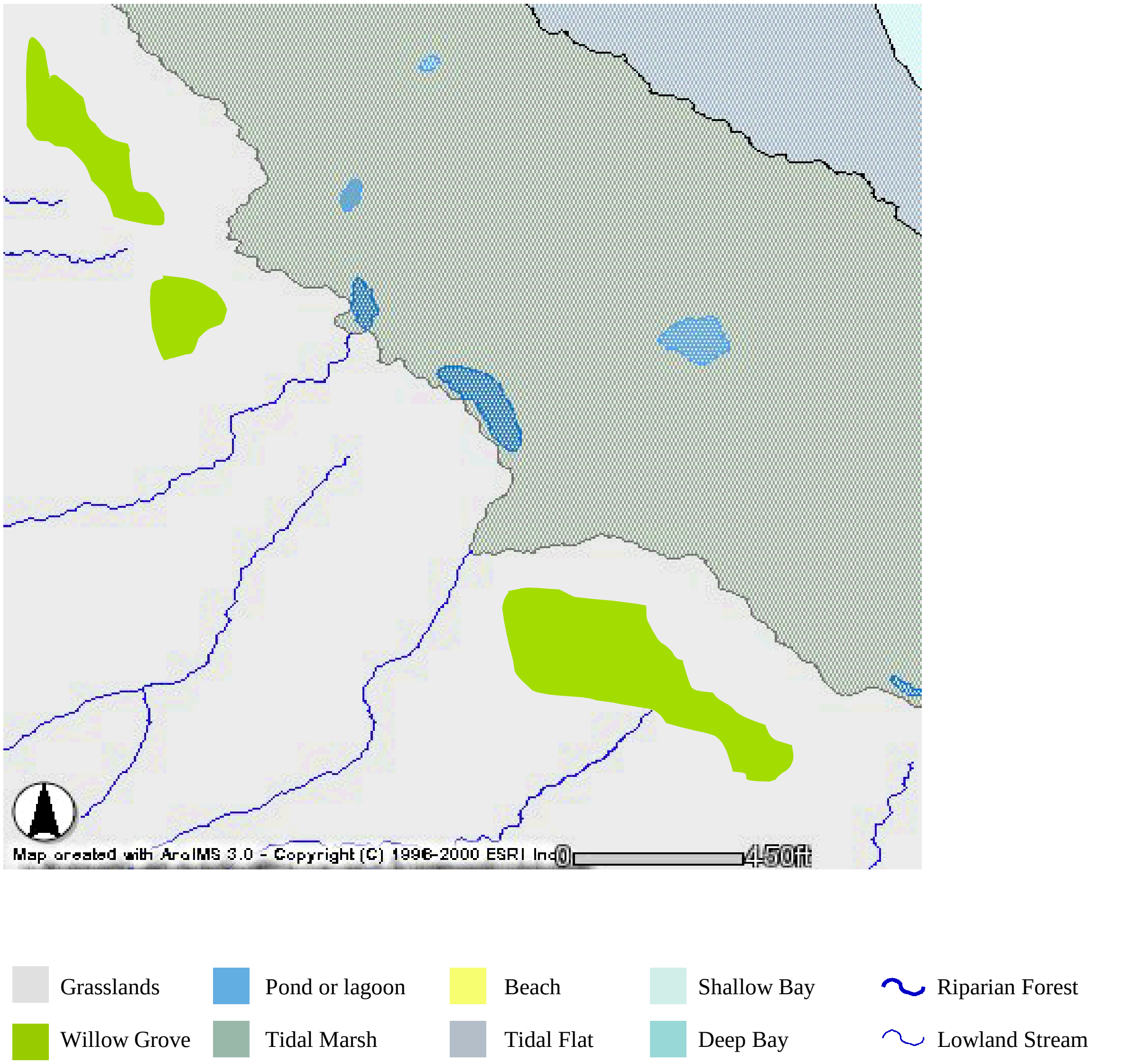
The historical landscape mosaic of North Bay typically consisted of steep perennial streams with very large sediment loads and narrow but dense riparian forests involving bays, oaks, ash, and willows that led across coarse-grain and well drained alluvium with small seeps and springs to salt or salt-brackish tidal marsh with moderate channel density and both transitional and drainage-divide pannes. The tidal flats were broad and extensive. Small willow groves existed near springs and seeps

Central Bay Sub-Region Historical Landscape Mosaic



The historical landscape mosaic of Central Bay typically consisted of steep perennial and seasonal streams with narrow and discontinuous riparian forests of mostly willows that led to lagoons and shallow embayments that were bordered in part by barrier beaches of sand and narrow tidal flats. The elevational gradients were steep from the hillsides to the deep bay waters. The tidal salt marshes were small and lacked pannes except behind wash-over berms created along the foreshores by high waves.

South Bay Sub-Region Historical Landscape Mosaic



The historical landscape mosaic of South Bay typically consisted of moderately steep perennial and seasonal streams with large sediment loads that led across fine-grained and poorly drained alluvium to saline tidal marsh with very high channel density and numerous large transitional pannes and numerous small drainage divide pannes. The shoreline is wavy in plan view due to the deposition of alluvium at the mouths of the streams. Some perennial streams did not reach the tidal marshes. Large willow groves existed away from the streams and along the uphill boundary of the fine-grained- alluvium. The tidal flats were very extensive.

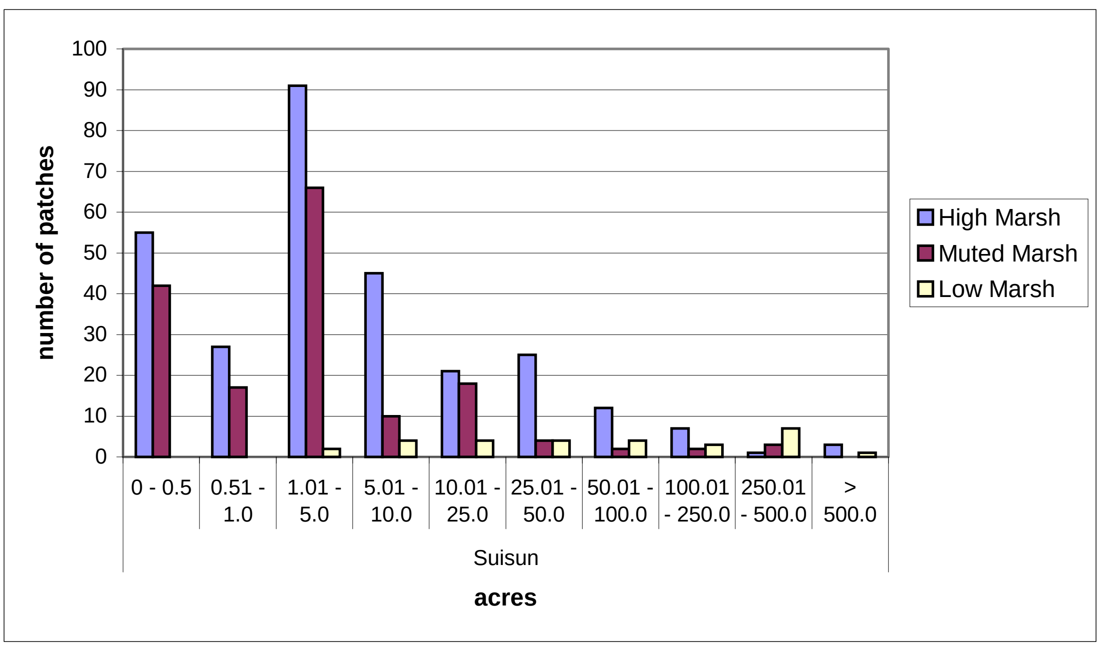
Habitat metrics are indicators of conditions within and among habitat mosaics, landscapes, subregions, and for the region as a whole. They include patch size statistics, inter-patch affinities, fragmentation, and connectedness. Large-scale ecological conditions and functions are sensitive to these metrics.

The calculation of habitat metrics depends on the spatial definitions of landscapes and subregions. The boundaries between landscapes and subregions are somewhat arbitrary and therefore not always obvious. Habitat metrics will tend to differ less near the boundaries between subregions or landscapes than away from their boundaries.

Habitat metrics are scale-dependent. For example, fragmentation is a function of habitat patch size, patch shape, and distance between patches, relative to the habitat needs and dispersal capabilities of the species of interest. A given array of habitat patches may be fragmented for one species and not for another. In general, any given patch of bayland represents more habitat for species of small organisms than for species of large organisms.

Example of Spatial Variability in Tidal Bayland Patch Type and Size-Frequency

The definition of habitat patch can be species-specific. In this examples, each patch of tidal marsh is defined by surrounding areas of uplands or open water that are wider than the mean dispersal distance for fledgling San Pablo Bay Salt Marsh Song Sparrows, *Melospiza melodia samuelis*. Considerations of another species that inhabits tidal marshes but has different dispersal barriers would define different tidal marsh patches.



5. HABITAT STRATIFICATION CAN CONTROL SAMPLE VARIANCE WITHIN SITES

Each patch of bayland has many habitat elements. Some of these elements are nested one within another. The careful stratification of monitoring sites should involve "zoom-lens-thinking" about the distribution of indicators among the elements within a patch. The effective habitat for a species usually corresponds to a habitat element. The habitat elements are arrayed predictably along gradients of tidal elevation and distance from tidal source. These gradients therefore can serve as a spatial template for within-site stratification.

In tidal marshes, the distance from the estuarine water source is measured along the channel network away from its tidal mouth, and/or across the marsh plain from the nearest channel bank. In either case the distance should be measured along the flow path of the flooding tide. The distance from the riverine water source is measured along the channel network from the nearest creek mouth or creek bank. In this context, an effluent outfall of non-saline water is considered a riverine source.

Natural channel networks in tidal marshes are dendritic and generally conform to the channel classification convention for fluvial systems. The lowest-order channels are the smallest and furthest from the estuarine source. The confluence of two or more first-order channels marks the beginning of a second-order channel; the confluence of two or more second-order channels marks the beginning of a third-order channel, and so forth.

Most tidal marshes consist of five major habitat strata. (1) The small channels (first- and second-order) tend to de-water during ebb tide. They lack natural levees, are rectangular in profile, can be shaded by overhanging vegetation, and have steep longitudinal profiles. (2) The large channels (third-order and larger) seldom completely drain, have v-shaped cross-section, are seldom shaded, do not have steep profiles. (3) The break in vegetation between a marsh and its adjacent tidal flat or bay is termed the foreshore. (4) The ecotone between the tidal marsh and the adjacent upland or riparian zone is termed the backshore. (5) The marsh plain extends between the backshore and foreshore. There are also zones of vegetation and a variety of other habitat elements, including channel scars and pannes, that are arrayed predictable along the elevation gradient. Pannes are shallow intertidal ponds that occur in the higher areas of the marsh plain, including the backshore.

The prevalence of these five major strata varies with tidal marsh age or elevation, size, and salinity regime. The number of small channels in a marsh decreases as the marsh evolves upwards through the inter-tidal zone. Freshwater tidal marshes tend to have truncated channel systems with few small channels. Small marshes lack large channels. Islands of marsh lack a backshore.

Each of the major strata consists of other, lesser strata. For example, a large channel consists of natural levees, the channel banks, and the channel bottom. The channel banks include slump blocks and exposed sedimentary layers, including the active root zone. The channel bottom includes shoals of shellfish and deeper pools. The pools themselves, like the inter-tidal pannes, have a surface, a bottom, and a water column.

Elevation Profile of Basic within-Site Sampling Strata
for a Third-order Tidal Marsh Channel System

The five major sampling strata (not including mud flat) are predictably distributed along the profile of elevation in a tidal marsh   There is a break in slope at the foreshore. Drainage from the marsh prevents the large channels from dewatering at low tide, although the base elevations can be above the tidal flat. The small channels occur near the upstream ends of the drainage networks. The backshore of the marsh is a zone of transition from terrestrial to marsh ecology.

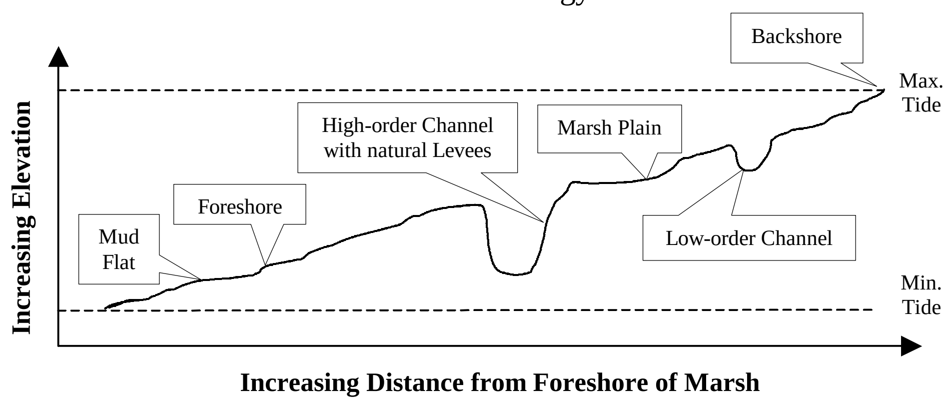
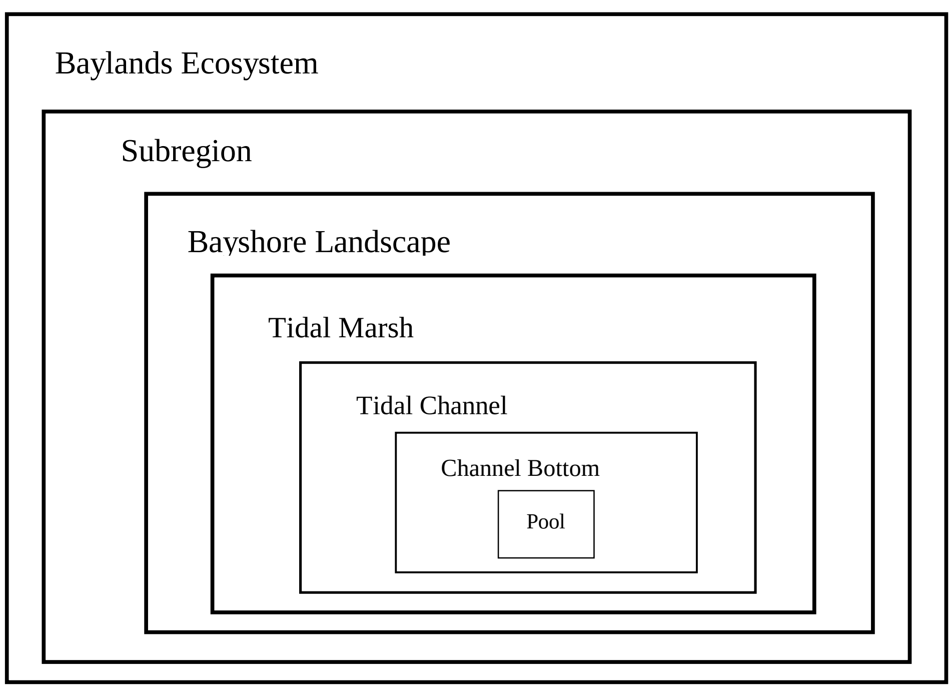


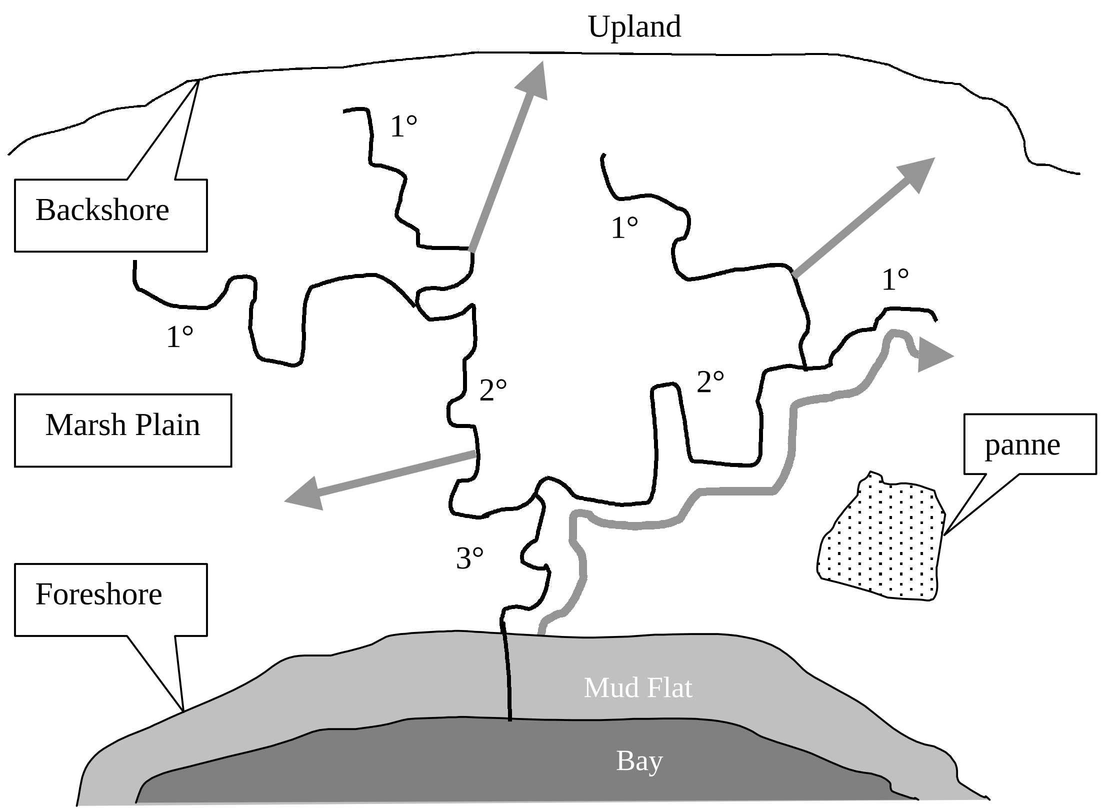
Illustration of Nested Sampling Strata

Smaller strata are nested within larger strata, which are nested within habitat patches, which are nested within habitat types, which are nested within landscapes, which are nested within subregions of the baylands ecosystem.



Plan View Diagram of Basic Within-site Sampling Strata for a Third-order Tidal Marsh System

The gray arrows point toward increasing elevation and distance from tidal source as proxies for decreases in tidal hydroperiod, decreases in tidal datum, decreases in tidal range, decreases in suspended sediment supply, increases in soil organics, decreases in soil pH, decreases in and plant height and plant diversity (except perhaps in brackish and fresh tidal marshes), and increases in the geomorphic importance of biotic processes compared to abiotic processes.

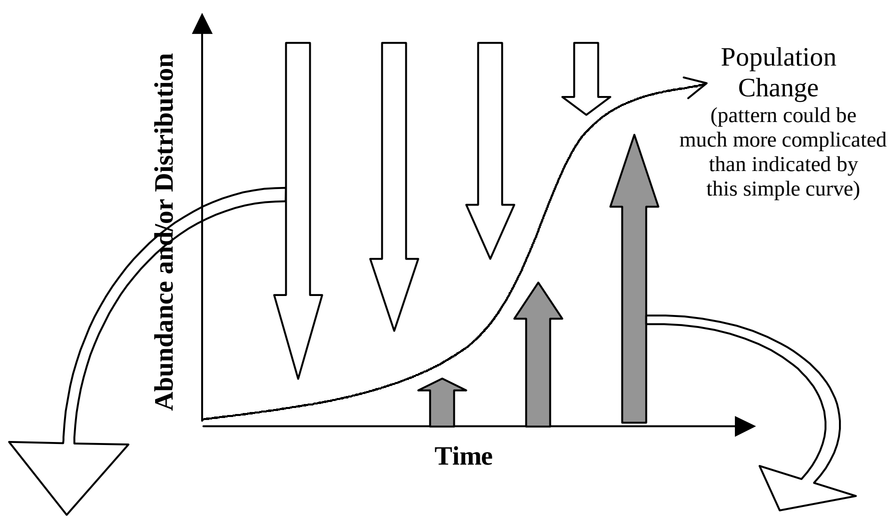


6. PLANT AND ANIMAL POPULATIONS CAN INDICATE ENVIRONMENTAL CHANGE

This model assumes that changes in state conditions for populations of baylands plants or animal, including microbes, relate in large part to changes in environmental pressures. There are always pressures, but they vary through space and over time in kind, frequency, duration, intensity, and magnitude. The population responses are also variable, being in some cases density-dependent, age-specific, or seasonal. State indicators will differ among populations but will usually represent the distribution and/or the abundance of the populations, or their productivity. Pressure indicators will also differ among populations but will usually represent habitat quality, habitat quantity, or some form of inter-specific interaction, such as predation or competition.

There are a variety of reasons to select populations or assemblages of plants, animal, and microbes as state indicators of the conditions of wetlands. They may be protected species that should be monitored to assess the effects of protection efforts, or they might have prevalent ecological functions as key-stone predators, common food resources, ecological engineers, disease vectors, links between the baylands and bays or local watersheds, or they might control major processes such as soil development or nutrient cycling.

Simple Diagram of State and Pressure Indicators for Populations



Focus Teams may have detailed models of pressures such as predation, disease, contaminants, habitat fragmentation, etc.

Focus Teams may have detailed models of population parameters such as sex ratio, age-specific survival, age structure, dispersal, etc.