Integrated Regional Wetland Monitoring Pilot Project (IRWM) Conceptual Model Update

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1 Overarching Conceptual Model

The IRWM conceptual model framework consists of two main elements. This section outlines the major forcing functions and biological outcomes important to tidal marsh restoration, and presents an overarching conceptual model of major regional, landscape, and within-site linkages. The next section presents the detailed conceptual models of each IRWM biological team that are derived from and integrate with the overarching conceptual model.

The physical and biological nature of every tidal wetland is fundamentally controlled by its hydrologic and salinity regimes and by its setting within a landscape mosaic of natural and human land uses. The San Francisco Estuary and Delta presents a unique estuarine setting due to its very large spatial scale, strong salinity and tidal amplitude gradients from the Golden Gate to the Delta, and extensive human modification to the landscape. In IRWM-1 we presented a conceptual model that integrated the physical processes and landscape ecology “setting” that describes these fundamental controls. The new insight into this region’s estuarine tidal wetlands that we have gained during IRWM-1 informs our “overarching” conceptual model, of which Figure 1 presents the elements.

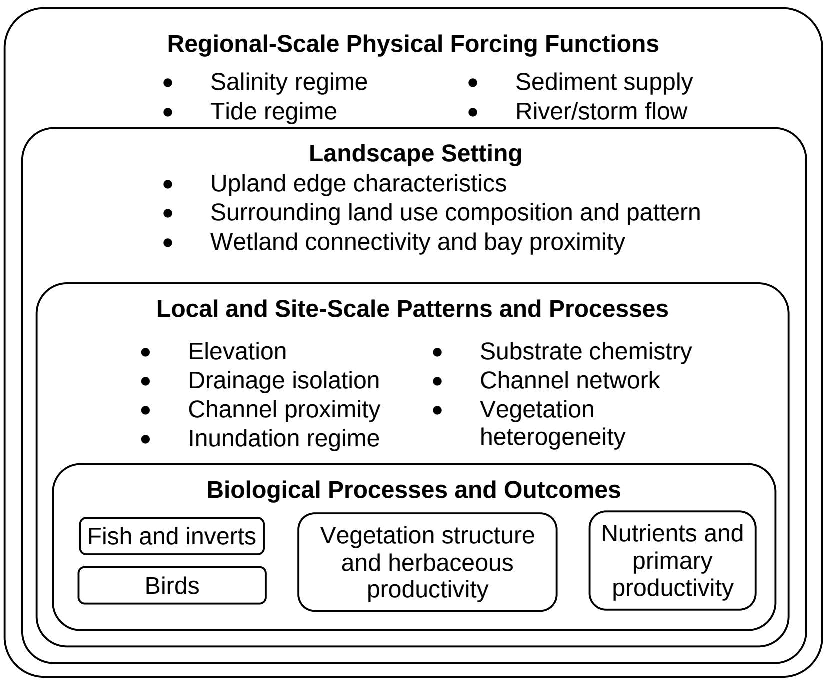

Figure 1. Elements of the IRWM integrated conceptual model relating key regional-, landscape- and site-scale processes to biological outcomes

1.1 Regional Scale Physical Forcing Functions

Hydrology and salinity exert the dominant influence on tidal marshes and accretion critically influences restoration evolution as well as topographic maintenance with relative sea level rise. In what ways are these forcing functions important and what affects their characteristics?

Role of forcing functions

The hydrologic regime defines the conditions in every wetland through its control on soil physical and chemical properties, habitat access and availability, and exchange of materials with waters outside the tidal marshes (Mitsch and Gosselink 2000). Salinity acts directly through physiological tolerances and requirements to control vegetation communities and water column organisms and indirectly to affect what higher trophic level species utilize tidal marshes (Weinstein and Kreeger 2001). Accretion acts to build and maintain intertidal marsh elevations (Warren and French 2001). Accretion results from deposition of suspended sediment and from accumulation of plant detritus. Suspended sediment concentrations, through its effect on water clarity, exerts control over algal primary production .

Forcing function characteristics

Hydrology combines two distinct forces operating in opposite spatial directions – the highly-predictable astronomic tides entering the Golden Gate and the very unpredictable river and storm flows from the Central Valley as well as local tributary rivers and streams. Tidal amplitude is greatest at the western edge of the system (approximately 2 meters at the Golden Gate) and diminishes to zero along the upper limits of the Delta. River flows, in contrast, are greatest at the Delta boundaries where 40% of California's watersheds converge and flow through the Delta and these flows diminish in relative magnitude as they enter and traverse the estuary on their way to the Pacific Ocean. Flow timing and magnitude are highly regulated by the Central Valley Project and State Water Project, comprise rainfall runoff and spring snow melt, and have strong intra- and interannual climate-driven variability. Tributary rivers and streams are generally less regulated and therefore their flow regimes are far more climate driven; these flows are of far less magnitude than Delta outflow.

Salinity reflects these hydrologic controls and in particular the role of human management of the system. Tidal marshes nearest the Golden Gate are saline, those within the Delta are freshwater (except during extreme drought conditions that can affect the western Delta), and those in between, in Suisun and San Pablo Bays, span the brackish range. Salinity also varies seasonally in our Mediterranean climate, with salinities lowest in winter and highest in late summer (e.g., Napa River marshes can be a few parts per thousand in winter and 20-30 ppt in summer [IRWM-1 unpublished data]). Interannual climatic variability also exerts a salinity effect at any given marsh particularly in winter and spring and these effects are exhibited more gradually in the biological communities.

Accretion controls the ability of a restored marsh to reach and maintain suitable intertidal elevations. Two key factors act to promote accretion: sediment supply and plant matter accumulation. Several factors act against *net* accretion: compaction, desiccation, subsidence, and sea level rise. Here we consider the critical factor of sediment supply as it is generally the dominant factor influencing marsh restoration evolution. Sediment supply originates from two main sources in the San Francisco Estuary – river and stream inputs and estuarine resuspension. These two supplies can differ in their character: riverine sediments have more grain size variability especially closer to their source (sands and silts as well as clays) whereas resuspended sediments generally have finer grained silts and clays. Once in the water column, landscape position and configuration affect suspended sediment transport into any given marsh. Finally, the specific tidal connections of any marsh, and at restoration sites in particular, affect sediment transport. Consequently, sediment supply can vary widely between marshes and is thus a very site-specific parameter.

1.2 Landscape Setting

Wetland restoration is also strongly influenced by landscape setting. Here we use the term "landscape" to refer to a mosaic of land use patches that can be defined by their structure, function and change (Turner 1990, Forman 1995 and 1997, Bell et al. 1997). The structure, function and change of these patches may affect and be affected by the fundamental ecosystem processes including physical site evolution, plant colonization and growth, community composition, and species interactions that influence tidal marsh restoration trajectories and ecological functions in both natural and restored marshes.

The spatial configuration of wetland patches, their size, shape and connectivity, and the composition of surrounding uplands and open water are the key components of landscape structure and are important for understanding wetland function and change (Kelly 2001, Tischendorf 2001). In coastal wetland landscapes, indices of landscape structure and spatial pattern have been associated with nutrient and sediment loadings (Comeleo et al. 1996, Hale et al. 2004), invasive species encroachment (Silliman and Bertness 2004), decapod densities (Minello and Rozas, 2002), breeding marsh bird abundance (Benoit and Askins 2002, Spautz et al. 2004), diversity (Shriver et al. 2004) and reproductive success (Powell and Collier 1998), and shorebird stopover dynamics (Farmer and Parent 1997).

1.3 Local and Site-Scale Patterns and Processes

The final step in the overarching conceptual model linking forcing functions to biological processes and outcomes are local and site scale patterns and processes (Figure 1). At this scale, physical processes, geomorphology, and vegetation heterogeneity define and control the environmental conditions and architecture of the habitats available for marsh flora and fauna. Also at this scale, feedback mechanisms provide for biological processes to modify these patterns and processes. Inundation regime is the single most important process affecting marsh ecology. At the site scale, elevation, tide regime, river and storm flows, channel proximity, drainage isolation, and vegetation collectively control how water arrives at and departs from any point within a tidal marsh and thus define the inundation regime (frequency, depth, and duration of inundation). Channel network structure controls two important aspects in tidal marshes – habitats for fish, birds, plants, and invertebrates and the circulatory system for exchanging materials within a marsh and between a marsh and its outside waters (Allen 2000, French and Reed 2001, Siegel 2002). Substrate chemistry along with the inundation regime controls the growing environment for marsh vegetation (Mahall and Park 1967a,b,c) , and the resulting vegetation heterogeneity defines the three-dimensional marsh architecture that provides habitats for birds, small mammals, and terrestrial invertebrates (Allen 2000, Mitsch and Gosselink 2000, Weinstein and Kreeger 2000).

2 Biological Outcomes Conceptual Models

The following sections contain more specific biological outcome conceptual models for vegetation, birds, and fish and invertebrates. We discuss detailed aspects of each conceptual model, how it stems from the overarching model presented in the previous section, and its relationship to IRWM-2's overarching goals.

2.1 Vegetation and Herbaceous Primary Production Conceptual Model

The distribution of plant species and their productivity across wetland sites and within a given wetland are influenced by a series of processes originating at different scales. Our model of these processes (Figure 2) is not intended to be a deterministic interpretation; instead, it displays the principal underlying processes or forcing functions governing both composition and productivity. This conceptual model provides the basis for developing predictive approaches to assessing the impact of restoration on vegetation processes.

In the San Pablo Bay-Suisun-Delta region, annual salinity regimes at any particular site strongly influence what species from the regional pool can germinate and reproduce in any particular wetland (Crain et al. 2004). Large-scale processes such as this set the constraints for other processes influencing marsh patterns (). Salt marshes, for example, are characterized by a high concentration of pore water salts, high densities of channels, sensitivity to inundation, and large tidal amplitudes. Brackish marshes experience similar processes but the tidal energy is somewhat reduced, gradually modifying the density and structure of within-marsh channel systems but magnifying the importance of other processes. In freshwater systems, tidal amplitude is further reduced but seasonal patterns of water flow, especially flooding events and storm water flow, have greater influences ().

Four main within-marsh vegetation variables – species composition, species assemblages, productivity, and structure – are cumulatively affected by regional, landscape, and within-marsh processes. Within wetlands, variable patterns in tides, inundation, elevation, and salinity, among others, lead to patches dominated by particular assemblages of species. For example, at Brown's Island, areas adjacent to the central channel are dominated by *Scirpus acutus* and *Typha domingensis*, while *Scirpus americanus* dominates areas away from channel edges that are slightly higher in elevation and less inundated (Parker *et al.* 2004). The overall productivity of any particular wetland depends both on the spatial area of the wetland and the extent of patches favoring particular species assemblages. Annual productivity varies greatly both among species (growth rates and allocation patterns) and within species (depending on local site conditions). Because assemblages found along within-marsh environmental gradients differ in the heights and life forms of the species involved, large changes in vegetation structure also may result. Therefore, the structural heterogeneity of vegetation in a wetland depends on the particular distribution and extent of different plant assemblages.

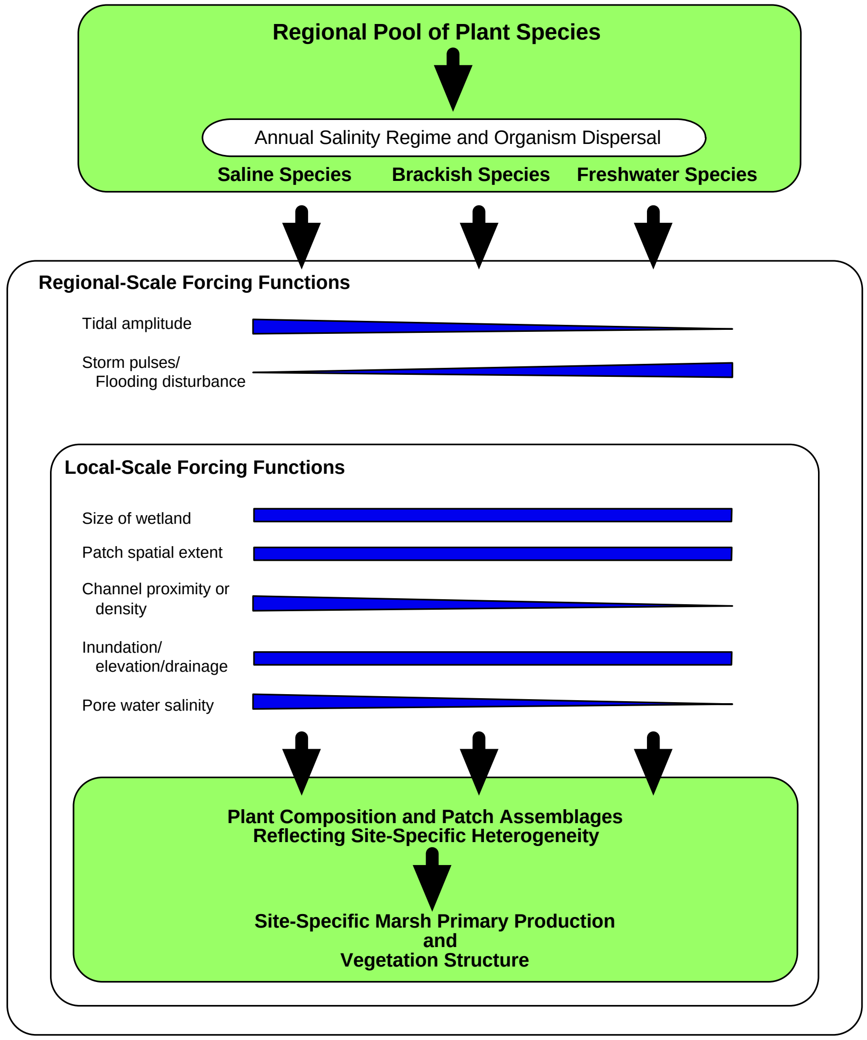

Figure 2. Conceptual model of wetland vegetation composition, structure, and primary production in the San Pablo Bay-Delta region structured by the regional species pool, tolerance to salinity, and regional and local forcing functions

2.2 Breeding and Foraging Bird Conceptual Models

For birds, the two most significant bottlenecks regulating their population dynamics, and thus affecting their abundance and population trajectories, are: reproductive success, for those birds that breed at tidal wetland sites, and foraging success. The former applies to the breeding season, which extends from March to July for most species. The latter is applicable year-round and is a consideration for all birds that use tidal wetlands in the San Francisco Estuary. Breeding birds need to obtain sufficient nutrients and reserves for successful breeding. Birds that over-winter in San Francisco Estuary need to maintain their energetic balance and finish the winter with adequate reserves to initiate breeding in the spring or initiate migration to breeding areas. Finally, birds that use tidal wetlands in the Estuary as migratory stop-over sites need to maximize their energy and nutrient (e.g., protein) reserves during migration, so they can arrive at their breeding grounds in good condition.

We present two conceptual sub-models (Figure 3), one for the reproductive phase of the life cycle for birds that breed in tidal wetlands at San Francisco Estuary sites, and a second sub-model with respect to foraging, applicable for all birds, whether breeding or over-wintering, and whether year-round resident or migratory. The breeding sub-model shows the factors that influence nest site choice (first phase of the reproductive process) and the factors that influence success once breeding is underway. Ultimately, reproductive success is measured as number of fledged young per adult of reproductive age, but important components of reproductive success are also listed. The foraging sub-model shows factors that influence suitability of foraging habitat (i.e., influence whether or not an individual chooses a habitat patch to forage in) and the factors that influence foraging success once an individual chooses a patch to forage in (though we recognize that the two processes, patch selection and success in a patch, are inter-related). In this project, we do not propose to determine foraging success per se; instead, we will assess the distribution and abundance of birds, which reflects decisions of where and when to forage. In addition, we will assess whether surveyed individuals are actively engaged in foraging vs. roosting or at rest.

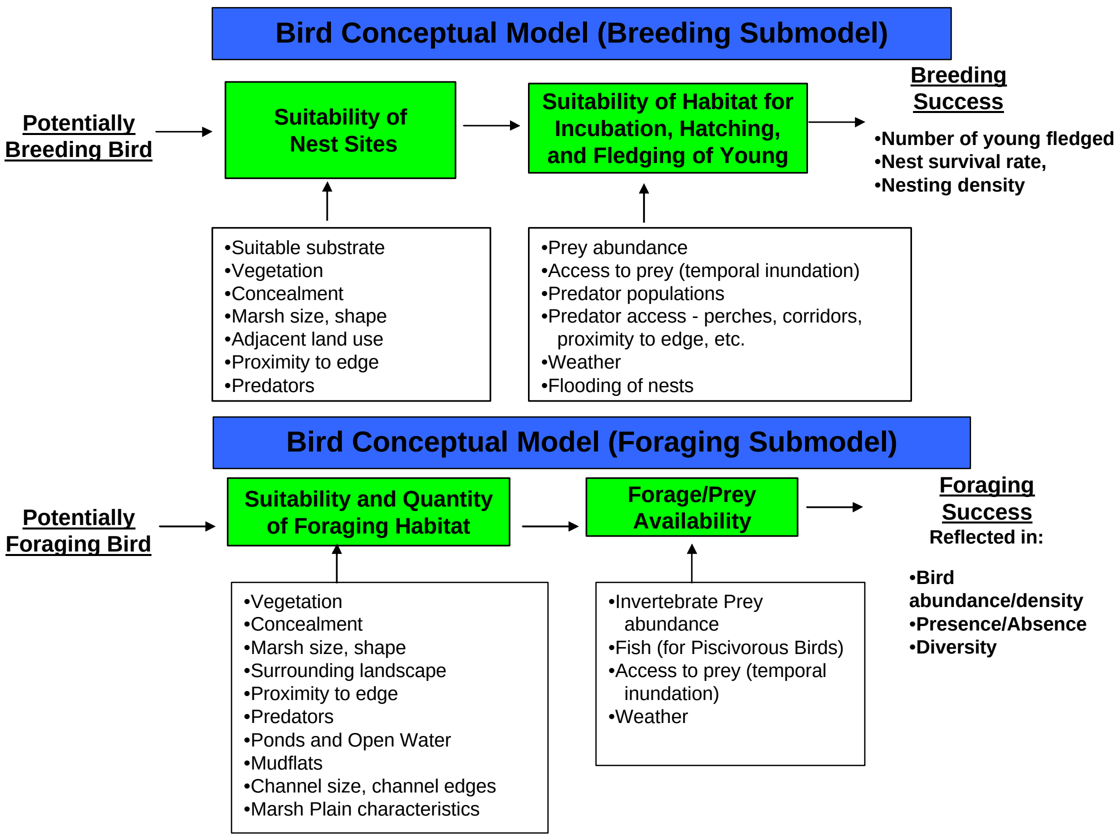

Figure 3. Breeding and foraging bird conceptual models

2.3 Fish-Invertebrate-Food Web Conceptual Model

Forcing functions and exchanges of organisms and organic matter originate from both within (autochthonous) and outside (allochthonous) restoring wetlands because they control both the access and suitability of the organism habitat and critical habitat functions, such as prey resources or refugia from predators. Influx and dispersal of organisms, such as zooplankton and pelagic nekton, and food driven by tidal hydrological exchanges with the adjacent shallows, channels and the Bay; flying and other highly mobile invertebrates may also exchange across the boundaries between the restoring wetland and adjacent wetlands, as well as adjacent riparian uplands. Conversely, the structure, and to some degree the organic matter supporting the production of resident nekton and macroinvertebrates is driven by the geomorphic structure of the marsh flats, channels and plain and by the state of vegetative development. Particularly important linkages are those between tidal channel geomorphology or emergent vegetation and macroinvertebrates or nekton that use the channels or marsh edge interface as corridors or ecotones wherein they forage or seek refuge. Metrics quantifying the relationships between the associated indicators and predictors are hypothesized to reflect the shift from allochthonous to autochthonous biotic assemblage structure and production as restoring wetlands develop and mature. Thus, this conceptual model is intended to capture changes in both the productive capacity for the wetland to support nekton and macroinvertebrates but also the opportunity for these organisms to exploit that capacity (Figure 4).

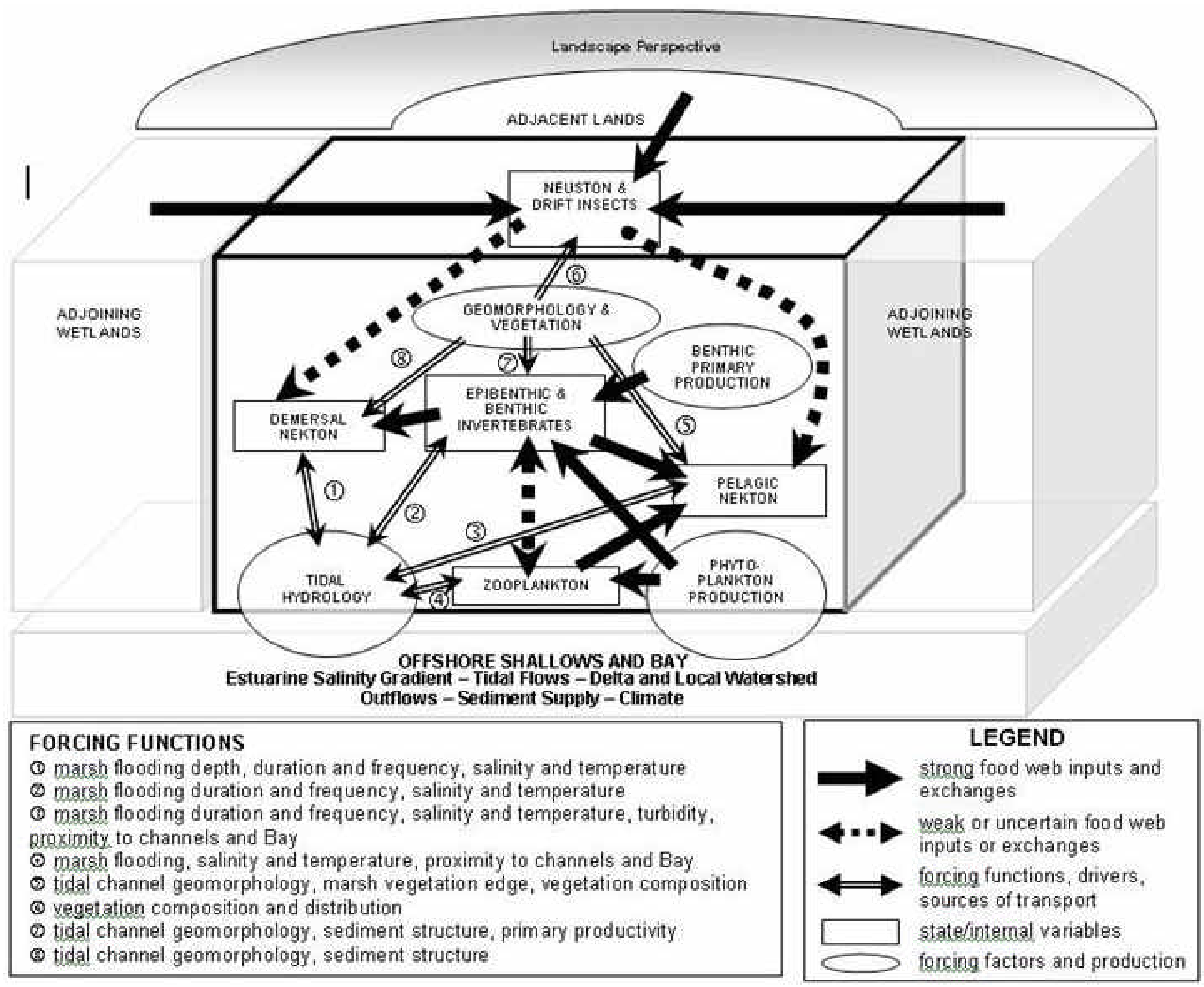

Figure 4. Fish-invertebrate-food web conceptual model

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