Beaches and Dunes

Located along the coastal border of the study region, beaches are composed of three distinct zones defined by the level of tidal inundation: the coastal strand and supra-littoral zone, which includes dunes, the middle intertidal zone, and the lower intertidal beach zone.

The bulk of the content for this report comes from the Climate Change Impacts Report (Largier et al. 2010), a working group report of the Gulf of the Farallones Sanctuary Advisory Council. Additional sources since the publication of this report are also cited.

Habitat Sensitivity

1. Direct Sensitivities to air and water temperature and precipitation

A. Temperature (content excerpted from Largier et al. 2010, except Ekstrom and Moser 2012)

- Lebassi et al. (2009) analyzed 253 California National Weather Stations from 1950 – 2005 and found that **air temperature** in low-elevation coastal areas cooled (-0.30°C/decade) and inland stations warmed (0.16° C/decade). However, a gradual retraction of the North Pacific High could contribute to decreased formation of the marine layer with declines in coastal fog and increases in temperature (Johnstone and Dawson 2010).
- By the end of the century **extreme heat days are expected to increase** dramatically for all areas in the Bay Area, but coastal areas (including San Francisco) are estimated to endure a much higher number of such events (Ekstrom and Moser 2012).
- **Water temperature** over the north-central California continental shelf has cooled over the last 30 years (by as much as 1C in some locations) due to stronger and/or more persistent upwelling winds during spring, summer and fall (Mendelssohn and Schwing 2002; Garcia-Reyes and Largier 2010)

Habitat sensitivity and response to changes in temperature

"The effects of increased [water] temperature on sandy beach biota include changes in physiological performance, tolerance and survival of organisms, geographical shifts in species ranges, increased prevalence of invasive species, altered community structure and dynamics, changes in reproductive traits and population dynamics, altered benthic metabolism (e.g. decomposition and mineralization rates, sediment oxygen saturation, microbial activity, production and respiration)" (Schlacher et al. 2008).

Observed increases in harmful algal blooms (HABs) may be an indirect effect of changes in ocean temperature (see HAB/Disease section below).

B. Precipitation (information excerpted from Climate Impacts Report)

Historical

- The past 200 years have consistently been wet when compared with longer-term records (Meko et al. 2001), and statistically significant trends indicate that precipitation (Groisman et al. 2001, Mote et al. 2005) in California has increased since the early 20th century. This is consistent with a 10% increase in precipitation for all of North America since 1910.
- However, analyses by California state climatologist James Goodridge suggest no trend in precipitation from 1890-2002 for the entire state (DWR 2006), with a slight increase in precipitation in northern California.

- Observed increases have been documented in extreme precipitation during single-day events (Groisman et al. 2001; Kundzewicz et al. 2007) and in precipitation variability (drier dry years, wetter wet years).

Future

- Kim et al. (2002) and Snyder et al. (2002) used global climate models to show that precipitation in California is likely to continue to increase, with the greatest change centered in northern California.
- The rising temperature will cause the form of some precipitation to shift from snow to rain. This is especially important for areas like California that depend on snowpack for water supply. The timing and intensity of precipitation may also change.
- Increased frequency of extreme events is expected, as is increased variability (drier dry years, wetter wet years).

Habitat sensitivity and response to changes in precipitation (information excerpted from Climate Impacts Report)

- Extreme precipitation events and increased storminess will likely continue to increase in frequency and severity (Meehl et al. 2007) which will greatly impact beach ecology through freshwater discharge from streams and rivers (Schlacher 2008) and increased rates of shoreline erosion and retreat (Largier at al. 2010).
- Changes in precipitation and sediment discharge may play an important role in altering coastal erosion. If precipitation occurs in short heavy events as projected (Dettinger and Cayan; 1995; Cayan et al. 2001; Kundzewicz et al. 2007), then sediment discharge is thought to increase, which may widen beaches and reduce coastal erosion in places. However, given the numerous sediment and water retention structures in the watersheds, the sediment and water discharge effect of these events may be reduced and thus have negligible effect on the shoreline.
- Changing climatic variables such as precipitation and salt spray may affect the composition of these communities by modifying soil salinity, with subsequent effects on plant physiology (Williams et al. 1999; Greaver and Sternberg 2007).

2. Sensitivities to other climate and climate-driven changes

A. Sea Level Rise: (information excerpted from Climate Impacts Report)

- Sea level rise and reduced habitat can disrupt the successional dynamics and coastal evolution that lead to the formation of mature coastal dune vegetation communities and biodiversity (Feagin et al. 2005).
- Sea level rise is expected to have significant impact on beach habitats within the study region, by increasing rates of shoreline erosion and retreat, and degrading habitat quality.
- As with salt marsh and intertidal ecosystems, the supralittoral coastal sand dune vegetation communities will be affected by several climate change related processes. Sea level rise may force the landward retreat of these communities as inundation floods existing habitat (Feagin et al. 2005). Where coastal dunes are backed by development that blocks retreat, upland habitat for the colonization and persistence of dune vegetation may become increasingly limited, fragmenting this ecosystem further (Feagin et al. 2005).
- Low slope beaches and intertidal sand bars where harbor seals breed snowy plovers nest are especially at risk to erosion. Mortality of elephant seal pups has already been documented to be higher during storm events such as El Niño years (Sydeman and Allen 1999; Pettee 1999). Sandy beaches are also important during the elephant seals molting season and for harbor seals year round. Since there is limited area for beaches to retreat, alternative locations for pinnipeds to

breed or rest are limited as well.

- A USGS Coastal Vulnerability analysis for 95 km of coastline in the Golden Gate National Recreation Area found 24% of the coastline at a very high vulnerability to sea level rise, 26% at a high vulnerability, 26% at a moderate vulnerability, and 24% at a low vulnerability. Ocean Beach and Stinson Beach were found to be the most vulnerable locations in the GGNRA.

B. Erosion, increased flooding and wave action

In a 2006 workshop of sandy beach and dune experts, the loss of habitat and associated biota caused by accelerated beach erosion was identified as the most immediate and severe ecological climate change-related threat to this habitat (Schlacher et al. 2008). However, there is some indication that erosion of cliffs may add sand to beaches, creating good sandy habitat (i.e. elephant seals at PRH) (Sarah Allen, personal communication, May 6, 2014).

Sandy Beaches (Content excerpted from Largier at al. 2010)

Changes in the relative proportions and condition of these [intertidal] zones from the combined effects of sea level rise and coastal development can result in strong ecological responses that propagate up the food web (Dugan et al. 2008). The majority of prey biomass available for birds and fish on beaches within the study region is provided by intertidal invertebrates, such as sand crabs (*Emerita analoga*) and polychaete worms, whose populations can be strongly affected by storm-generated erosion and coastal evolution, as well as alteration of ocean currents delivering planktonic larvae. Another major prey resource on beaches in the region are the intertidal wrack consumers, such as talitrid amphipods (*Megalorchestia* spp.) and insects, whose populations and presence are strongly affected by erosion, storms and upper beach conditions as well by the availability and production of drift macroalgae from kelp forests and reefs, all of which are vulnerable to climate change effects. These invertebrates are also crucial to wrack processing and subsequent nutrient cycling on beaches (Lastra et al. 2008). Habitat loss, fragmentation, and alteration from sea level rise will have profound ecological implications, as beaches become narrower and steeper and as once continuous habitat in front of coastal bluffs and cliffs is converted to isolated pocket beaches.

Dunes (content excerpted from Revell et al. 2011)

- On average, dunes are projected to erode about 170 m. The dune methodology incorporated three factors, SLR, a 100 year storm event, and historic trends in shoreline change. The relative contribution to the overall average dune erosion hazard zone was 48% for SLR, 45% for a 100 year storm event, and 7% for historic trends. The highest dune hazard zones (>500 m) were found along the northern California coast near Humboldt Bay and nearby lagoon systems, where dunes are projected to erode potentially by as much as 600 m by 2100. In this area, the primary factors contributing to the high hazard predictions were the low lying dunes and ephemeral sandspits located at the entrances to the Mad River and Eel River and various large lagoon systems (e.g., Big Lagoon and Stone Lagoon).
- The historic shoreline change rates included areas of accretion (Hapke et al. 2006). With these accretion rates projected into the future combined with the effect of SLR subtracted from the accretion, we observe a change in sign from accretion to erosion between 2050 and 2100, when SLR outpaces present day rates of rise and depositional processes.
- Results predict 214 km^2 of land eroded by 2100 under a 1.4 m sea level rise scenario. Average erosion distances range from 170 m along dune-backed shorelines to a maximum of 600 m.
- Changes in sediment transport dynamics may also contribute to a reduction of beach width, increased exposure of the dune to wave attack and the subsequent loss of dunes.

C. Water Chemistry

The continued, predictable reduction of pH in surface waters of the study region will result in aragonite undersaturation, causing potentially disastrous ecological repercussions for organisms with carbonate shells or exoskeletons, including the reduction of calcification rates and calcium metabolism for mollusks and crustaceans (Schlacher et al. 2008, Defoe et al. 2009).

D. Species range shifts (content excerpted from Climate Impacts Report, Largier et al. 2010)

Ecological zonation on exposed sandy beaches is extremely dynamic due to the highly mobile nature of the sandy substrate, the intertidal animals and the resources on which these animals depend (McLachlan and Jaramillo 1995; McLachlan and Brown 2006). Changes in the relative proportions and condition of these zones from the combined effects of sea level rise and coastal development can result in strong ecological responses that propagate up the food web (Dugan et al. 2008).

Forecasting changes in marine communities is limited because of the large number of complex interactions that can result from climate change. Theory predicts that species will shift their ranges towards the poles in response to warming (Peters and Darling 1985). However this prediction is complicated by the fact that species not only respond to climate but they also respond to other species (e.g., predators, habitat-forming flora and fauna). For the purposes of evaluating climate change, it can therefore be useful to focus on the response of key species that have large roles in structuring marine communities.

E. Wind

Stronger alongshore winds are expected as a result of an increasing difference in land-ocean atmospheric pressure associated with an increasing difference in land-ocean temperature as climate warms. Wind is an important variable in the alongshore transport of sand. Sand deposition and wind affect many species in this system, either by burying them (eggs of snowy plovers) or exposing them (roots of native plants) (Sarah Allen, personal communication, May 6, 2014). Of 8 protected snowy plover nests that failed to hatch in a 2008 monitoring study, 3 of those nests were found to have been buried by blowing sand from strong spring wind events (Peterlein 2009).

3. Sensitivities to non-climate stressors

A. Shoreline armoring (content excerpted from Largier et al. 2010)

The expected proliferation of shoreline armoring to protect upland properties can significantly degrade sandy beach habitats. Passive erosion associated with this armoring response effectively drowns beaches and shifts the sandy beach habitat zones downward on the beach profile, disproportionately affecting the mid and upper beach zones with resulting effects on biota, biodiversity and food webs (Dugan et al. 2008). Such biotic effects are projected to expand with sea level rise which will alter the position of existing armoring on the beach profile and act to increase the degree of interaction of these manmade structures with waves and tides (Dugan et al. 2008). Birds of all types, including shorebirds, seabirds and gulls, have been shown to respond negatively to beach width and zone losses associated with coastal armoring (Dugan et al 2008). An inventory in 1998 determined that 2% of the Marin coastline, 17% of the San Francisco shoreline and 11% of the San Mateo coastline was armored (Griggs 1998). Heberger et al (2009) also estimates that approximately 4,000 property parcels in Marin, San Francisco and San Mateo are located within the projected erosion hazard and 1.4 m sea level rise zone. Many of these would be completely lost to accelerated coastal erosion. (content excerpted from Largier et al. 2010)

Beach nourishment is being increasingly used as an alternative to shoreline armoring, and is preferred both economically and for conservation interests, but does have impacts of its own, including the direct mortality of invertebrates, disturbance of nesting and foraging birds, destruction of dune vegetation and sand compaction (Defeo et al. 2009). Recovery, however, can often be swift (on the order of months), as beaches are adapted to seasonal physical disturbance (Defeo et al. 2009).

B. Human use (content excerpted from Largier et al. 2010)
Sandy beaches are under increasing stress from direct human activity, including trampling, camping, recreation, and recreational fishing, and from indirect human activity, including stormwater discharge, eutrophication and development (Schlacher et al. 2008). (content excerpted from Largier et al. 2010)

Behavioral modification of wildlife such as shorebirds and seals is a common result of human disturbance, including reduction in foraging behavior, decreased parental care and nest abandonment, and decreased nesting density on disturbed beaches (Defeo et al. 2009). Human disturbance of seals can result in seals shifting to other sites or abandonment of sites (Grigg et al. 2002).

C. Pollutants/Contaminants

A number of stormwater outfalls discharge combined effluent treated stormwater and treated sanitary flow directly onto beaches in San Francisco, resulting in periodic beach closures. As ocean temperature rises, the nutrient inputs from wastewater discharge to the ocean, may contribute to increased toxic algal blooms and poorer beach water quality. Flood waters from increasingly intense storms and early snowpack melt will carry a greater load of nutrients and contaminants into the Pacific Ocean. (content excerpted from Largier et al. 2010)

Beaches are sensitive to oil spills, particularly protected beaches that are less well flushed by wave action and coarser grained beaches that receive more extensive oil penetration (Defoe et al. 2009)

D. Invasive Species

Coastal dunes along the Pacific Coast from central California to British Columbia have been invaded and altered by European beachgrass (*Ammophila arenaria*). Dunes in infested areas are generally steeper and oriented roughly parallel to the coast rather than nearly perpendicular to it as they are in areas dominated *by Leymus mollis, L. pacificus*, and other natives (Barbour and Johnson 1988). Species richness on foredunes dominated by European beachgrass may be half that on adjacent dunes dominated by *Leymus* species (Barbour et al. 1976). Changes in the shape and orientation of the dunes also alter the hydrology and microclimate of the swales and other habitats behind the dunes, affecting species in these areas (excerpted from Randall and Hoshovsky 2000).

Iceplant (*Carpobrotus edulis)* is also a very harmful non-native dune plant that is resilient, drought-resistant and creates deep mats of vegetation, quickly invading large areas and out-competing natives. As a succulent, iceplant stores great amounts of water and nutrients, removing these from the soil for native species (California State Parks, 2009).

Additional non-native species that may impact the dune ecosystem in the study region include the hottentot fig (*Carpobrotus edulis*), sea fig (*Carpobrotus chilensis*), and the Uruguayan pampas grass *(Cortaderia selloana*) (CBNMS/GFNMS Expansion DEIS).

E. Harmful Algal Blooms/Disease (content excerpted from Largier et al. 2010)
Over the past couple of decades, HABs that produce biotoxins such as domoic acid have increased, resulting in episodes of sick and dead California sea lions in central California, and of other species in southern California (Gulland et al. 2002). With a possible rise in ocean temperature, the emergence and spread of other diseases associated with warmer sea temperatures may increase, affecting productivity and marine mammal health (Gulland and Hall 2005).

In the North Sea, pinniped (seals, walruses, sea lions) populations experienced mass mortalities caused by a virus linked to increased temperatures and high population densities (Lavigne and Schmitz 1990). In this case, small increases in air temperature caused the mammals to 'haul out' and bask in extremely high densities, resulting in increased contact and facilitating the spread of the disease. Rising sea level could additionally interact with disease transmission by decreasing available haul out area and thereby increasing densities for transmission.

Habitat Adaptive Capacity

1. Extent, Integrity and Continuity

A. Geographic extent of habitat (content excerpted from SIMoN website)
Sandy beaches dominate the open coastlines of the world's oceans and are a dominant coastal feature of the California coast, especially in southern California and Monterey Bay. Sandy beaches form a small but important part of the North-central California coastline. Sandy shores in Marin and San Francisco Counties are characterized mainly by relatively short stretches of sandy beach and several pocket beaches. Most beaches here are characterized by medium- and fine-grained sand. Extensive beaches do occur along San Francisco County's outer coast, Bolinas Bay, Drake's Bay, and the northern edge of Point Reyes (see "continuity of habitat" for more information).

B. Structural and functional integrity in study region (content excerpted from Largier et al. 2010)
Sandy beach and dune habitats are increasingly squeezed between the impacts of human land development and manifestations of climate change at sea (Schlacher et al. 2007; Nordstrom 2000). Human alterations severely limit the ability of beach ecosystems to adjust to changes in shoreline stability (Clark 1996) as well as sea level rise and erosion caused by climate change. Sea level rise and other projected effects of climate change, including increased storminess, are expected to intensify pressures on these exposed ecosystems by increasing rates of shoreline erosion and retreat, and degrading habitat (Nordstrom 2000; Slott et al. 2006). Along with environmental drivers associated with climate change, evolution in beach and strand geomorphology, sediment dynamics, coastal and watershed perturbations, recreational activity and beach front development all affect these coastal ecosystems, the wildlife that depends on them and the ecosystem function and services they provide.

C. Continuity of the habitat
Much of Northern California is highly crenulated, rocky coastline with small sections of pocket beaches, except for near the Russian River mouth, and a few areas where steep coastal cliffs are fronted by narrow beaches. Between Point Arena and Tomales Bay, there are few linear stretches of sandy shoreline, especially in the northern half of the region. The most extensive beaches are formed near the Gualala and Russian Rivers, and a wide sandy beach and dune system exist at Salmon Creek Beach just north of Bodega Head. Much of Central California is predominantly rocky, with isolated pocket beaches and a few continuous, linear beaches. North of San Francisco is "primarily rocky coastline, with narrow beaches backed by high coastal cliffs, small isolated pocket beaches between rocky headlands and an

expansive dune field at Point Reyes", with notable exceptions along the Point Reyes peninsula. South of San Francisco, to Davenport, is variable, with "linear beaches backed by dunes, steep cliffs with narrow fronting beaches, rocky coast with small pocket beaches, and high-relief coast with no sandy shoreline" (Hapke et al. 2006).

2. Habitat Diversity

A. Diversity in topographic and physical characteristics (content excerpted from Largier et al. 2010)

Composed of unconsolidated sand from watersheds and coastal bluffs that is constantly shaped by wind, waves and tides, sandy beach ecosystems are strongly influenced by marine and terrestrial processes. The biodiversity and unique ecological functions and resources supported by sandy beach ecosystems are important to include along with their high socio-economic values (Brown and McLachlan 2002; Schlacher et al. 2007).

Central California is the most diverse coastal region of the state having characteristics of both the north and south regions plus a few unique features of its own. This section represents the transition zone between the relatively wet and high wave energy north and the drier and lower wave energy southern section. Unique embayments at Tomales, San Francisco Bays…form natural harbors along the rugged coastline. High relief coastal slopes occur at the Marin Headlands and Devils Slide north and south of San Francisco. There are large dune complexes at Point Reyes. (excerpted from Hapke et al. 2006).

B. Diversity in species/functional groups: (content excerpted from Largier et al. 2010)

- Ecosystem services and ecological values and functions of beaches and dunes in the study region include unique vegetation, rich invertebrate communities that are prey for shorebirds and fish, absorption of wave energy, the filtration of large volumes of seawater, nutrient recycling, and critical habitat for pinnipeds, declining and endangered wildlife, such as shorebirds, and a variety of threatened plants (McLachlan and Brown 2006; PWA 2008).
- Fish, such as the California grunion and smelt, also depend on these vulnerable uppermost intertidal zones of open sandy beaches for spawning, burying their eggs at the driftline for incubation in the region (Thompson 1918). Finally, pinnipeds, including elephant seals, sea lions, and harbor seals, pup and raise their young on sandy beaches, again using the upper and intertidal beach zones within the study region, such as at Point Reyes and Año Nuevo.
- Shorebird use of beaches can be high and has been positively correlated with the availability of invertebrate prey, the amount and type of macroalgae wrack, beach slope and beach width (Dugan 1999; Dugan et al. 2003; Dugan et al. 2004; Neuman et al. 2008; Revell et al. *in press*) in California, including shores in the study region. Threatened birds, such as the western snowy plover (*Charadrius alexandrinus nivosus*), nest in open beach and dune habitats on GFNMS shorelines (Lehman 1994, Page et al. 1995) making use of the dry sand zone, a habitat where erosive impacts from climate change will be strongly expressed.

C. Dependence on a single keystone species: (content excerpted from Largier et al. 2010 and SIMoN website)

The majority of prey biomass available for birds on beaches within the study region is provided by intertidal invertebrates, such as sand crabs (*Emerita analoga*). Sand crabs are often the most abundant invertebrate animal on the beach, reaching numbers of up to 100,000 individuals per meter (30,000 individuals per foot) of shoreline. These crabs settle on the beach from the plankton as tiny larvae the size of a large grain of rice in late winter and spring. Sand crabs, which filter-feed plankton from the water, are important organisms in this ecosystem. They are eaten by coastal birds throughout the study region and by sea otters in the southern portion of the study region. Some invertebrates, such as talitrid amphipods and insects, are crucial to wrack processing and subsequent nutrient cycling on beaches (Lastra et al. 2008).

Additional Considerations (Provided by Peter Baye, Independent Consultant and Coastal Ecologist)
Barrier beach retreat and western snowy plover habitat: overwash frequency and magnitude as habitat state-change driver. Currently, barrier beaches potentially suitable or currently supporting Western snowy plover (WSP) habitat in the study area include Stinson/Bolinas, Drakes-Limantour, Doran/Bodega, Dillon Beach/Sand Point. They are constrained as WSP habitat due to either *Ammophila arenaria* (marram) dominance in artificially steep, high foredune topography (caused by *Ammophila*), or armoring and beach narrowing in developed areas (Stinson). Near-term (1-2 decades) progressive erosion and retreat of *Ammophila* foredunes, or increased armoring of developed shorelines would predictably reduce WSP habitat. However, by mid-century or late century, combined acceleration of SLR and shorter recurrence intervals of extreme El Nino events are likely to accelerate barrier "rollover" (washover dominance), which may cause step-changes in barrier morphology and processes – switch from foredune or dune ridge dominated systems to washover-dominated systems with limited or intermittent pioneer foredune development, similar to Atlantic coastal plain barriers. Central Coast examples of this barrier state occur in Monterey Bay, particularly at the mouth of the Salinas River (USFWS NWR). Salinas River mouth barrier beach habitat structure consistes of extensive washover fans with patchy (discontinuous) low unstable (sparsely vegetated) foredune hummocks – also similar to the distal end of Drakes and Limantour Spits. This may increase rather than decrease the extent of WSP and also tern breeding habitat as barriers destabilize and 20th c vegetated barrier dune fields convert to washover terraces. Similarly, highly habitat- constrained developed Stinson Beach may shift from no WSP habitat (armored shore with no high tide beach) early 21st c, to extensive washover fan and high beach habitat, shifted landward with barrier rollover, once storm damage recurrence intervals make residential land uses (rebuilding) economically infeasible. Again, Atlantic barrier beach development in some rapid-retreat shores of the Outer Banks may serve as a model here.

Dune remobilization and cannibalization: net direct and indirect loss of paleodune habitat. Stabilized older dunes (including gaps and blowouts within them) at Point Reyes support most of the native dune plant species diversity in the N-C coast region. The direct loss of old stabilized dune habitats with native seed banks, high native species diversity, and weathered incipient dune soils is likely to increase progressively with shoreline retreat. In addition, as shoreline retreat exposes erosional surfaces in steep, mobilized dunes migrating landward from foredune blowouts would bury more extensive stable older dune vegetation and replace them with re-invigorated *Ammophila* (naturally stimulated by sand burial) wherever *Ammophila* occurs in foredunes or backdunes. The rate at which new stable dune habitat forms will likely be negative, causing significant net loss of the seaward populations of rare plants in stabilized dunes. Stable dune plant populations will also likely be "squeezed" by progressive spread of range-extended (partly non-native) yellow bush lupine (*Lupinus arboreus*), which leaves nutrient-enriched sand in its wake, favoring other invasive species in stabilized dunes.

Lagoon breach and overwash frequency. Rodeo Lagoon and Abbott's Lagoon in 20th c have been predominantly non-tidal and brackish coastal lagoons. With accelerated landward retreat and barrier rollover, and potential increase in frequency and intensity of droughts, haline to hyperhaline phases of the seaward portions of these lagoons may increase, and the extent of their groundwater seep-influenced higher brackish margins may diminish. This may reduce and shift landward the extent of brackish transition zones, including California red-legged frog breeding habitats in Abbott's Lagoon. The absolute supratidal water level of outer Rodeo Lagoon in non-tidal phase would be expected to rise, and eventually match or overtake the level of the landward impoundment (above culvert/weir at road). This would likely increase hydrologic connectivity of the lagoon and restore at least intermittent brackish influence to the inner lagoon, re-establishing an oligohaline-brackish ecotone.

Tidal marsh submergence and shift to washover margins. Unlike SF Estuary (which has large residual pools of fine sediment), fine suspended sediment deposition and organic matter accretion rates in maritime tidal marshes are likely to be insignificant relative to sea level rise. Existing backbarrier tidal lagoon marshes are likely to drown out by mid-late century except (a) near deltas of small streams where episodic extreme storm deposits of mixed fine and coarse fluvial sediments provide a platform for salt-brackish marsh gradients; and (b) on the margins of washover fans in the back of barriers. Peat-dominated old salt marshes (with relatively high species diversity) are likely to convert to low marsh or tidal flat. Conservation of high marsh species populations may require active management to local geomorphic refuges of high marsh topography with higher disturbance regimes (washover, fluvial delta deposits)

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