

## Global Warming, Sea-level Rise, and Coastal Marsh Survival



**C**oastal wetlands are among the most productive ecosystems in the world. These wetlands at the land-ocean margin provide many direct benefits to humans, including habitat for commercially important fisheries and wildlife; storm protection; improved water quality through sediment, nutrient, and pollution removal; recreation; and aesthetic values. These valuable ecosystems will be highly vulnerable to the effects of the rapid rise in sea level predicted to occur during the next century as a result of global warming.

A coastal wetland becomes submerged and disappears if sea level rises faster than the marsh surface builds up. Hence, determining the potential for submergence is a critical first step for managing these valuable coastal habitats in the next century. Research conducted by U.S. Geological Survey scientists has improved our understanding of the natural processes controlling wetland elevation and the potential for submergence of our coastal wetland habitats.

### Sea-level Rise

There are two processes by which sea level can increase relative to the marsh surface: (1) sea level rises because of increases in the volume of the oceans, and (2) the marsh surface sinks because of soil compaction and other geologic processes (collectively called **subsidence**). The volume of the oceans increases as global warming thermally expands seawater and melts glaciers, resulting in a global change of sea level. The rate of global sea-level rise is expected to accelerate during the next century as atmospheric temperatures continue to increase. Sinking of the soil surface occurs in nearly every marsh but varies greatly among locales. River deltas with thick, unconsolidated sediment deposits, such as the Mississippi River delta, have high rates of sinking, while coastal fringe marshes with thin sediment deposits have low rates of sinking. Global sea-level rise and local marsh surface

sinking occur simultaneously, and their combined effect is referred to as **relative sea-level rise**. Vulnerability to relative sea-level rise and to coastal submergence varies greatly among marshes because of local variation in marsh sinking rate, indicating that site-specific information is needed to develop appropriate management strategies for each wetland.

### Coastal Marsh Response

There are two processes by which marshes build vertically: surface sediment deposition (**sedimentation**) and subsurface accumulation of live plant roots and decaying plant parts (Fig. 1). Both processes are controlled by marsh flooding (hydrology) and both contribute to soil volume, which directly influences surface elevation. Flooding patterns control the delivery of sediment to the marsh surface and the oxygen content of the soil, which

influences the rate of plant growth and decay. Sedimentation enhances plant growth by delivering plant nutrients to the soil while vegetation enhances sedimentation by trapping sediments suspended in flood waters. Hence, a rising sea level can influence all of these processes by changing flooding patterns. In a healthy marsh under a moderate rate of sea-level rise, marsh elevation increases at the same rate as sea-level rises and the flooding patterns remain unchanged. In a deteriorating marsh or under an accelerated rate of sea-level rise, plant growth is reduced because of excessive flooding, and soil volume cannot keep pace with subsidence and sea-level rise. As elevation lags further behind relative sea-level rise, the plant stress increases until the plants die, the soil volume collapses, and the marsh becomes submerged.

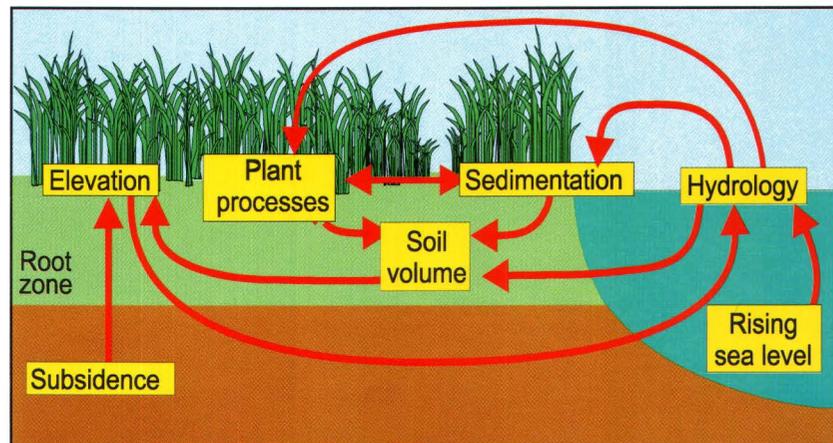
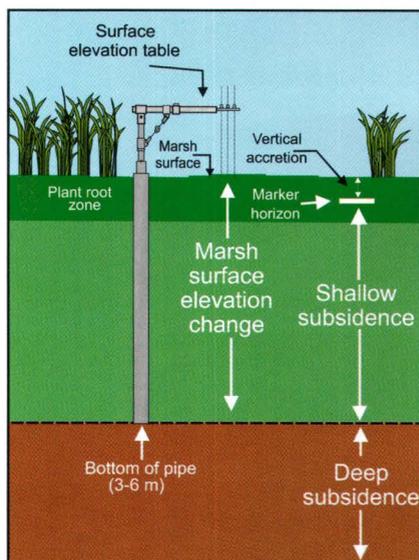


Fig. 1. Relationships influencing marsh elevation.

## Determining Potential for Marsh Submergence

Traditionally, the potential for marshes to become submerged has been determined by comparing the rate of **vertical accretion** (surface sedimentation) to the rate of relative sea-level rise. If accretion lags behind sea-level rise, then an **accretion deficit** exists and the potential for submergence is high. The concept of accretion deficit assumes that vertical accretion equals marsh elevation change. Yet we know that marsh surfaces sink as a result of subsidence (Fig. 1). Therefore, we tested this assumption by simultaneously measuring both vertical accretion and marsh elevation (Fig. 2). If the assumption were false (i.e., if elevation gain were less than vertical accretion), the accretion deficit would underestimate the potential for submergence. Therefore, the elevation data would be used to calculate an elevation deficit, which would give a more accurate estimate of the potential for submergence. In addition, we made the measurements with a level of accuracy sufficient to distinguish between the influence of surface sedimentation and subsurface soil processes (e.g., root growth and soil

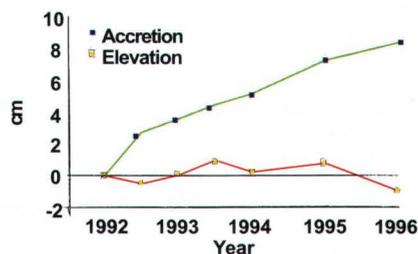


**Fig. 2.** Methods used to measure marsh elevation change and shallow subsidence.

compaction) on soil elevation. This approach allowed us to determine for each locale whether surface or subsurface processes were controlling elevation.

After at least 2 years of measurements, accretion and elevation were not equal at a majority of the 12 marshes we studied. **Shallow subsidence** (the difference between vertical buildup and the effects of surface and subsurface processes on elevation) at these marshes typically ranged from 3 to 4 mm/yr. These findings indicate that soil processes occurring below the marker horizon had as strong or stronger an influence on elevation than surface sedimentation. Therefore, accretion deficits for these marshes underestimated the potential for submergence. This potential was best estimated by elevation deficits. The processes which controlled elevation included sedimentation, plant root growth, decay of plant matter in the soil, water storage/drainage, and soil compaction. Natural forces driving these processes included seasonal patterns in hydrology and major storms.

Findings from a submerging marsh at Bayou Chitigue, Louisiana, provide an excellent example of the processes influencing elevation (Fig. 3). The relative sea-level rise rate for this marsh is 1.38 cm/yr, estimated from local tide gauges. For 4 years, vertical accretion averaged 2.07 cm/yr, suggesting that marsh elevation was keeping pace with sea-level rise. However, elevation remained virtually unchanged. The persistence of the



**Fig. 3.** Comparison of accretion (soil buildup) and elevation at Bayou Chitigue, Louisiana.

marker horizon and high rate of accretion indicate that the lack of elevation gain was not caused by erosion. Therefore, the lack of elevation gain must be caused by sinking of the marsh surface from shallow subsidence, as indicated by the distance between the two lines in Figure 3. The accretion data alone gave a misleading indication of the potential for submergence. The simultaneous accretion and elevation data indicate that the marsh surface moved downward 2.28 cm/yr. Estimates of sea-level rise from tide gauges do not include shallow subsidence. Therefore, the actual relative sea-level rise rate for this marsh is 3.66 cm/yr (1.38 + 2.28), which explains why the marsh is rapidly submerging.

The existence of shallow subsidence does not always mean that an elevation deficit exists. A study in south Florida found that both fringe and exposed island mangrove forests experienced significant shallow subsidence but soil elevation kept pace with sea-level rise. The sheltered island studied, however, appears to be experiencing an elevation deficit.

## Conclusions

The potential for submergence of some coastal marshes is best determined by calculating elevation deficits rather than accretion deficits. Moreover, measures of total subsidence based on tide gauge records are underestimated by the amount of shallow subsidence. Trends in elevation of coastal marsh cannot be extrapolated among sites, and site-specific data are required to develop appropriate management practices.

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