TIDAL EROSION AT ELKHORN SLOUGH

Virtually all of California's tidal wetlands have been dramatically altered. Hydrological manipulations – changes in water flow – are widespread. Either flow has been decreased by diking and draining lands for agricultural uses, or it has been increased by dredging of deep channels for boat traffic. Both of these sorts of alterations have been carried out at Elkhorn Slough, a large estuary on the central Monterey Bay coast. The most substantial diking project was the creation in the 1880s of an embankment to carry the railroad line right through Slough wetlands. All marshes to the south and east were separated from the main channel by this dike, and many of them were subsequently used as pastureland. While dikes decreased tidal flow to some parts of the Slough, another project radically increased tidal flow to the undiked main channel and marshes. This was the 1947 opening of a large artificial mouth to the Slough.

Prior to 1947, the Slough was an estuary with sluggish tidal flow entering from a mouth a few miles to the north of the main channel, shared with the Salinas river. This small opening was sometimes obscured by a sand bar for months at a time, and even when open let only relatively small volumes of seawater into the Slough system. In 1946, the Army Corps of Engineers built jetties directly west of the main channel of the Slough, and in 1947, they breached the shoreline dunes and dredged a wide, deep channel to permit entry of boats into the newly created Moss Landing Harbor (Fig. 1 [August 1946 aerial photo of the historic mouth and construction of the artificial mouth.]). Original construction plans called for tide gates to be built between the harbor and the main Slough channel (under the current Highway 1 bridge), prior to the opening of the harbor mouth. This would have maintained the sluggish tidal character of the Slough. However, these plans were never implemented.

On the first high tide following the opening of the new mouth, an unprecedented volume of tidal flow inundated Slough wetlands. Ever since, Slough habitats have continued to be altered by this increase in tidal volume, resulting in tidal erosion of channels and loss of salt marsh. Most of California's tidal marshes have already been lost to human uses, particularly agriculture and development. Elkhorn Slough boasts the second largest remaining area of salt marsh in the state, so documentation of further loss is of great concern. In this report, we review the evidence of changes that have occurred, with emphasis on what has taken place during the last decade since the creation of Monterey Bay National Marine Sanctuary (MBNMS), which incorporates much of Elkhorn Slough.

Tracking changes due to tidal erosion

The morphology of the main channel and tidal creeks of the Slough evolved with a small natural opening to Monterey Bay. After 1947, there was a gross mismatch between the size of the new artificial opening and the narrow meandering channels. Eventually, tidal scour will have eroded the channels sufficiently such that there is a stable match between their size and the opening. But when will this happen? If such an equilibrium were reached soon, Slough habitats might persist indefinitely with the current diverse mix of habitat types. However, if an equilibrium is only reached many decades from now, the Slough may by then resemble a muddy fiord, due to loss of most marsh and intertidal mudflat habitats.

To predict the trajectory of tidal scour and resulting marsh and mudflat loss at the Slough, investigators are carefully tracking rates of habitat change, using a combination of direct measurements in the field and remote sensing. These investigations began in the 1980s with the seminal work of J. Oliver and colleagues at Moss Landing Marine Laboratories (MLML). In the

1990s, various graduate students tackled aspects of the problem. Erosion research continues today, mostly carried out by R. Kvitek and his students at California State University Monterey Bay (CSUMB), and by researchers at Elkhorn Slough National Estuarine Research Reserve (ESNERR). These scientists have established long-term monitoring programs incorporating recent technological advances that allow for high spatial and temporal resolution of habitat changes.

Main channel bathymetry

Subtidal bathymetry was measured manually with poles in several channel cross-sections, by NOAA researchers in the 1940s prior to the harbor opening, by J. Oliver and colleagues, and by UC Santa Cruz graduate student T. Crampton in 1993. Also in 1993, bathymetry was assessed at many more cross sections using a single beam echosounder, by MLML graduate student C. Malzone together with R. Kvitek. Sampling at 1-meter intervals along selected cross-sections yielded only a very approximate picture of Slough bathymetry, but temporal patterns were strong nonetheless. Comparison of measurements over time revealed a dramatic increase in the subtidal area of the main channel of the Slough between the 1940s and the 1990s. The depth at the mouth has increased from about 1.5 m in 1947 to greater than 7 m. Overall, Crampton estimated that 1.6 million cubic meters of sediments have been eroded from the Slough since the harbor opening.

Tidal volume of the Slough sharply increased not only following the opening of the harbor mouth, but also in recent decades following the breaching of dikes to restore pasturelands that were former marshes to tidal flow. Since current speed is a function of tidal volume and channel size, the increases in tidal flow resulted in substantial increases in current speed in Slough channels, which in turn has led to tidal scour. Malzone found current speeds near the mouth have doubled in just the last 20 years, presumably in part due to the restoration of wetlands at ESNERR and elsewhere, which increased tidal volume in the Slough by 43%.

In April 2001, Kvitek and his student J. Brantner began a new phase in bathymetric studies of the main channel, using the new CSUMB research vessel, the MacGinitie, equipped with a multibeam echosounder and high resolution global positioning system. In just one day of surveying, they were able to obtain soundings approximately every quarter meter for the subtidal portion of the main channel. Their data have been incorporated into by far the highest resolution map of Slough bathymetry to date. Brantner and Kvitek compared their bathymetric results to those of Malzone from 1993. They detected high erosion rates in this period, with channel depths increasing on average by 0.5 m, with highest percent depth gain at the mouth (24%) and Seal Bend (30%), where the channel turns northward (Fig. 2 [line graph showing 1993 and 2001 depth vs. distance from mouth]). Overall, they estimated that volume of the entire main channel increased by about 15% in just these seven years, translating into a loss of 58,000 cubic meters of sediment per year. Figure 3 [shaded map of main channel] illustrates which areas have undergone the highest rates of erosion, which have remained steady, and which have gained sediments during this period. Currently, another CSUMB student, E. Dean, is working with Kvitek to characterize the bathymetry of shallow intertidal mudflats along the periphery and head of the main channel, using a smaller boat. This work will complement Brantner's and provide a more complete picture of the main channel habitats of the Slough.

Precise comparison of erosion rates obtained recently by Kvitek and students vs. previous studies is difficult, because methods differed, and the resolution of the earlier studies was so much lower. Yet tracking erosion rates over time is critical for determining whether equilibrium is being approached, as would be indicated by decelerating rates. To this end, Kvitek will resurvey main channel bathymetry regularly. Such detailed long-term monitoring would not have been possible just a few years ago; the sophisticated new technology being employed permits annual high-resolution comparisons of Slough bathymetry.

Bank erosion

In contrast to some of the sophisticated investigations of subtidal changes, studies of intertidal erosion have been carried out much more simply. In the early 1990s, Crampton and Malzone set up about fifty markers along the main channel and tidal creeks of the Slough, returning after months or years to measure how the distance from the markers to the bank edge had changed. Both their studies revealed astoundingly high rates of erosion. These markers were abandoned in the late 1990s, but were reinstated in summer 2000 as a joint effort between MBNMS, ESNERR, and graduate research by San Jose State University student S. Bane. The first year of data reveals that erosion rates along Slough banks are still high, averaging 40 cm/year, with a maximum approaching 2 m/year at some sites. Erosion at these markers will continue to be monitored annually.

Tidal creek width

Since the Slough's tidal creeks are quite shallow, their bathymetry cannot readily be characterized by boat-based instruments. Instead of tracking their subtidal contours, we rely on analysis of aerial photos to investigate how their width and structure is changing. Examination of a few tidal creeks by Oliver and co-workers led to an estimate of a 70% average increase in width in the first forty years following the opening of the harbor mouth. E. Van Dyke at ESNERR is currently taking a closer look at changes in tidal creek structure. He is using dozens of photos taken at five to ten year intervals between the 1930s and present to very closely document rates of change over time. Moreover, he has developed image-analysis techniques for outlining creek banks, making results more consistent and repeatable. His work is supporting Oliver's findings of widening of tidal creeks over time, and is also revealing that they have become more reticulated and extensive at their margins, bringing water into more areas of interior marsh (see Fig 4 [diagrammatic illustration of same tidal creeks in 30s, 60s, 90s]).

As the creeks become wider, they become more similar to the main channel. A MLML thesis completed in 1998 by D. Lindquist suggests that there has been a corresponding shift in animal assemblages in tidal creeks. He found the diet of fish feeding in the creeks had become more homogenous over time, with a lower diversity of prey items available. Tidal creek fauna is apparently becoming ever more similar to that of the main channel. This aspect of tidal erosion at the Slough may thus have serious consequences for tidal creek communities, with eventual loss of species dependent on these characteristic estuarine features.

Salt marsh deterioration

Some vegetation has been lost over time at marsh edges, associated with the bank erosion and subsequent widening of creeks described above. Outweighing this loss at the edges, interior thinning has dramatically decreased the acreage of vegetated salt marsh at the Slough since the opening of the harbor mouth. Examination of aerial photographs over the last 70 years reveals that many marshes that once had dense pickleweed cover now have extensive bare patches and areas with only very sparse cover. Oliver and co-workers were the first to detect this trend, and interested MLML graduate student P. Lowe in taking a closer look. Lowe's 1998 thesis describes a sharp decline in percent cover of pickleweed in the decade following the opening of the harbor, and then another decline in late 1980s. The early decline is likely due to the immediate increase in tidal range due to the creation of the wide artificial mouth. The more recent decline appears to be due to subsidence of the marsh plain.

The elevation of the marsh plain has decreased by an average of 12 cm since the opening of the harbor, according to work by Crampton. Tidal scour of surface sediments, groundwater overdraft in the region, and earthquakes may all contribute to this subsidence. In any case, it is clear that erosional forces now outweigh depositional ones in the Slough, so subsidence can no longer be countered by pickleweed trapping of sediments. Lowe carried out transplant experiments with pickleweed, and found that a decrease in elevation of 12 cm significantly affected growth and survival – the lower plants almost all died, while the higher ones grew vigorously.

Restoring and managing Slough wetlands

The research described above indicates that Elkhorn Slough's channels have deepened and widened, banks have eroded, and salt marsh has been lost, all as a result of tidal erosion. Our new monitoring programs, carried out at higher resolution in both time and space, should soon reveal whether rates of tidal erosion are decreasing over time, but so far there is no evidence to support that this is occurring or that an equilibrium will soon be approached. Prediction of the trajectory of habitat change also requires that hydrology and sediment transport processes in the Slough to be modeled; we hope that such studies will soon be undertaken as a part of the MBNMS integrated monitoring network.

It appears likely that erosion at Elkhorn Slough will continue at high rates for decades to come, with substantial loss of 5000 year-old salt marsh and intertidal mudflat habitats. These habitats play a critical role at the base of estuarine food webs, provide shelter for birds, crabs, and other animals, and serve as a filter between the land and the sea. Continued erosion would threaten these rare natural communities, and also might contribute to salt water intrusion in the area, and pose a danger to the rail line that bisects the Slough. Coastal decision-makers in the region may need to consider intervention to mitigate for the effects of the creation and maintenance of the large artificial mouth to the Slough. One possibility to explore is eelgrass restoration in the main channel. Dense eelgrass beds apparently thrived in the main channel almost to Kirby Park before the opening of the harbor, but are now limited to a few relatively small areas. Eelgrass traps sediments and slows tidal currents, so if methods could be developed to enhance beds this might ameliorate some of the erosion problems. Another possibility is to reduce tidal flow to some of the peripheral marshes. In this unusual system, wetland restoration may best be accomplished by maintaining dikes, rather than removing them. Muting tidal flow to some of the Slough's wetlands may be the best way of preserving salt marshes and intertidal wetlands and the diverse invertebrates, fish, and shorebirds they sustain.

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Figures

Figure 1: 1946 aerial photo showing construction of new artificial Slough mouth in line with main channel, and smaller natural mouth to the north [ESNERR collection].

Figure 2: Depth of main channel from mouth to head of Slough, with blue line for 2001 data and green line for 1993 data. Note significant increase in depth in just these seven years, especially near the mouth [R. Kvitek & J. Brantner].

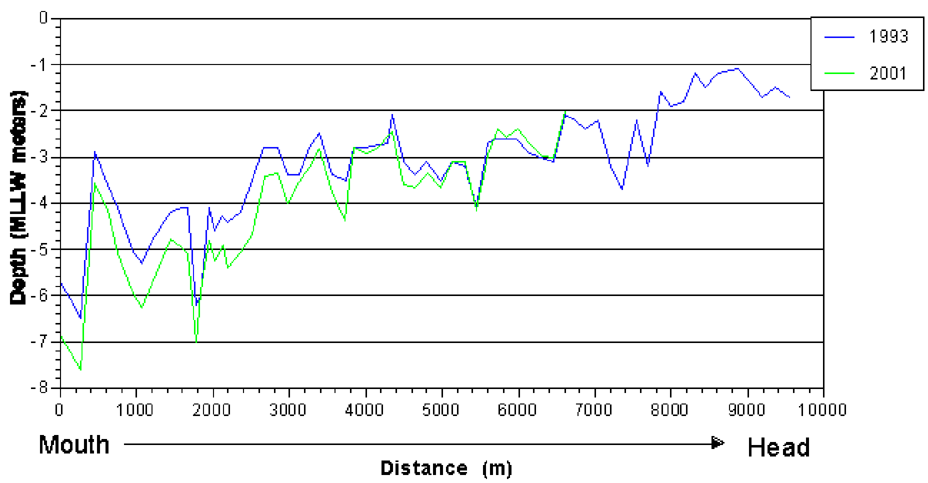

Figure 3: Map of the main Slough channel showing rates of sediment loss between 1993 and 2001. Shades of red indicate areas of loss; gains in sediment are shown in greens. [R. Kvitek and J. Brantner].

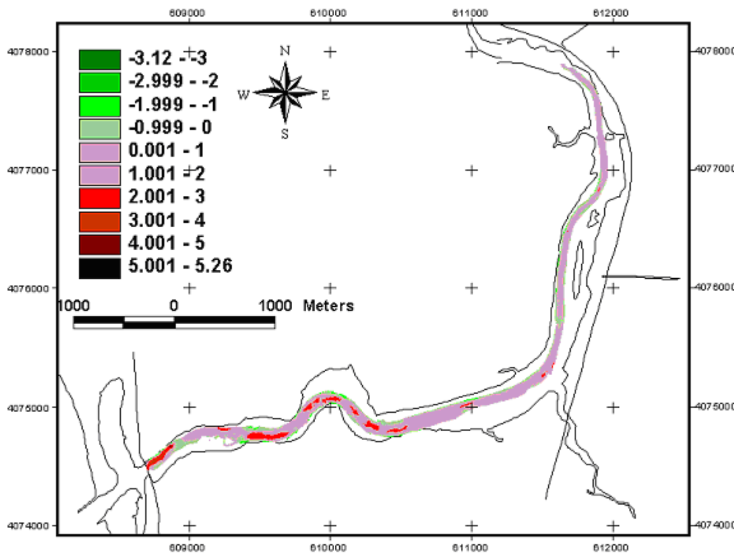

Figure 4: Diagrammatic representation of change in tidal creeks over time in northwestern Slough. Note increasing branchiness of creeks [E. Van Dyke].