Salt Marsh Secrets

Who uncovered them and how?

By Joy B. Zedler

An e-book about southern California coastal wetlands for readers who want to learn while exploring

2015

Zedler, Joy B. 2015. Salt Marsh Secrets: Who uncovered them and how?
Tijuana River National Estuarine Research Reserve. Imperial Beach, California
(http://trnerr.org/SaltMarshSecrets).

This e-book records favorite stories about salt marsh secrets that my collaborators and I uncovered while studying southern California coastal wetlands, from the 1970s to date. In 1986, we became the Pacific Estuarine Research Lab.

Please download the files as they appear online and enjoy learning what we learned…and more. You'll meet many "detectives," and you'll be able to appreciate how they learned so much--undeterred by mud and flood. Learn while exploring the salt marshes near you!

Each chapter (1-21) is being posted at the TRNERR as a separate file (PDF).
Chapter numbers precede page numbers (for chapter 1: 1.1...1.14).
Layout by Emily L. Rosenthal. Photos by the author or as noted.

PDF name and brief description:

Sediment: Too much, too little, or just right?

Maybe you call it dirt. It might be too soon to call it soil. What is sediment? Sediment describes all those loose bits of sand, silt and clay (meaning coarse, medium and fine particles). Soil has more structure; it is bound together by microorganisms and invertebrates and roots. In contrast, sediment is "restless." Sediment can cloud the water where it's wet, and blow with the wind where it's dry. Sediment is often "on the move."

Worms slither along the bottom of a tidal channel and stir up the sediment, making a "cloud" in the water, and the particles move to new positions. In the transition above the high tide line, small birds scratch a wallow to have a dust bath, and ground-nesting bees dig and kick the particles behind them as they create burrows. In ponds, large birds dig for edible bulbs and tubers (plant parts that store carbohydrates), uprooting entire plants in the process. In ecology, we call such animal-caused disturbances "bioturbation." That separates the physical effects from the biological impacts.

Disturbed sediments are eroded (removed) from one position and moved to another by wind and water. They erode upstream and upwind and accrete (accumulate) downstream and downwind. If the water and winds flow mainly in one direction, there will be a net gain downstream or downwind. In a tidal marsh, however, the water flows in and out, but the river only flows out.

The effect of sediment in river water can be large, as in the 1980 flood at Tijuana Estuary. Water slowed down and sediments accumulated in the estuary (where a river meets the sea). The effect can be small when water flows rapidly through the estuary, depositing sediments outside the river mouth. Nature is variable. At the top of the photo below, sediment is flowing down the Tijuana River and into the Tijuana Estuary. At the same time, at the bottom of the photo, sediment is flowing out the mouth.

Why do we care about sedimentation?

The reason sediment is important in salt marshes is our changing climate. Storms are predicted to become more extreme and more frequent, so we have to worry about too much sediment flowing downstream and filling in tidal channels and blanketing the marsh plain. But because sea level is rising, the marshes do need to accrete enough sediment to keep up with water levels. If they accrete too much, the amount of tidal influence will decrease.

How much sedimentation is too much; how little is too little? Is it possible for sedimentation to be "just right"? Rarely will the amount of sediment that settles in a salt marsh exactly match the rate of sea level rise. Some California estuaries are filling in because they receive too much sediment; some are sediment-starved so they are "losing ground." Some might be accreting sediment at just the right amount to keep up with rising sea levels.

Where does the sediment come from and where does it go? Let's begin at the beginning……big rocks break apart into smaller rocks, and smaller rocks (like gravel size) break down into sand, silt and clay particles, becoming ever smaller and smaller. When the parent rock is near a coastal river or stream, the "offspring" particles can move with water, aided by gravity, down to the coast.

This big (1.7 m wide) rock was left behind by the Wisconsin glacier. It's near my house, so I can watch it break apart. Every year the crack (15 cm in 2014) grows a bit wider as debris fills the space and water collects and swells when that water freezes in winter. It's called "weathering." Also, it's covered with lichens that help the weathering process at the surface. My rock is a long way from being gravel and sand, but the process is underway.

A steep, rapidly-flowing creek will move smaller particles very fast—so fast that they will stay suspended in the water for long distances. But as soon as the land becomes flatter and the water slows down, larger particles yield to gravity and settle on the bottom. The finest particles (clay) keep on flowing, till they settle out where water barely trickles. Places where clay settles are where wetlands form. Why is that? It begins with seeds. If the water is flowing slowly, then seeds aren't washed away so fast. Some might become waterlogged and sink. Others might simply rest on the wet sediment as the water recedes. If the seeds germinate and grow roots quickly, which is a great adaptation for a floodplain plant (invest in an anchor first). Imagine if a plant produced a lot of leaves first, before growing a deep root—the next flood pulse would uproot it due to all the leaf area.

My colleague at UW-Madison, Dr. Anita Thompson, is a Biological Systems Engineer. She has a long flume in her lab. That's a big long tank where water can flow in and out at controlled depths and flow speeds. Sometimes students put plants in the flume to test their resistance to water flow. The technical term is "drag coefficient." That information helps her predict how fast water will flow in a channel that is vegetated by different plant species.

(freeaussiestock.com/free/Queensland/slides/st_helens_beach_estuary)

Queensland's Murray River is slow-flowing where it enters the Coral Sea in the South Pacific Ocean. There, sediment can move coastward when the tide flows out and landward when it flows in.

Salt water actually helps particles settle by forming a floc—clusters of particles that are large and settle readily. Large deposits of sediment develop where rivers meet the sea. That's where sandflats and mudflats form.

Sediments won't tend to stabilize, however, without some help from micro-organisms and algal mats and vascular plants. Bacteria stick to sediment particles and secrete "slime"; so do algae, especially bluegreen algae. And the bluegreen algae produce even more slime. Because they are photosynthetic, bluegreen algae can turn light energy into carbohydrates that form slime. A more pleasant term, perhaps, is "biofilm." All that slime can cement a lot of sediment particles into globs (cemented sediment particles). And a lot of globs can build a fairly stable mudflat, at least until a flood or storm tide comes along.

As sediment flows into the estuary, the slime and globs can collect seeds and debris. As the mudflat becomes habitable for germinating seeds, roots will puncture the slime (which is soft, unless it has dried in the sun during a low tide). With lots of roots growing through the biofilm, the mudflat becomes more stable and the stems grow and slow water flow near the roots, the roots collect and hold more sediment, increasing the elevation and converting the mudflat to a marsh. Some marshes, then, are former mudflats that became vegetated.

Here, sediment is flowing into Tijuana Estuary's Old River Channel, south of the mouth. The sediment source is a small urban watershed in Mexico that is hilly and has highly erodible soil. The sediment flows across the border and down Goat Canyon, where some--but not all--the particles are trapped.

Peggy Fong and a helper, knee deep in mud at Sweetwater Marsh; cordgrass was planted next to the mudflat.

Returning to the upstream rocks that break down over millennia to produce stones, gravel, and sand particles, you might wonder if that's where the sand on our beaches came from. It is! It's a long journey in both time and space. Sand, silt and clay wash downstream and eventually reach the estuary, where some settles and some flows out the river mouth during floods. Once alongshore, sand can settle on a nearby beach or move up or down the coast, depending on the prevailing direction of the local longshore currents, which are surface-water flows running parallel to the coast. Coasts are shaped in part by the currents, and currents can move sand to places where there is slower water flow, forming beaches where the sand drops out of the water column.

When does an estuary have just enough sediment, not too much and not too little?

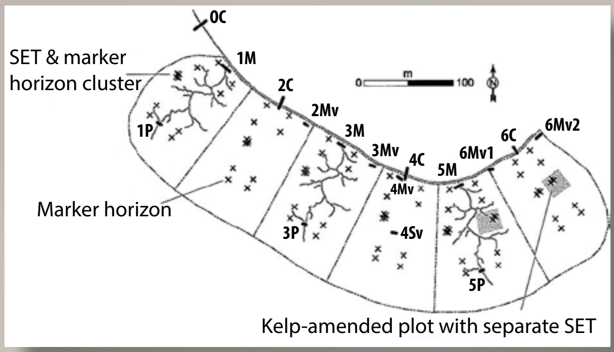
And how can we learn how much sediment is accreting?

First, let's see how sedimentation and erosion are measured. Dr. John Callaway places large round filter papers on the surface of the mud in San Francisco Bay to measure short-term sediment accretion. After a few days, he collects the paper, returns it to the lab, dries, and weighs it to assess grams of sediment per cm^2. Then, with data from several locations, he can calculate the average rate and extrapolate (scale up) to the total for the area where he sampled.

Another approach is to create a "marker horizon." That's a layer of white clay (feldspar) or glitter sprinkled over the sediment to mark the starting point, time zero, T_o. Any sediment that accretes over the marker horizon will be measurable by pushing a tube into the soil and removing a core with the marker for at T_o before new sediment accreted at T_1. The sedimentation rate is the thickness accreted divided by the time span, $T_1 - T_0$.

Sediment might be accreting sometimes and eroding at other times, so another approach is needed to capture both accretion and erosion. John uses a SET (surface elevation table) for this purpose (see www.pwrc.usgs.gov/set/). First, he installs a post into the soil so it will not move up or down even a millimeter. The SET is attached to an arm that is attached to the post when it is time to measure either accretion or loss of substrate. The arm is needed to extend the SET away from any trampling (compaction) or mounding caused during post installation. Then rods are dropped through the SET to determine the precise distance to the soil surface.

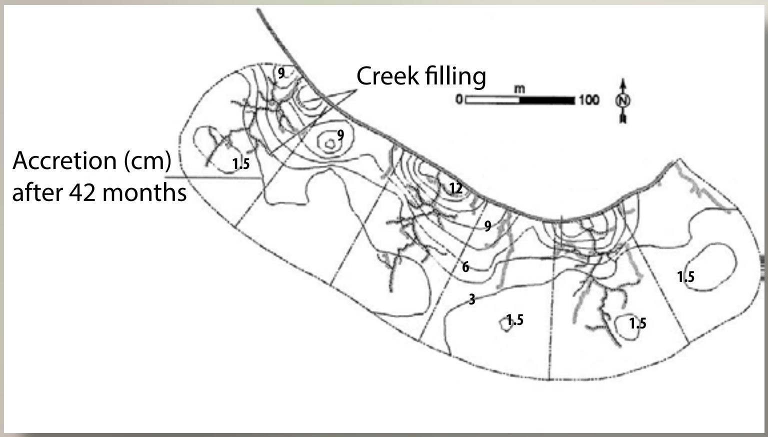
SET (pwrc.usgs.gov/set)



Model Marsh with 6 conceptual "cells" and SETs

John installed six SETs in the Model Marsh and created many marker horizons. The Model Marsh was opened to tidal flow in February 2000. Then, 42 months later, the extreme flood of 2004 moved a great deal of sediment into the the 20-ac (8-ha) site.

Too much sediment at the Model Marsh



John Callaway and Katy Wallace reported 1.5 to 13.5 cm of accretion. The new contour map showed that the Model Marsh lost its mudflat! Accretion along the tidal channel made the mudflat higher than the marsh plain—the opposite of the design. That was too much sediment!

Why was there so much sedimentation? First, the Model Marsh was in the direct path of the Goat Canyon flow. This photo was taken standing on the edge of the Model Marsh. Second, the Model Marsh is far from the estuary mouth. There were no rapidly-flowing tidewaters to wash muddy water out the mouth and into the ocean.

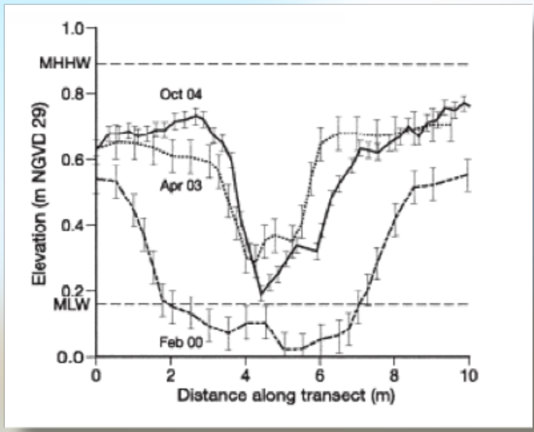
A third cause of heavy sediment inflows was the "loaded gun" in Goat Canyon, where giant sediment-retention basins were under construction. Bare-soil berms and beds were easily eroded when heavy rainfall and runoff filled the basins and then overflowed.

Goat Canyon before sediment basins had enough riprap to stabilize the berms; photo taken just after the Nov. 2004 deluge.

Looking up Goat Canyon after the 2004 flood and sedimentation event, you can see that the basins trapped some sediment but also eroded and overflowed!

Later, the basins were completed using riprap to armor the berms.

On the right are cross-sections (average depths with S.E.) of the Model Marsh channels on three sampling dates. In February 2000, the channels were deep and broad just before tidal flushing was restored. When remeasured in April 2003, the channels were shallower and narrower. By the October 2004 remeasurement, they had shifted due to both sediment accretion and erosion. In general, deep wide channels became shallow, narrow creeks.



Below, you can see the flooded marsh bathed in sediment. The plants were covered by a thick layer of mud.

As the contour diagram above shows, there was more sediment to the north, along the tidal channel, and less toward the southern berm, in the foreground.

Over a foot of sediment was deposited next to the Model Marsh's main channel. What was designed to be a mudflat became mid-marsh that was later colonized and dominated by perennial pickleweed.

That's because the water flowed around the Model Marsh and breached the berm on the west side. Sandbags were no match for heavy rain and strong surface-water flows.

While sediment was eroding the Model Marsh berm, it was accreting on the Model Marsh plain (above).

The 2004 flood and sedimentation event were not the first that the southern arm of Tijuana Estuary experienced. In the photo below, you can see many layers of historical sedimentation events that were exposed by the erosive water. The top layer, which covered existing vegetation with several inches of sediment, was deposited in 2004.

Too much sediment at Mugu Lagoon

(Aerial photography of southern CA, Ventura County region.)

Mugu Lagoon, near Oxnard, CA, experienced major flooding following a series of storms in 1978 (>20 cm of local rainfall within 9 days in February; Onuf 1987). Tons of sediment flowed downstream into the lagoon, filling the deepest channel areas.

Why so much sediment? The upstream watershed was largely agricultural, with a 332-day growing season, meaning that continual cultivation would make the sediment unstable year-round. Lots of loose soil was poised to move downstream with extreme rainfall. And it did. It was too much sediment. Imagine all the clams and mussels and worms that were buried--Yikes!

Chris Onuf and Millicent Quammen learned a lot about the ecological effects of sedimentation at Mugu Lagoon during their research on plants and animals.

You can find Onuf's "Community Profile of Mugu Lagoon" in a regional university library.

Too little sediment:

In contrast to the Model Marsh and Mugu Lagoon, Elkhorn Slough (central CA) experienced sediment loss during three major earthquakes in 150 years: in 1868, 1906, and 1989. Both the 1868 and 1989 quakes were about 7 units on the Richter Scale, and the 1906 quake was over 8 units. Because the Richter Scale is logarithmic, this means that the1906 'quake was 10 times as severe as the other two.

Earthquakes can shake the mud and cause wetland soils to subside (lose ground relative to sea level). Other things that can cause subsidence are nearby pumping of groundwater and diking areas that would otherwise contribute sediment. However, the history of earthquakes likely explains the continual sinking of the salt marsh and conversion of vegetated area to mudflats.

(friendsofpajarodunes.org/places-to-go/places-to-go-elkhorn-slough-national-reserve/)

Humans disturb this estuary, too. The mouth of the Slough is kept open and the channels are dredged to allow recreational boating.

Because tide flows have been artificially increased, a large volume of water moves into and out the estuary mouth.

Inflowing and outflowing tides move faster than they would if the mouth were narrower and the channels shallower. So the mudflats and channels and banks erode.

Elkhorn Slough has been changing for many decades. Salt marsh is converting to mudflat and subtidal habitat. It has **too little sediment**. The solution is not clear to me. Just because subsidence exceeds sedimentation doesn't mean we should dump sediments in this estuary. Fortunately, Elkhorn Slough is part of the National Estuarine Research Reserve system, which encourages research to solve management and restoration problems (http://www.elkhornslough.org/research/conserv_marsh.htm).

Is the sedimentation rate ever just right?

Probably not. Estuaries are dynamic systems that erode sometimes and accrete sediment at other times. On average, they might keep up with rising sea level, but it's hard to predict the variations.

According to Jeff Haltiner, a hydrological engineer who worked with us at Sweetwater Marsh, San Diego Bay constrasts sharply with Tijuana Estuary. San Diego Bay has very little sediment inflow, because the bay's watersheds are stabilized (not eroding). Tijuana Estuary has a large watershed within soils that are eroding. Erosion results from intensive land use (agricultural cultivation and urban development without stabilizing landscaping).

To predict the long-term sedimentation rates, hydrological engineers like Jeff need to be able to predict extreme events—among the toughest tasks. Extreme events will occur and they will probably be more extreme and more frequent in your lifetimes than in mine. But we can't say when and where the next extreme event will occur.

RISING SEA LEVEL (a topic I discuss further in chapter nineteen): What determines how fast sea levels are rising? Global warming is causing ice to melt and the ocean to warm up. The long-term warming trend, as well as extreme events and various shorter-term episodes, all affect sea levels. You can find various estimates of rates for southern California online.

> Here are sea level rise projections for increases beyond the levels in the year 2000: For the Southern California coast and the globe as a whole:
> By 2050: 0.1 - 0.6 m (5 - 24 inches) and by 2100: 0.4 - 1.7 m (17 - 66 inches). Compare those projections to sea-level-rise over the past ~80 years:
>
> Sea levels rose 7 inches in LaJolla and 3 inches in Los Angeles.
>
> Sea level could rise 24 inches in 50 years, compared to 3 inches in 80 years at the Los Angeles monitoring station. Yikes!

The main cause of future flooding will be global warming. Note that local variations are mostly due to different rates of sinking or rising land. Both La Jolla and Los Angeles and the coastline in between have many low-lying areas with roads and buildings that will eventually flood, especially during storm surges.

Why does the sea rise when the globe warms? Ocean waters cover about 70% of the earth. Ocean water expands and melting ice increases the volume of water in the ocean.

Sea storm effects

Extreme winds and waves in 1986 produced the greatest sea level anomaly recorded in southern CA. I'll never forget that event. I thought the wind would topple me, so I stayed long enough to take some photos, then decided to leave before my car and I got trapped in sand!

I had traveled to Tijuana Estuary to see how Brian Fink's dune plants were faring as waves crashed onto shore (see photo). The answer was "not well." Some of the sand verbena (*Abronia maritima*) seedlings that he had planted behind one fence were able to hold their ground, literally, but most were washed away. Some of the debris in the above picture was giant kelp, washed up from the subtidal area and deposited on top of the sand.

Sediment was pouring onto Seacoast Drive in between the apartment houses; the asphalt was wet and slick; sand bars were forming in the street!

This view looks south along Seacoast Drive. The flooded salt marsh is on the left; the ocean is behind the apartments on the right.

If the sand dunes had been undisturbed, the native vegetation might have held some sand in place, because the native dominant, sand verbena, has deep roots and widely spreading "branches" that cover the surface substrate. But most of the coastal vegetation had been trampled by people and vehicles for so long that we don't really know how high the dunes were naturally or how well the sand was held in place by native plants. At one time, this part of Tijuana Estuary served military activities (see photos in *The Ecology of Tijuana Estuary).*

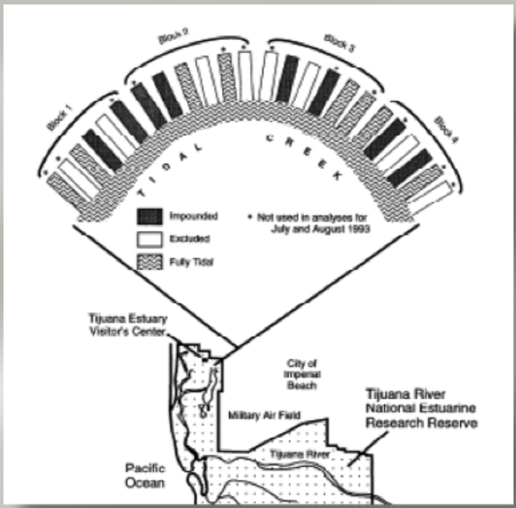
WHEN DOES TOO MUCH SEDIMENT COME FROM OFFSHORE (the ocean side of the estuary)? Aerial photos capture the impacts of historical sea storms. In 1983, sand moved inland from the beach and dunes.Sand blocked the main south arm of the estuary, and sand covered parts of the salt marsh.

Sand offshore has washed over the dunes in past decades. When the beach retreats, sand fills in tidal channels. For example, in 1983, the northern tidal channel, called Oneonta Slough, filled in so much that the estuary could not accommodate much tidal water.

With little tide water flowing into the estuary, the water currents slowed down, and sandy sediment accumulated. In April 1984, the tidal flows could no longer keep the mouth from filling with sediment. It closed to tidal flushing. That was definitely too much sediment--all from the ocean side of the estuary.

The estuary mouth closed during a year without rainfall, and the salt marsh shifted to dominance by perennial pickleweed. That led us to test the role of tidal closure on pickleweed growth, several years after tidal flow was restored to Tijuana Estuary. We excavated 24 large intertidal mesocosms adjacent to the northern tidal lagoon.

In one treatment, we blocked tidal access, and in another we attempted to impound tidal flows, leaving a third set as controls.



Despite our intent to create waterlogged soil conditions, the coarse (sandy) sediments of the mesocosms allowed impounded water to drain out via subsurface flow. As a result, we could not show differences between fully tidal conditions and our intended impounded conditions. We did, however, see a 20-50% increase in soil salinities and 30% decrease in pickleweed growth where tidal flows were blocked for 10 months (Callaway et al. 1997). Even though productivity was reduced, perennial pickleweed persisted.

Donna Ross sampled epibenthic mats in each mesocosm in1993, but algal chlorophyll did not differ among treatments (Ross 1994), Rainfall and groundwater flows from adjacent tidal mesocoms kept the nontidal soil moist enough for epibenthic algae. Later, we found another way to learn by using our less-than-intended, tidal-manipulated mesocosms. Read on….

Over time, the beach at Tijuana Estuary has retreated, except where beachfront apartments are armored with riprap. With huge waves, dune sand can erode and cobbles can be thrown onshore. That takes a lot of wave energy!

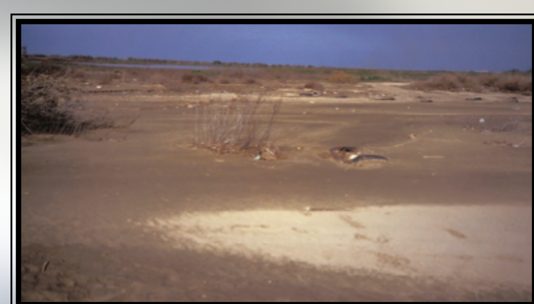
Efforts to restore and maintain the dunes and beaches have involved a lot of sand replenishment. After dunes were flattened in 1983, bulldozers were brought in to re-build them.

Bulldozers were also needed to re-open the mouth of Tijuana Estuary after 8 months of closure (April to December 1984).

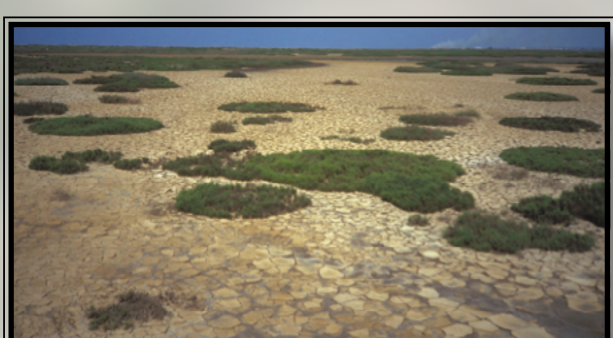
WHEN DOES TOO MUCH SEDIMENT COME FROM THE WATERSHED? In 2004, the estuary received too much sediment flow from upstream sources. Major floods took place, with many rain storms pelting the slopes upstream. Because people had disturbed the land, there was too little vegetation to hold the soil in place. The soil washed into the creeks and moved into the estuary and over the salt marsh. The rates of sedimentation varied, of course, and as much as 30 cm (a foot) deep next to one small creek (Callaway and Zedler 2004).

A new project is underway to characterize the history of sedimentation and vegetation throughout the Tijuana River Valley. The research is being done by the San Francisco Estuary Institute. New maps will show where the Tijuana River used to flow and where there were different kinds of vegetation, from willows to grassland.

Tijuana Estuary receives muddy floodwater. After floods recede, sediment deposits look like moonscapes.



Sediment has been filling Tijuana Estuary for decades, mostly because of human impacts to the lands upstream. Note how the turbid water spreads over the salt marsh during high tide conditions.



Patches of subshrubs (glasswort and others) survived sedimentation within the salt pans.

I wonder, however, if the tiger beetles (*Cicindela* spp.) survived burial in sediment. These 1-cm-long burrowing insects are quite rare. Perhaps increased dune washovers and flood-borne sediments contribute to their rarity.

How much sediment can pickleweed tolerate?

Urbanization of the Goat Canyon watershed allowed extreme flooding to transport massive amounts of sediment from a small local watershed of ~12 km^2, 90% of which is in Mexico) downstream via Goat Canyon. About 10-30 cm of sediment was deposited on the perennial pickleweed marsh along the Old River Channel during a short-term, catastrophic event in winter 1994–95.

Here's the Old River Channel before flooding and sediment deposition. The narrow band of green vegetation adjacent to the channel is perennial pickleweed.

New sediment, up to 30 cm deep, was deposited on top of the pickleweed, suggesting another study: How much sedimentation can perennial pickleweed tolerate?

We used two approaches to answer the question, first, an experiment to test increasing amounts of sedimentation, and second, a field study to document tolerance of different depths of sedimentation along the Old River Channel.

We already had lots of pickleweed growing under uniform conditions in our tidal mesocosms, so we added small-scale treatments of 10, 20 or 30 cm of sediment onto replicate subplots of pickleweed. Those depths mimicked impacts along the Old River Channel site, and the one-time addition mimicked the flood, which added sediment all at once. Then we waited and watched.

Pickleweed survived 20 cm but could not grow through 30 cm of sediment. Did that match what happened along the Old River Channel? That question was more difficult to answer.

To find out, John Callaway and I laid out a 75-m-long transect along the sediment plume (newly deposited sand and silt) in June 1995. Then we divided the transect into three sections.

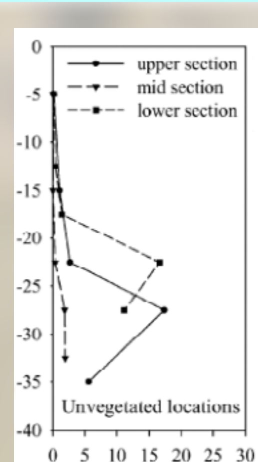
The hard part was driving a 10-cm diameter tube into the soil. John used our razor-sharp corer equipped with a plunger to extrude (push out) the core intact onto a trough with a v-shape bottom. This held the core in place so we could measure each sediment layer.

John dug up 4 deep soil cores within the bare plume and 4 cores within pickleweed for a total of 24 cores (12 pairs, with ~2 m between bare and vegetated cores in each section). Storm-deposited sediment was light-colored and sandy; pre-storm sediment was dark and had fine texture. Layers had sharp transitions (≤1 cm), so we could easily measure the 1995 sediment layer. Next, John transported the cores to the lab and compared soil texture and organic content of sediment above, below, and across the plume. John extracted soil water to measure porewater salinity with a refractometer.

The depth of new sediment decreased from 30 cm upstream to 20 cm downstream. After John rinsed the soil cores over a 0.45-mm screen, he collected the buried shoots and oven-dried the biomass at 80◦C for 24 hr. The dry weights (graph on right; Callaway and Zedler 2004) show no biomass above 20-cm depth. Pickleweed had been buried alive in new sediment. Pickleweed persisted where the depth of new sediment was <25 cm.

To determine soil texture, we used the hydrometer method, comparing the specific gravity of a well-mixed slurry of soil and water. Specific gravity changed as sand and silt settled in sequence. If you like the idea of mixing your own malt in a commercial-size malt-mixer, you will like this method. Using about 40 grams of dry soil and a liter of deionized water, you mix up a homogeneous slurry and immediately measure its specific gravity. Take another reading 40 seconds later, because sand settles out in 40 seconds. Then wait 2 hours for silt to settle and take a third reading. That leaves clay, which takes many hours to settle, so it's easier to estimate clay content by subtracting the sand and silt from the total (100%). Simple calculations give data on % sand, % silt and % clay.

Adjacent to the sediment plume, pickleweed cover was reduced to ~30% downstream, compared to ~90% upstream. To determine how rapidly pickleweed could recover, if at all, we measured the width of bare sediment between the creek and the vegetated marsh in June 1995, June 1996, and July 1997, recording cover in 10-cm increments along permanent transects perpendicular to the plume. Those data and the 2000 photo on the next page show that the site never really recovered. People trying to get from Mexico to jobs in the US walked along the creek looking for a narrow section to jump or bridge with driftwood. Foot traffic sustained the bare soil that began as a sediment deposit!



Our small-scale study of a single sedimentation event shows how to reveal the secrets of deposition, impacts and persistence of salt marsh in the path of floodwater.

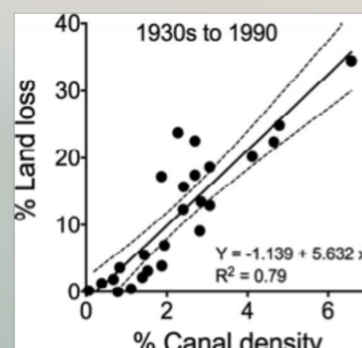
What's the difference between sediment and soil?

Soil is not just a bunch of dirt. It has millions to billions of organisms and is usually full of plant roots that structure the mineral particles. A soil core usually reveals layers that differ as a result of different biological and physical processes. Organisms are usually most active in the top layers, where they incorporate organic matter and make the topsoil dark in color. In wetlands, the deeper layers can also be dark but for different reasons—in the absence of oxygen, iron compounds turn black (in contrast to orange when the iron is oxidized, which we call "rust"). A root that carries oxygen deep into the soil will often have a rust-colored surface layer, showing that the rest of that soil layer is anaerobic.

Here's another secret about the role of the plants in marsh building. Vascular plant roots do more than bind and trap sediments, they also elevate the marsh surface by growing roots and rhizomes that push up soil from below. If you eliminate all the marsh vegetation and leave everything else as it was, the roots will decay and the soil will subside (slump). Some of the marsh's ability to keep up with rising sea level is due to the ability of plants to keep growing roots at and near the soil surface.

Do you know why roots are so important for marsh-building in coastal Louisiana? That coast has the nation's highest wetland loss rate, and much of it is due to subsidence—the slumping of marshes as sediments compact, as subsurface geology changes, and as marsh roots die and decompose. And why do the marsh plants die? For one thing, the marshes are criss-crossed with canals that have been dug to allow boats to travel to and from the offshore oil well rigs. When the canals are dug, the sediments are sidecast (cast aside = piled up along the edge). The pile of sediments along the canal forms a berm that prevents high tide water from flooding the salt marsh. It also prevents rain from running off the marsh. Together, these disruptions make the marsh soil anaerobic, stresses the plant roots, and kills the plants.

Dr. Gene Turner, from Louisiana State University (LSU), has argued for years that canals (excavated so workers could travel in boats to offshore oil platforms) are an important cause of wetland loss along coastal Louisiana. Here's a compelling graph based on maps covering 12,872 km^2 (from Turner 2014). It's rare that a single factor can explain 80% of the variation in a landscape feature, but canal density explains 79% of the variation in land loss.



Note that the relationship shown is a linear (straight-line model) and that it goes through the origin (0,0 point on graph), indicating that when there were zero canals, land loss was also zero. Another LSU professor, Dr. Irv Mendelssohn, showed how anaerobic soils stress Louisiana's salt marsh plants and cause mortality. Although the cordgrass that dominates their wetlands is not the same species as ours, it is a member of the same genus, *Spartina.* Research from Louisiana marshes (the Nation's most extensive coastal wetlands) has been very useful in suggesting studies of southern California salt marshes.

Try an experiment at home: First germinate several bean seeds, watching for them to send out a root. You'll need several healthy seedlings. You can germinate the seeds in tap water in a plastic jar lid with about half the bean above water.

• Find a plastic bottle and cut off the top to make a pot. Fill it about 1/3 full with fine dry sand mixed with a bit of plant fertilizer. Now weigh the container + sand as the starting point. [Always record the date and activity when performing an experiment.] Use a measuring spoon and record the volume of water you add, as needed, to moisten the sand. Now mark the sand surface on the bottle with a felt pen. Place the pot in full sun next to a window and add 5-10 new bean seedlings just under the surface of the sand. Keep the sand moist with daily watering, which you measure and record. Keep the sand moist but not waterlogged. After a couple of weeks, see if the roots have pushed up the surface of the sand. I haven't tried this, but it should demonstrate that roots displace the sand. Let me know what you learn!

• You can learn more about plant growth by reweighing your pot with sand, moisture and bean plants. Add up the water you have provided and convert volume to weight (1 milliliter of water = 1 g). Now cut the bean plant at the soil surface and weigh it before drying; then dry in the sun and reweigh---the weight loss is water retained by the plant shoots. The dry weight is the aboveground production. Reweigh the pot and record the amount. Now dump out the sand and the roots onto dry paper and see if you can separate them—this gets easier as the sand dries. Placing the mess in the sun will speed up drying. Once the sand has dried, reweigh it to see if the weight is the same as the starting condition. If it weighs more, where is the error? Were some roots left attached? Some water still present?

Next, weigh the dry roots and compare belowground and aboveground biomass. Which is greater? If the roots are greater, the sand was likely nutrient-poor. With ample fertilizer, you might have more shoot than root biomass.

• If you want to set up more experiments, try adding different water amounts and different fertilizer amounts to individual bottle pots, making sure that all other variables remain the same. And if you want to become more sophisticated, set up replicates and assess the variation among pots that you treated the same. Ecologists call this experimental error. It's not really "error" unless you made a mistake; there are reasons why beans would vary; it's just that you can't know why they're different from one another (unless you continue research in botany!).

Do you think this kind of research is fun? Productivity studies, in particular, require a lot of effort. By experimenting at home, you can develop appreciation for the work that ecologists have to do to measure plant growth—there's a lot of harvesting, sorting species, drying and weighing involved, and that's just for shoots. For roots, the additional work of washing soil cores over sieves is tedious and time-consuming. Roots growing in clay are much harder to wash than those in sand. Also, washing roots too vigorously breaks up the fine roots, so they pass through the sieve along with the water and soil particles. Roots get overestimated if the clay isn't entirely removed and underestimated if lots of fine roots are lost.

This was our root-washing station, set up for four helpers at a time--mass producing the assessment of biomass.

Southern California is a great place to do this kind of work. You can wash roots outdoors all year round. We employed a lot of helpers who seemed to prefer the work to indoor tasks.