# 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

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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:

# Discovering salt marsh secrets

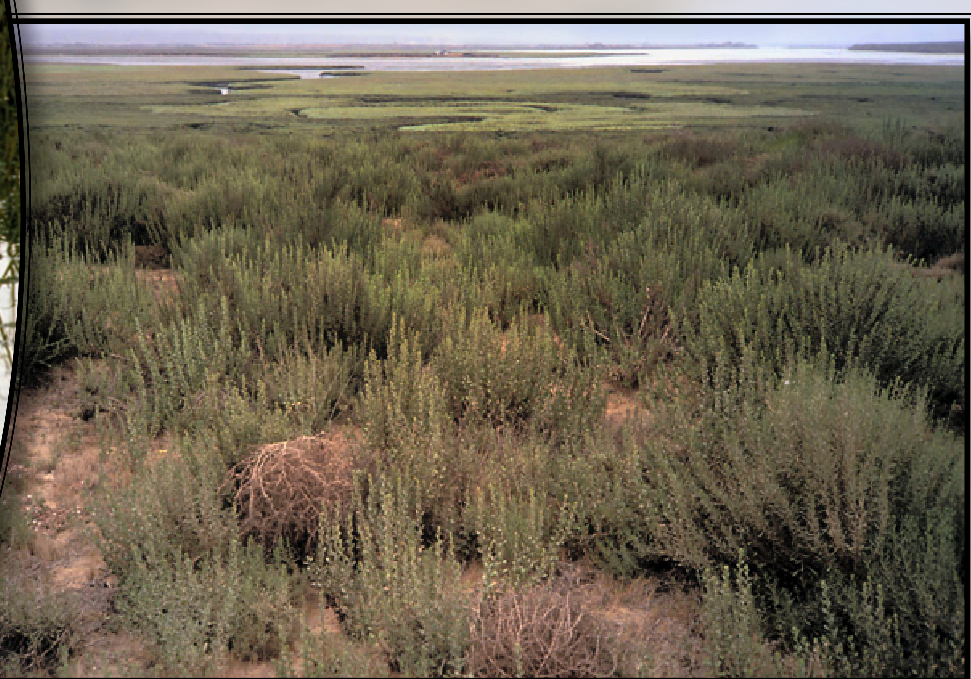
California's salt marshes are full of secrets about the plants and animals that live there, what they do during low and high tide (pictured below) and the reasons they thrive or decline toward extinction. This book is about secrets that my collaborators and I revealed over many years of study—often when we expected something quite different.

You can discover salt marsh secrets, too, by visiting a salt marsh and describing what you see.  Use this book to learn how scientists act like detectives—always trying to understand what we see.

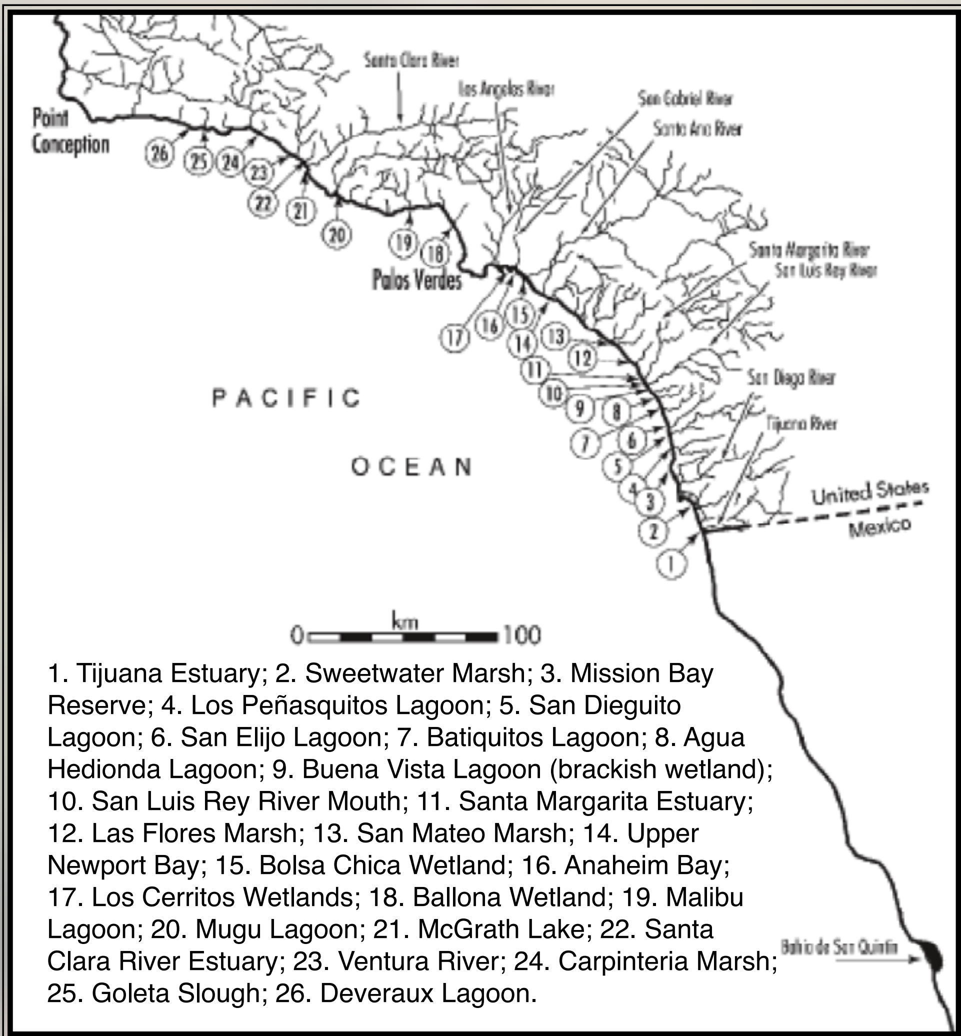
Volcano Marsh, Bahia de San Quinín, Mexico.

Every good scientist is a good observer, so be prepared to describe what you see in words, drawings and photos. The least disturbed salt marshes occur in Mexico, like this one in San Quintín Bay.

(photo by Juliette Murguia ©)



Left: Great Egret. Right: Volcano Marsh, looking from the high marsh toward the bay.




1. Tijuana Estuary; 2. Sweetwater Marsh; 3. Mission Bay Reserve; 4. Los Peñasquitos Lagoon; 5. San Dieguito Lagoon; 6. San Elijo Lagoon; 7. Batiquitos Lagoon; 8. Agua Hedionda Lagoon; 9. Buena Vista Lagoon (brackish wetland); 10. San Luis Rey River Mouth; 11. Santa Margarita Estuary; 12. Las Flores Marsh; 13. San Mateo Marsh; 14. Upper Newport Bay; 15. Bolsa Chica Wetland; 16. Anaheim Bay; 17. Los Cerritos Wetlands; 18. Ballona Wetland; 19. Malibu Lagoon; 20. Mugu Lagoon; 21. McGrath Lake; 22. Santa Clara River Estuary; 23. Ventura River; 24. Carpinteria Marsh; 25. Goleta Slough; 26. Deveraux Lagoon.

The Californian biogeographic region stretches from Point Conception south along the Baja California peninsula (regional map from Zedler et al. 2005). Twenty-six coastal wetlands occur in the US portion of the region. Which one is closest to you?

If your computer is suitable, you can view maps of individual wetlands from [http://ceres.ca.gov/wetlands/geo_info/so_cal/so_cal_wetland_index.html](http://ceres.ca.gov/wetlands/geo_info/so_cal/so_cal_wetland_index.html).

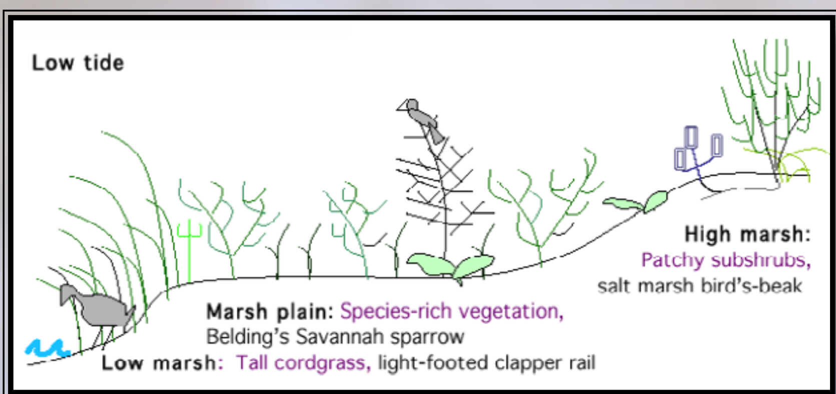

US coastal watersheds (NOAA): Coastal watersheds are smaller on the Pacific Coast, where mountains are near the ocean.

Where is your nearest salt marsh?

All of the region's salt marshes are near urban areas, and many have a visitor center and walking trails. Try not to disturb the animals or the plants—don't even leave footprints if you can avoid it. But do return again and again, because something new happens every day, every week, and every season. I'll write more about that in the next chapter.

My earliest observations of southern California salt marshes were with students from San Diego State University. I was teaching ecology and demonstrating how plants change in response to the environment (vegetation patterns).

Students in a field class helped me sample vegetation in relation to elevation at Tijuana Estuary. **Jeff Crooks**, third from the right, is now the Research Coordinator at Tijuana Estuary. Jeff continued his education and obtained his PhD at Scripps Institution of Oceanography. You'll meet other former students in later chapters.




The intertidal marsh extends from the lowest limit of vegetation (next to the mudflat) to the highest elevation covered by high tides (next to the upland). The vertical range is only about 1 meter (3 feet)!

You might not recognize these plants, which I drew on my computer—but later, you'll see that a digital drawing allows me to move the birds to show where they are during high tide.

Why is the salt marsh such a great place to bring students on a field trip? Here are three reasons:

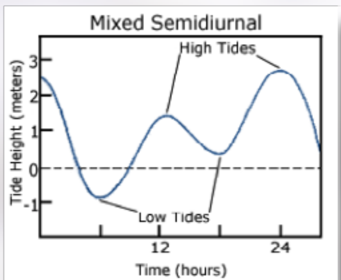
• It's easy to see patterns, because environmental conditions change so much with just a small change in elevation (but a big difference in tidal inundation regime).

• The vegetation doesn't include very many species (a plant species is a group of plants that can interbreed and produce like offspring).

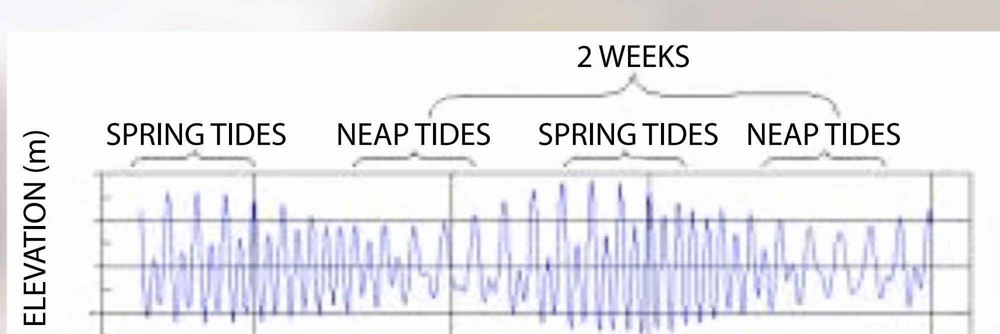
• It's easy to see that the species differ with elevation (meters above Mean Sea Level). Can you see differences in the Volcano Marsh photo, from the high marsh, across the marsh plain, and down into the cordgrass? Those changes occur within just a 1-meter elevation range!


--I wanted to know more! I didn't expect to spend most of my career helping students uncover salt marsh secrets, but once we got started, it was hard to stop.

If you understand the tides, you can visit the marsh when the tide is low and have plenty of time to observe the entire marsh when it's not inundated. September and March are great months, because the tidal range (amplitude) is minimum at those times.

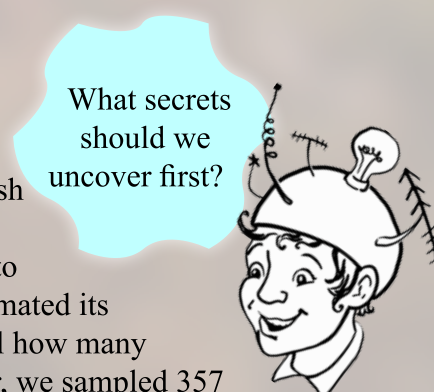



Southern California has a mixed semidiurnal tide cycle with two high and two low tides with different water levels every lunar day. "Mixed" refers to those different high levels and different low levels. "Semidiurnal" means partial day. Many areas on the western coast of North America experience semi-diurnal mixed tidal cycles. On the Atlantic Coast, diurnal tides are common, with two high tides of the same water level and two low tides of the same level.




Study tide graphs for southern California online (see oceanservice.noaa.gov) to see how much the water level changes in a few hours, a day, a month, and over the entire year. The low intertidal elevation is wet most of the time, while the high intertidal marsh elevation is only wetted by seawater during the highest high tides of the year, which occur in January and June.

The most obvious place to begin was to quantify (describe, using data) the distributions of plant species over the intertidal elevation range at Tijuana Estuary. Students seemed interested, so I asked the class to lay out long transects (using meter tapes) from the high marsh toward the cordgrass. At a random point within each 10-m segment of the transect, we placed a circular sampling frame over the plants to outline a 0.25-$m^2$ plot. We recorded each species in the plot and estimated its cover (imagining the shade it would cast at high noon). I don't recall how many students worked with me, but I am grateful for all the help. Together, we sampled 357 plots. At the same time, lots of students learned about vegetation patterns.



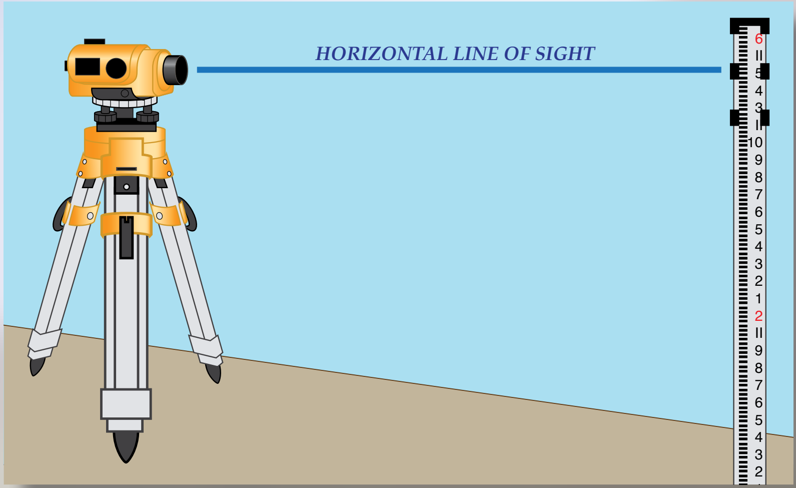
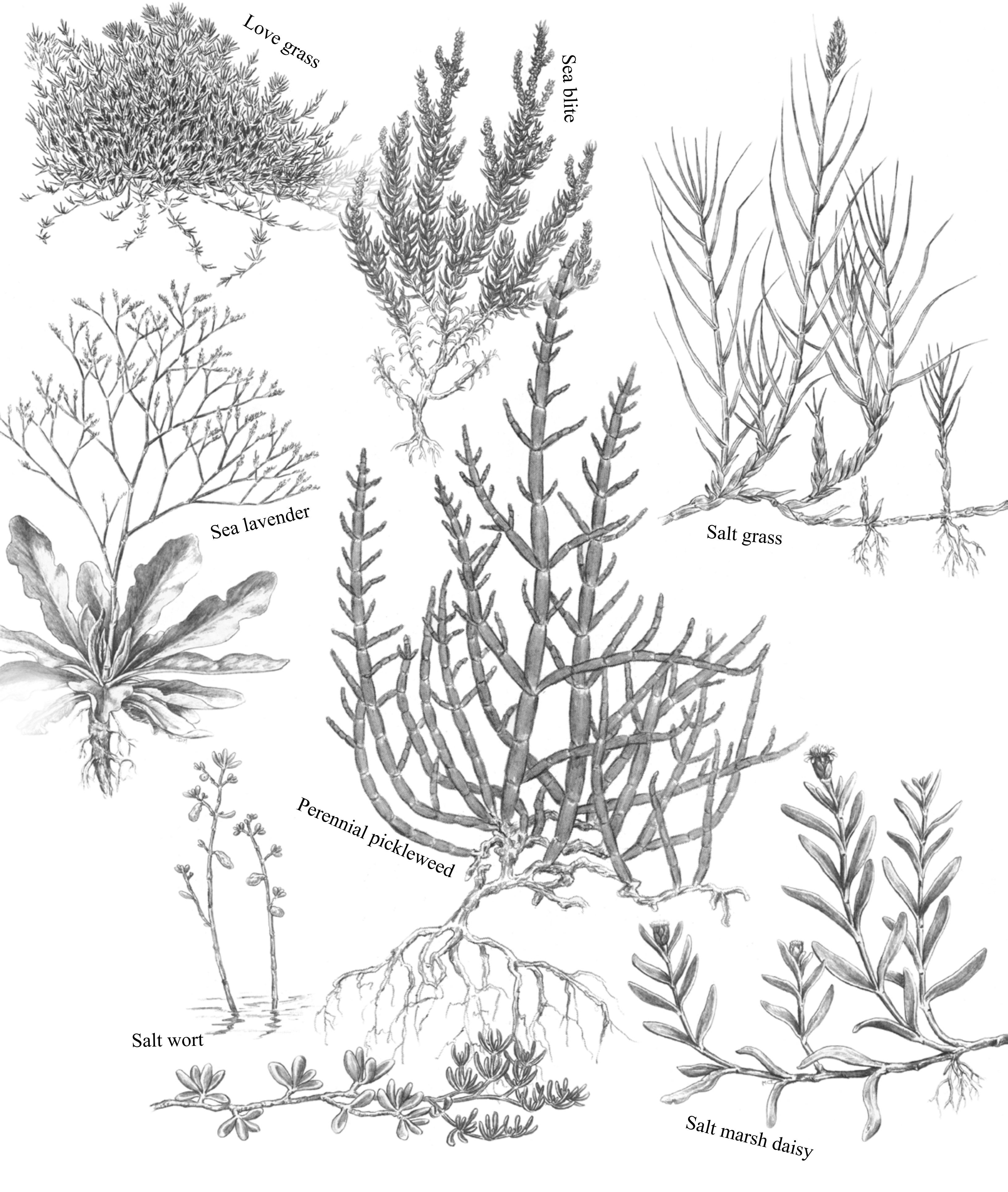



Diagram of an autolevel.

We also measured the elevation of each plot using an auto level. There were lots of benchmarks (points with known elevation above mean sea level) in the salt marsh from an old survey of mean higher high water (MHHW; I explain tide lines later) made by the US Army Corps of Engineers. We placed our auto level in the high marsh and got its elevation by surveying to the benchmark. Then we were ready to measure elevations of all other plots. One student would stand at the level, point it at the second student at the plot being sampled, and read numbers on the stadia rod (stick with metric ruler) placed in the middle of each plot. Knowing the height of the auto level and each position of the stadia rod as you move from plot to plot, you can determine the elevation of the ground relative to a reference point.

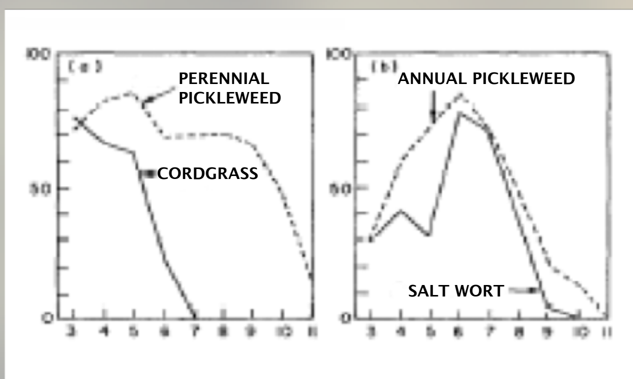
Here's part of a 0.25-$m^2$ circular plot. How many species do you see?

Common names of plants (illus. by Donovan McIntire © Zedler).


Love grass
Sea blite
Salt grass
Sea lavender
Perennial pickleweed
Salt wort
Salt marsh daisy

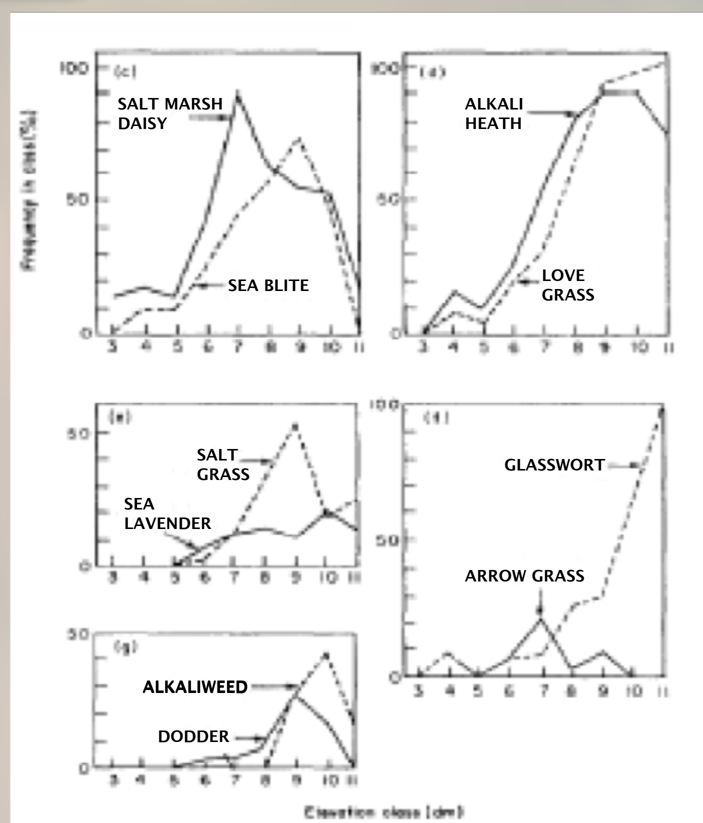
Now for the fun part—analyzing the data. First, the information on data sheets had to be entered into digital spreadsheets. That made it easier to count the species of vascular plants (they have xylem to transport water up and phloem to transport liquid food down—unlike the more primitive mosses and algae). There were just 14 species in our data (see illustrations above). Later, when we sampled vegetation at higher elevation and after winter rainfall, we encountered many more species—but the ones below are a good starting point for learning about the southern California salt marsh.

My goal was to describe changes in plant composition from low to high marsh, so I sorted the 0.25-$m^2$ plots into elevation "classes" above mean sea level (MSL). The lowest vegetation grew at 30 cm MSL, so the classes were 30-40 cm, 40-50 cm, etc. Then I counted the number of times each species occurred in plots of each elevation class. The graphs below show how each species changed from low to high elevation.




Cordgrass dominated the marsh-channel edge and only the marsh edge! Why was it's distribution so narrow (read Edith Purer's hypothesis in this chapter and Jordan Covin's work in a later chapter). However, perennial pickleweed was also abundant at low elevation and across the marsh plain, along with annual pickleweed and salt wort.

A little higher in elevation were Salt marsh daisy, Sea blite, then Alkali heath, Love grass and Glasswort, Salt grass, the parasitic Dodder, Alkali weed and Sea lavender were less common, but some were found at many elevations. Check the species' elevations in the graphs to see the elevation of each one's peak occurrence (the top point of each curve).




Are any two peaks the same? Or does each species thrive at a unique elevation?

Graphs like these are useful in predicting which environmental conditions are most suitable for each species. More patterns were visible in the field, however. The vegetation changed most obviously where the tallest plant of the salt marsh, cordgrass, was replaced by a mixture of shorter succulent species at 6-7 decimeters (dm = 60-70 cm) above Mean Sea Level (MSL). Also, clonal species (vegetatively reproducing, after establishing from seed) formed large circular patches. Salt wort and salt marsh daisy are great examples. Both have unique colors that make their patches very obvious. Salt wort is yellow-green, and saltmarsh daisy is bluish-green.

Why are salt marshes different from freshwater marshes and from uplands?

Salt and water depth are critical factors for salt marsh plants and animals: Who discovered that southern CA salt marshes are hypersaline and strongly affected by tidal inundation?

**Edith Purer** Before I was born, Dr. Edith Purer had already published her 1942 monograph (a very long paper), called "Plant ecology of the coastal salt marshlands of San Diego County, California." You can read more about her at www.naturespeace.org/purerantholgy.htm. From 1939-40, she measured water salinity every month at 12 estuaries, from Tijuana Estuary north to Santa Margarita Estuary. I wonder what kind of car she drove and how much time it took to visit all those places, sample the water, dig a hole and sample the soil, and then to measure the salt concentrations.

We were luckier—my team had a refractometer to measure salinity in the field.

Hand-held refractometer showing the reading for seawater (3.5 % = 35 parts per thousand). www.aquaseasalt.com

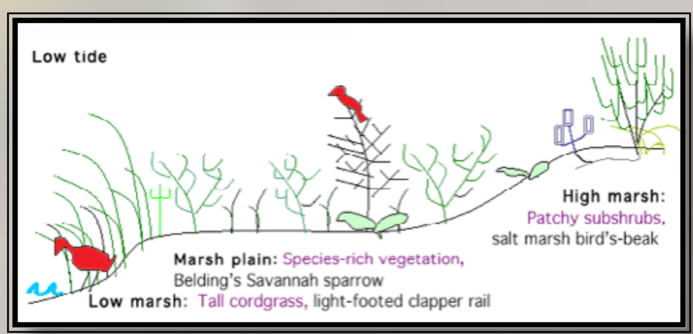
In 1939, Purer monitored (sampled consistently over time) water and soil salinity at 12 estuaries every month by collecting samples and transporting them back to the lab in La Jolla. Here's what she said on page 83:

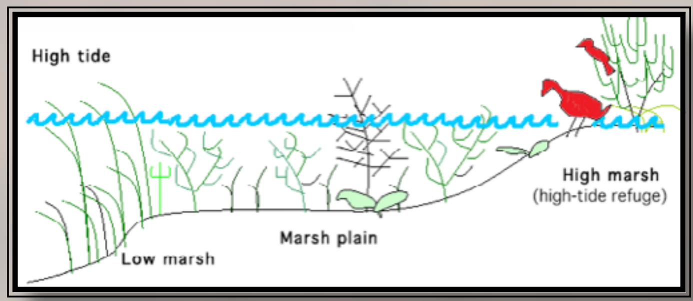
> *"The water samples were obtained by dipping a glass container into the saline water and immediately corking. The soil samples were obtained by digging, allowing the water in the hole to settle. All the water and soil analyses for salinity were made by the Scripps Institution of Oceanography, La Jolla, through the kindness of Dr. E. G. Moberg."*

A little digging on the internet revealed that Dr. Moberg was in charge of navigating the Scripps' boat and sampling seawater, as summarized in a July 1929 Annual Report (http://scilib.ucsd.edu/sio/annual/sio_1928-1929.pdf):

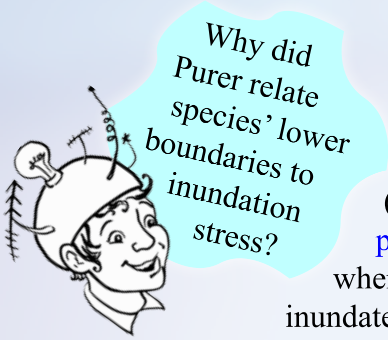
*"Dr. E. G. Moberg continued in charge of the scientific work and the navigation of the "Scripps." During July and part of August 1928, and June 1929, the boat was used once or usually twice a week for collecting trips to stations located five and ten miles from the Institution pier. At these stations surface and subsurface temperatures, water samples for various chemical analyses, and plankton samples were obtained."* I suspect that Dr. Moberg could analyze a few more samples from the estuaries while doing his own monitoring.

**Dr. Purer** was a botanist (person who studies plants) by training, but her holistic (broadly-viewed) explanations of coastal marshes would make her an ecosystem scientist today. Now, most of us need an entire team to address matters of water, soil, vegetation, and animal life. Not Dr. Purer. Her descriptions of vegetation in estuaries (usually tidal) versus lagoons (usually non-tidal) and from low to high intertidal elevations show that she was a keen observer. She developed an early idea about what caused the change in plant composition from low elevation to high elevation. Today, that idea would be called a hypothesis since it had not been tested experimentally to show cause → effect. Here's what Purer decided: The lower limits of species distributions are due to physical limiting factors at their more stressful boundary and the upper limits are due to competitive interactions at their more benign (non-stressful) boundary.

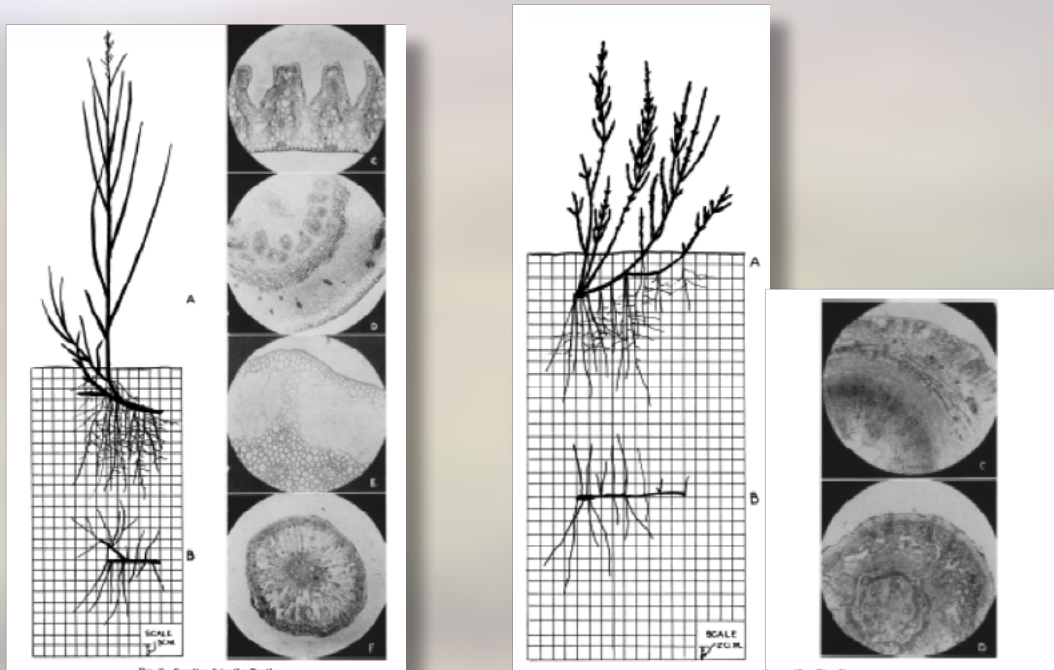


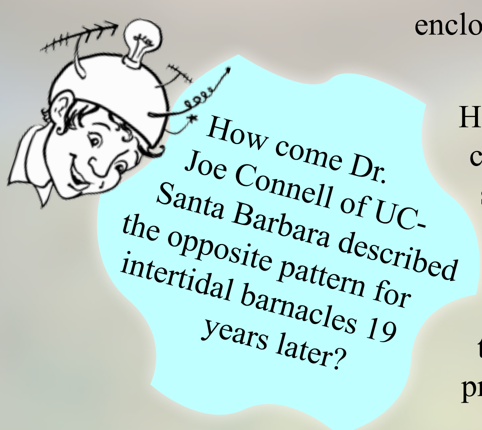

Cordgrass cannot grow in subtidal (always inundated) conditions. It can grow lower in the intertidal area than all the other halophytes. I suspect that's because it is a tall plant. Even when the tide is high, some parts of some leaves are above water, where they can take in carbon dioxide and convert the energy of sunlight into organic matter via photosynthesis. Leaves below water wouldn't produce much organic matter, however, because the water absorbs so much of the energy and "shades" those leaves. So cordgrass can only grow as deep as it can show a net gain in photosynthesis (that is, more organic matter production than it burns in maintaining itself via respiration). A lot of the respiration occurs in the roots and rhizomes (horizontal stems that grow new shoots) belowground. Because the soil has very little oxygen, the roots and rhizomes have lots of air tissue that helps oxygen move to cells that are busy respiring to stay alive. Cordgrass does not grow in subtidal conditions because they are too stressful!




She looked for causes of distribution limits both macroscopically (visible to the eye) and microscopicically (inside the plant using magnification). Check out her illustrations of root cross-sections (slices cut to see inside). She also kept records of each species' phenology (events, such as flowering). These data helped her explain where each species occurs, from frequently inundated (e.g., Cordgrass, inundated twice-daily) to what is now a very rare plant, Watson's saltbush *Atriplex watsonii*, at the salt marsh transition to upland.



Here are Purer's illustrations of cordgrass (left) and perennial pickleweed right), circles enclose root cross-sections. Note the air spaces.




He said the lower elevation conditions were benign and that allowed competitors to determine how deep barnacles could grow. He said the upper, more-exposed conditions were more stressful, so physical conditions limited the upper extent of barnacles. Which animals are stressed when the tide is in? Which are stressed when the tide is out? The clapper rail can move upslope, to avoid being inundated. However, it might be stressed by predators from upland ecosystems (coyotes?).

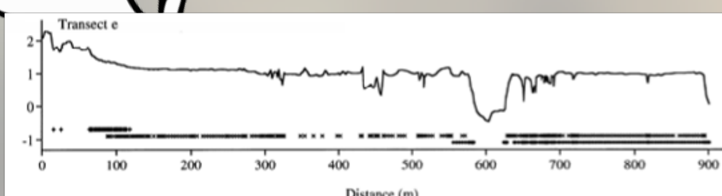
Are you confused? If so, you are not alone. The literature on this topic is misleading. Let's think about it: "Stress" is not an absolute variable. Instead, it depends on the species and how it can cope with the physical environment. Stress is the reduction in productivity of whichever species you are considering. What is stressful to a barnacle is not the same as what is stressful to cordgrass. Inundation can be stressful to a plant and benign to an animal.

The hypothesized differences in stress are reversed for barnacles, which are aquatic animals that thrive and feed when inundated, but experience desiccation stress (drying) when the tide leaves the marsh and exposes the rocky shore. In reverse, salt marsh plants are stressed by inundation (water covering most of the plant) at high tide but easily tolerate exposure. The generalization is that physical factors (non-living) limit a species at the stressful end of their distribution and competition limits a species at the benign (less-stressful) distributional limit.

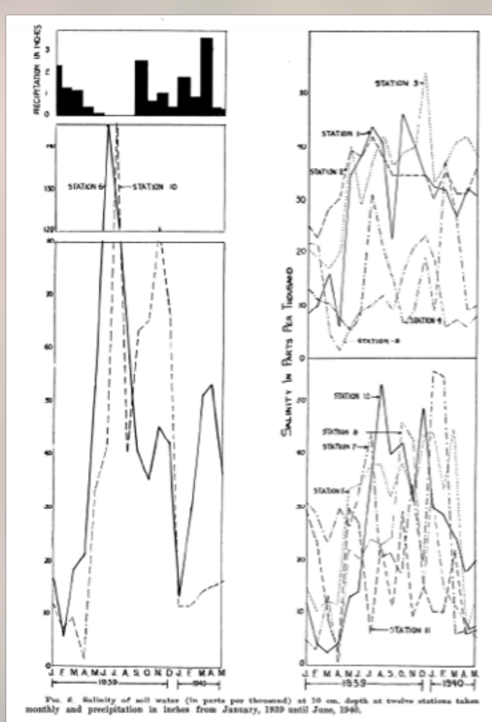
Dr. Purer identified adaptations that explained the patterns she saw. Ample air tissue (aerenchyma) in roots explained which species could tolerate the most inundation.  Armed with a hypothesis for cause → effect, she grouped the salt marsh vegetation into three vertical bands, a characterization that persists to date:

- lower marsh with cordgrass,
- middle marsh with pickleweed, and
- high or upper marsh with alkali heath, salt grass, and love grass and others.

In 1999, we showed that these three bands were related to complex changes in elevation, not a simple gradient (gradual change).  Elevation changes rapidly near the upland, is relatively flat across the "marsh plain" and changes rapidly again near the bay or estuary channels.  Dips in topography represent cross-sections of tidal channels and creeks




Surveyed elevations for Volcano Marsh from the upland to the waters edge, at San Quintín Bay (Zedler et al. 1999)



Purer's graph of monthly water salinities at 12 sites shows a range from near 0 during heavy rainfall periods to over 140 ppt – yikes, that's 14% sea salt.  Seawater is only 3.4% salt.
Then she plotted the *soil* salinities.  Only 3 of her soil salinity plots were under 3.4% during her 1939-40 study—these were: Soledad (a.k.a. Los Peñasquitos Lagoon), Del Mar Lagoon, and San Luis Rey R.  All three brackish sites (between seawater and freshwater in salinity) must have had substantial freshwater inflows and minimal tidal influence during her study.

Based on salinity, Purer grouped the 12 marshes into three types:

- large bodies of water, connected to the ocean, with near-constant salinity,
- fluctuating salinity with inflows from freshwater streams, and
- small area, usually nontidal, seasonal stream inflows, widely-ranging salinity.

Lessons:

- Few ideas are truly original. Scientists can usually trace their hypotheses back to earlier publications. This is much easier now that we can search the literature electronically!
- Simple explanations are not likely to be complete (cordgrass responds to both elevation and to bay proximity).

Exercise: Visit a nearby salt marsh and record your observations in a field notebook with a date for each visit. Here are some things to record:

- Estuary and salt marsh area you're describing
- Date, including year
- Water level relative to some permanent fixture that you can revisit
- Level of the debris line from the last high tide
- Condition of plants—lush and green? Stressed and brownish?
- Any animals you spot and where you saw them
- Other observations
- Sketches

Edith Purer learned so much so early, with so little technological equipment, and no collaborators that I know about. I only quibble with one thing that Dr. Purer wrote, that "Algae play an insignificant role in these marshlands." In the 1980s, the secrets of algae were revealed (described in a later chapter).

You can explore the past by locating the region's "T-sheets" (T = topographic), which are maps drawn in the 1800's. Thanks to Eric Stein et al. (2010), these long-held secrets are now assisting our understanding of the historical distribution of a great diversity of wetland types, as well as the diminished status of species that are now rare.


Knowing the urbanized San Gabriel watershed today (this entire mapped area is covered with Los Angeles urban development), it seems hard to believe that it once supported "complex expanses of channels, ponds, sloughs, seeps, marshes, and seasonal wetlands that alternated between wet and dry conditions on multi-year to decadal cycles. We estimate that >86% of historical wetlands have been lost since ca. 1870, with the greatest losses occurring to palustrine alkali meadows in the lower floodplain" (Stein et al. 2010).

At the same time, historical analyses suggest ways that former conditions might and might not be restored. Ballona Wetland in Los Angeles, for example, used to have deep tidal channels with adjacent salt marshes. The channels were expanded and modified to create Marina del Rey. To restore deep-tidal-channel habitat, areas that have been filled or riprapped are now planned for reconfigurations that accommodate existing infrastructure (oil wells, roads, power lines, etc.).