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).
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PDF name and brief description:

Fishing for answers!

In the 1970s, estuarine scientists debated whether or not salt marshes were the source of food for coastal fisheries. Professor Eugene Odum (1971), from the U. of Georgia, called it the "outwelling hypothesis." He meant that the highly productive cordgrass marshes of the US Atlantic Coast must be contributing more than the occasional snack for coastal fishes. It was already known that the large, widespread saltmarshes were dominated by smooth corgrass (*Spartina alterniflora),* which often produced over a kilogram of dry biomass per square meter per year. Surely, fishes that came into the estuaries used them as a nursery because of abundant food. Just as surely, the large, twice-daily ebb tides would carry the dead biomass (detritus) out to sea, and all that food from the salt marshes would fuel the coastal food web.

It was Evelyn Haines who found a way to evaluate the base of the food web (see chapter sixteen). Her work showed that algae play a more important part in the food web than cordgrass-based detritus. She helped debunk the paradigm (widely accepted description) that salt marsh detritus fuels coastal food webs.

Wouldn't you expect Pacific Coast estuaries to be different? After all, our estuaries are smaller and separate from one another along the southern California coast. Also, our cordgrass is not as productive (see chart in the Preface to this e-book). We questioned some of the ideas from the Atlantic Coast studies:

Is detritus a suitable food base?
Is detritus a better food if it is aged (by decomposers)?
How useful are southern California's salt marshes for fish?
Are the coastal wetlands too variable in salinity to be habitable?

Topsmelt (illus. Mcintire © Zedler)

Invertebrates and fish are good indicators of estuarine conditions, because they are sensitive to several aspects of water quality, and especially salt content. Benthic (living on the substrate) invertebrates are very good indicators, because they are stationary; they can't escape when a low tide exposes them to drought, or a freshwater flood pours into the estuary. Their numbers over time record useful information on estuary condition. For those reasons, PERL sampled benthic macroinvertebrates and fishes of Tijuana Estuary and Los Peñasquitos Lagoon annually--monitoring that continues to date. That revealed who lives where, but not what they eat.

Phil Williams tested the value of salt marsh plant biomass as a suitable food for mussels (*Mytilus edulis*). Mussels weren't his first choice for study, however. He had planned to use the little-neck clam (*Protothaca staminea*). Unfortunately, flooding in 1978 wiped out populations of that clam and most other bivalves (two-shelled molluscs). That left mussels. The mussels became an indicator species—if they could grow on cordgrass or pickleweed biomass, then other species could probably grow on them as well. Phil asked, could mussels from Tijuana Estuary grow better if supplied with fresh detritus or his "enriched soup" or in filtered or unfiltered seawater?

How did Phil answer his question? First, he dried cordgrass and pickleweed and created artificial detritus by breaking up dry leaves in a Wiley Mill (which produces particles of uniform size by grinding till they pass through a screen with known pore size). Then he aged some of the detritus to make an enriched soup. Would you like his recipe?

How to make an "enriched soup" to feed mussels: Grind dry leaves in a Wiley Mill (which produces particles of uniform size by grinding till they pass through a screen with known pore size). Age some of the detritus by soaking it in channel water (full of micro-organisms) for four days. Aging allows bacteria and fungi to attach to the detritus particles. In the process, the detritus is enriched with protein added by microbial biomass.

Phil collected small mussels (2-15 mm shell width, measured with a Vernier caliper). He tagged each with a numbered tape label that he attached with waterproof cement. Phil designed experiments to measure growth of mussels on different diets in both field and laboratory experiments. He submerged experimental mussels in a tidal channel at Tijuana Estuary that drained a marsh of mixed vegetation. He expected much of the detrital nutrition in the creek water to come from the vegetation and from algal and animal remains in the marsh.

At the SDSU Marine Laboratory on Mission Bay, he placed mussels in plastic buckets that he modified to circulate and filter the water. The laboratory treatments were additions of fresh detritus and aged detritus in filtered or unfiltered seawater. Every week, he compared water samples from the tidal channel and laboratory by measuring suspended organic matter, microbial activity and phytoplankton biomass. His measure of "good food" was increased growth of mussels, meaning that he measured shell width and weight of every mussel at the beginning and at the end of his study.

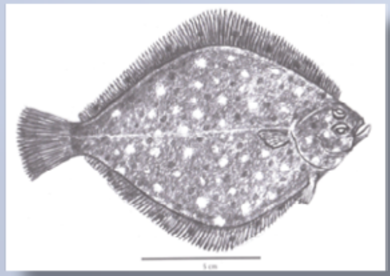
MUSSELS PREFERRED AUTHENTIC FOOD. Phil's experiments showed that mussels grew well in the Tijuana Estuary tidal channel. Growth was less obvious in the laboratory and not significantly different among the various diets. Mussels on some diets of detritus added weight, while mussels on other diets lost weight, whether the detritus was aged or not. All mussels grew in size, so mussels were adding calcium carbonate to their shells.

Phil tested to see if his aquaria inhibited growth. He placed mussels in Mission Bay and compared their growth to those in the laboratory. Those in the Bay grew significantly more than those in the aquaria. Phil's laboratory study led him to conclude that plant detritus was of little importance to mussels in the Tijuana Estuary channel.

Tidal water likely had other nutritious foods, such as phytoplankton. It is possible that the abundant algae growing on the salt marsh soil (chapter two) were also fueling the marsh food web. The importance of algae to the marsh food web was supported by stable isotope analyses (chapter sixteen). Remember that high-tide water flowing over the marsh surface can pick up and transport bits of algae to channels at low tide.

Do fish use salt marsh channels as a nursery?

If people knew more about how salt marshes support fish, I think they would support salt marsh conservation and restoration efforts. For example, bird watchers would care because the salt marsh produces prey for predaceous birds.



Diamond turbot (illus. Mcintire © Zedler)

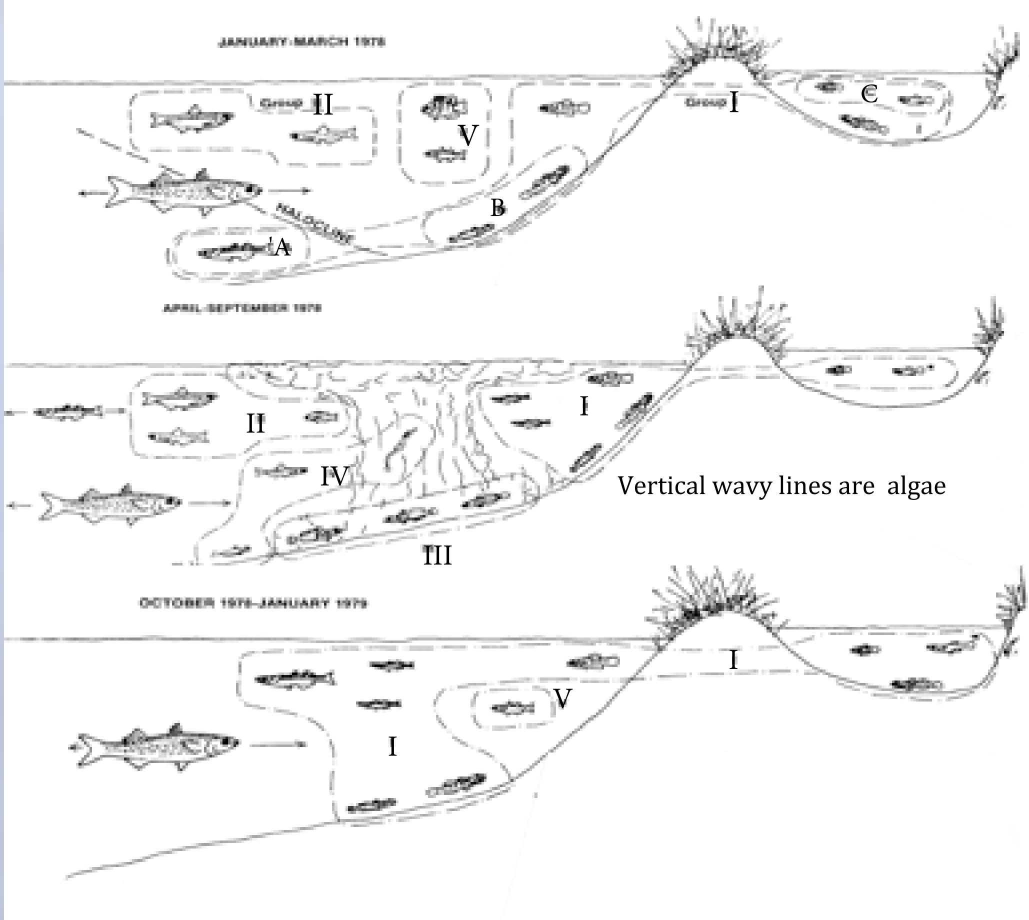
People who like to fish offshore for diamond turbot (*Hypsopsetta guttulata*) and California halibut (*Paralichthys californicus*) would want to conserve salt marshes if they knew that's the home of their larvae (newly hatched from eggs, with yolk sac as a food supply). The idea of a nursery is that fish spawn there or their larvae come into the estuaries to grow and fatten up. Channels provide nursery habitat. It's one thing to describe the pattern; it's harder to know the cause of the pattern.

Fish might make use of salt marsh channels as a nursery because, relative to the nearshore ocean, the channels and creeks have warmer water and more food. At the same time, fish larvae that venture into shallow waters might be eaten by bigger fish.

Chris Nordby was an early proponent of research on fish use of our local coastal wetlands. Studies on the Atlantic Coast had already shown that salt marsh and estuarine habitats were “nurseries” for juvenile fish. Chris introduced me to Larry Allen’s (1982) fish habitat profiles for Upper Newport Bay. You can read Allen’s paper online (http://fishbull.noaa.gov/80-4/allen.pdf).

Below, I modified Allen’s diagram that shows how fish use different habitats over the seasons. . Five groups are correspond to each list of fish on the right. Note that year-round residents = Group I, which has three subgroups, A, B & C.

Note: YOY = young of the year



I.A. Topsmelt
I.B. Arrow goby,
Longjaw mudsucker
I.C. California killifish
Mosquitofish

II. Slough anchovy
Aggregate goby YOY
Deep body anchovy

III. American shadow goby
Cheekspot goby
Pacific staghorn sculpin

IV. Northern anchovy
Pipefish species
Diamond turbot

V. Striped mullet
Bluegill sunfish
Green sunfish
California grunion

Collectively, the fish eggs and larvae are called ichthyoplankton. After using up their yolk sac, the larva becomes a juvenile that needs to find its own food.

For his MS research, Chris Nordby asked a basic question about which fish eggs and larvae use the salt marsh channels at Tijuana Estuary—were they similar to those that lived in nearshore shallow waters of the Pacific Ocean, or were they more similar to fish in the smaller tidal creeks? Compared to the ocean, the estuary's warmer water and plentiful food is more like a nursery.

Chris asked four questions:

Does Tijuana Estuary provide unique spawning or nursery functions?
Do tidal creeks and main channels provide different fish habitat?
Do nearshore surface and bottom waters differ in fish use?
Do fish use the estuary and nearshore areas differently during day versus night high tides?

SAMPLING FISH EGGS AND LARVAE. Chris's plan was ambitious—involving sampling of both eggs and larvae, both nearshore and estuarine, and both day and night. That's a lot of samples to inspect under the microscope back at the lab! Also, the gear needed differed with the objectives. In most cases he needed a boat. Not a little kayak or canoe but a 4.9-m Boston Whaler for use in the nearshore water. It had a 70-horsepower outboard motor and an A-frame to use in retrieving the plankton net. In the estuary, he used a 4.9-meter (16-foot) inflatable boat and a 4.9-m aluminum dinghy, both with a 6 horsepower motor, so he could pull a 30-cm-diameter plankton net behind the boat in the estuary channels and the 50-cm net offshore. The plankton net had a flowmeter in the center of the net's opening to calculate water volume being filtered as he cruised alongshore or in the main estuary channel.

In tidal creeks, Chris anchored a channel net that sampled from top to bottom as the high tide receded (see photo of Julie Desmond using a similar net below and on the e-book cover). Lots of macroalgae were collected along with fish eggs and larvae. The algae were not discarded. Why not? Because topsmelt were known to attach their eggs on the blades of such algae! Chris had to devise a subsampling procedure to account for eggs on algae, so that he did not have inspect every mile of algal filaments collected in his creek sampling.

The channel net did not prevent fish escapes under the net—a problem he corrected by December 1980. In smaller creeks he attached the plankton net to a long aluminum rod and pulled it through the water column while walking along the creek edge.

Between September 1980 and August 1981, Chris collected 379 samples from the nearshore waters and 197 from within the estuary. Can you guess how many fish and eggs he found?

SORTING AND COUNTING. In total, Chris counted 49,971 eggs, of which 41,127 eggs came from the nearshore water and 8,844 eggs from the estuary. And what about larvae? In all, he found 21,370, with 8,232 from nearshore water and 13,138 from the estuary.

But which species were they? First the larvae: A whopping 23 species of larvae were identified and 6 more were not identifiable at their young age. Some of the larvae were identified only to family level (silversides [including topsmelt], gobies, clingfishes and pricklebacks). Some of the identified larvae represented multiple species that could not be distinguished, like 3 species of blennies (genus *Hypsoblennius).*

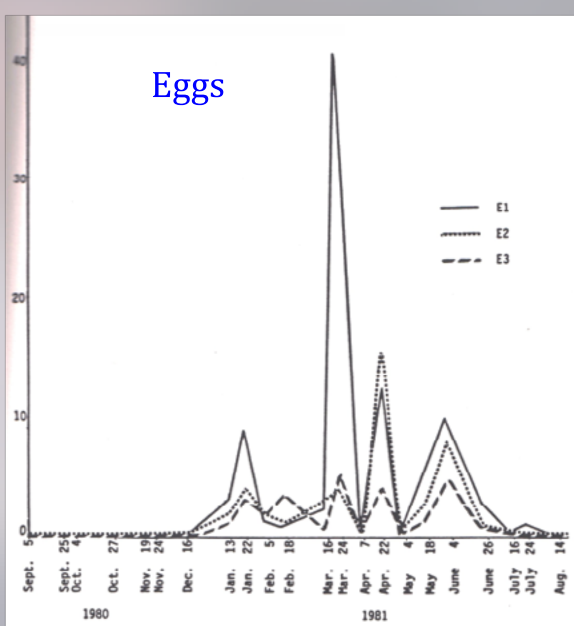
Next the eggs: can you imagine trying to tell different species of eggs apart? Chris was able to identify 14 species, plus a genus and a family. Wow; that's 16 taxa (some not identified to species).

Combining larvae and eggs, the total number was 34 taxa from 21 families. What a feat! Here's a secret about Chris—much of his later career concerned plants—figuring out how to restore them in various salt marshes. His work with plants benefited from his knowledge of fish and channels and creeks and tidal flushing. In fact, the use of the estuary by fish is a major reason to restore tidal flushing for fish and plants.

Spatial and temporal variation in ichthyoplankton

Of the eggs found in the main channels of Tijuana Estuary, 69% were those of drum (Sciaenidae). Of the larvae, 61% were gobies (type I).

Channels were far from uniform in their species composition and abundance of eggs and larvae. These graphs show stations E1, E2 and E3 in the north arm of the estuary; each is unique.



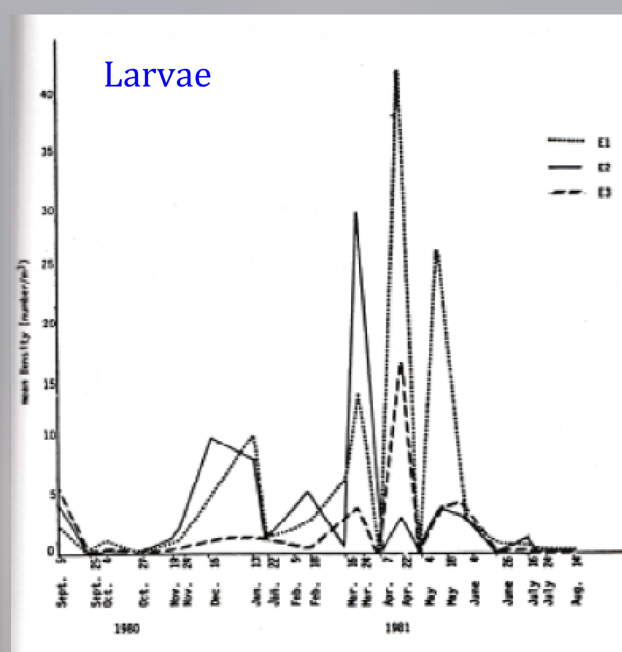


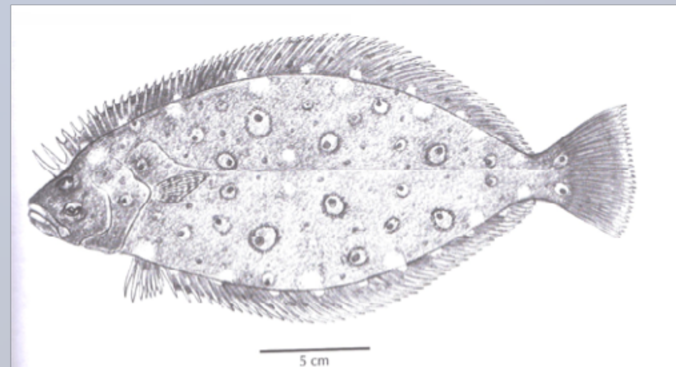
Figure 2. Mean densities (n=3) of larvae collected at three main channel sampling stations at Tijuana Estuary.

With high variability among his sampling areas, Chris could not test for cause → effect, but he could speculate about how differences in channel morphology and food resources were responsible. Future studies can build on his research findings (Nordby 1982).

LARVAE AND EGGS WERE HIGHLY VARIABLE OVER TIME. The highest densities of larvae were collected in March, April and May—especially gobies and especially near the ocean mouth. The highest numbers of eggs were in March (big peak) and April, again near the mouth, with drum eggs in the lead and Pacific sardine (*Sardinops sagax caeruleus*) in second place.

Chris found that nearshore water and estuary channels were similar in their ichthyoplankton. Pacific halibut and flounder were, indeed, using the deeper estuary channels.

However, the smaller tidal creeks were different. Unlike deeper channels, the creeks supported mudsuckers, gobies and topsmelt.

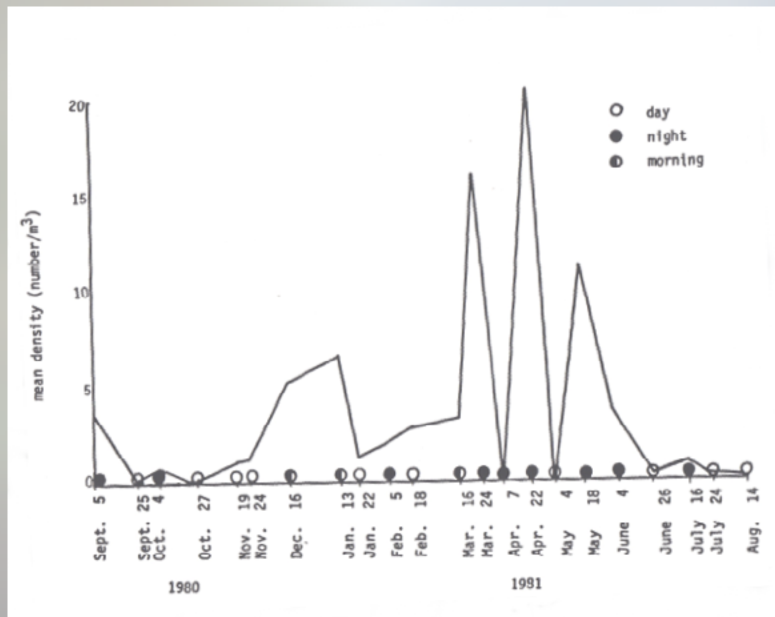


Pacific halibut (illus. Mcintire © Zedler)

In plankton tows of two tidal creeks, Chris found lots of topsmelt larvae and drum eggs. He also demonstrated the importance of creeks for winter spawning of longjaw mudsuckers in January and topsmelt and northern anchovy in February. A further experiment in April 1981 showed that topsmelt larvae and eggs were indeed associated with macroalgae. The algae might provide a refuge; they also provide food for juveniles and adults. They certainly provide spawning and nursery functions for topsmelt.

Meanwhile, offshore, eggs were similar in composition but larvae were more different. Goby (type I) made up 40% of the total caught, with two drums (queenfish and white croaker) at 20 and 16%. Northern anchovy made up 15% of the total.

DID EGGS & LARVAE DIFFER WITH WATER DEPTH OR TIME OF DAY? Yes and yes (see graph, next page). Larvae were far more abundant in sample near the bottom of the water column than near the top. Eggs, in contrast, were often more abundant near the surface. Additional sampling showed that eggs of some species (notably drums) were more abundant in inflowing tidewater than outflowing water.



Day and night sampling produced differences that were difficult to interpret. Above are densities of larvae sampled in the three main estuary channels during high tides that occurred during day (open circles), night (dark circles) and night samples that ended in the early morning (half-dark circles).

Some differences in day and night samples could be explained by larval behavior, if they avoid the net during the daytime. Perhaps some of the variation is due to short-term spawning events or vertical migration of gobies during full moon.

ARE MORE DATA NEEDED? Of course! Keep in mind that the ichthyoplankton data represent a single year. Knowing how variable the eggs and larvae of various species of fish can be, it is easy to call for more data. But when you consider how much effort went into this early study—both sampling and microscopic identification—it's easy to understand why most students choose to work on macroscopic species (those that can be identified without the aid of a microscope).

For similar reasons, my stint as a phycologist (one who studies algae) was brief and born out of necessity. I needed a job in a place at a time when teaching phycology was all that was available. While life under the microscope was like entering a new and exciting world, it was not easy for me to sit still long enough to quantify types and numbers of diatoms or other algae. I much prefer working with vascular plants. But how can we learn such lessons without trying alternatives. Looking back, I certainly don't regret the opportunity to explore that other world. It got me interested in ponds and wetlands and epibenthic mats and other things aquatic. My advice? Be adaptable!

Are the smaller tidal creeks important? Yes.

In 1995-96, Julie Desmond studied the fishes in tidal creeks in both Tijuana Estuary and Sweetwater Marsh. Over a one-year period, the smallest creeks (1st order) in both wetlands supported up to eight species and were dominated by longjaw mudsucker, California killifish, and arrow goby *(Clevelandia ios)*. The presence of juvenile killifish, California halibut, and diamond turbot suggested a "nursery" function (Desmond et al. 2000).

And the big channels? Also important.

At low tide, the fish congregate in the channels, where our fishing team stretched nets across the channel to block off a "sampling station." They dragged a bag seine from one side of the station to the other, repeating a few times. Walking in front of the bag drove the fish into the bag, where the fishes congregated and were removed for counting and measuring (then returning to the water).

During high tide, fish are free to move onto (over) the marsh plain to feed. At high tide, there is also more water in the channels for fish to tank up on marsh invertebrates. I should mention algae, too, for the vegetarian fish. I'm not kidding; adult topsmelt eat (and are able to digest) green algae (see chapter sixteen).

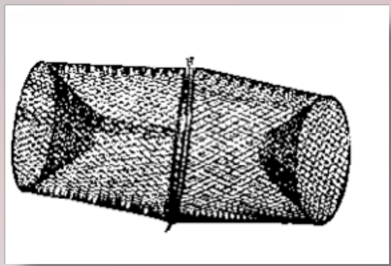
Which "marsh" foods are available to fish?

As part of her MS research on estuarine fish, Janelle West reviewed the literature and found about five studies of Atlantic and Gulf Coast fish for every Pacific Coast study. It was time to learn more about "our" fish. Because the southern California estuaries are small in size and dominated by resident fishes (not migratory species) and because the tides are mixed (one higher high tide per day), she expedcterd the salt marsh to be less important in providing food for fish.

Given our mixed semidiurnal tide, the "salt marsh buffet" is only open for a short visit every day. As a result, fish don't have much time to benefit from marsh food. Janelle wanted to know where she would find fish within the salt marsh at high tides and whether or not they found lots of food. She expected California killifish to be the most abundant and that their guts would be more full when trapped during high tide than when confined to tidal creeks by low water levels.

SAMPLING ON THE MARSH PLAIN. Janelle chose Sweetwater Marsh for her study. She used minnow traps to sample where creeks were not altered by major flooding or loss of tidal influence.

The minnow trap is a wire mesh cylinder with a funnel entrance that allows fish in but makes it hard for them to exit. Adding bait makes traps attractive, especially when the bait is something smelly like squid, used later to sample fish in pools at the Model Marsh.



During June 1997 to June 1998, Janelle placed baited traps on the marsh plain to compare with those placed in rivulets (very small tidal creeks). By referring to tide tables and summing the times when predicted tides were 20 cm higher than the marsh plain, she found that fish had access to the marsh foods only 9.3% of the time! Marsh plain access was predicted to be greatest from August through October 1997 and most limited (<5% per day) during April and May 1998. Access to the marsh edge was greater, of course, but the seasonal pattern was the same--and <10% of the time in April and May. So if fish depend on the marsh for food, they will not be treated to a smorgasbord in spring!

The minnow traps captured 790 fish with 5 species dominant: California killifish, longjaw mudsuckers, topsmelt, arrow goby and cheekspot goby. Only the cheekspot goby was restricted to subtidal areas of creeks; the others used the marsh surface in addition to tidal creeks. Most of the fish that Janelle trapped were California killifish (189) and longjaw mudsuckers (191). And most of them were caught in September and October. Most of the fish were caught in the small creeks that retained water for long time periods.

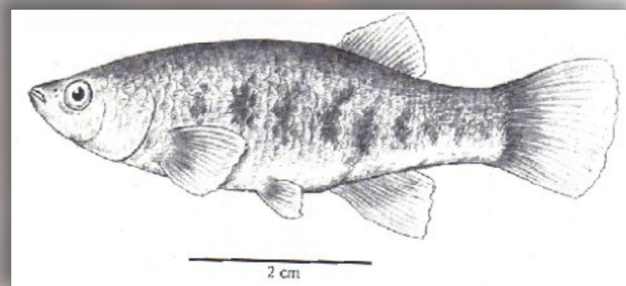
But that doesn't mean the creeks had the most food…..

WOW!

WERE THE FISHES' TRAVELS OVER THE MARSH PLAIN PROFITABLE?

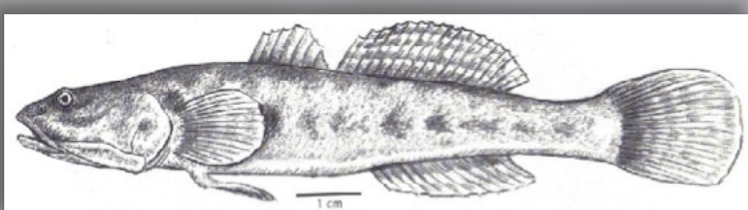
Yes! Killifish were able to obtain large volumes of food when they had access to the marsh at high tide—in fact, 6 times the "gut fullness index" for fish restricted to creeks (West and Zedler 2000). That's very high, given the short time that fish have access to the marsh.

> How did Janelle figure that out? This is a bit gory, so skip this paragraph if you'd rather not know. Janelle sampled a subset of fish in summer, collecting them as the high tide was ebbing, to represent feeding with and without access to the salt marsh. Fish were handled humanely, first by anesthetizing to make them unconscious and to slow digestion of prey. They were then preserved until the guts could be examined for "fullness." Back at the lab, she removed the foregut, where foods were least digested and most identifiable. She weighed the contents and then identified and sorted the prey. The general groups were polychaetes, amphipods, and copepods. What a task! Remember, these are mostly very small fish with even smaller guts. Weighing small prey required a high precision balance and careful handling.



Killifish (illus. Mcintire © Zedler)

Janelle's gut content index (GCI) was based on estimates of food weight per length of fish. Killifish that had access to the marsh foods had a GCI about 3 times as high as fish that were confined to the tidal creeks. The prey that they ate while on the marsh were mostly the same as those in the creeks, just more of them. Killifish without marsh access ate mostly amphipods, polychaetes, ostracods, detritus and copepods. Those making the journey onto the marsh plain also ate isopods, insects, insect larvae, small snails, and the occasional beetle and spider. Later, Sharook Madon used Janelle's data and his bioenergetics model to calculate that killifish could grow faster when the marsh surface was included in their "buffet."



Longjaw mudsucker (illus. Mcintire © Zedler)

Longjaw mudsuckers were also trapped on both the marsh plain and in small creeks, although their differences in feeding patterns were less than for killifish. Both fish species found different types of prey on the marsh and the data suggest that they found more food on the marsh.

Surprise!

Some longjaw mudsuckers fed on killifish both in creeks and on the marsh (making them piscivores). A few mudsuckers had also eaten other mudsuckers! Yikes—they were cannibals! Did this represent natural behavior or an effect of being confined in limited space in a minnow trap? We don't know.

Can you outline the kind of experiment that would be needed to separate natural behavior from trap-caused behavior?

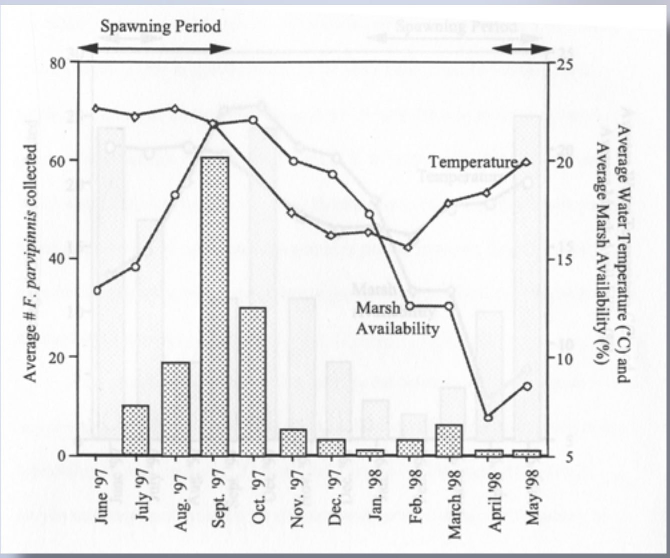
Do fish feed during the day and night? Yes.

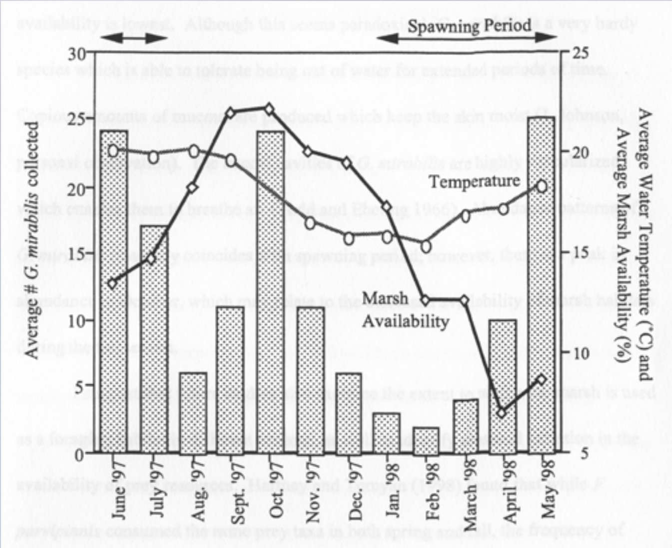
Both species of fish fed in the daytime and at night, whenever the there was a higher high tide. Their behavior responded to tide levels more than to light. For both species, the individuals that Julie caught in summer within the marsh were larger, on average, than those that did not have marsh access. This suggests some other interesting behavior—larger fish might be more able to swim onto the marsh than small fish. Perhaps there is a positive feedback, with well-fed fish being more likely to swim onto the marsh where they find more food and become larger. More research could reveal the patterns and their cause.

Below are two summary graphs that answer four questions:

When did killifish (*F. parvipinnus*) and longjaw mudsuckers (*G. mirabilis*) spawn? See arrows on top of graph.
How many did Janelle catch? See bars and left y axis.
What % of the time did the marsh have 20+ cm of high tide water? See right axis.
How warm was the water? Also on the right y axis.

Notice how numbers caught increase as the spawning period progresses. Of the two fishes, California killifish were most "in tune" with marsh availability and warm water.

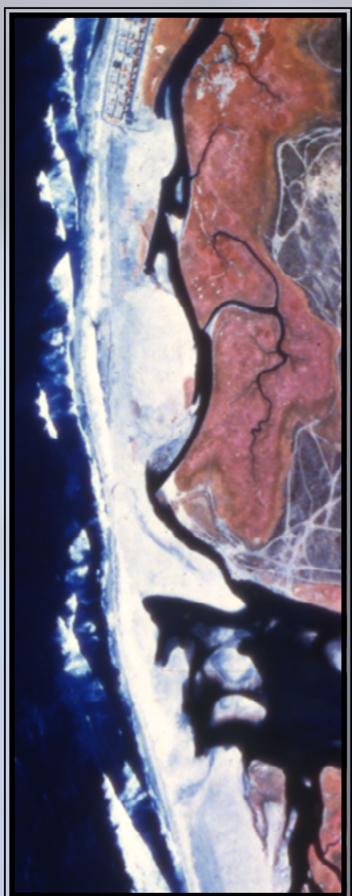




SUMMARY. Because tidal rivulets and creeks and channels are all important for fish habitat and fish foods, planners of coastal wetland restoration projects should include diverse habitats with dependable tidal flushing. All are part of the salt marsh system that supports fish.

How do fish react to warmer, more saline water?

Suppose that fish get trapped in an estuary when the inlet closes. Without tidal flushing, the channel water temperature and salinity rise. How might that affect fish growth and survival?



In Tijuana Estuary, large halibut were only present in the broad, deep channel along Seacoast Drive, where water temperatures were suitable. Unfortunately, the halibut did not consume enough food to grow.

Dr. Sharook Madon used his bioenergetics model to predict the impacts of tidal mouth closure between November and March. At those times, estuary water conditions can change quickly when water is diluted by rainfall and streamflows. For example, in March 1998, the mouth of Los Peñasquitos Lagoon closed, and both temperature and salinity increased when water was impounded. Small juvenile halibut were predicted to lose weight under those conditions, regardless of prey availability. Large juvenile halibut are less tolerant of variable temperatures and salinities and predicted to be more stressed by tidal mouth closure, especially given limited prey.

Sharook's bioenergetics modeling added to our understanding of habitat value for California killifish, topsmelt, and juvenile California halibut. Using data on fish sizes and gut contents, he could simulate various scenarios that allow fish to swim onto the marsh surface and take advantage of the foods available there.

In his model, the salt marsh foods (algae, inverts) grow with minimal predation when the tide is low, when fish cannot access them. Recal that it's the high tide water that allows fish to swim freely over the marsh. By measuring feeding and metabolism rates in controlled mesocosms in our greenhouse, Sharook used his model to estimate the importance of marsh access, temperature, and salinity to fish feeding.

Here's an example of a simple model:

California killifish growth was estimated as

$$dB/Bdt = C - (R + F + U)$$

where B is the weight of the fish, t is time, C is consumption, R is respiration, F is egestion, and U is excretion.

TESTING RESPONSES TO WARM WATER. Sharook sampled California killifish, topsmelt and California halibut in Los Peñasquitos Lagoon and Tijuana Estuary to assess foods in their guts (Madon 2002). He selected fish to take to our greenhouse, where he measured their growth rates in aquatic mesocosms (large aquaria) with controlled water temperature.

Sharook calculated that killifish can eat 2 to 5 times more food when they have access to the marsh surface. Furthermore, they can grow 10 times faster if they feed in both subtidal and intertidal marsh surfaces. In Tijuana Estuary, topsmelt consumed food equal to ~22-59% of their body weight per day. That's not hard when your preferred food is green algae! Large topsmelt (> 10 cm long) foraged almost exclusively on macroalgae. Eating gobs of algae compensates for its low protein content. Topsmelt feeding was estimated to be half as great without access to marsh food.

What went on in the nursery?

Juvenile California halibut used tidal channels in one way when they were young and another as they grew, like graduating from a tricycle to a bike as a kid. Small halibut (<12 cm Total Length = nose to tail = TL) were abundant in smaller channels where they had access to small prey, and larger halibut (> 20 cm TL) preferred deeper channels with cooler water (a thermal refuge).

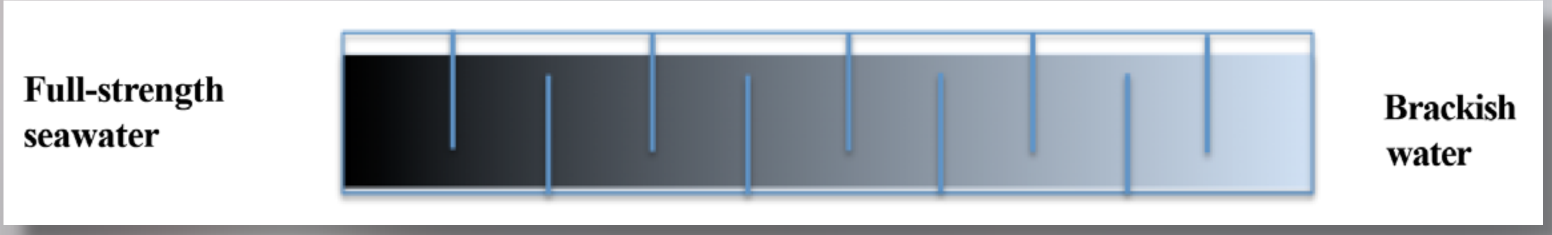
WHAT'S FOR LUNCH? What do juvenile halibut like to eat? The arrow goby is its primary prey. And goby densities are greatest in tidal creeks (West et al. 2003). Unfortunately, tidal creeks and channels are not always saline.

PLEASE PASS THE SALT! Chris Nordby documented declining densities of California halibut when excess freshwater inflows reduced water salinities (Nordby and Zedler 1991).

Chris's work led Stacey Baczkowski to ask how lowered salinity affects halibut growth and survival—is a short pulse of low salinity enough to impair growth, or does it take prolonged low salinity? And are the smaller young-of-the-year (YOY) more tolerant of salinity shifts than larger YOY? Larger YOY (~19 cm long) might be less abundant than smaller YOY (~13 cm long), either because they experience higher mortality or because they simply leave the estuary during freshwater flooding! Inquiring minds want to know.

Stacey made great use of seawater tanks at Sea World to create test conditions (full, half, quarter and zero seawater). Her "pulsed" treatment involved moving YOY halibut from full seawater tanks to reduced salinities for 5 hours every 2 days. The result? Larger YOY were more tolerant of pulses and continuous exposure to both half-strength and quarter-strength seawater. In contrast, small YOY could not tolerate lowered salinity, not even in short pulses. Small YOY survived only 25 days of continuous exposure to quarter-strength seawater.

CAN YOUNG HALIBUT FIND FAVORABLE WATER SALINITIES? Stacy compared fish preferences by setting up a system of baffles that created a gradient in salinity from 3.4% salt (full-strength seawater) at one end of a long aquarium to 1% at the other. Creating and sustaining the salinity gradient required careful filling of the "enclosures"! A fish was released in the middle, where salinity was about half seawater, and Stacey watched to see which direction the YOY halibut moved and where each one spent the most time.



The results: Large YOY spent more time at the seawater end of the gradient, but were able to use the entire tank. In contrast, Small YOY avoided the brackish water and spent most of their time in full-strength seawater. Apparently, the nose knows where conditions are favorable. In more scientific language, the halibut has chemical/olfactory sensors in its nares.

Lastly, Stacey placed young halibut in a chamber and measured their oxygen consumption when in water of decreasing salinity. As hypothesized, the fish used more oxygen in lower-salinity water. This indicates increased metabolism, which is a clear sign of stress. Stacy concluded that low salinity harms halibut, whether the exposure is pulsed or prolonged.

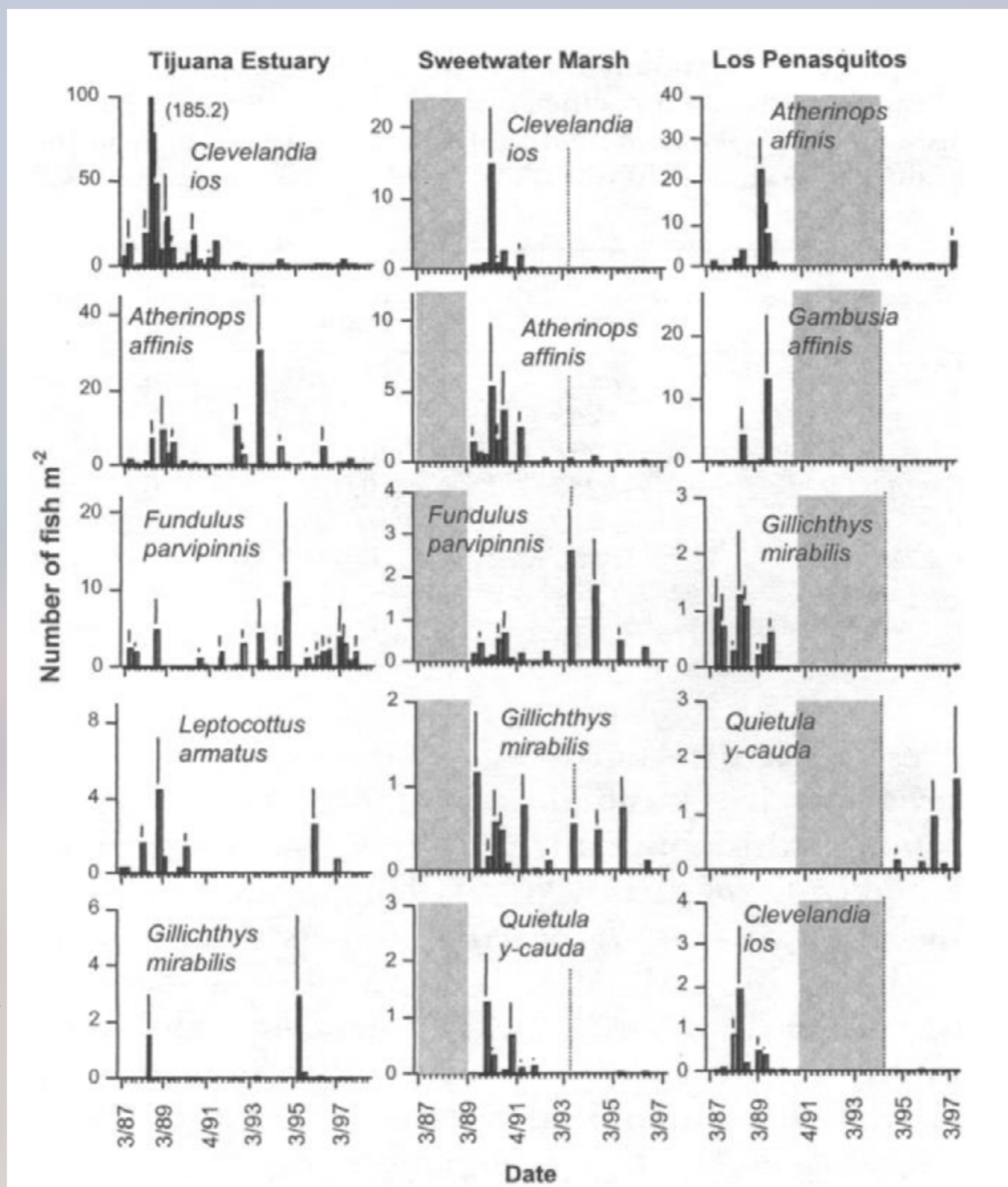
Monitoring fish and invertebrates

DYNAMICS OF FISH. How would you test the hypothesis that tidal channels are nurseries for turbot and halibut? Right; you would sample channels and creeks to learn which sizes of each fish live in each habitat during the year.

That and related questions drove our monitoring of fishes in southern California coastal wetlands.

Greg Williams
led our fish monitoring program, which documented fish use at Sweetwater Marsh, then expanded to include Tijuana Estuary and Los Peñasquitos Lagoon. At Tijuana Estuary, we had the added benefit of automated samplers for water temperature, dissolved oxygen and salinity.

Note: The NERR Office provided uniform equipment for all 20+ Research Reserves. Having a national system makes it easier to compare our country's many types of estuaries—from small, saline systems like Tijuana Estuary to large mesosaline estuarine bays, like the Chesapeake.



This graph shows average densities of the 5 most common fish species at each site beginning in 1987.

Complicated, isn't it? The fish are highly variable! So are the benthic invertebrates....

CHANNEL BENTHOS. Earlier, Chris Nordby had documented effects of wastewater inflows at Tijuana Estuary and impounded sreamflows at Los Peñasquitos Lagoon (Nordby and Zedler 1991). In both places, lowered salinity had negative impacts on channel organisms. Benthic infauna responded faster than fishes, but prolonged low-salinities extirpated (wiped out) most species. Their demise (mortality) did not eliminate all invertebrates but shifted the benthos toward more opportunistic "colonizers" (species that can reproduce at an early age and continue reproducing over an extended period).

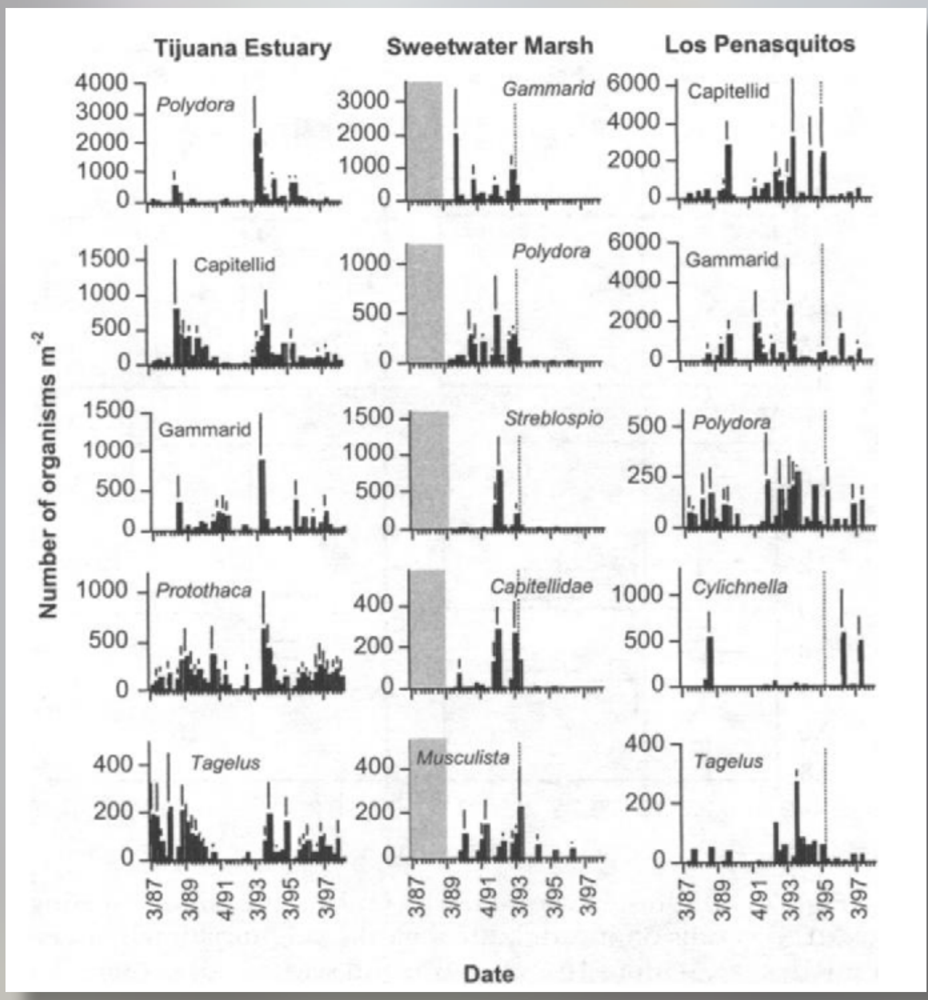
Michelle Cordrey and Janelle West kept track of the benthic invertebrates (nicknamed "inverts." For logistical reasons, the team focused on macroinverts—ones that they could sieve in the field and count without using a microscope. The team used a cylindrical corer (15-cm diameter) with a very sharp edge to collect 3 cores at each channel station (usually 3 per estuary).

Prior to 1991, all three cores extended to 20 cm depth. The cores were pooled (dumped together) and sieved through a 1-mm screen in the field. Imagine how heavy those wet cores were and how long it took to separate the inverts from the sediment! Too heavy and too long. So in 1991, we switched the sampling to three 5-cm shallow cores per station (pooled and sieved through a 1-mm screen in the field) and three 20-cm deep cores (pooled and sieved through a 3-mm screen). The shallow cores collected smaller, near-surface inverts (such as polychaete worms and amphipods); the deeper cores included large, deep-burrowing inverts (mainly bivalve mussels).

It was still lots of work to process the shallow cores: After submersing the samples in a Rose Bengal dye, most animals were stained pink, which helped Janelle and Michelle separate them from the sediment. Then, each animal was identified to species.

In 2002, Julie Desmond and co-authors published our 11-year record of fish and invertebrate monitoring in three southern California estuaries (all sampled four seasons per year with multiple stations per site).

On the right are average densities of the five most common taxa of invertebrates at the three monitoring sites, beginning in 1987.



Summary of long-term monitoring data

Here are the conclusions, with details in Desmond et al. (2002).

- Fish composition and abundance were more predictable in than macroinvertebrates.
- Fish changed seasonally in response to temperature. Invertebrates changed annually, responding more to annual streamflows and dissolved oxygen in the water.
- Both fish and invertebrates differed among the three estuaries and among sampling sites within each estuary.

More research is needed to identify cause → effect factors that determine distributions. Wouldn't you like to be the one who leads the next study in other estuaries that are not yet monitored for fishes and invertebrates? Then you could write the follow-up paper (the excerpt below is just the abstract).

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Spatial and Temporal Variation in Estuarine Fish and Invertebrate Assemblages: Analysis of an 11-year Data Set

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ABSTRACT: Protocols for monitoring wetland mitigation and restoration projects call for routine counts of animals, yet long-term spatial and temporal patterns are rarely examined. An analysis of monitoring data from three southern California estuaries spanning 11 years, four seasons, and multiple stations within the estuaries revealed differences in spatio-temporal patterns between fish and invertebrates. Ordination analysis showed that fish assemblages were more predictable from environmental variables than were invertebrate assemblages. Variation in the fish assemblage was primarily due to seasonal differences that were driven by changes in temperature. Invertebrates showed little seasonal variation, but a much higher degree of interannual variation than fish. Streamflow and dissolved oxygen were significant predictors of the invertebrate assemblage, indicating that irregular disturbances such as flooding events had a more important effect on the invertebrate assemblage than predictable seasonal cues such as temperature. Variation in fish and invertebrates was high both between and within the three estuaries, indicating that differences exist on multiple spatial scales. The influence of spatial and temporal factors on estuarine invertebrate and fish communities should be considered in planning monitoring programs for wetland mitigation or restoration sites.