1. ECOLOGY

Estuaries are subject to constant and often unpredictable fluctuations from many sources. These fluctuations define estuarine ecology by both enriching and destroying resources. Being so dynamic, the Tijuana River Estuary is of immense interest to scientists and nature lovers. Alex, a local high school student, grew up nearby in Imperial Beach. During the summer, he volunteered as an intern at the Tijuana Estuary, an event that triggered exciting and important research.

Trudging past the mounted Golden eagle into the research director's office, Alex announced loudly, "It's an invasion! These weren't here when I was a kid. They're ruining everything!" he added frantically.

With skepticism, Dr. Bender eyed Alex, who was muddy up to his knees. "Invaded by what?" he asked. Visions of downed Navy helicopters and scavengers doubled over from bad mussels passed through the director's head.

"Those *trees* over where the river meets the ocean," said Alex, his hands waving with wild exasperation. "They're out of control!"

"What are you talking about, Alex?" Dr. Bender looked questioningly at his intern over the tops of his glasses. "You're supposed to be studying ecology here, not having a breakdown."

Alex stared back at him blandly. He'd come here to help out, not be hassled.

Dr. Bender sighed. "What's an ecosystem, Alex?"

"It's a distinct, self-supporting unit of interacting organisms and their environment," Alex rattled off the definition automatically and without taking a breath, then looked at Dr. Bender, who said nothing. "Yeah," Alex continued, "and this ecosystem is an estuary, a place where fresh water flows down into the sea and salty tidal waters move up into the river basin."

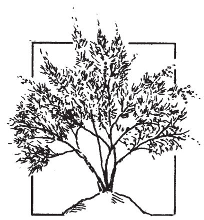
"Very good, Alex," with what seemed to Alex like condescension.

"*But I already know that*. But those bushes, those trees with the grayish leaves and pink blooms. They're changing everything completely," the teenager added with vexation."

"Ahhh!" A look of realization swept over Dr. Bender's face. "You mean the salt cedar, the *Tamarix spp.*, the water-guzzling scourge of the West. It's not an essential component in this ecosystem, Alex."

"But you've explained that…that even though an ecosystem is distinct, whatever happens in nearby ecosystems will eventually affect it. I want to see what the *Tamarix*…the what-ever-it-is… is doing here."

“It's also called tamarisk," Bender said dryly. "I just want you to observe the eight habitats we already know something about. The salt cedar…it's an *exotic plant*, imported to the U.S. from far, far away…the Eastern Mediterranean. People planted it along stream banks in the southwest, as windbreaks and to prevent erosion, during the early twentieth century."



"And now it's here, all the way to the Pacific." Alex was almost beside himself with frustration. It was never here before and it's wiping everything out!"

"Well, yes. But it's complicated, Alex. And we have lots of priorities here at the Estuary. Tamarisk doesn't seem like an issue on a par with, for example, massive sedimentation and the smothering of the salt marshes."

"Well it could be."

"Fine, Alex. *Show me*. But I can't get involved in this now." Then the director added,"And show me its relationship to the eight habitats."

Alex stomped out of Dr. Bender's office. He was really frustrated. Part of the reason he'd wanted to work at the estuary was the feeling that no one elsewhere was listening to him. Now it was happening here. Alex desperately wanted to make a difference. *Well, I'll show him. I'll be very scientific about this*, he thought to himself.

Alex then said aloud, "Why has tamarisk *colonized* here? What do I know about what to look for in a habitat? First, I'll look at abiotic factors, which don't come from living things."

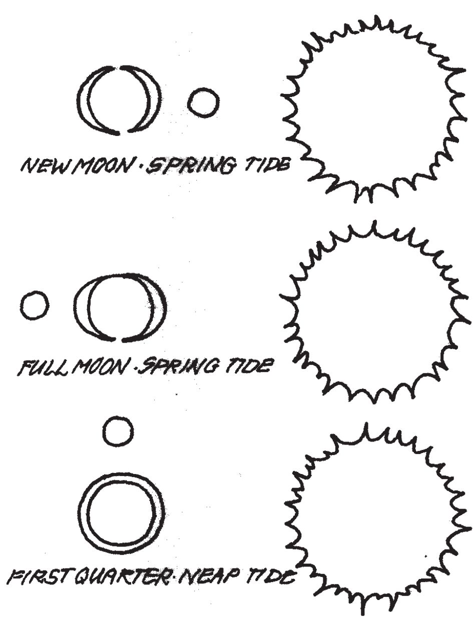
ABIOTIC ESTUARY

Temperature

Alex set off towards the southwest from the Center. Even though it was the middle of the summer and close to noon, it was cool out. *Probably an inferno inland*, thought Alex, glad to be near shore. Alex knew that estuarine temperatures are more variable than ocean temperatures, fluctuating both daily and seasonally. Like fresh water temperatures, estuarine water is colder than the ocean in the winter and warmer than the ocean in the summer. Plus, the estuary's shallow water heats and cools easily. Estuarine species have to be able to deal with these frequent temperature shifts. *Obviously temperature changes don't bother the tamarisk*, Alex mused, thinking of the broad temperature ranges of the southwest. Just like the rest of the species along the channels, the tamarisk just has to accommodate the daily temperature variations that accompany the changing tides.

Tides

With difficulty, Alex turned his back on the tamarisk issue and went down to the beach. Each day there are two high tides and two low tides. Alex remembered how he struggled to understand the difficult concept of tides. He had studied the two physical forces at work, *centrifugal force and gravity*, as do all students. But a common misunderstanding complicates the matter of tides. Most people think the moon rotates around the earth, and while this is close to the truth, it is not quite right. Both the earth and the moon rotate around a point in between the earth and the moon, as if the two were fixed on a rod. Because the earth is so much more massive than the moon, the rotational point is actually at a point below the surface of the earth, not at its center. Therefore, the earth rotates around this point, (the center of its mass, or *barycenter*), and it is this motion that causes the centrifugal force. In other words, centrifugal forces are the outward flinging force the earth exerts when spinning around the center of the earth-moon system. Outwardly directed centrifugal forces are the same all over earth's surface, but gravity is not. It is this imbalance-or differential gravity-- that creates the tides.

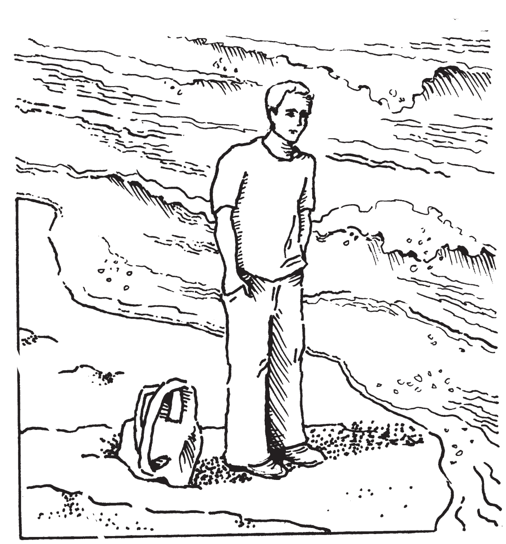


THE POSITIONS OF THE EARTH, MOON AND SUN AFFECT THE TIDES.

The moon, meanwhile, has a gravitational pull on the earth. The farther away any point on the earth is from the moon, the weaker the lunar gravity. At a point at the center of the earth, the gravitational and centrifugal forces are equal. In other words, the earth and moon neither get flung apart nor sucked together. However, on the side of the earth closest to the moon, gravity is greater than the centrifugal force and the pull toward the moon is greater. This causes tidal bulge on the side of the earth facing the moon. On the opposite side of the earth, the centrifugal force is greater than the gravitational force. This creates an outward force, producing another tidal bulge on the side of the earth opposite the moon.

Factor in the sun's gravitational pull, as well as the rotation of the earth and moon around the sun. Then think about tidal forces rebounding from bodies of land. The complexity of tides was pretty overwhelming. Alex could sort of understand why Dr. Bender wanted him to concentrate on studying the systems he already knew something about, particularly since aspects like tide were so complicated.

Alex noted that the tide did not extend very far up the beach; it must be low tide. The average tidal range is about five vertical feet, meaning that on average the water level moves up and down five feet with every tidal cycle. The maximum tidal range, which is ten feet, defines the upper boundary of the estuary, creating salinity levels high enough to eliminate all but true



halophytes (plants that thrive in saline soil). Life forms have to be able to adapt to the changing water levels too. Succulent plants like pickleweed (*Salicornia spp*) can completely dry out at low tide and still survive. Others like algae don't grow where they can't stay wet. It's similar for animals, thought Alex. Fish can simply swim out with the tide. Others that aren't so mobile, like some mollusks, have adaptations for staying wet. Clams and mussels close their shells tightly. Snails clamp onto rocks. Invertebrates just burrow deeper into the mud to avoid drying out. Alex studied the shorebirds scuttling along after the ebbing waves, poking their long beaks into the sand for food. Many birds get their best meals when the water is out. Tides deliver and disperse nutrients. All life forms are dependent on the moon, whether they know it or not.

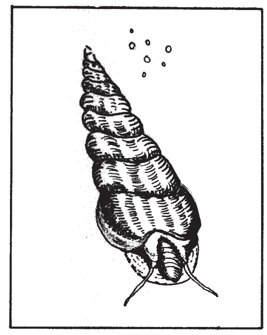
Salinity

Tides change more than temperature and water level; they also change water quality. One of Alex's assignments was routine water testing. Many of Alex's friends and even his family found the way Alex relished water quality testing a bit odd, to say the least. But for Alex, the ability to discern so much about outside influences from a small jar of liquid was like being psychic.

Alex pulled off his shoes and waded into the water. He captured a drop of water and put it on an instrument called a *refractometer*. The measure of light the seawater refracted was an indicator of salinity, the ratio of salt to water. When the tide rises, salt water dominates the estuary. When the tide is out, the salinity decreases, due to fresh water run-off from the watershed. Alex had found that differences in salinity are more dramatic farther up the channels and river; near the ocean less so. Water is the least salty during and after rains, because the influx of fresh water is so great.

Fresh water squares off against salt water at certain places in the intertidal channels, ponds and tidal creeks. These junctions, which are called *salinity gradients*, move up and down the stream as the tides and run-off compete.

Animals have pretty crafty adaptations to survive the inconstant salinity. Some species, like fish, actively regulate the salinity in their bodies. Others are like sea hares (*Aplysia* spp.) and California horn snails (*Cerithidea californica*) let their inter-



nal salinity vary with the external environment. Knowing humans couldn't begin cope with such fluctuation gave Alex fresh respect for these *osmoregulators*. Their cellular membranes are permeable, allowing water to pass in and out freely until the salt concentration is equalized. These animals shrivel up in salty water, because they've expelled extra moisture to keep their salt content consistent with the water. When salinity levels are lower, they puff up taking in more water, to reduce salinity within their cellular membranes. Animals like clams simply close up when the salinity gets beyond their tolerated range. Salt concentrations don't change as quickly in mud as they do in other types of sediment. Therefore, *osmoconformers*, such as mud-dwellers, can maintain a balance of salt concentration in their bodies by burrowing into the mud.

Sediment

Estuaries are repositories of muddy sediment. Sedimentation occurs when sand, silt, and clay particles, carried in suspension by river water, wash down from the *watershed*. Alex had many times noted how the texture of the sediment varied from place to place in the estuary. The more motion there was, such as there on the wave-swept beach, the coarser the sediments -- big sand, cobbles, and rocks. As the current slows, the largest particles drop out. In quiet estuaries, small particles have a chance to settle out into mud.

Mixed with the silt are particles of dead plants and animals called detritus. This detritus is rich in nutrients and is one of the estuary's biggest sources of energy. *It's not just muck*, exclaimed Alex, *it's a meal*.

Run off

Not everything in the sediment and water is beneficial though, as Alex well knew. Being surrounded by two large metropolitan areas, the modern estuary is impacted by chemicals, fertilizers, herbicides, pesticides, oil, and sewage, sometimes dramatically.

The International Wastewater Treatment Plant, built in 1997, helped diminish the sewage impacts. It treats 25 million gallons of sewage daily and sends the treated water three miles offshore in 90 feet of water. But sewage isn't the only problem. Urban run-off is an important and unpredictable consideration too, particularly during storms. *Rain just picks up all the stuff that people deposit in their yards and gutters, on the roads, oil leaks, and industrial waste …you-name-it*…thought Alex grimly, *and carries it right down into the estuary*.

Luckily the estuary is a biological filter, dramatically decreasing pollution loads and helping clean the water before it reaches the sea, but as pollution levels increase, it becomes more than the estuary can effectively filter. Alex was always shocked to observe how radically storms raised pollution levels in the water. Sudden and extreme loads of substances like lead, arsenic, mercury and bacterial contaminates can't help but compromise estuary life forms. For plants and many animal organisms there is no escape from the noxious environment. Even animals that can get away may not and often unwittingly ingest poisons. Because urban run-off is inconstant and often toxic, conditions for organisms are even tougher…

"…except for tamarisk!" Alex cursed under his breath.

Oxygen

No ecosystem thrives without healthy oxygen levels. In the presence of sunlight, plants undergo a series of biochemical reactions called photosynthesis, producing glucose (a form of sugar) and oxygen. Oxygen is a byproduct of the process of photosynthesis. In water, turbulence increases the dissolved oxygen in the water. Lower temperatures increase the oxygen level too.

Alex dug into the mud, using his pocket tool. The first few centimeters were light brown, a sign that oxygen was present. But deeper the sediment was deep black, an indication of little oxygen. This *anoxic* character is okay for *anaerobic* bacteria, which don't require oxygen. But *aerobic* organisms must live closer to the surface or dig tunnels through which the oxygen-filled

water can flow.
Alex was concentrating on taking readings with his back to the oncoming waves. Big mistake. Taken off-guard by an oncoming breaker, he lost his balance, dropping the kit.

He scrambled to get a hold on the scattered contents, cursing his clumsiness. *"Real scientific, Alex. You're a real pro,"* he thought. To worsen matters, Alex heard an "a-hem" behind him. He looked around and there was Dr. Bender himself. Alex, now completely soaked, looked at him sullenly and muttered, "Well, I've done my water testing."

"Head first?"

Alex threw his mentor a scornful look.

BIOLOGICAL PROCESSES

"Look, Alex. It's not that your tamarisk idea is a bad one," admitted Dr. Bender. "I really admire your incentive. It's just that there's a lot to do here, and we have to choose our battles."

"Tamarisk seems like a worthy enemy to me."

“It is a non-native species, Alex, and a highly invasive one at that. It has few biological controls, meaning that the plants and animals that limit its invasion in its native environment don't exist here. Tamarisk survives heat, as long as surface or subsurface water is available. It survives fire, because it will vigorously re-spout. Insects and birds help pollinate the invader, but it has little value to most native amphibians, reptiles, birds, and mammals. Since it can out-compete native plants and keep native species from reseeding, it just keeps thriving and expanding its range.”

"Sounds like the Terminator," Alex mumbled.
"That's right. And invasive plants, like all plants, respond to biology as well as influence it. They're like other plants interacting with animals, microbes, everything. They play by the same broad biological rules. You already have a good sense of how tremendously mercurial everything is here. Since virtually nothing in an estuary remains static, biota must have coping strategies. Living organisms also shift in place and time continually so they don't die. The most adaptable flourish. It certainly seems like tamarisk is a survivor and maybe even a champion."

"Doesn't seem like any of the abiotic elements bother it," Alex reflected, "Not even the salt."

"One of the reasons they call it 'salt cedar'," said Bender dryly.

Producers and Consumers

"So salt cedar…tamarisk…can alter the cycle of energy flow here?"

"Can and very likely is. As you seem obsessed with this, you might focus on observing its impact on *producers* and *consumers* in the estuary."

To grow and reproduce, all organisms need energy, of course. But they get it in three different ways, Alex had learned. Aside from the *chemotrophs*, which acquire energy by *oxidizing* inorganic chemicals like ammonia, nitrite and sulfide, there are *autotrophs*, which are photosynthetic plants and algae, and *heterotrophs*, which include animals.

Auto means "self" and *troph* means "feeding." Autotrophs initiate an energy flow by capturing energy from the sun and converting inorganic carbon dioxide and water into an organic compound - glucose.

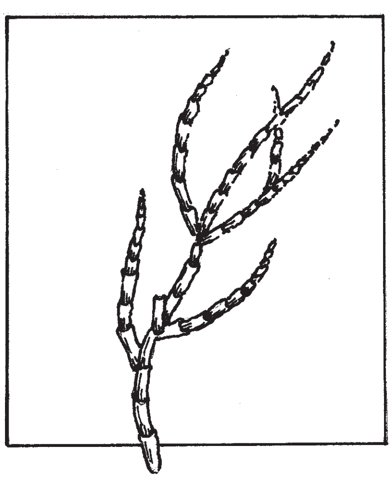
Profiting from the autotrophs' production are the heterotrophs. *Hetero* means "other," so heterotrophs are "other feeders." Heterotrophs - which include insects, crustaceans, reptiles, fish, birds, mammals, and some bacteria - eat autotrophs. They also eat other heterotrophs. Heterotrophs are the *consumers.*

Interdependence between producers and consumers is tightly meshed. So when changes are introduced into an ecosystem, changes like tamarisk, subsequent transformations are hard to predict.

"What do you remember about the autotrophs' productivity in an estuary, Alex?" Dr. Bender asked, gesturing back over his shoulder to the east toward the marshes.

Alex hesitated. Dr. Bender was like the overlord at the estuary. Even though he was sopping wet, he somehow needed to regain Dr. Bender' respect, or he'd never get the go-ahead on the tamarisk project. This conversation seemed like it was heading in the right direction - towards his being able to study salt cedar - and Alex didn't want to blow it with a lame answer.

"Well, I know that *productivity* here is greater than any other ecosystem, even



farms or forests. *Salicornia* and cordgrass are producers, of course. But lots of productivity occurs where it's hard to spot."

"Yes…and?"

"Like at the microscopic level… like *phytoplankton*, the floating plants such as diatoms and dinoflagellates. Most are photosynthesizing, drifting through the water. And the algae mats that are found on marsh sediments are photosynthetic too. Algae's a producer."

"So enter this tamarisk." Seemed like Dr. Bender was becoming convinced. "Apparently a full-grown salt cedar guzzles up to 300 gallons of water a day," he said meaningfully.

"Talk about a giant sucking sound!" Alex exclaimed.

"Yes and worse, tamarisk deprives native estuarine plants, which are the foundation of the wetland food web. What's the other distinctive element of an estuary's energy cycle?"

Alex looked quizzically at Dr. Bender. "Not sure what you mean."

"Where is the *biomass* going? It's not as if the marshes are 30 feet high or anything."

"Oh! I know!" exclaimed Alex, with a rush of recognition. "*Detritus*! It's leaving the estuary as detritus."

Detritus and the Food Web

"Not technically *leaving*, at least not always. But yes, although much detritus floats out into the sea to nourish organisms there, many *detrivores* live here."

"Detrivores?"

"Detritus eaters. Detritus is a major component in an estuary, and its domination in an estuarine food web distinguishes this ecosystem from others. Remember, where does detritus come from?"

Alex already had some idea about detritus as an important nutrient source for primary consumers. "Bacteria, fungi, and zooplankton break down algal cells and dead animals and plant parts."

"And that is just the beginning," Dr. Bender continued. "Mixed with the phytoplankton, the detritus circulates in the marsh channels and mudflats, carried along by tidal waters. Some detrivores derive energy from the microorganisms that live on this decaying soup. Consumers (detrivores) that eat other consumers (microorganisms) are known as secondary consumers. Omnivorous filter feeders suck in water and anything small that is floating in it. Invertebrate *detrivores*, though relatively inconspicuous, comprise a major portion of the estuarine food web. These worms, snails, crabs, and mollusks are widely distributed throughout the estuary."

"Obviously, larger, more mobile animals, like birds and fish, feed on the detrivores," Dr. Bender continued. "Birds also feed on plant matter and fish. Still each consumer has a niche in which it feeds. The estuarine food web is a lot more interdependent than you would think."

"Man!" Alex exclaimed, taking in the full intricacy of the ecosystem around him, as he dried in the sun. It was so subtle, people would have no idea, unless someone explained it to them. Then he commented, "Sure seems as if the salt cedar might interrupt the food web here."

"As I've said," Dr. Bender rejoined, "it could be a concern, but *Tamarix ramossisima* hasn't invaded other estuaries. So we're counting on it not being able to withstand extreme conditions here."

"But it's already here!"

"I suggest you look at each habitat very carefully, starting with this beach. I'll see you back at the Visitor Center." Dr. Bender said sternly. With that, the researcher turned on his heel.

Alex's frustration was growing over what seemed like his mentor's short-sightedness. He had to discipline himself to assess the plant and animal community at hand.

ZONES

Organisms sort themselves out along *environmental gradients*, winding up in recognizably different zones. A variety of biotic and abiotic factors regulate where these zones are, but in estuaries the big factors are a) tidal height, b) salinity, and c) biological interactions.

Beach and Dunes

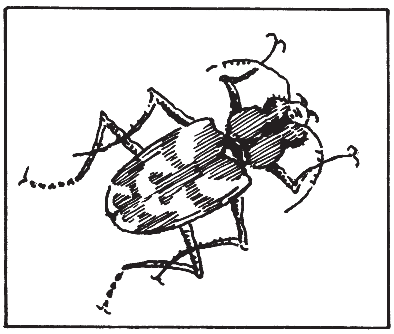
By comparison to the lush green around the channels, the beach and dunes always seemed a bit empty. *Probably the reason people don't take care of them*, he thought. *They think if there's room for a beach towel or a condo, there's nothing wrong*. Much of the length of California was once edged with dunes, he knew, though tidal flushing, storms, and ever-changing creek and river flows constantly rearranged them.

Now California's dunes are almost entirely gone; a mere 10% remain. Construction. Recreation. Horses. Vehicles and other diversions have eroded or destroyed the dunes. Erosion is brought about by de-vegetation and stormwater is channeled by inland development. Even the sand is endangered because dams and reservoirs catch the sand eroded from watersheds and keep it from reaching the beach.

Alex scoured the dunes for tamarisk but saw none. The vegetation was scarce, but all marvelously adapted to sand burial and salt. The mats of salt grass (*Dichtilis spica-*

ta), sand verbena (*Abronia maritima*), and dune ragweed (*Ambrosia chamissonis*) were native and helped stabilize the dunes. Hottentot fig (*Carpobrotus edulis*) and sea rocket (*Cakile maritima*), both non-native introductions, had taken over. He knew that non-natives provide little food or habitat for native insects.

Alex bent over to get a closer look at the vegetation. He'd heard it was a beetle haven, so he looked among the plants to see if he could find any. The globose dune beetle (*Coelus globosus*), sandy beach



tiger beetle (*Coelus hirticollis gravida*), sand dune tiger beetle (*Coelus latesignata latesignata*), and flower beetles (*Notoxus monodon*) supposedly live off the detritus and burrow beneath the plants to lay their eggs.

Though Alex couldn't see lizards, he knew several species continue to use the dune habitat, however scarce it may be - the San Diego coast horned lizard (*Phrynosoma coronatum blainvillei*), silvery legless lizard (*Anniella pulchra pulchra*) and the side-blotched lizard (*Uta stansburiana*), are three of the lizards found in the dunes.

Whereas insects and lizards prefer the vegetated areas, birds gravitate to open sand. Numerable shorebirds feed on invertebrates along the shoreline. In summer, numbers and variety diminish. Alex only spotted Willets (*Catoptrophorus semipalmatus*) and Godwits (*Limosa fedoa*), but expected that they'd be joined by species such as Whimbrels (*Numenius phaeopus*), and Black-Bellied Plovers (*Pluvialis squatarola*) when the weather cooled down. One of his favorite pastimes was watching flocks of Sanderlings (*Calisdris alba*) follow the changing laps of waves, quickly probing the sand for tiny crustaceans and worms.

Even with the wild beauty of the Pacific, the beach and dunes always made Alex sad because human impacts had jeopardized and even extinguished so many plants and animals that require these areas. The Western Snowy Plover (*Charadrius alexandrius nivosis*) has been a Southern California beach dweller for thousands of years. Before beachgoers took over their habitat, their nesting in simple scrapes wasn't a problem. Now there are fewer than 1,500 breeding plovers in the world, nesting at only 26 remaining locations, including the Tijuana Estuary. Another listed species, the California Least Tern (*Sterna antillarum browni*), still occupies the beach and dunes, but is barely hanging on. The terns nesting and fledging habits make them highly vulnerable. They too nest in depressions in the open sand. The eggs and the chicks are exposed to natural predators including another threatened bird, the Gull-Billed Tern (*Sterna nilotica vanrossemi*). Interference from humans and human pets persists too.

Tidal Creeks and Channels

Alex worked his way inland into the fingers of estuarine waterways, each abundant with macroalgae, phytoplankton, invertebrates and fish.

Alex lay on his stomach and stared down into the water. It's not easy to see much activity, and he wondered how biologists had been able to learn so much. Supposedly, more than 75 species of benthic invertebrates burrow in the sediments. Mollusks such as littleneck clams (*Protothaca staminea*), purple clams

(*Sanquinolaria nuttalli*), gaper clams (*Tresus nuttallii*) and crustaceans such as the ghost shrimp (*Neotrypaea californiensis*) are some of the most populous now.

A striped mullet (*Mugil cephalus*) leapt out and landed a full six feet away from where it breached. Alex had heard that diamond turbot (*Hypsopsetta guttulata*) and halibut (*Paralichthys californicus*) prowl the channel bottom, feeding on the organisms that live in or on the sediments. Usually calm estuarine waters assure their young a place to develop. Also active are California killifish (*Fundulus parvinpinnis*). Topsmelt (*Atherinops affinis*) lay eggs right within the macroalgae's built-in food supply. Small fish, such as the arrow goby (*Clevelandia ios*) and long-jawed mudsucker (*Gillichthys mirabilis*) reside in channel banks as well as mudflat burrows.

That was just below water. Alex looked up through the grasses at the above-water food web - shorebirds, diving birds and wading birds. There, not far away, his mentor made his way back to his office.

Mudflats

Ed Bender scuffed across the unvegetated muddy stretches on the limits of the salt marsh, too low for marsh plants and too high for seagrasses. He had to admit that Alex's obsession touched a nerve. He'd been worried about the tamarisk too, fighting the urge to engage in what he knew would be an unceasing battle against the invading species. It might disrupt food webs or produce an unnaturally high canopy in what should be a low-lying marsh.

The estuary's most adaptable denizens were here where lower tides intermittently bared the mud. The mudflats were pretty similar to tidal channels, only they held less water. Dr. Bender thought about the California horn snails (*Cerithidea californica*), the purple-striped shore crabs (*Pachygrapsus crassipes*), and fiddler crabs (*Uca crenulata*) -- easy pickings for Long-Billed Dowitchers (*Limnodromus scolopaceus*), Dunlins (*Calidris alpina*) and other sandpipers.

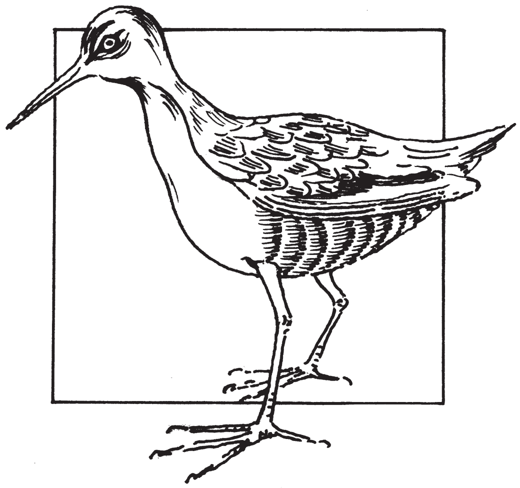
Birds with many differing bills eat together on the mudflats. This is because they're each after something at a different level in the mud. Waders such as Greater Yellowlegs (*Tringa melanoleuca*) fed in the sediment surface and nearby water column. Short-billed sandpipers plucked their meals from just a few centimeters down. Long-billed sandpipers probe deep into the sediment, sometimes into the water. Plovers feed on the semi-dry surface of the flats.

The mudflats and sandflats are used by more animal species than any other habitat type in the Estuary. To his relief, the researcher caught no sight of tamarisk, however.

Lower Marsh

Edging the unvegetated flats are dense fringes of Pacific cordgrass (*Spartina foliosa*). Cordgrass is what they call a salt "excreter." Making his way through the lower marsh, Alex pulled his fingers over a few blades. Salt from the underside of its leaf came away on his hands. The cordgrass contains a shin-high kingdom of low-lying creatures such as insects, crustaceans, and snails.

Alex was very careful where he walked, because the lower marsh is the domain of the estuary's most endangered bird. No more than a thousand breeding pairs remain of the Light-Footed Clapper Rail (*Rallus longirostris levipes*), so-called for its thin form and clattering beak. The rail is often heard more than it's spotted. Since the birds remain largely hidden from preda-



tors in high cordgrass, this species evolved with few self-protecting adaptations. Their food, mostly fiddler crabs, yellow shore crabs and striped shore crabs, is very handy. Over the Clapper Rails' woven-cordgrass nests, they weave live grass canopies, so they are very difficult to spot. Although the nests float and can raise and lower with the tide, they can't escape careless human feet. Alex made his way very slowly, coming to a full stop between steps.

Alex's distractions were great here, however, because he was on the lookout for tamarisk too. A movement nearby caught his attention. Alex saw a Clapper Rail's thin brown head duck back into the tall grass. "Man, those birds are trusting," he whispered to himself.

High Marsh

Alex moved to higher ground each step undertaken warily. But a few steps away, there was a small tamarisk plant right in front of him. The soil was already mounded and raised up beneath it. And worse, it was already barren of other vegetation. Why couldn't anything else grow there? There was plenty of water…

Alex wrapped his hand around the feathery leaf and pulled outward. It was as wet as a wet sponge and left his palm gritty with salt just like the cordgrass. *No wonder it's called salt cedar*, he thought. *It must be an excreter too*. Indeed, the tamarisk was exhibiting its notoriously high *evapo-transpiration* rate.

The pickleweed (*Salicornia virginica*) and sea-blite (*Suaeda esteroa*), which dominate and define the high marsh, are a variety of plant called "succulents." Instead of excreting salt, their fleshy stems and leaves swell up with stored water and nutrients. By contrast with excreters such as cordgrass and salt cedar, succulents are "accumulators." The salt works its way to the tips, which gradually turn red and drop off. Sea lavender (*Limonium californicum*) and shoregrass (*Monanthochloe littoralis*) are other high marsh plants.

Alex looked around for salt marsh bird's beak (*Cordylanthus maritimus maritimus*), an endangered annual plant that only grows for a brief time during spring and summer. Seedlings sprout in openings in the foliage, but in these same openings seeds from other high marsh plant species avail themselves and this limits the success of this endangered plant. *Tamarisk could outcompete it*, Alex reasoned.

Among the ubiquitous beetles is the swift raven (*Tachys corax*). Other prominent arthropods include a spider (*Tetragnatha laboriosa*) and the pseudoscorpion (*Halobisium occidenta*). These arthropods contribute to the decay of plants and double as avian fast food.

Saltwort (*Batis maritima*) and annual pickleweed (*Salicornia bigelovii*) dominate areas that are poorly drained close to the water. Dozens of species of algae cover the soil and plant stem bases in thick, tufted mats. Insects such as water boatman (*Trichocorixia reticulata*) feed on the algae, and are eaten in turn by spawning California killifish (*Fundulus parvipinnis*). Ephidrid flies deposit their larvae on decaying plants.

Alex scratched at the soil between the pickleweed and brought up a handful of small, black Melampus snails (*Melampus olivaceus*), as he'd watched Dr. Bender do many times before. He tried this close to the tamarisk, though, and there were no snails. "Bad sign," he reflected quietly, knowing the potential role of this grazing snail in the larger food web.

Small brown birds grazed on the salt cedar. Alex could plainly see that they were not the endangered Belding's Savannah Sparrows (*Passerculus sandwichensis beldigni*), for whom the high marsh is home base. "Probably Song Sparrows," he muttered, recalling that this other species (*Melospiza melodia*) is a *generalist*. Unlike the Belding's, they can live in several habitats. Savannah sparrows hop about and scamper like a mouse through the saltgrass (*Distichlis spicata*) looking for insects and snails. Their nests, scraped out on the ground and lined with fine grass, are very vulnerable to disturbance and predators. Alex turned, hearing the tuneful trill of a Western Meadowlark (*Sternella neglecta*), another insect eater. Yellow breasted, it too had perched on the tamarisk, to boast its expanding territory. The reasons to be worried about the salt cedar were compounding by the minute. "Geez…The tamarisk is converting treeless marsh into forest!" Alex gasped.

As he watched Northern Harriers (*Circus cyaneus*) and American Kestrels (*Falco sparverius*) fly above, Alex groaned out loud with another realization. These raptors would perch in the salt cedar too, all the better vantage point for plucking off whatever was around. He wondered if they'd ever eaten a clapper rail?

Upland Transition Zone

This area is basically beyond tidal influence, although it occasionally floods during extremely high tides or storms. It is the place where the marine and terrestrial worlds co-mingle. Some of the transition areas are salt-encrusted pannes. Although these have algae and aquatic insects that ducks enjoy during rainy seasons, their dry phase has neither vegetation nor insects above ground because accumulations of saline water have made the salinity too high. Alex knew that all the action during the summer was below ground. Insects such as the rove beetle (*Bledius* sp.) and the threatened Gabb's tiger beetle (*Cicindela gabbi*) have air cavities that extend up to 20 cm down. Belding's Savannah Sparrows forage at the pannes, as do Snowy Plovers when the pannes are inundated. Both Plovers and Least Terns sometimes nest in depressions in the salt pannes.

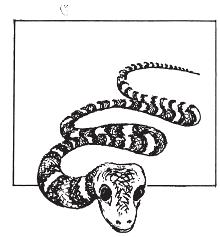
Troubled, Alex made his way back to the Visitor Center, with alkali weed (*Cressa truxillensis*) and alkali heath (*Frankenia salina*) underfoot. Silently, he logged reasons for undertaking his salt cedar…*tamarisk*… study in earnest, the biggest being its transformation of native estuarine habitats. He was all but oblivious as the plants blended into patchy scrub. The highly tolerant exotic, saltbush (*Atriplex semibaccata*) was prevalent. Creeping up the slopes was saltgrass (*Distichlis spicata*), a host plant for a wandering skipper (*Panoquina errans*). Mounds of Golden bush (*Isocoma menziesii*) and California buckwheat (*Eriogonum fasciculatum*) were an early indication of the fairly abrupt transition from wetland to upland plants.

Almost all of the Reserve's upland areas have been destroyed by development. Alex walked slowly through a part of the estuary at the northern corner that, since the late 1980s, had been restored to approximate conditions before human settlement. It was dense with the sorts of species that once covered most of coastal San Diego, part of a plant community called "Coastal Sage Scrub."

The fragrance of feathery-leafed California sagebrush (*Artemesia californica*) and black sage (*Salvia mellifera*) scented the air. Even with the ocean nearby, it was dry…good habitat for snakes, though Alex didn't see any that day. Little side-blotched lizards (*Uta stansburiana*) and western fence lizards (*Sceloporous occidentalis*) darted between sandy open areas. A desert cottontail (*Sylvilagus audubonii*) hopped in front of him and hid beneath mingled clumps of shiny lemonadeberry (*Rhus integrifolia*) and jojoba (*Simmondsia chinensis*). Other mammals, though in diminishing numbers due to the encroachment of civilization, skulk about at dawn, dusk and into the night. In the past, Alex had spotted the striped skunk (*Mephitis mephitis*), the long-tailed weasel (*Mustela californicus*) and even an occasional coyote (*Canis latrans*). A shadow passed over Alex and he looked up to see what caused it on such a clear-skied day. A Northern Harrier (*Circus cyaneus*) flew low overhead. A few wingbeats, then a glide as it scanned the ground for mice and rabbits.

Alex had heard that other raptors -- the Short-Eared Owl (*Asio flammeus*) and White-Tailed Kite (*Elanus caeruleus*) -- also frequented the transition region, though he'd never seen them. What he did see in the Upland Transition Zone was salt cedar. Just as he suspected, the trees were converting high marsh to upland by trapping and stablizing sediment with their roots. They were actually part of the sediment problem that so concerned Dr. Bender. And maybe because of its high evapo-transpiration rates, the tamarisk was lowering the water table!

Drier areas of the upland transition zone accommodate species such as the Great Basin fence lizard (*Sceloporus occidentalis biseriatus*), the California kingsnake (*Lampropeltis getulus californiae*) and San Diego gopher snake (*Pituophis melanoleucus annectens*). Ground squirrels, the western harvest mouse (*Reithrodontomys*



megalotis), deer mouse (*Peromyscus maniculatus*) and the non-native house mouse (*Mus musculus*) make themselves at home in the high salt marsh hummocks.

Cranky, he tramped into the Visitor Center toward Dr. Bender's office. The mounted Golden Eagle in the entry appeared to glare at him, either taunting him or egging him on. After the eagle got hung up and electrocuted in utility wires, the Reserve had it mounted.

"…another sign of how development is encroaching," Alex said under his breath.

"Well, what'd you find, Alex?" asked the researcher when he saw Alex.

Alex told Dr. Bender about the high marsh and how tamarisk seemed unaffected by what appeared to be relatively high salinity soils. He also told him about the raised and barren dirt he observed surrounding the areas where the tamarisk grew.

"Gee, I wonder if it'll raise the elevations here?" reflected Dr. Bender, thinking about the salt marsh. "Have you been everywhere?

"I haven't checked out the mudflats or brackish regions or the river-- the riparian areas…yet, " Alex admitted.

"I suspect you'll see even more there. You can skip the mudflats today. If we can correlate salt cedar's occurrence to depletion of habitat…"

We? Alex thought. Bender finally seemed interested, but now he was acting as if it was his idea. Typical.

"You've heard that San Diego is a biological 'hotspot'?" Bender asked.

"Hot?"

"Our county has inordinate species diversity - both in terms of flora and fauna, as you know. Incredibly enough, there is more diversity here than anywhere else in the continental United States. The tragedy is that the county also has the highest rate of extinction. Therefore, it's a hotspot, tagged with a fiery red flag."

"Well, you're the expert, Dr. Bender. But to me, it seems like salt cedar's speeding up extinction."

"When the tide gets higher, why don't you grab a canoe and take it down to the river channel? Paddle on up a ways and see what kinds of salt cedar densities you find. It would be helpful if you can think of percentages in terms of total vegetated area. How much out of the whole does salt cedar take up?"

Brackish Marsh

After Alex left, Ed Bender put down his paperwork. Hurriedly pulling on his waders, he left the Center. He made his way toward the river. "I'd better see for myself just how prevalent the tamarisk is," he muttered under his breath. Alex's findings could be an embarrassment to him and to the Reserve, if he himself wasn't fully aware of them. *There was just so much to combat, to protect, here. Too much, really, for one researcher and a small team*…

A shadow moved across his path, too fast to be a cloud, and the scientist looked up. He squinted into the late afternoon sun. *What was it?* As smooth and steady as a UFO, a wide-winged Golden Eagle (*Aquila chrysaetos*) glided overhead. The sight shocked him, truly. Golden Eagles were rare at the Reserve, and seeing one in summer months was down right flabbergasting.

Keeping the eagle in view, Dr. Bender plucked his way across a brackish area. Salt marsh goes "brackish" when fresh water lowers the salinity to between .5 and 25 parts per thousand. This only occurs where runoff is fairly steady and/or can't readily seep away. Intertidal plants can't take hold in submerged land. Being less saline, these areas resemble freshwater marshes, supporting thickets of cattails (*Typha domingensis*) and bulrushes (*Scirpus cailfornica*).

Red-Winged Blackbirds (*Agelaius phoeniceus*), their song like cellphones ringing, clung to the tall dense plants surrounding Dr. Bender. They scattered as the researcher plowed through, trying to keep an eye on the eagle, which had circled back behind him.

The rushes were too high. Testily, Dr. Bender thrashed his boot from the clutching aquatic dish grass (*Ruppia maritima*). With a slurp, his boot and foot came free, and he pulled himself up out of the brackish area onto the mat of salt-tolerant pickleweed and saltgrass. Breathless, he pushed his glasses back up his nose. There, right next to him was a bare mound from which salt cedar ranged upward. There were mounds scattered everywhere, all with barren soil beneath them.

"This has the makings of a habitat-type conversion," he muttered to himself with concern.

Hearing a helicopter from the nearby airfield, Dr. Bender looked up, hoping the eagle's flight hadn't been disturbed. Seeing the bird in the distance, up river, he struggled quickly to his feet. Whether with lightheadedness, haste or both, the scientist stumbled in a channel and lurched forward, face down into the pickleweed. Twisting his leg in the process, the scientist cried out in agony. His ankle felt as if it was in pieces in his boot. Straining, he grabbed his left leg under the knee and tried to get it into a less excruciating position. He then realized that everything was blurry, but not just from pain.

Where were his glasses?

<u>Riparian Region</u>

Some time later, Alex shoved the canoe into the river mouth, and climbing in, lowered the paddle over the side. How many other kids could go canoeing just a few minutes away from home? *Bender's intense, but I'm still glad I'm here*, he thought. Making his way eastward, upstream, he passed a sandbar thick with squawking gulls (*Larus californicus* and *Larus occidentalis*) and Brown Pelicans (*Pelecanus occidentalis*), all facing into the onshore breeze, like sentries, thought Alex. Black Skimmers (*Rynchops niger*) flew low along the water, scissorlike bills agape to gather in small fishes and crustaceans from the water surface. Very cool birds, in Alex's estimation.

As Alex made his way up the narrowing river channel, the forest got higher with

several species of willow (*Salix* spp.) and cottonwood (*Populus fremontii*) soaring as tall as twenty meters. Alex apprised the pesky salt cedar (*Tamarix spp.*) coverage -- about 30 percent. Evidently, it was not just surviving. It was thriving on saline soils where most riparian plants cannot, plus it exudes salt. This increased salinity inhibits growth and germination of native riparian species. Cottonwood and willow, as examples, die if the water or soil is too saline.

Alex paddled up to the bank. Hopping out, he pulled the canoe partially out of the water and lashed it to one of the salt cedars.

"At least its good for something," he said to himself, looking around him.

Riparian forests have more birds than any other California habitat and many mammals as well. They are diverse because the forest supports a huge stratum of *microclimates*: different elevations harbor different species, and proximity or distance from the water contributes variation too. High humidity and cooler temperatures attract insects. *Insects that eat and are eaten*, thought Alex, slapping a mosquito on his arm. The shade and isolation from human interference are rare, relative to other southern California environments.

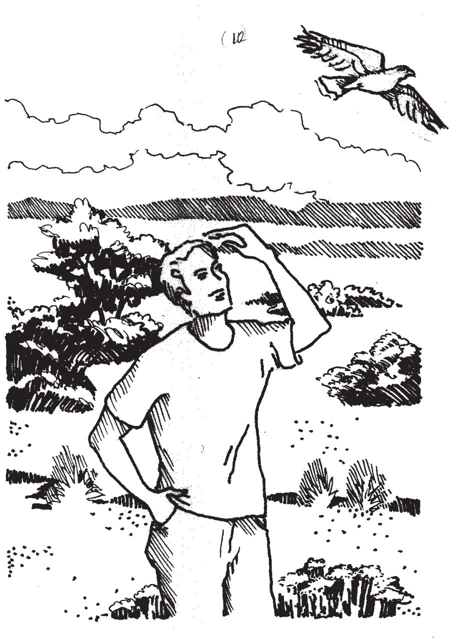
Only problem being, thought Alex, there is so little left. Development interests lobby hard to keep the government from listing more threatened and endangered species. One riparian bird species of which few remain is the Least Bell's Vireo (*Vireo bellii pusillus*). Alex had never seen one or even heard its *cheedle-cheedle chee? Cheedle-cheedle chew!* song. As if shrinking river bottoms weren't already problem enough, the Least Bell's Vireo is also thwarted by the Brown-Headed Cowbird (*Molothrus ater*). Cowbirds lay their eggs in the vireos' nests and their aggressive young out compete vireo chicks.

A bird version of salt cedar, thought Alex.

Eradicating salt cedar from the river area, without hurting other species, would be tough…

A helicopter thwacked loudly above Alex's head. Just then a dragonfly (*Libellula* sp.), a chopper-look-alike, planed in front of his nose. The student smiled wryly, glad there were still dragonflies, but angry about technology's intrusion on nature.

Over the years of exploring the estuary on his own, Alex had learned that the more motionless he was, the more nature's rhythm restored itself. Holding still, he soon heard a squealing cackle, gull-like, but not quite. Turning toward the sound, he saw huge silhouette soaring in front of the setting sun. Alex couldn't make out the bird until it circled around to the north, and was then lit up. Alex appraised the wash of gold on the hind neck, the broad flat wings, the glistening tail. Just like the mounted bird in the Center's entry. For how many hours had Alex stood staring at it since he was a child? But Alex had never seen a live Golden Eagle.



The Golden Eagle was what Alex would choose to be, other than a human, if he had a choice. Far-sighted and resourceful -- that was everything he aspired to. However, *I shouldn't be thinking about that now*, he thought. In another few minutes, the sun would be down. He knew he ought to be getting back, that Dr. Bender would have more reasons to think he was unprofessional. *Who cares*? Alex boldly considered. He moved stealthfully in the bird's direction, making long strides, but slowly. The giant raptor was probably combing the uplands for small mammals. To Alex, though, the elegant bird seemed to be playing with him, beckoning him on.

In the dusk, the riverside almost palpitated with colliding birdcalls too complicated to distinguish from one another. Then, suddenly, Alex overheard a lower pitched moaning sound, not far away. *What was that?* Alex made his way, clomping, through the dense curtains of willow, out into the lower understory, still punctuated with salt cedar. Now he heard nothing. It hadn't sounded like a bird, too mammalian. Maybe he had imagined it. It was really getting dark. He turned back into the willow.

Then he heard it again, the moaning.

"Aaaal-ex."

It was barely audible, but it was his name. Swiftly, the tall teenager loped in the direction of the call. Then he saw the dark shape against hillocks of *Salicornia*.

"Dr. Bender?"

Alex kneeled down next to his mentor, whose big bony fingers closed on Alex's wrist.

"My ankle…" the scientist murmured with difficulty. "Broken. And I've lost my glasses."

Keeping a hand on Dr. Bender, Alex looked around in the diminishing light. He spotted the big double lenses, enlarging the narrow *Salicornia* stems into what looked like full-sized pickles. Alex reached for them and restored them gently to Dr. Bender's nose. "We'll get you out of here, Dr. Bender."

"Thanks, Alex," he said. "Thanks, quite literally, for the heads up."

"About what?"

"Seems as if I had to lose my glasses to see the forest for the trees," the scientist admitted ruefully. "You were right. Tamarisk could upset biodiversity here, upset it greatly."

Alex smiled appreciatively at Dr. Bender. Above, the eagle plunged downward past them, past the tamarisk. The men followed its trajectory toward the river's edge. The bold bird seemed finally to have found what it was looking for.