

# Assessing Estuarine Biota in Southern California<sup>1</sup>

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## Abstract

In southern California, most estuarine wetlands are gone, and what little habitat remains is degraded. For this reason, it is often of interest to assess the condition of estuaries over time, such as when determining the success of a restoration project. To identify impacts or opportunities for restoration, we also may want to know how a particular estuary, or area within an estuary, compares with neighboring areas. Comparisons among wetlands require knowledge of different estuary types. The seven types of estuaries described in this paper can be easily grouped into two functional types, fully tidal and seasonally tidal, based on a simple biotic index: presence of horn snails. A description of the distribution, diversity, and abundance of organisms in estuaries is one way to assess resources, determine the success of a habitat restoration, and compare estuaries to evaluate the biotic consequences of degradation. In this review, I summarize techniques that may be useful for managers charged with biotic inventory and monitoring, emphasizing techniques to categorize wetlands and quantify plants, invertebrates, fishes, birds, and trematode parasites.

*Key words:* bird, estuary, fish, indicator, invertebrate, trematode

## Introduction

Although California has a Mediterranean climate, it contains many types of wetlands. Along the coast, estuaries are the most familiar. In this paper, I first describe estuaries, provide examples of the functions that they provide, and discuss impacts, losses, and restoration. I then describe methods for characterizing and comparing the biota of southern California's estuaries.

Cowardin and others (1979) define estuaries as subtidal habitats and their adjacent tidal wetlands that are usually partially enclosed by land but have open, partly obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by freshwater runoff from the land. A combination of ample nutrients and sunlight make estuaries productive, though easily perturbed, habitats. Often, species found in estuaries are specially adapted to and, therefore, dependent on estuaries. From an ecosystem perspective, estuaries provide the following functions: (1) food chain support and nutrient cycling functions such as primary production, decomposition, nutrient export, and nutrient utilization; (2) habitat functions for native plants, invertebrates, fish, birds, mammals, and herpetofauna; (3) hydrological functions including flood conveyance, sediment control, ground water recharge and discharge, and shoreline protection; and, (4) water quality functions including water supply, waste-water treatment, detoxification

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of toxic substances, and modification of pollution from nutrient enrichment (Ferren and others 1995).

Why should people care about estuaries? To some, they are ugly swamps, unproductive lands, or mosquito breeding areas. Through most of history, governments around the world actively worked to eliminate estuarine habitats or convert them to more “productive” uses. A more modern view considers that estuaries, in addition to the ecosystem functions described above, provide the following socio-economic functions: (1) non-consumptive values such as recreation, research, and education; (2) consumptive values of “harvestable” physical resources such as water, gravel, and petrochemicals, and biotic resources such as fisheries, lumber, and crops; (3) cultural values by Native Americans, including activities such as basketry, gathering of food and medicinal plants, and acquisition of house building materials; and, (4) aesthetic and natural heritage values including natural landscape features, setting, and other aspects of California’s natural heritage (Ferren and others 1995).

One reason that wetlands are an area of concern is that we have lost ~90 percent of the original coastal wetland habitat in southern California as a result of filling or dredging during the last century (NOAA 1990). What is left has been degraded through fragmentation, water quality degradation, introduction of invasive plants and animals, unregulated public access, and other forms of environmental perturbation. In addition, damming, agriculture, and urbanization have greatly altered the magnitude and timing of freshwater inputs. Even in a degraded state, however, estuaries continue to provide important ecosystem functions. Of these functions, perhaps that of habitat for rare and endangered species is most important because of the many plants and animals restricted to the remaining estuary habitat (Zedler and others 1990).

Ferren and others (1995) group anthropogenic impacts to Californian estuarine ecosystems as: (1) agricultural development (for example, deforestation, draining, increased sedimentation, fragmentation, nutrient enrichment, pesticide pollution); (2) urbanization (for example, filling for development, landfill, excavation, fragmentation, diking, impoundment, runoff, effluent pollution, nutrient enrichment, and sedimentation); (3) agency activities (for example, channelization, flood control, ditching, and chemical treatment for mosquito abatement); (4) resource extraction (for example, petrochemicals, sediments, water, salts, fisheries); (5) public access (for example, compaction of soil, removal and disturbance of organisms); and (6) introduction of invasive exotic species.

The sad state of our coastal wetlands has led to increased efforts to enhance, restore, create, and recreate estuarine habitat. Such attempts are either due to conservation actions or as required mitigation for the destruction of wetland habitat elsewhere. Throughout southern California, many estuaries have been subject to habitat restoration. Unfortunately, studies of the effectiveness of estuarine restoration have been sobering (Zedler 1984, Zedler and Langis 1991). At best, most restoration has converted one type of wetland to another, often arguably resulting in an overall net loss in wetland function (Zedler and Langis 1991). Thus, mitigation as a technique to compensate for losses or impacts should presently be viewed with concern, and the ability to assess success becomes critical to wetland conservation.

## Assessment

There are many reasons to assess estuarine functions. In some cases, we may wish to evaluate the success of a restoration project. We also may try to determine the extent to which a particular wetland is degraded or to obtain baseline information to be able to detect changes in function in the future. If the assessment is related to a specific function, its goals may be quite narrow. Such assessments might attempt to determine the presence of an endangered or fisheries species, the ability of a wetland to hold storm runoff, the quality of water exiting an estuary into the littoral zone, or the presence of mosquitoes. The habitat role of estuarine wetlands may be the most comprehensive function of all and the most difficult to assess. The following sections provide ideas for sampling plants and animals that use the estuary habitat.

For any assessment, it is important to consider that we can categorize southern California's estuaries along many different descriptive axes. Because the biotic community that occurs in an estuary may be influenced by the estuary's type as much as by the quality of the habitat, Ferren and others (1996) provide the following hierarchical categorization scheme for the seven distinct types of estuaries that occur in southern California:

River Mouth Estuaries: These estuaries occur at the mouths of large rivers that generally have some perennial flow, producing nearly permanently brackish conditions in the estuary. The Santa Clara River Estuary, the Ventura River Estuary and the Tijuana River Estuary are representative.

Canyon Mouth Estuaries: Emergent portions of the southern California coastline have canyons that drain watersheds. Creeks flowing through these canyons empty into the ocean through small estuaries that vary greatly in size, frequency of tidal flushing, salinity regimes and biota. Arroyo Burro and Devereux Slough in Santa Barbara County are examples of canyon mouth estuaries.

Lagoonal Estuaries: These estuaries have mouths closed by sand bars most of the year, usually have brackish fringe-marshes rather than vegetated flats, often have salinities that can approach fresh water, and support fauna typical of brackish to fresh water conditions (this is especially true where freshwater input has been enhanced by wastewater discharges and agricultural and urban runoff). Although many estuaries in southern California have lagoons at their mouths, lagoonal estuaries, such as Buena Vista Lagoon, primarily occur in San Diego County.

Coastal Dune-Creek Estuaries: These estuaries develop when wetlands near dunes occasionally connect with the ocean but have a seasonal sand bar. They are generally slightly brackish most of the year. Examples include the San Antonio Creek Estuary and Shuman Creek Estuary in Santa Barbara County. Dune encroachment into the wetlands keeps these wetlands small.

Bay Estuaries: These estuaries have large areas of subtidal habitat (bays) and low elevation salt marsh. Bolsa Chica, Anaheim Bay, Upper Newport Bay and Mission Bay are examples. There is a strong marine influence in bay estuaries because there is a consistently open and generally wide mouth. Intertidal mud flats, cord grass, and eelgrass characterize bay estuaries (Zedler 1982, Zedler and others 1992).

Structural Basin Estuaries: Tectonic activity that leads to down-faulted and down-folded geologic structures below sea-level may create estuaries of moderate

size that are most common in Santa Barbara County. Down-faulted basins include Goleta Slough, and down-folded (synclinal) basins include Carpinteria Salt Marsh.

Artificial Drain Estuaries: Agricultural and urban drains along the coast can form small, narrow estuaries when they reach the coast. They may be all that remains of a historically larger estuary or they may be new creations. Some of these exist in the form of small wetlands on sandy beaches at the mouths of culverts and storm drains, such as along Cabrillo Blvd. in downtown Santa Barbara. Others reach the coast as canals and have tidal channels with fringe marshes. Agricultural or urban runoff often pollutes these small estuaries.

An estuary is not a homogeneous habitat; each has a unique composition of landforms characterized by a specific origin, geomorphic setting, water source, and water regime (Ferren and others 1996). Associated with the large water body that defines the estuary may be channels, ditches, and ponds. Seeps and springs may provide freshwater. The water bodies may cover bottoms, beds, bars, and reefs (such as may be formed by oysters and mussels). Affiliated with the margins of water bodies may be shores, beaches, and banks. Tidal (mud) flats and deltas can be quite extensive in West Coast estuaries. They may form with the accumulation of sediments and are exposed by the retreating tide. Although natural hard substrate is uncommon in estuaries, woody and shelly debris and artificial structures such as pilings, levees, docks, and buoys can provide habitat for attached invertebrates and algae (Ferren and others 1996). The landforms an estuary possesses may affect the sorts of animals and plants that the estuary supports. In addition, because community composition may vary from landform to landform, characterizing landforms at each sampling site within an estuary will facilitate comparing communities among sites.

Another important factor associated with habitat function is how salinity varies in space and time. Two physical features influence salinity in an estuary: (1) the amount and seasonality of freshwater input and (2) the presence of a bar that can close off the mouth of the estuary from the ocean. As discussed later, invertebrates seem to be the biota most sensitive to these factors. Bay and structural-basin estuaries tend to have year-round tidal influence and relatively little freshwater input. River mouth estuaries have perennial freshwater inputs and relatively less tidal influence. Canyon mouth, lagoonal, coastal dune-creek, and artificial drain estuaries have seasonal freshwater inputs and seasonal bars that isolate them from the sea. These latter estuaries have periods of low salinity, high salinity, and tidal flushing that vary with the season. Their water levels also can fluctuate well beyond the normal tidal range.

A final physical aspect of wetlands to consider in an assessment is size. Although the technical boundaries of an estuary are based on salinity, it is more practical to use the plant community to indicate the extent of the estuary. The main reason for measuring wetland size is that it can act as a useful covariate when comparing assessments among wetlands. For example, the general ecological association between species richness and the size of a habitat sampled predicts that large estuaries should have higher species diversity by means of their size, independent of their quality of habitat. If this ecological rule holds for estuaries, large estuaries, all else being equal, generally could appear to be in better shape than small ones. For example, to determine the extent to which different estuaries are degraded, one could plot a measure of the estuary, such as species richness of a particular set of organisms, against estuary size. The prediction is that richness should increase with size, but that more degraded estuaries should fall below the line that describes the size-richness curve. Preliminary efforts show that the richness of both fishes and

birds increases with wetland size but that estuaries that have few fish species for their size do not have few bird species for their size, suggesting that these two biota respond independently to environmental factors. I have also found it useful to separately measure the flooded, unvegetated area of the marsh (the sum of pans, channels, and mudflats) because fishes and birds seem to respond more to flooded area than wetland size per se. Vegetated marsh and flooded habitats can be mapped from aerial photographs.

## Sampling the Biota

An enjoyable way to understand an estuarine community is to put on waders, grab sampling gear, and count the plants and animals that live there. Plants, invertebrates, fishes, and birds all require different sampling methods. The biggest challenge when sampling wetlands is to obtain data that are comparable over time or across estuaries. This means that substantial thought must be given to standardized timing, habitat, methods, and efforts. An excellent primer on sampling estuaries is from the Pacific Estuarine Research Laboratory (PERL 1990), and interested readers should consult this reference.

Sampling strategies will vary according to the types of questions being asked. Here I briefly describe the basic rationale behind the most common types of sampling in wetlands. Central to sampling design is the selection of sampling sites. It is useful to avoid the temptation of simply sampling adjacent to access points. In most cases, it will be necessary to stratify sampling by habitat type (for example, vegetated marsh, pans, narrow channels, and mudflats adjacent to the shores of large channels) so that comparisons among sites are not confounded by differences in habitat type.

It is also important to account for gradients that may exist within habitat types. For example, when targeting a single tidal channel, we often stratify sampling so that our sites are spaced along the upstream-downstream gradient (mouth, upper extent of tidal influence, and one or more points in between). Within a channel site, we may also stratify sampling according to tidal height.

Site selection will obviously be affected by the goals of the study. If the goal is to follow some aspect of the community over time, sites can be targeted that are home to the species or community of interest. In this case, it is usually permissible to choose sites that can be conveniently revisited for monitoring. Another common goal is to assess a distinct location (for example, an impact or restoration site) and compare it to similar sites (often these comparisons are made over time). In this case, the location of the target area is often predetermined, and comparison sites are chosen in similar habitat either along a gradient of impact or free from the variable of interest. If the goal is to assess the distribution and abundance of organisms in an entire wetland, it is necessary to randomly select multiple sample sites. For this, we have used an aerial photograph of a marsh, and divided it into discrete habitat types. From each of these types, we randomly select a subset of sampling locations by using GIS or a grid system (we employ a rule so that sites are no closer than 50 m).

The remainder of this section gives a rapid introduction to some of the sampling methods that I have found most useful.

## Plants

Estuaries often support thick vegetation that forms marshes and provides important habitat for animals (see Zedler 1982). Because plant assemblages are often zoned according to tolerance to inundation and soil salinity, these two characteristics can be useful estuarine indicators. Cord grass (*Spartina foliosa*) and pickleweed (*Salicornia virginica*) often dominate the lower salt marsh. The middle salt marsh is generally irregularly flooded and has varying salinities. Pickleweed usually dominates here in association with other species such as salt grass (*Distichlis spicata*), alkali heath (*Frankenia* spp.), jaumea (*Jaumea carnosa*), and sea lavender (*Limonium californicum*). Parish's glasswort (*Salicornia subterminalis*), shore grass (*Monanthochloe littoralis*), and pickleweed (*Salicornia* spp.) dominate the high marsh with its irregular flooding and euryhaline or hyperhaline salinity. Cattails (*Typha* spp.) and rushes (*Scirpus* spp., *Juncus* spp., and so forth) occur where salinity is persistently low. Zedler and others (1999) argue convincingly that the elevation-based terms (“low,” “middle,” and “high” marsh) should be replaced by a system that also considers landscape position and conspicuous species. They suggest three alternative habitat designations: (1) the high marsh—a 30- to 70-cm elevation range with *Salicornia subterminalis*; (2) the marsh plain—a 30-cm elevation range with heterogeneous topography and a mix of several species; and (3) cord grass habitat—the bayward portion of the marsh plain and lower elevations, all occupied by *Spartina foliosa*. In addition, vegetation adjacent to channel edges tends to be distinct from vegetation away from edges.

Emergent plants are food for a number of terrestrial arthropods, several of which are salt-marsh specialists. The contribution of salt-marsh plants to the diet of marine animals, however, is thought to be primarily through detritus. Fully aquatic vegetation is less apparent in estuaries but includes flowering plants such as widgeon grass (*Ruppia* spp.), eelgrass (*Zostera* spp.), and algae such as epipellic diatoms and the mat-forming filamentous alga, *Enteromorpha* spp.

Sampling estuarine plants can be relatively straightforward because plant species lists are not long, the topography is simple, and canopy heights are short enough that percent cover estimates are usually adequate. For example, in our field work, we run a series of 10-m transects in which we make point-contact assessments of the plant species composition every 10 cm and canopy height estimates every meter. Good aerial photographs are often available of southern California estuaries, and one can usually discern large patches of different plant communities. However, one almost always needs to go to the field to ground-truth these maps and determine the composition of vegetation mosaics. There are good field guides and keys to salt marsh plants (Abbott and Hollenberg 1976, Faber 1996, Jepson 1993, <http://elib.cs.berkeley.edu/photos/flora/>). Probably the single best visual indicator of an estuary in southern California is the ubiquitous and easy to identify pickleweed. It is difficult to find an estuary in southern California that lacks this plant.

Epipellic micro-algae (for example, diatoms) and mat forming macro-algae are important components of estuarine food webs. Micro-algae can be assessed microscopically or through the chlorophyll content of the sediment. Macro-algae can be quantified in transects and quadrats (like those used to quantify invertebrates; see the next section). Some macro-algal flats are extensive enough to be quantified through aerial photographs. The nutrient content of algae can be used as an indicator of nutrient enrichment in an estuary (Fong and others 1998).

## ***Invertebrates***

Estuarine invertebrates live in the water, on vegetation, on the mud, and in the mud. Most species reach peak abundance in the summer. They are relatively rare in winter after high freshwater flows. One can visually survey for crabs and snails at low tide. Some invertebrates, particularly crustaceans, will come to baited minnow traps, while some small invertebrates will seek out litter traps (see PERL 1990). Many invertebrates are out in the open or give away their presence with burrows of distinctive shapes (burrows can be difficult for novices to identify with any certainty). Estimating density requires setting a sampling unit, usually in the form of a quadrat, transect, or core. A factor that complicates density estimates is that most animals are neither uniformly nor randomly distributed across a mudflat or tidal channel. Since many species are patchy, large numbers of sampling sites are necessary to estimate density. In addition, many species are zoned according to tidal height, meaning that tidal height should be accounted for when making comparisons among sites. One method to sample invertebrates in a tidal channel is to extend band transects from the vegetated margin of the salt marsh down into the intertidal zone, noting the change in elevation and density of organisms at regular intervals of the transect.

Sediment cores are useful for sampling shallow-burrowing species but often miss the deeper-dwelling clams, shrimp, and worms. Labor increases with the length and diameter of the core taken and decreases with the size of the screen the sediment is passed through. To accommodate this difference, we take large diameter (for example, 15 cm), deep cores (for example, 40-50 mm in depth) which are passed through a coarse mesh (for example, 3-5 mm) in the field and small diameter (for example, 5 cm), shallow (5-10 cm deep) cores that are preserved and then passed through a fine mesh (1-0.5 mm) in the laboratory. Large cores can be sieved in the field. In cases where many cores are taken or the site is far from water, we find that a water pump running off a small generator greatly speeds the task. Once captured, most of the larger marine invertebrates are relatively easy to identify to species. Unfortunately, there are many small species that can be quite a challenge to identify even using the several good keys available (for example, Smith and Carlton 1975, Morris and others 1980).

Because coring is labor intensive, it is usually necessary to limit the number of cores taken. Randomly selecting coring locations provides the best estimate of densities, but, due to the patchy distribution of animals, a large number of cores is needed to obtain a representative sample of even the most numerically dominant species. Patchiness is accentuated if there is significant variation in tidal height within the sampling area. Stratifying coring effort by tidal height helps to distribute effort across zones. Nonetheless, variation in the depth profile from site to site limits comparisons among sites. More recently, we have experimented with mapping the presence of beds of benthic infauna (as indicated by clam, crab, and shrimp burrows, and so forth) within transects and then randomly subsampling these beds with cores. Such targeted sampling intensifies effort in the areas where animals are most likely to occur, thereby increasing the efficiency of coring.

In the subtidal areas of larger estuaries, coring is relatively difficult to accomplish and not frequently undertaken. Using SCUBA (self-contained underwater breathing apparatus), divers can obtain cores similar to those obtained in the intertidal zone. However, in most estuaries, diving conditions can be challenging due to low visibility and strong tidal flux. Alternatively, sediment samples can be taken by grabs

deployed off boats. Unfortunately, these usually only capture animals on the surface or in relatively shallow parts of the sediment.

One component of the estuarine invertebrate community that is often overlooked, particularly by those with training in marine biology, is the insect fauna. Aquatic insects (many of which are larval forms) can dominate the invertebrate community of some estuaries. Terrestrial insects are abundant in the warm months in and around estuaries and may play important, unappreciated roles in estuarine ecology. There are several insects, such as the pygmy blue butterfly caterpillar (*Brephidium exilis*), that feed specifically on estuarine plants.

Although assessing invertebrate communities can be very difficult (one needs to consider the resources available before embarking on an ambitious sampling program), this does not mean that one should ignore invertebrates when assessing wetlands. In particular, the invertebrate community can be a useful indicator of the type of tidal inundation that an estuary receives. As mentioned earlier, invertebrates are particularly sensitive to variations in salinity (especially compared with fishes and birds). Sandoval and Lafferty (1995) found that the invertebrate community of estuaries with regular tidal influence is dominated by relatively *marine* species such as crabs, shrimp, polychaete worms, clams, mussels, and horn snails. In estuaries with variable salinity, these species are usually absent. Instead, aquatic insects, amphipods, isopods, crayfish, small snails, and oligochaete worms can be abundant. One species, the California horn snail (*Cerithidea californica*), is abundant and is easy to see and identify because it often carpets the mudflats and channel banks where it occurs (Lafferty 1993). For example, out of the approximately three dozen estuaries in Ventura, Santa Barbara and San Luis Obispo Counties, the only four natural wetlands with horn snails (Mugu Lagoon, Carpinteria Salt Marsh, Goleta Slough and Morro Bay) are also the only four with consistent tidal flushing (nearly all the others have records of tidewater gobies, see below). The broad distribution and abundance of *C. californica* within its range make it an excellent reflection of regular tidal flushing and the associated marine invertebrate community. Horn snails may even provide a historical record of tidal influence: their shells are preserved in sediment and can be retrieved from cores. The presence of horn snails also provides the possibility for using larval trematode parasites as indicators (as discussed later). One exception to the “horn-snail rule” is Elkhorn Slough in Monterey County, a fully tidal estuary. Here, instead of horn snails, one finds an introduced ecological analogue, the mud snail, *Batillaria attramentaria*. A second exception is Campus Lagoon (in Santa Barbara County), an artificial marine pond without tidal influence (the seawater source is the outflow of the UCSB marine lab) where horns snails were planted and survived for several years.

## **Fishes**

A few dozen fishes use southern California estuaries (a dozen are common). Particularly common or apparent species include killifish (*Fundulus parvipinnis*), topsmelt (*Atherinops affinis*), arrow gobies (*Clevelandia ios*), longjaw mudsuckers (*Gillichthys mirabilis*), tidewater gobies (*Eucyclogobius newberryi*), and mullet (*Mugil cephalus*). Diversity is relatively low, and although species are well represented in field guides for the area, it is useful to have a guide for both freshwater (for example, McGinnis 1984) and marine fishes (Miller and Lea 1972 or Eschmeyer and Herald 1983). Some, such as sharks and rays, are more typical of the open ocean but will

enter estuaries at high tide. Juveniles of reef species that are common in the near shore may enter an estuary and stay if patches of hard substrate are present. Historically, steelhead and lamprey migrated seasonally through estuaries.

There are several methods for sampling fishes in estuaries. Like invertebrates, the abundance of fishes is higher in the warmer months, and sampling in the late summer/early fall yields the greatest catch. Because estuaries are relatively calm and shallow and often have smooth bottoms, seining, when conducted properly, can give a very good indication of the diversity and relative abundance of fishes at a particular location. If one is interested primarily in obtaining a list of common fishes, the following approach works fairly well with a crew of two to five people: At slack tide, when currents are weak, we select three or more shallow locations (<1.5 m deep) within the estuary. We then take relatively short seine hauls (<30 m) that can terminate on a gently sloping, unvegetated bank or shore (avoiding areas with excessive submerged rocks or other hazards). We find that a seine 10-20 m long by 2 m high with a 1/8 – 1/4 inch (3-6 mm) mesh works well. Small mesh is better for capturing small gobies, but the extra drag associated with small mesh necessitates using a shorter seine (which is not as good for capturing large fish or schools of fish). We fish until three to five successive seine hauls do not add any additional fish species to the accumulated species list.

Minnow seines will not adequately sample larger wetlands with substantial subtidal areas. Traps can be used in areas that are too deep to seine, because most estuarine fishes will enter minnow traps (tidewater gobies are a notable exception). Traps require relatively little effort (except that they require two visits to a site) and do a better job at capturing large individuals that are able to out-swim seines. They work best when baited and left out overnight; dry dog food makes a convenient bait. However, in shallow areas fish may die if traps are left out too long because low tides may expose traps to the air; anoxia may kill fish at night in traps set in deep water; or the captives may eat one another. In general, traps seem to have a high variance in what they catch: some traps come up empty next to traps filled with fish. There is also a tendency for some fish species to enter traps more than others (Layman and Smith 2001). Although trapping is not a substitute for seining, often traps can add new species not seen in a day's seining. Gill nets are similar to traps in the sense that they are set and later retrieved. They are able to catch larger fish than minnow traps but mostly yield dead fish.

In larger wetlands, benthic trawls (and, to a lesser degree, midwater trawls) are the most tractable way to sample substantial subtidal areas. Trawling in an estuary requires a small boat, preferably one with a shallow draft. When trawling, it is important to keep track of the depth of the trawl and the area over which the trawl was pulled. Trawls can also sample subtidal epibenthic invertebrates.

Sampling fish for abundance is challenging. For traps and gill nets, the area sampled is not known and certain fishes are better able to avoid seines and trawls (by swimming or burrowing) than others. Rozas and Mellor (1997) advocate enclosure devices such as drop traps and throw samplers instead of seines. One way to obtain more accurate densities with seines is to first set up blocking nets that trap fish into a moderately sized area and then seine repeatedly (for example, at least five times) inside the area until no more fish are captured on three successive passes. Then, pull in the blocking nets carefully, one behind the other, to capture fishes that have sought refuge in the nets. Blocking nets 20 m long are sufficient to block off most narrow channels. A smaller seine (5-10 m long) can be used for the successive passes. In

areas where small gobies are abundant, 20 or more passes may be necessary to adequately sample the area due to the habit of gobies to rapidly burrow. Narrow channels are easy to sample this way because blocking nets can be run from bank to bank. Areas adjacent to open shores can be blocked by forming a triangle, with the shore acting as one side and the blocking nets meeting at the apex offshore.

A very useful indicator that an estuary is closed off to tidal flushing for at least part of the year is the presence of the tidewater goby, *Eucyclogobius newberryi*. Tidewater gobies are often the most common fish in wetlands where they occur, particularly in the summer and fall. Unfortunately, tidewater gobies are an endangered species and have been extirpated from large parts of their range, particularly in Los Angeles and Orange Counties (Lafferty and others 1996). Therefore, the absence of tidewater gobies does not indicate year-round tidal flushing; it may simply represent a local extirpation (Lafferty and others 1999).

## **Birds**

Birds use estuaries in large numbers for food and rest during migration periods. Some species breed in southern California wetlands. Due to declines in the abundance of several species (for example, California least tern [*Sterna antillarum browni*], light-footed clapper rail [*Rallus longirostris levipes*], Belding's savannah sparrow [*Passerculus sandwichensis beldingi*], western snowy plover [*Charadrius alexandrinus nivosus*], and brown pelican [*Pelecanus occidentalis*] are federally protected, and several shorebirds are considered to be in decline), there is a growing need for understanding their status and trends. In addition, because they are charismatic and easy to view, bird communities appeal to the general public. The low topographical relief in most estuaries makes it possible to observe most bird species in a particular field of view. Some wetlands in southern California are sufficiently small that all birds can be counted from just a few fixed points. With a few exceptions (such as female ducks, dowitchers (*Limnodromus* spp.), some terns, immature gulls, and some sandpipers), most species of birds that use estuaries can be identified given a good look, basic birding experience, and a field guide (for example, Sibley 2000). Often data on birds exist in the form of notes from experienced birders, who often visit estuaries for their rich bird communities. Such notes can be useful but usually cannot replace a systematic sampling effort. However, amateur birders represent a potential pool of expert volunteers and, when using an appropriate sampling protocol, can provide excellent data.

Because migration and breeding alter the sorts of birds that visit our estuaries from month to month, it is necessary to limit comparisons among estuaries to samples taken in the same season. In addition, the bird community can be affected over short periods of time by weather, tide, and time of day. For example, as the tide retreats, birds may move from roosting sites in the upper marsh or beach to forage on exposed mudflats. Tide and other variables should be controlled for in sampling or accounted for in comparisons.

Sampling in the spring provides a chance to detect breeders such as least terns, while sampling in the fall yields a community augmented by migrants. Limiting sampling effort to aquatic birds (for example, gulls and terns, shorebirds, waterfowl, divers, rails, kingfishers, herons, and egrets) and birds of prey, while ignoring terrestrial passerines, is one means to reduce effort and simplify analyses. However, in many cases, terrestrial passerines may be of particular importance if they are of

conservation concern or use the margins of the estuary. Due to their smaller size and more cryptic habits, terrestrial birds may not be effectively sampled by the techniques described below.

One may be able to survey a small (<50 acre) estuary in a few hours, but large estuaries may require subsampling or substantial sampling effort. In a small estuary, a simple and repeatable approach is to count and identify all birds visible within defined perimeters from fixed locations and fixed periods of time (for example, 30 minutes). Choosing locations that provide good vantage of the mouth, middle and back sections of an estuary provides a good estimate of abundance by species. Then, to determine a more complete total species list, one can roam throughout the estuary for 30-minute viewing periods until a period passes without detecting any new bird species. This facilitates the inclusion of the presence/absence of uncommon birds.

To quantitatively subsample birds in an estuary, we have employed the following sampling method: Sites are selected from a map of the estuary (in our case, these sites are the randomly chosen locations for sampling other taxa). A 100-m radius is then drawn around the sampling point. Using a GPS unit and a map of the site, observers approach the perimeter of this circle, mapping the location of birds once they have a vantage of the interior of the plot. Then, over a 20-minute time interval, observers walk to and along a transect located along the circumference of a 50 m radius around the central point. Birds are counted and mapped when observed. This approach has the advantage of standardizing sampling time and transect length. It also tends to flush cryptic species that would otherwise not be observed from a fixed point.

Recently, (with R. Hechinger) we have used remote video surveillance to determine bird visitation rates of small areas (on the scale of 10 by 10 meters). We have had success by taking five seconds of video every minute over a two week period. Although this is the only way that we know how to effectively sample birds in small areas, it has various limitations such as the expense and effort required to sample several remote sites simultaneously. Improvements in remote surveillance technology may soon increase the practicality of this approach for larger scale studies.

## **New Approaches**

The Environmental Protection Agency is presently funding over 30 investigators in the exploration and development of new ecosystem indicators through the Pacific Estuarine Ecosystem Indicator Research (PEEIR) Consortium. The objective of this project is to develop indicators of wetland ecosystem health through evaluations of stressor-response patterns in wetland biota. The goal is to create an integrated suite of indicators to evaluate impacts of toxic contaminants, nutrient enrichment, microbial contamination, and exotic species invasions. The ecosystem-indicators component of PEEIR (led by S. Morgan) is investigating new ways of sampling the biota that may some day be added to the more traditional methods discussed previously. Some examples are described below.

Measures of microbial community composition and diversity (led by T. Holden) using DNA from the T-RFLP (terminal restriction length polymorphism) method are highly transferable among sites and ecosystems, making them potentially valuable indicators of pollution and enrichment. Assessment of nitrogen isotope ratios in

selected biota at southern California sites (led by M. Page) has promise for assessing ecosystem responses to nutrients. Refinement of methods to describe ammonification, decomposition, and nitrification rates (led by S. Williams) may generate information on trophic support and biogeochemical performance indicators. One method to investigate impacts to ecosystems is to evaluate changes in growth and reproduction of individual organisms by linking contaminant effects in dynamic mass-energy budget models. For example, analysis of fish otoliths to indicate growth and rates (led by W. Bennett and A. Brooks) may provide a means to indirectly assess habitat suitability for fishes under different contaminant regimes. This information might then be integrated into mathematical models designed to assess impacts at the population level. Parallel to the development of ecosystem indicators is research into other new technologies for assessment. For example, more sophisticated application of remote sensing, such as high spatial resolution airborne hyperspectral imagery (led by S. Ustin), could provide quantitative mapping of canopy pigments, water content, and dry standing litter. A value to the collaborative approach in developing indicators is that there may be important links among indicators that would not emerge from the development of each alone.

### **Trematodes**

Using parasites as indicators of ecosystem function is the aspect of PEEIR that I oversee. Trematodes are parasitic worms with complex lifecycles. Several species use the common horn snail as a first intermediate host. There are 17 described species in California, and it is not unusual for half or more of the snails in an estuary to be infected by larval trematodes. The trematodes leave the snail in a free-swimming cercarial stage and (with the exception of a blood fluke) seek out a second intermediate host. This is usually a fish, but it can also be a crab or a mollusk, depending on the species of trematode. Most trematodes encyst inside their second intermediate host, but some encyst on the outside of snails or crabs. Mammals (such as raccoons) and birds become infected when they eat infected second intermediate hosts. Trematodes mature and reproduce in birds and mammals, their eggs being dispersed along with the final host's feces.

Because each trematode species has a unique life cycle that depends on many interacting free-living animals, an estuary with a rich food web of fishes, birds, and invertebrates can support a diverse and abundant community of trematodes. Therefore, the trematode community within a snail population provides, in a glance, the sum effect of several interacting communities of free-living animals. It is relatively easy to sample a population of snails for trematodes, all of which can be identified to species with a practiced eye using a dissecting scope. Because snails and their trematodes are long lived (up to more than 15 years), the community of trematodes in a population of snails provides an integrated history of the free-living animals that have used the estuary on the scale of months or years (depending on the age of snails sampled). This is potentially more satisfying than the single day snapshot surveys that are usually the only possible way to sample birds, fishes, and invertebrates because these are subject to seasonal and, especially for birds, even daily fluctuations in abundance. It also makes trematodes ineffective for assessing rapid changes occurring on short time frames.

An observation of an urban population of horn snails first suggested to me that parasites could indicate habitat function (Lafferty 1993). I was sampling a site

separated from a marsh by a parking lot and bordered by a busy highway intersection. Birds were conspicuously absent (presumably due to the proximity of vehicle traffic), and the snails were completely uninfected compared with a prevalence of 25 percent in the adjacent marsh, suggesting that degradation had reduced trematode prevalence. Other authors have also speculated that the prevalence of trematodes in snails corresponds to the degree of habitat degradation (reviewed by Lafferty 1997). Cort and others (1960) made the first such comparison in Michigan. They found that larval trematode diversity and species richness had declined since studies conducted 20 years before. They also noted an increase in human disturbance and a reduction in the shorebird population.

With Todd Huspeni, I have used trematode communities to assess the success of restoration at Carpinteria Salt Marsh. As one would expect, degraded areas showed significantly reduced diversity and abundance of trematodes compared with reference areas. While trematode communities sampled from reference sites did not vary much from year to year, those in the degraded area rapidly increased in prevalence after restoration. Newly created habitat produced trematode communities similar in prevalence to reference sites. Still, at present, the reference sites and the created sites are not yet identical in their species diversities or compositions; restored areas have relatively more trematodes that use mollusks as intermediate hosts and relatively few trematodes that use fishes (Huspeni and Lafferty, unpublished manuscript). This underscores previous studies that indicate that newly restored estuarine habitat is not automatically the same as natural estuarine habitat. To make this approach broadly useable will require the additional ground-truthing of methods and their eventual publication and dissemination.

## Conclusion

In summary, there are several ways that we can describe estuaries when we seek to better understand their function. The most appropriate method varies with the goals and expertise of the evaluator. It is important to understand that there are a variety of types of estuaries that have unique properties, and these may be inappropriate to directly compare with one another. For example, when choosing an estuary or estuaries to act as a reference site, it would be important to be sure that size and tidal regime were similar to the target estuary. The horn snail makes an excellent indicator of regular tidal flushing. Because sampling a single taxon will likely provide an incomplete picture of an estuarine community, attempting a variety of assessments is important. New technologies and ideas may provide innovative methods to assess estuary biota. A description of a larval trematode assemblage is a single measure that captures the ability of an estuary to support a rich and functioning community of invertebrates, fishes, birds, and mammals. However, sampling must be consistent in methodology, and effort must be comparable among sites.

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## References

- Abbot, I.A.; Hollenberg, G.J. 1976. **Marine algae of California**. Palo Alto, CA: Stanford University Press; 827 p.
- Cort, W.W.; Hussey, K.L.; Ameel, D.J. 1960. **Seasonal fluctuations in larval trematode infections in *Stagnicola emarginata angulata* from Phragmites flats on Douglas Lake**. Proceedings of the Helminthological Society of Washington 27: 11-12.
- Cowardin, L. M.; Carter, V.; Golet, F; LaRoe, E.T. 1979. **Classification of wetlands and deepwater habitats of the United States**. Office of Biological Services, U.S. Fish and Wildlife Service, FWS/OBS-79/31; 131 p.
- Eschmeyer, W.N.; Herald, E.S. 1983. **A field guide to Pacific Coast fishes of North America: From the Gulf of Alaska to Baja, California**. Boston: Houghton Mifflin; 336 p.
- Faber, P.M. 1996. **Common wetland plants of coastal California: A field guide for the layman**. Mill Valley, CA: Pickleweed Press; 122 p.
- Ferren, W.R., Jr.; Fiedler, P.L.; Leidy, R.A; Lafferty, K.D. 1995. **Estuarine wetlands**. In: Ferren, W.R., Jr.; Fiedler, P.L.; Leidy, R.A., editors. Wetlands of the central and southern California coast and coastal watersheds: A methodology for their classification and description. Final Report prepared for the United States Environmental Protection Agency, Region IX. See <http://lily.MIP.Berkeley.EDU/wetlands>.
- Ferren, W.R., Jr.; Fiedler, P.L.; Leidy, R.A; Lafferty, K.D.; Mertes, L.A.K. 1996. **Wetlands of California, part II: A method for their classification and description**. Madroño 43: 125-182.
- Fong, P.; Boyer, K.E.; Zedler, J.B. 1998. **Developing an indicator of nutrient enrichment in coastal estuaries and lagoons using tissue nitrogen content of the opportunistic alga, *Enteromorpha intestinalis* (L. Link)**. Journal of Experimental Marine Biology and Ecology 231: 63-79.
- Huspeni, T.C.; Lafferty, K.D. **Using larval trematodes that parasitize snails to evaluate a salt-marsh restoration**. Unpublished manuscript in revision at Ecological Applications.
- Jepson, W.L. 1993. **The Jepson manual: Higher plants of California**. Berkeley: University of California Press; 1400 p.
- Lafferty, K.D. 1993. **The marine snail, *Cerithidea californica*, matures at smaller sizes where parasitism is high**. Oikos 68: 3-11.
- Lafferty, K.D. 1997. **Environmental parasitology: What can parasites tell us about human impacts on the environment?** Parasitology Today 13: 251-255.

- Lafferty, K.D.; Swenson, R.O.; Swift, C.C. 1996. **Threatened fishes of the world: *Eucyclogobius newberryi* Girard, 1857 (Gobiidae).** Environmental Biology of Fishes 46: 254.
- Lafferty, K.D.; Swift, C.C.; Ambrose, R.F. 1999. **Extirpation and recolonization in a metapopulation of an endangered fish, the tidewater goby.** Conservation Biology 13: 1-8.
- Layman, C.A.; Smith, D.E. 2001. **Sampling bias of minnow traps in shallow aquatic habitats on the Eastern Shore of Virginia.** Wetlands 21: 145-154.
- McGinnis, S.M. 1984. **Freshwater fishes of California.** Berkeley: University of California Press; 316 p.
- Miller, D.J.; Lea, R.N. 1972. **Guide to the coastal marine fishes of California.** Sacramento: State of California, Dept. of Fish and Game; 235 p.
- Morris, R.H.; Abbott, D.P.; Haderlie, E.C. 1980. **Intertidal invertebrates of California.** Palo Alto, CA: Stanford University Press; 690 p.
- NOAA (National Oceanic and Atmospheric Administration). 1990. **Estuaries of the United States, statistics of a national resource base.** Special NOAA 20<sup>th</sup> Anniversary Report, Strategic Assessment Branch, Office of Oceanography and Marine Assessment, Washington, DC.; 79 p.
- Pacific Estuarine Research Laboratory (PERL). 1990. **A manual for assessing restored and natural coastal wetlands with examples from southern California.** California Sea Grant Report No. T-CSGCP-021. La Jolla, California. 105 p.
- Rozas, L.P.; Minello, T.J. 1997. **Estimating densities of small fishes and decapod crustaceans in shallow estuarine habitats: A review of sampling design with focus on gear selection.** Estuaries 20: 199-213.
- Sandoval, C.P.; Lafferty, K.D. 1995. **Invertebrate communities.** In Ambrose, R.F., editor. Coastal wetland resources: Santa Barbara County Mainland. Final Report to the County of Santa Barbara; 39-45.
- Sibley, D.A. 2000. **The Sibley guide to birds.** New York: Knopf; 545 p.
- Smith, R.I.; Carlton, J.T. 1975. **Light's manual: Intertidal invertebrates of the central California coast.** Berkeley, CA: University of California Press; 716 p.
- Zedler, J.B. 1982. **Salt marsh algal mat composition: Spatial and temporal comparisons.** Bulletin of the Southern California Academy of Sciences 81: 41-50.
- Zedler, J.B. 1984. **Salt marsh restoration: A guidebook for southern California.** California Sea Grant College Program, Institute of Marine Resources, University of California, A-032, California Sea Grant Report no. T-CSGCP-009; 46 p.
- Zedler, J.B. 1982. **The ecology of southern California coastal salt marshes: A community profile.** (Second printing, with corrections 1984). U.S. Fish and Wildlife Service, FWS/OBS-81-54; 110 p.
- Zedler, J.B.; Huffman, T; Josselyn, M., editors. 1990. **Pacific regional wetland functions: Proceedings of a workshop held at Mill Valley, California, April 14-16, 1985.** Amherst, MA: The Environmental Institute, Univ. of Massachusetts at Amherst; 162 p.
- Zedler, J.B.; Langis, R. 1991. **Comparisons of constructed and natural salt marshes of San Diego Bay.** Restoration and Management Notes 9: 21-25.
- Zedler, J.B.; Nordby, C.S.; Kus, B.E. 1992. **The ecology of Tijuana Estuary, California: A national estuarine research reserve.** Washington DC: National Oceanic and Atmospheric Administration Office of Coastal Resource Management, Sanctuaries and Reserves Division; 151 p.