Salmon and Steelhead Ecology of the Central California Coast (emphasizing San Lorenzo River)

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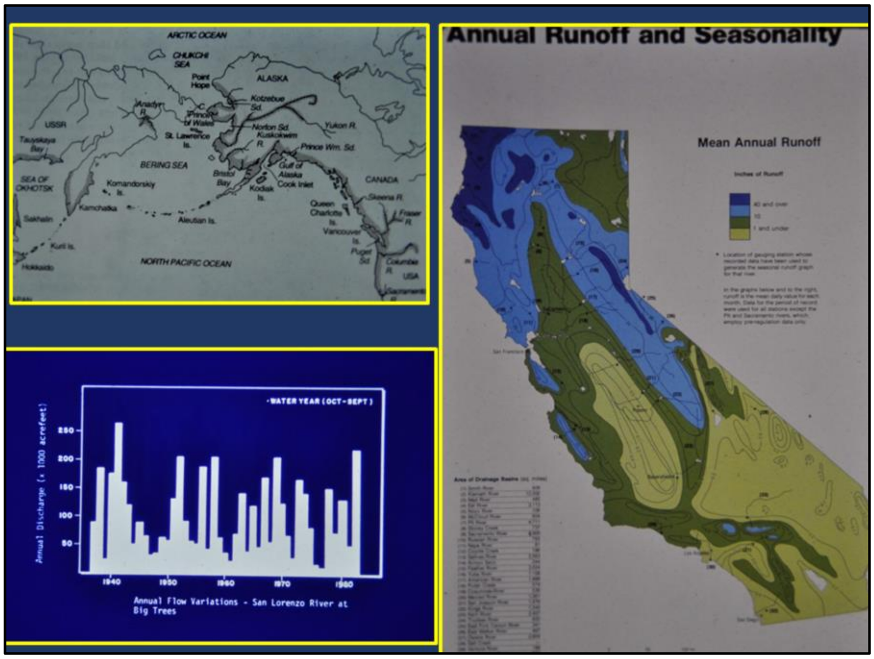
Steelhead usually spend 1 or 2 years in the ocean before returning to central California streams to reproduce. The female steelhead in the upper left spent 2 years before returning. Her larger size upon return greatly increased her egg production, and she is also stronger for long or difficult stream migrations; she also can dig a deeper red (nest) that is more resistant to scour and damage or loss during storms. The smaller female on the right spent 1 year in the ocean before returning. She has fewer eggs, but since many steelhead (especially females) survive the spawning effort, she can potentially spawn more times—a definite advantage in in streams with highly variable reproductive and rearing success ("bet hedging"). In short streams with few migration challenges she is just as likely as a large female to migrate, successfully spawn, and successfully return to the ocean. Because of the cost of eggs used in spawning she will never be as large the fish on the left, even if she lives longer. In Waddell Creek, a short, easily-accessible stream the majority of first time spawning females spent only 1 year in the ocean. The silver, counter-shaded coloration of both fish indicates that they recently entered freshwater from the ocean (both were caught in Pescadero Creek Lagoon in San Mateo County).

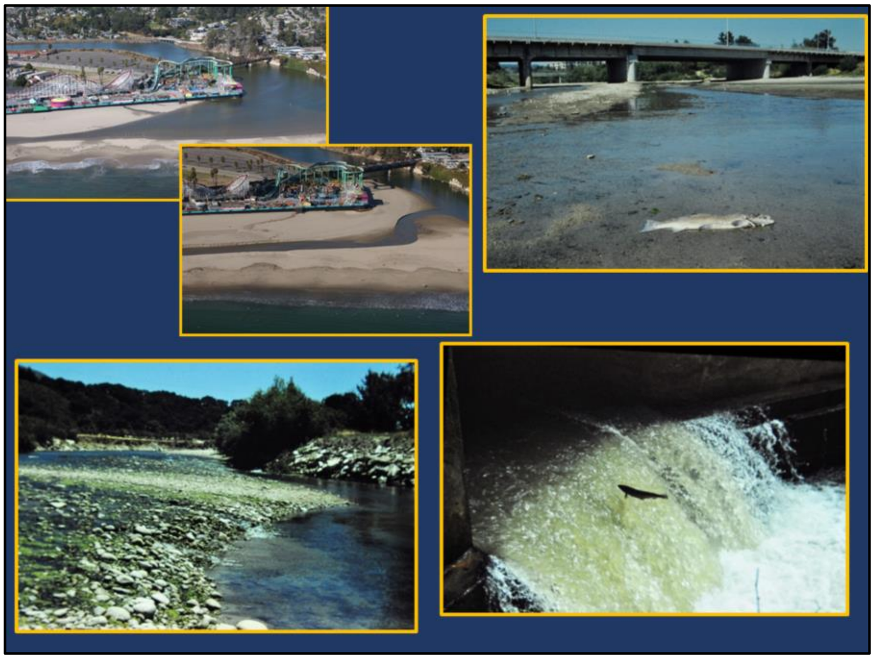
The male steelhead in the upper left spent 1 year in the ocean and has been in freshwater for an extended period, so its silver coloration has been replaced by the darker “rainbow trout” coloration. He also has a more hooked snout for fighting with other males for access to females. In addition this 1 year old male was produced in the local hatchery and spent 1 year in the hatchery before release as a smolt (a juvenile migrating to the ocean). The smaller, deformed dorsal (top) fin resulted from aggressive nipping (and fungal infection) by fish in the rearing raceways. The paired pelvic fins are also smaller, due to abrasion on the bottom of the raceway. The fish has stayed from its rearing stream (Scott Creek) to Waddell Creek because of delayed sandbar opening at Scott Creek in 1992.   Males lose about as much weight as females during spawning runs, because they spend a more extensive period in freshwater trying to mate with multiple females. Because they delay returning to the ocean they are much more likely to be trapped in the stream and often have poorer subsequent growth and survival than females. The 2-year ocean female in the lower right is still silvery, but has already spawned (note the skinny belly) and is returning to the ocean, she has lost much less feeding time than most males and is more likely to return as a repeat spawner (both fish are from Waddell Creek in Santa Cruz County).

Coho salmon males spend 1 year (a “jack”, lower left) or 2 years (upper right) in the ocean. Like steelhead they are silvery when they enter freshwater (left) and develop intense red/maroon color after time in freshwater. The older male has a very large hooked upper jaw, and the younger male a more modest hook for fighting other males. Jacks appear to be more common from strong juvenile year classes and from larger size during hatchery rearing. The scrapes near the tail of the younger male are scars from seal or sea lion attacks; attacks (and presumably mortality) are more common when fish are forced to wait offshore for streams to open.

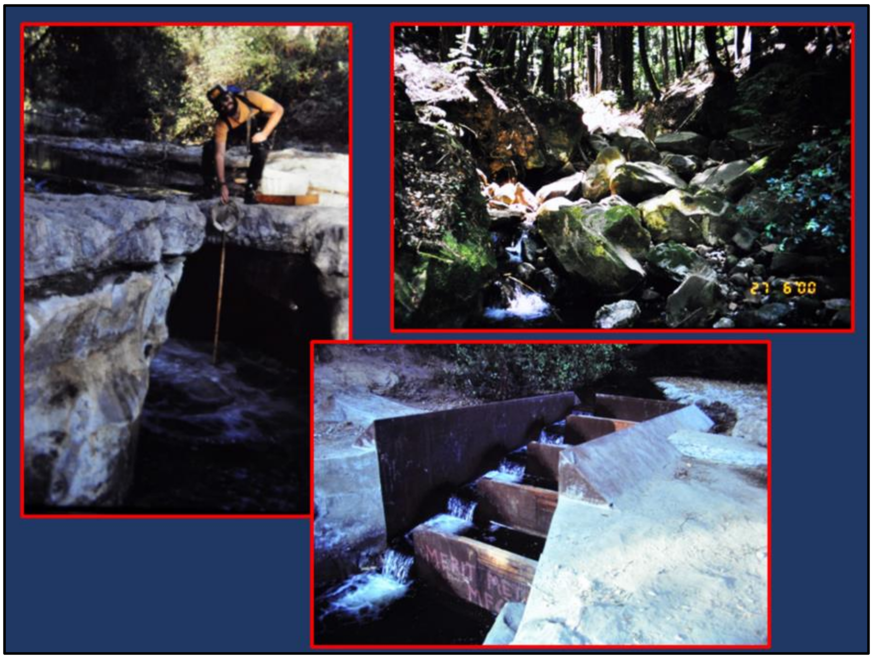
Wild coho females in the central coast almost always spend 2 years in the ocean, a strategy which results in maximum “annual” egg production. A third year would increase eggs, but not sufficiently to make up for the extra year, and a female spending only 1 year in the ocean would produce far fewer eggs and be unable to bury them very deep as protection against storms. Usually coho spend only 1 year in freshwater, so the central coast coho females (and resulting juveniles) have a dominant 3 year life cycle. The presence of numerous 2 year old males results in genetic exchange between the 3 numerically distinct year classes. Since coho die after maturing and attempting to migrate and spawn, the immune system shuts down and fungal growth develops with time in freshwater. Males move around continue to attempt matings with multiple females, but females that have spawned remain near or on the redd to attempt to protect the site from superimposed redds by other spawning fish. Since female coho fight to defend their redd , they also have a modestly hooked jaw (upper left), and can sometimes be mistaken for males. Since the female uses her tail during the digging of the redd, the damage results in the white fungus on the tail, seen in the female (lower left) guarding her redd.



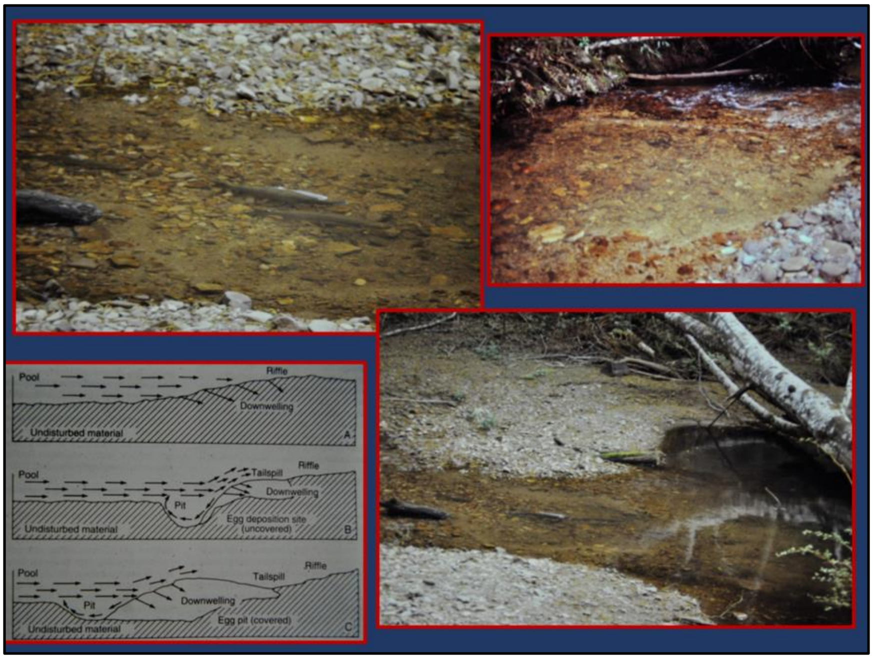
Coho salmon range from Kamchatka in Asia around and down the west coast to Santa Cruz County (the edge of the range!). Rainfall and runoff decline (right) farther south in California, and both become much more variable to the south. The rigid life cycle (1 time spawning, 3 year life cycle) of coho is limited to the south by variable rain and runoff, and this variability is also a problem in central California. Because about 2/3 of rain is lost to evaporation and transpiration (vegetation use of water) runoff is much more variable than rainfall; a “dry” year with 60% of average rain, may only have 10-25% of average runoff (1976 and 1977, lower left). With their more flexible life cycle (multiple spawning and ages of maturation) steelhead can cope with the increased variability to the south within California and extend south to Malibu Creek.



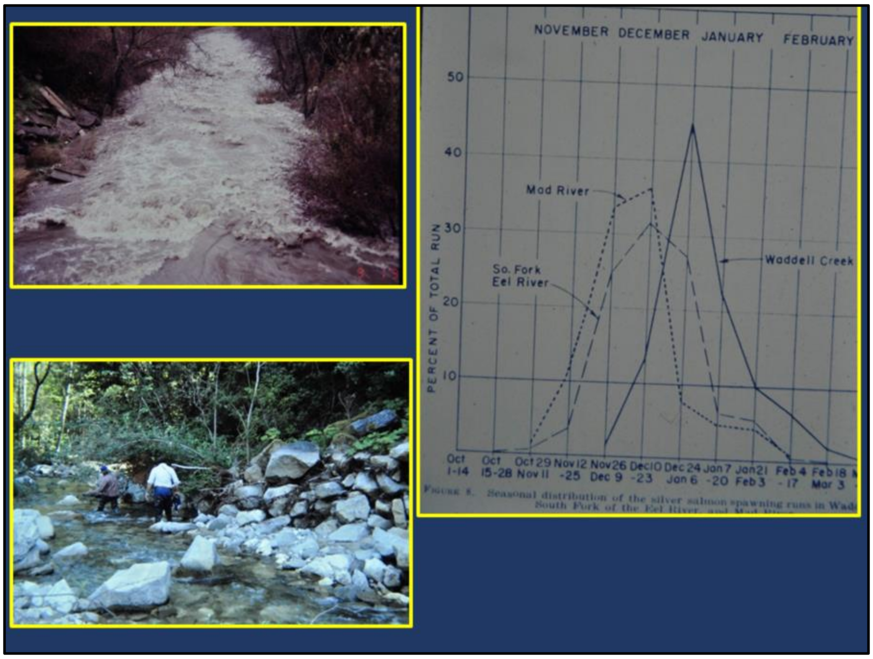
A major problem for coho in some years is delayed rains and opening of sandbars, but this has not been an issue for coho in the San Lorenzo (top left). Since coho migrate and spawn early (peak = late December through January) they can be forced to wait in the ocean (and be subject to marine mammal predation) for most of their spawning period. In 1991 the first large rains were delayed until 8 March, and a strong coho year class at Scott Creek was decimated by the delay. Steelhead migrate over a more extended period (January through April), and the delay has much less effect. Even when streams are open, low stream flows can restrict or block passage. The upper right picture shows a portion of the San Lorenzo River flood control channel, where the broad, shallow channel and low stream flows can block up and downstream movement of adult and juvenile fish. The diagonal riffle in the Carmel River (lower left) spreads the limited flow producing shallow impassable conditions. Measurements along transects in these “critical riffles” can be can be taken at a variety of flows to determine when there is sufficient depth (ie. 0.5-0.6 feet deep) and width (ie. 10% of the channel width) of pathways through the riffle for adult passage. Culverts often result in channel down-cutting downstream, producing a required jump for migrating fish; velocity in the culvert is also often an issue. Current guidelines require passage for juveniles, as well as adults, at new culverts or when modifying culverts for passage; however, in most cases passage for juveniles is not a major population issue, and providing passage for juveniles can increase costs of modifying culverts by 500%.



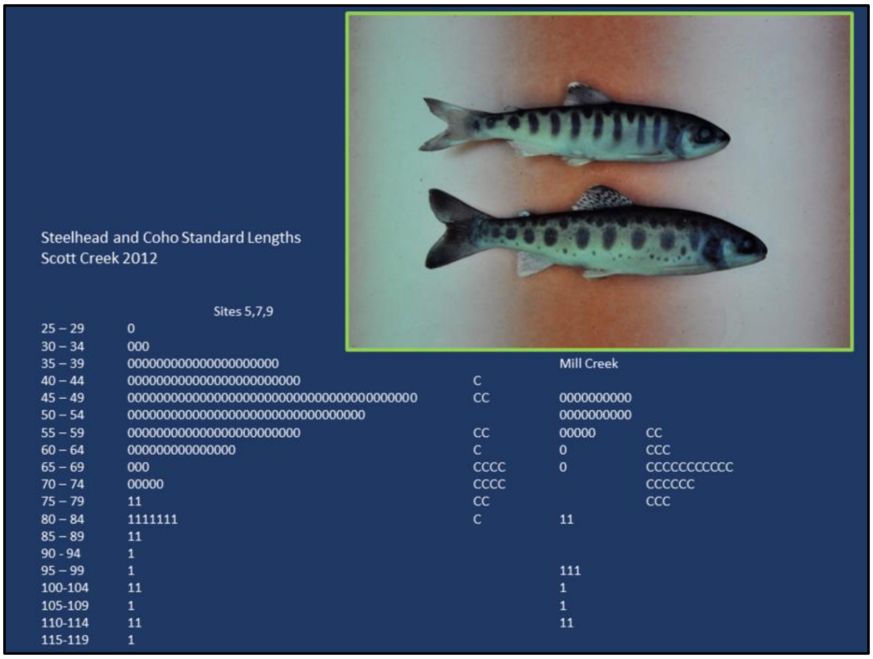
Natural barriers, like the boulder falls in the upper right often limit the upstream extent of steelhead access. Even this falls is occasionally passable during some stream flow conditions because of its stair-step arrangement. The natural falls in the upper left (Quail Hollow Falls on Zayante Creek) was formed by a resistant bedrock layer. It was a serious impediment to steelhead passage and blocked poorer swimming/jumping coho until a fish ladder (lower right) was installed to provide adult passage. The resulting jumps are about 1 foot and easily passable by adults at a variety of flows, and can be passed by most juveniles, however, they do not met the current passage criteria.



Spawning coho and steelhead usually pick their spawning sites in the *gravels* at the top of a *channel break* into an inclined riffle (coho redds in upper right). However, *depth* at the redd needs to be sufficient to so that the fish is fully submerged. In the upper left photo, low stream flows and shallow pool tail crest have forced the steelhead pair (and smaller male downstream) to move forward into deeper water with very sandy substrate where redd scour and poor egg oxygenation can be issues. The expanded picture (lower right) shows the other redd site preference, for a *nearby pool as escape refuge* if disturbed and for staging between spawning efforts. The channel break results in down-welling flow through the substrate to oxygenate the eggs. Coarser gravels free of fine sediment also increase oxygenation, and are less likely to be mobilized by high flows (bottom left).

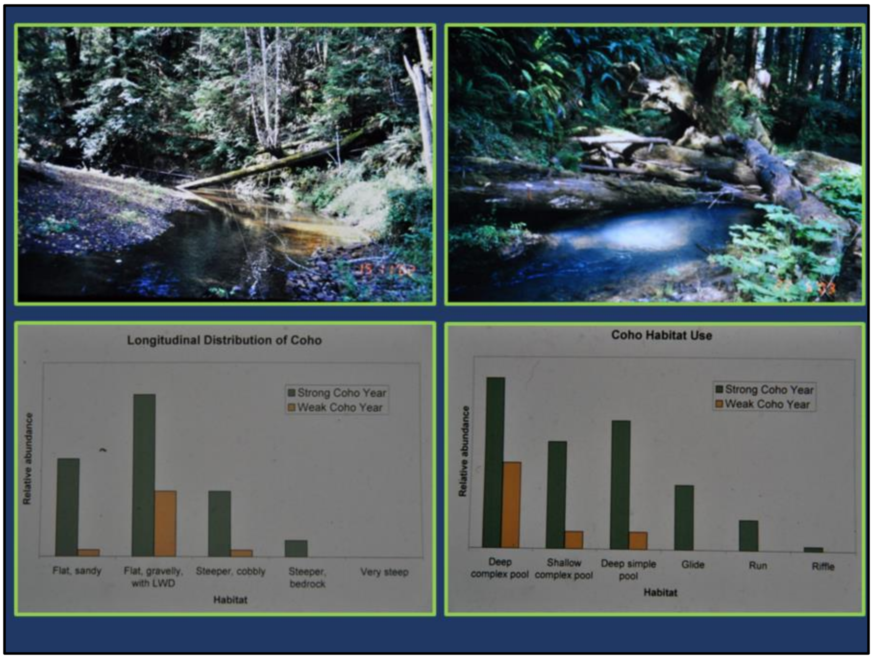


Coho spawn early in winter (right), and their redds are frequently destroyed by later storms (upper left). Steelhead spawn later and over a more extended period, so even in wet winters the later redds are likely to survive. In the photo in the lower left the scour line can be seen from the 4 January 1982 flood in San Vicente Creek, which destroyed all previous redds and also nearly eliminated all overwintering juvenile fish.

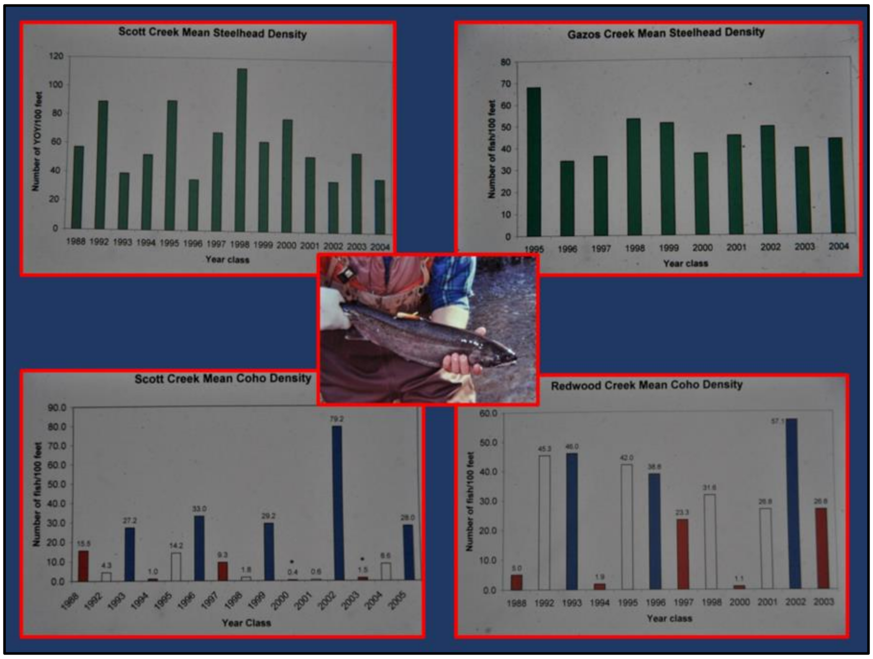


Juvenile coho (top) and steelhead (bottom) can be told apart by the presence of spots on the dorsal fin in steelhead and the much narrower parr marks (narrower than the space between them) in coho. The two differ in their morphological adaptations, with the more compressed, deeper body of coho, the larger eye, and especially by the much more forked tail and narrower caudal peduncle (the area in front of the tail fin). The body shape of coho is more adapted to continuous cruising in more open water (the ocean as an adult, and pools in freshwater), while the steelhead is more adapted to bursts of acceleration, useful in feeding at the heads of pools or in faster riffles and runs; steelhead adults are stronger swimmers and jumpers at barriers than coho. The larger eye of juvenile coho allows them to feed better in heavily shaded pools.

Coho spawn and emerge from the gravels earlier than steelhead, so in small streams with low summer stream flows they are normally bigger than young-of-year (YOY) steelhead. Most coho emigrate to the ocean as yearlings, so older, larger coho are usually absent. However, even a 2-8% holdover rate has significant effects when a weak year class follows a strong one and is bolstered by the yearling fish. Even coho that remain a second year tend to be not much larger than YOY fish. Steelhead in small streams usually spend a second year (or a third year) in the stream before emigrating to the ocean; therefore there is a wide range in sizes of juvenile steelhead in the stream compared to the one size group of coho. The relatively scarcity of older steelhead compared to YOY is due to heavy over-winter mortality, a (the) major limiting factor in smolt production in smaller, steeper streams.

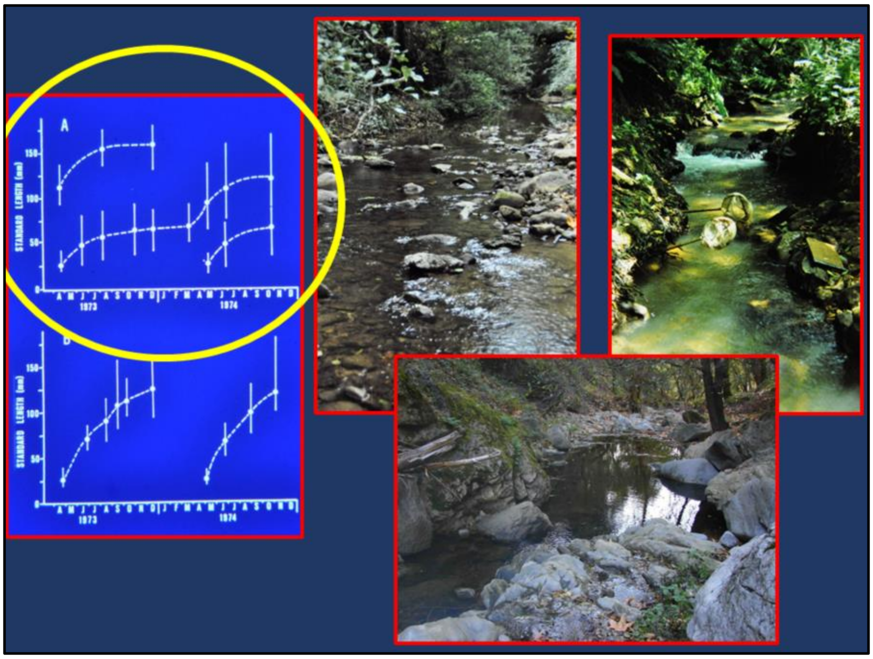


Juvenile coho have much narrower habitat use patterns than steelhead. At the reach level (left) they tend to be concentrated in the cool, flat, portions of the stream, especially with those areas with coarser substrate and good escape cover and pool development associated with large wood (LWD). However, in years of high juvenile coho abundance they may be more dispersed, with some fish in steeper reaches, and with much greater use of flatter, sandier, downstream habitats. In the San Lorenzo River watershed suitable flat, cool habitat is relatively scarce, since muich of the flat habitat iswarm and has a sandy streambed in the pools, and the cool water tends to be restricted to steeper streams. Zayante, Bean, lower Bear, and Branciforte creeks appear to be most suitable in providing cool water and relatively flat habitat. Within individual reaches (right) coho tend to be concentrated in deeper, complex pools, especially when coho are not abundant. In years of good access and spawning success, the abundant coho successively spread into the less preferred shallower and simpler pools, and may even make significant use of glides and runs; even when abundant they make little use of riffles.

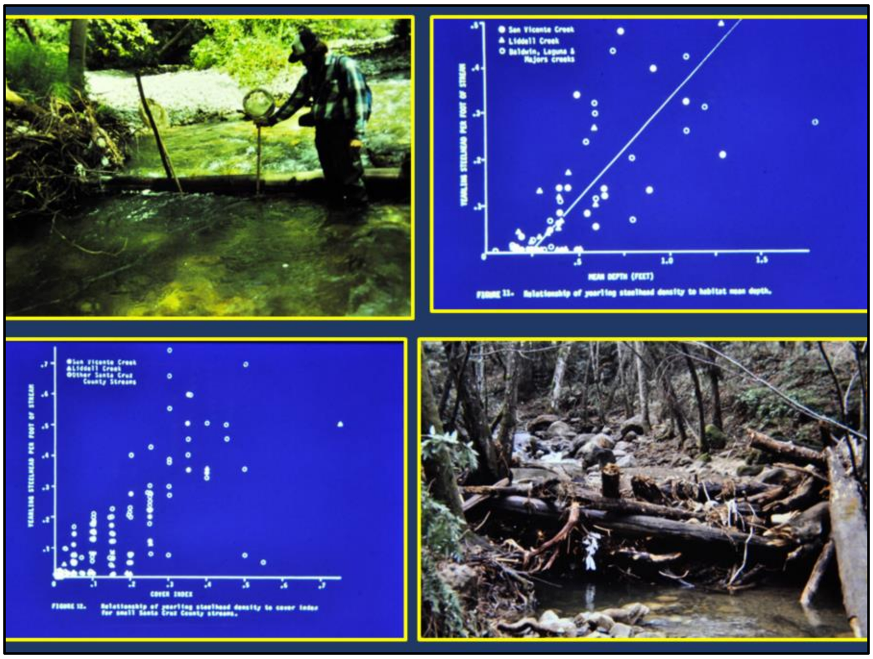


Steelhead in Gazos Creek (upper right) were similar in abundance annually through 2004, despite wide variation in winter and summer stream flows. Scott Creek steelhead (upper left) were somewhat less regular in abundance, partially because of steelhead suppression by abundant coho in 1993, 1996, and 2002. In comparison, coho in Scott Creek (lower left) and Redwood Creek (lower, right;, Marin County) showed sharp differences among the 3 relatively independent years classes; droughts (1988), floods (1982, 1983, 1998), and delayed access (1991) reduced individual year classes, and the relatively fixed 3 year life cycle of coho maintained these legacy effects. In Scott Creek large hatchery-reared coho smolts resulted in returns of some 2 year old females (center), and with some coho from strong 1993, 1996, 1999, and 2002 year classes staying in freshwater for an extra year, boosted weak year classes in 1995, 1997, 2004, and 2006. All year classes were present in 2003-2005, and the 2004 and 2005 year classes were relatively abundant. However, poor ocean conditions in 2005 and 2006 apparently resulted in no coho adult returns to Scott Creek in in 2007-2011; the wild coho were essentially eliminated south of San Francisco and sharply reduced farther north, including in Redwood Creek.

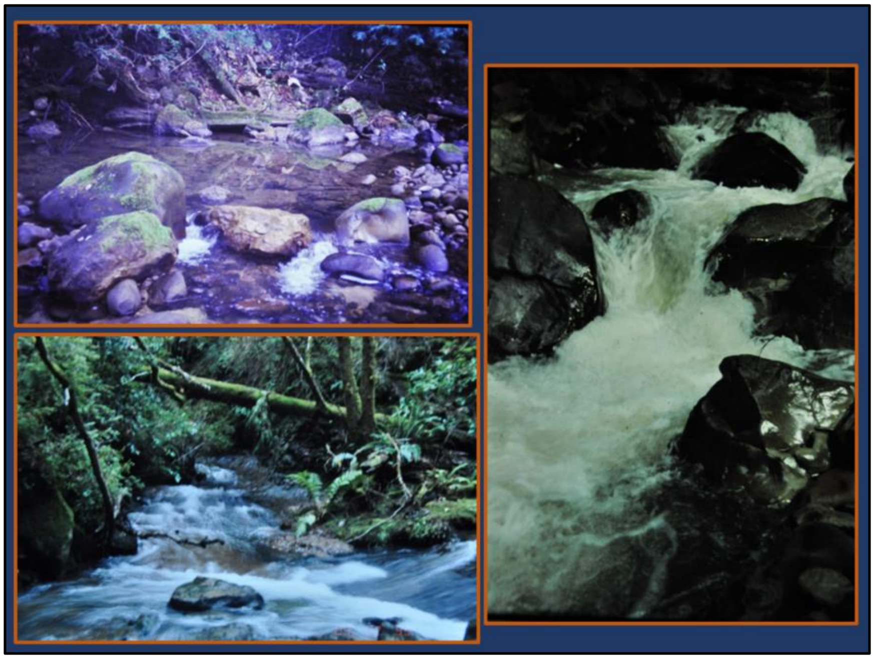
Fortunately for coho south of San Francisco, captive brood stock had been kept at the Hatchery on Big Creek in the Scott Creek watershed, at the NOAA facility in Santa Cruz, and at Warm Springs Hatchery in the Russian River watershed. Reared for 3 years in captivity (upper left) they have provided the adults (upper right) necessary for hatchery spawning or adult release to Scott and San Vicente Creek (in 2012-2014). Fish are individually tagged with microchips (PIT tags) for identification (reader in photo lower left) and mated according to genetic testing results to maintain maximum genetic diversity (the clip board sheets indicate preferred matings). Russian River and Olema Creek fish have also been used in matings to increase genetic diversity and egg survival in the remnant, inbreed Scott Creek fish. Females are periodically checked for egg development (lower, center) and injected with an anti-biotic to control Bacterial Kidney Disease. The eggs of each female are divided into four portions for fertilization by four different males. Hatchery out-plants will be used to restore lost coho runs in Waddell*, Gazos*, Pescadero*, San Gregorio, and Soquel creeks and in the San Lorenzo River, with initial priority going to streams (*) that had maintained significant coho runs into 2005, or at least the 1990's. Returns of hatchery-reared coho smolts, or wild spawning by hatchery-reared brood stock, resulted in coho spawning and significant juvenile production in Scott Creek and San Vicente Creek in 2012, 2013, and 2015, Waddell Creek in 2015, and lower juvenile abundance in Scott and Waddell creeks in 2016 (reduced success due to redd destruction in storms).



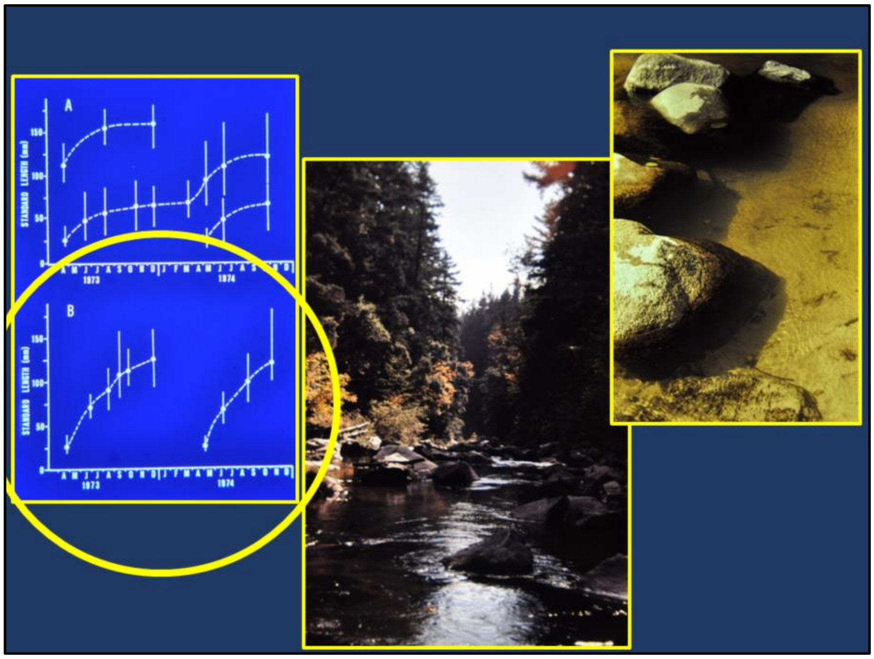
For steelhead in small streams, with low summer stream flow, two years of growth are needed, with little growth in summer (A, in the graph on the left). In these small streams young-of-year utilize all habitats (middle), but yearlings are associated with pools with cover, like undercut banks (upper right) or boulders (lower right). The pools with good cover are essential to provide the overwintering habitat that limits smolt production.



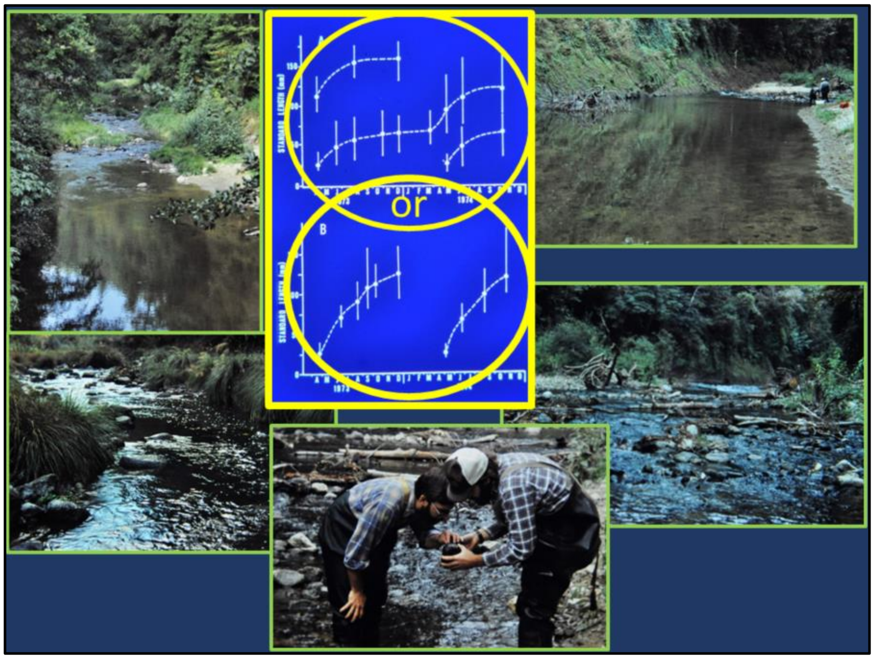
Yearling abundance in these small, low flow streams is strongly related to the combination of habitat depth (upper right) and escape cover (lower left). Both habitat features are not only preferred in summer and fall by yearling steelhead, but are also the features associated with carrying the fish over the high flow period in winter. Natural structure, like roots (producing undercut banks) and fallen trees provide both escape cover and pool development (upper left), increasing steelhead (especially yearlings) and coho. Partial log jams and other complex wood (lower right) was often removed in the 1980's (often usually "restoration" money) as potential passage problems, but should be left in place or modified, rather than removed, because of its importance in providing pool depth and escape and high flow cover.



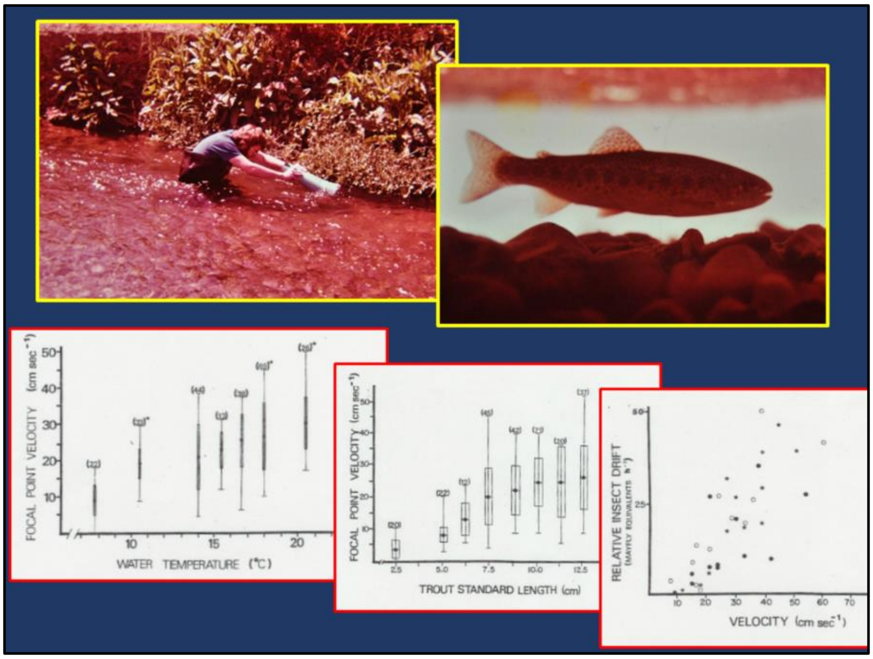
Unlike coho, which are largely restricted to complex pools in low gradient (<3 %) habitats, steelhead extend much farther upstream to areas of bedrock and boulders (left), and even very steep (6+ %) stair-step habitats.



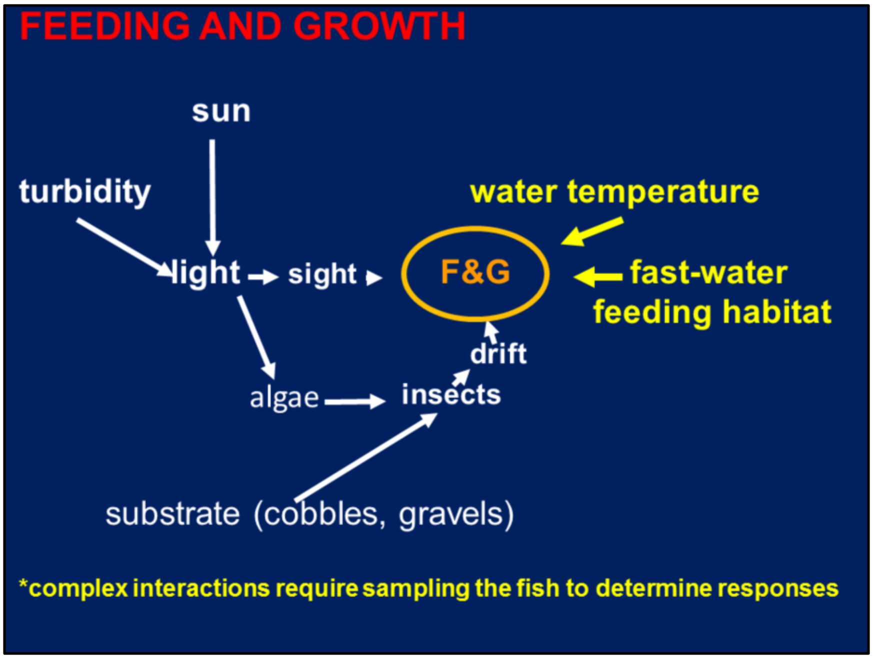
Where summer/fall stream flow is high, such below reservoirs where flow is augmented by releases for ground water percolation, steelhead are able to grow all summer and fall (B in the graph on the left), using the fast-water habitat to feed on the conveyor belt of drifting insects. In Santa Cruz County the mainstem of the San Lorenzo River provides higher flow habitat, except in very dry years. Even in dry years the reaches downstream of Felton have the combined the stream flow of the San Lorenzo River and the Zayante Creek sub-watershed; in addition the gradient is high within the gorge, (middle) providing abundant fast-water habitat for feeding. Substrate in the San Lorenzo River now contains abundant sand following development and logging in the 1950’s – early 1970’s (right). Still food production is sufficient among the boulders and the cobbles of the riffles to support summer-long growth within the abundant fast-water feeding habitat, despite relatively warm water temperatures. Steelhead are able to reach smolt size in their first summer/fall of growth. However, the fast-water habitat that feeds steelhead is unsuitable for use by significant numbers of coho salmon. In addition, because of the sandy substrate, suitable spawning conditions are scarce or absent (especially for eartly spawning coho), so the reach must be seeded by juveniles from upstream or tributaries (like Fall and Zayante creeks).



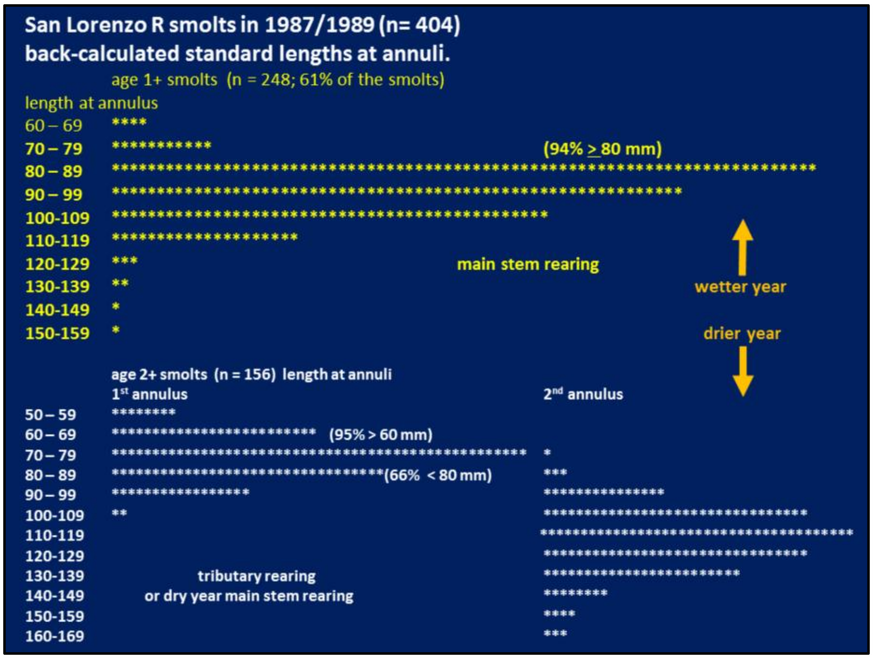
Upstream in Brookdale (left) and above Felton (right), the gradient and stream flows are less, and late summer/fall growth is less and limited to average and especially wet years. The abundant, sandy-bedded pools that dominate available habitat serve as overwintering habitat, but relatively scarce pool-rearing steelhead are concentrated in the fast water at the heads of the pools. However fast-growing steelhead can be abundant in the fast-water runs and riffles (bottom), where aquatic insects are abundant in and on the gravels and cobbles (lower middle). Coho, if present, would be very scarce because the water is relatively warm and their pool habitat has little or no food, except in the limited fast-water at the head of the pool; before substrate quality was degraded by sand, these pools may have supported coho. In wetter years, when stream flows are higher, steelhead can growth to large size in summer in the riffles and emigrate as yearlings; in dry years and with substantial water diversion, the growth is substantially reduced, requiring 2 years of fresh-water rearing.



Where dams and reservoirs (like Uvas Reservoir) are used to store winter storm runoff and transport it in streams and/or percolate it into groundwater aquifers in stream channels, the summer/fall stream flow can be high. The releases from the bottom of the reservoirs also provide relatively cool water, at least in the early part of summer. Under the right combinations of conditions of high stream flow (and resulting fast-water feeding habitat), and good food availability (dependent on suitable substrate for insects, water clear enough for fast-water feeding, and partially open canopy to provide light for feeding and to support growth of algae and insects), steelhead can be present and grow throughout the summer, despite warmer water temperatures, especially in late summer. Studies at Uvas Creek in the late 1970's found that the microhabitats and specific feeding positions (focal points) that steelhead used produced fast-growing fish that were quite large by fall and smolted as yearlings. In warmer water (lower left) or as fish grew (lower middle), increasing food demands, the fish moved to faster habitats to meet their food (lower right) needs.

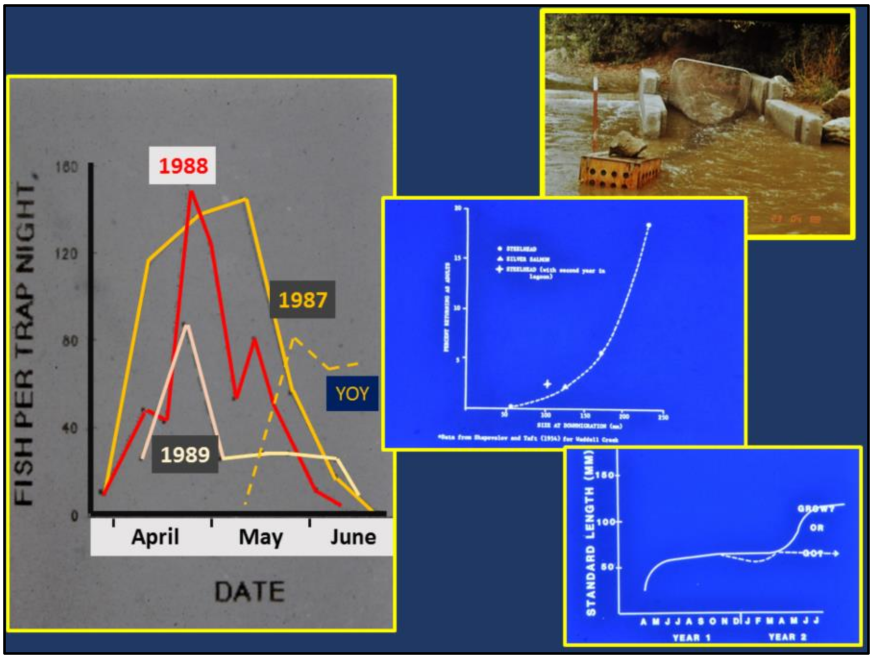


Feeding and growth are not controlled by a single factor, but by a complex interaction of visibility for feeding, insect productivity from algal growth and substrate conditions, and especially by fast-water feeding habitat that allows fish to feeding on drifting insects. Water temperature affects metabolic rate and the amount of food it takes to meet energy needs and the speed of digestion of that food. They all interact in a complex web that can't easily be modeled or its responses to individual factors measured; it is easier to measure fish growth and abundance.

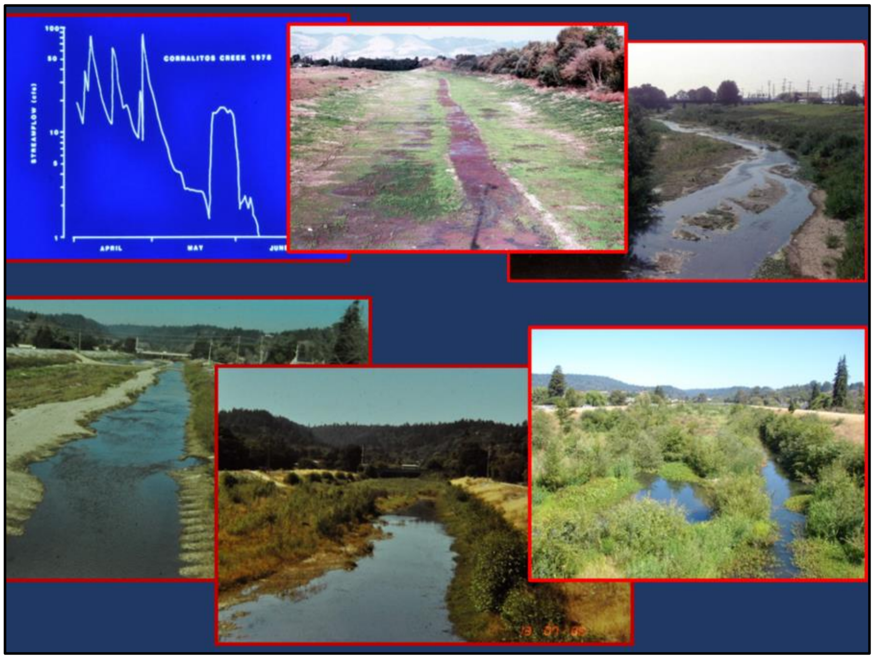


Most of the juvenile steelhead in the San Lorenzo River watershed are small young-of-year fish in tributaries and other slow growth areas. Based upon numbers of fish, many erroneously consider the tributaries to be the most important steelhead producers, and discount the warmer main stem of the San Lorenzo River. However, the scales of a random sample (n= 404) of steelhead smolts trapped in 1987 and 1989 (both dry springs), found that 61 % of the smolts had reared the previous year in high flow areas, like the main stem San Lorenzo River, and smolted as yearlings (left). Most (97%) of the yearling smolts were 76 mm standard length or larger at their scale annulus (the mark on the scale where growth stopped in winter). Of the 39 % of smolts that emigrated as 2 year olds, 1/3 were larger than 80 mm SL at their first annulus (right), and also may have reared in the faster-growth portions of the watershed. Although the tributaries are important spawning areas and have more juvenile steelhead, the major smolt-producing area is primarily the main stem of the San Lorenzo River. Also of interest, almost none of the smolts (8 of 404) was smaller than 60 mm SL at its first annulus; most small fish (which may be a majority of tributary steelhead) apparently don't survive winters and don't become smolts. In wetter years, with higher stream flows in the main stem of the San Lorenzo, more fish are able to reach smolt size in one year of rearing.

Overwintering of coho and steelhead through large winter storms (upper left) is a major limiting factor for both species. The impact can be best seen by the sharp abundance difference in steelhead between young-of-year compared to the much scarcer yearlings. Similar declines over winter undoubtedly occur in coho, but aren't observed because coho usually only spend 1 year in the stream. Complex pools (lower right), large low-gradient pools (center), large cobble substrate that is not buried in sand (lower left), backwaters (like the constructed backwater in San Vicente Creek, upper right), and flood plain habitat are crucial for over-wintering. This includes such structures as flood plain trees or debris jams that may be over-looked as crucial habitat during surveys of the low-flow summer stream channels.

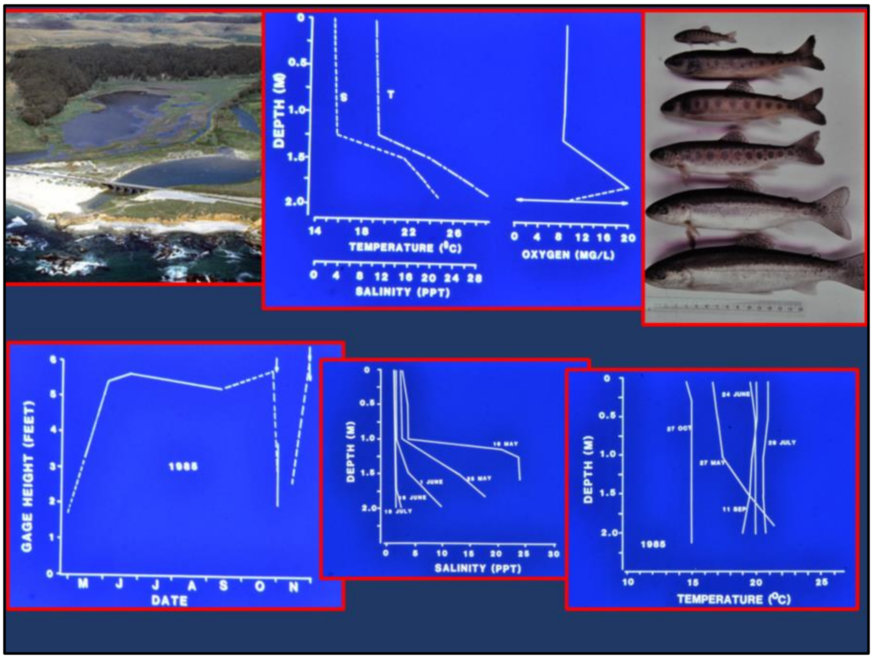


For those fish that survive winter conditions, smolt trapping (upper right) shows a counterintuitive smolt migration pattern (left). Most of the smolts do not migrate in winter when passage flows are assured, but wait until late March through May, when declining stream flows can be very problematic. The reason is that survival in the ocean is very size-dependent (middle), and spring is a time of clearer, warming water, increasing insect abundance, and good juvenile fish growth. Fish that emigrate early are small with poor survival; those that linger and grow increase their potential ocean survival, but risk passage difficulties from declining flows during outmigration (the “go or grow” conflict, lower right). Young of year (dotted line) and smaller yearlings were found to also migrate downstream (to the lagoon) in late May and June

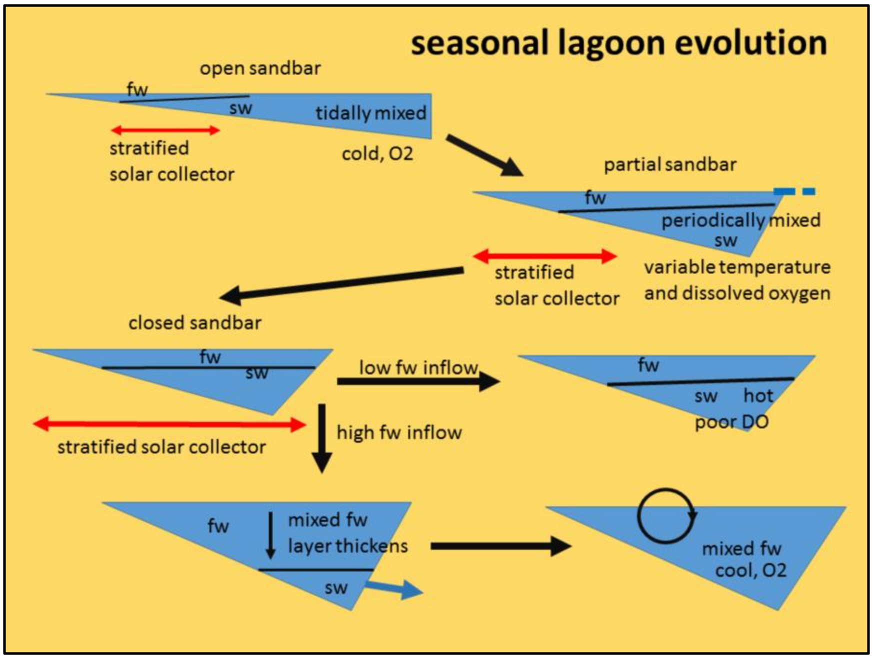


The ability to delay migration in order to feeding may not be likely in streams with early low flow bottlenecks. Even in a wet year (1978) stream flow in lower Corralitos Creek (upper left) dropped below the 4-5 cfs required for emigration by mid-May, and in drier years passage is often blocked there and farther downstream in Salsipuedes Creek (“get out if you can”!) by early April.   Farther inland in the Pajaro River system steelhead have spawning and suitable rearing habitat, but the lower river has broad, early drying channels (upper right). Conditions have improved since 1972, due to environmental laws, preventing the barren channel seen in Watsonville (upper middle). Broad simple channels (left, San Lorenzo River flood control channel in 1986) produced shallow habitat difficult for passage and subject to predators. Since 1988 (bottom middle, and more recent bottom right) a stream-side border of small willows and alders has resulted in a deeper, defined channel allowing much easier passage for emigration smolts and kelts (emigrating adults).

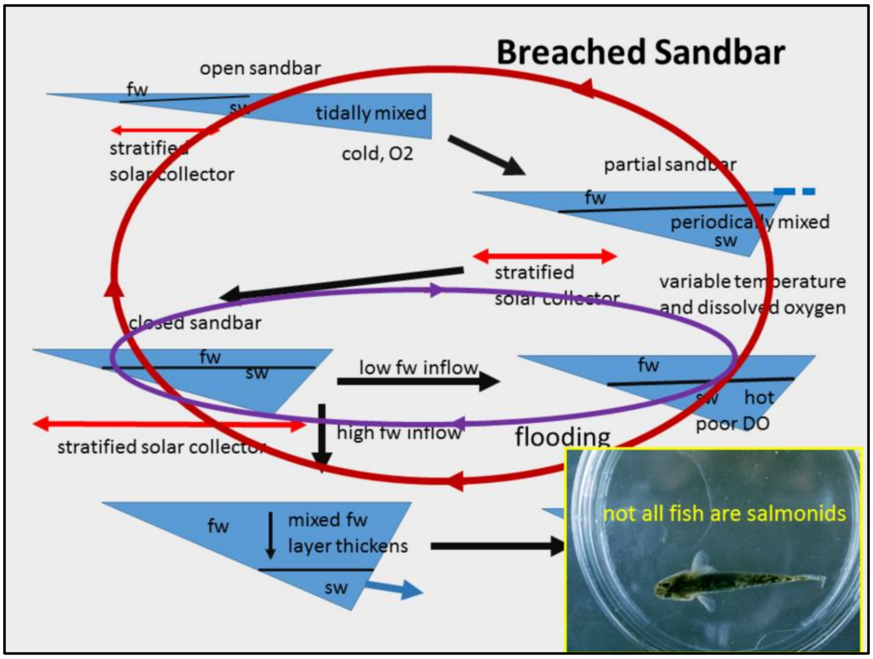
In estuaries with large residual embayments when the sandbar is open (Pescadero Creek, upper left) emigrating smolts can feed and grow and also adjust to brackish water before entering the ocean. The potential summer rearing value of lagoons has been recognized for several decades, but the value of the estuary for feeding and salt-water adaptation by smolts may be even more important in some streams, especially for smolts from the upper watershed. This value of estuaries in spring is especially important for coho since they are usually not abundant in summer lagoons because of warm water and competition with steelhead. Some streams like Scott Creek, with well-documented importance of the lagoon for summer rearing of steelhead, have little residual depth in spring when the sandbar is fully eroded (right); in spring there are extremely limited feeding opportunities and little or no brackish habitat for salt-water adaption for emigrating smolts. The channel at the mouth of the San Lorenzo River usually provides residual depth (between the trestle and the bend above Riverside) that can provide feeding conditions and brackish water adaptation habitat in spring, especially in drier years when a partial sand bar may form eraly.



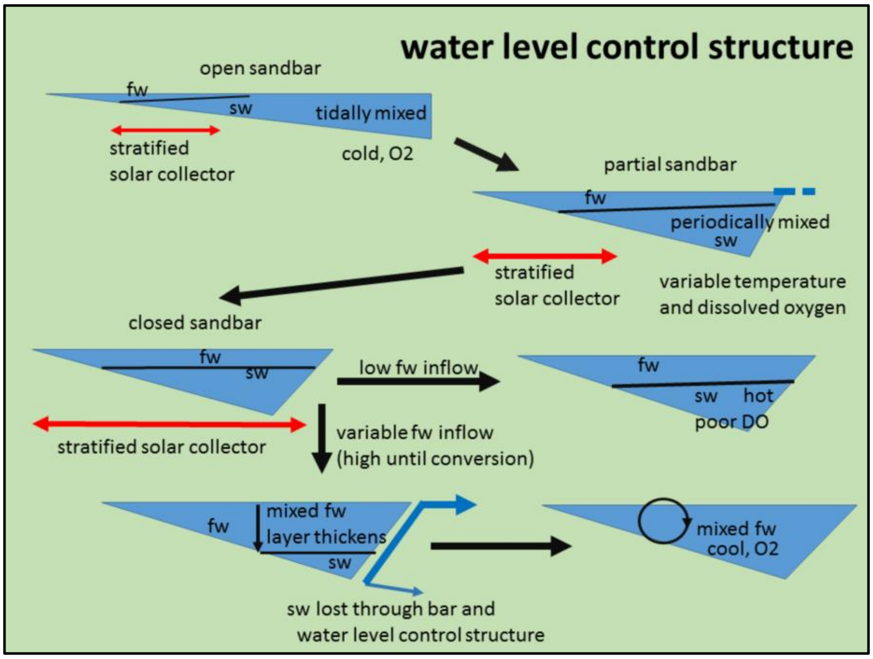
When sandbars form at the mouth of central coast streams in late spring through early summer they produce relatively deep lagoons and can flood adjacent marshes (Pescadero Creek, left top). In 1985 the habitat rapidly increased after the sandbar formed at Pescadero Creek in May (upper right; the arrows in October and November indicate artificial sandbar breaches). However, salt water (upper middle) impounded behind the sandbar can retard mixing of the saline (S) bottom water, resulting in a solar collector effect, producing high temperatures (T) and poor dissolved oxygen of the bottom water (Lower left). If there is sufficient freshwater inflow, the bottom salt water is squeezed out through the bar (lower middle), and the lagoon is usually well mixed, with cool water (lower right) and good dissolved oxygen throughout the water column. In 1985 steelhead were abundant and large in the fresh-water lagoon at Pescadero (upper right); the bottom two fish are a 7 and 8 inch young-of-year and yearling reared in the lagoon, compared to a YOY from the stream (top) and 2-year upper watershed steelhead smolts.



Even in a tidally mixed open sandbar in spring, the upstream portion of the estuary may be stratified and act like a solar collector (trapping solar heat in the non-mixed lower salt water layer) upstream of direct tidal influence. When the bar partially closes the lagoon tends to heat and can have poor dissolved oxygen in the bottom layer during periods of weak (neap) tides, but can be cooled during high (spring) tide periods and its dissolved oxygen replenished. After the bar fully closes the bottom salt water can percolate through the sandbar, especially as the lagoon level and hydraulic pressure increases. If the inflow is low the salt water loss will be gradual and the inflowing freshwater will only slowly thicken the upper freshwater layer. Water column profiles (rather than just surface and bottom recorders) are necessary to determine the relative thickness of the freshwater surface layer and the warmer, salty bottom layer. At higher inflow flow rates the freshwater layer will rather quickly thicken as the saltwater is driven out. The resulting freshwater lagoon will lose heat at night and mix for temperature and dissolved oxygen.



The high lagoon levels after sandbar formation can result in flooding and also result in legal or illegal sandbar breaching. With a full sandbar breach the lagoon is substantially drained, the cycle is turned back; the sandbar rebuilds, repeating the process without adequately solving the flooding problem or producing good water quality conditions for steelhead (and tidewater goby) in the lagoon. With a controlled breach the bar is opened, partially drained, water level lowered, and reclosed; this drains off primarily the surface, cooler freshwater, leaving the warm saltwater and making lagoon water quality much worse for steelhead. Because inflows decline over the summer, repeated full or partial breaches result in progressively worse impacts. Full breaching that produces draining and restoration of tidal action also strands and eliminates calm lagoon habitat for tidewater goby, a small endangered fish confined to California lagoons; gobies require calm water and avoid strong currents—they should be called the lagoon goby, rather than the tidewater goby.



With a water level control structure that controls the lagoon height and also preferentially siphons and discharges bottom salt water from the lagoon, flooding can be averted and the lagoon can be converted to a mixed, productive rearing habitat for steelhead (and tidewater goby). Initial inflow should be relatively high to speed the conversion, but can be reduced after conversion of the lagoon to freshwater.