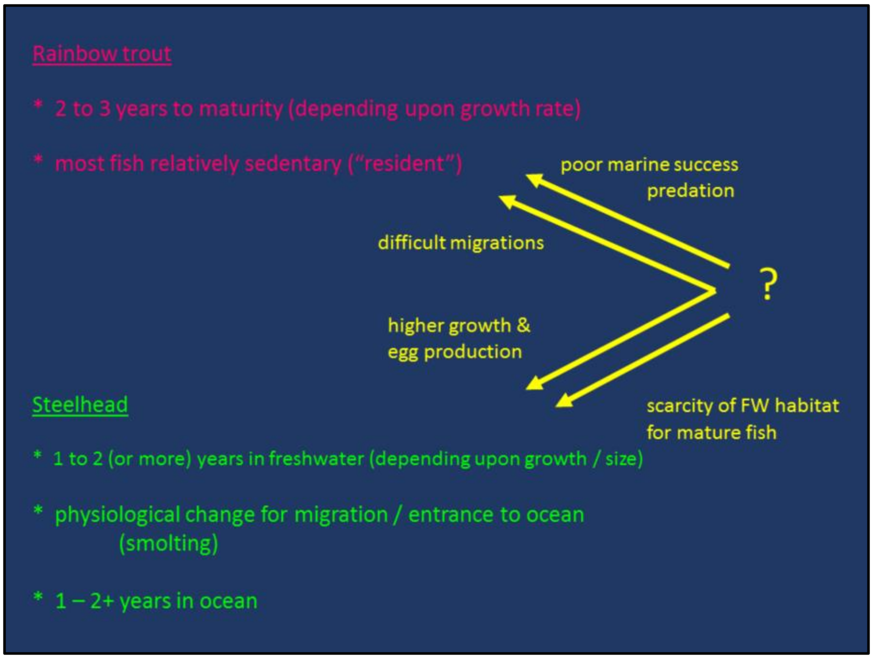
# Salmon and Steelhead Ecology of the Central California Coast

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).

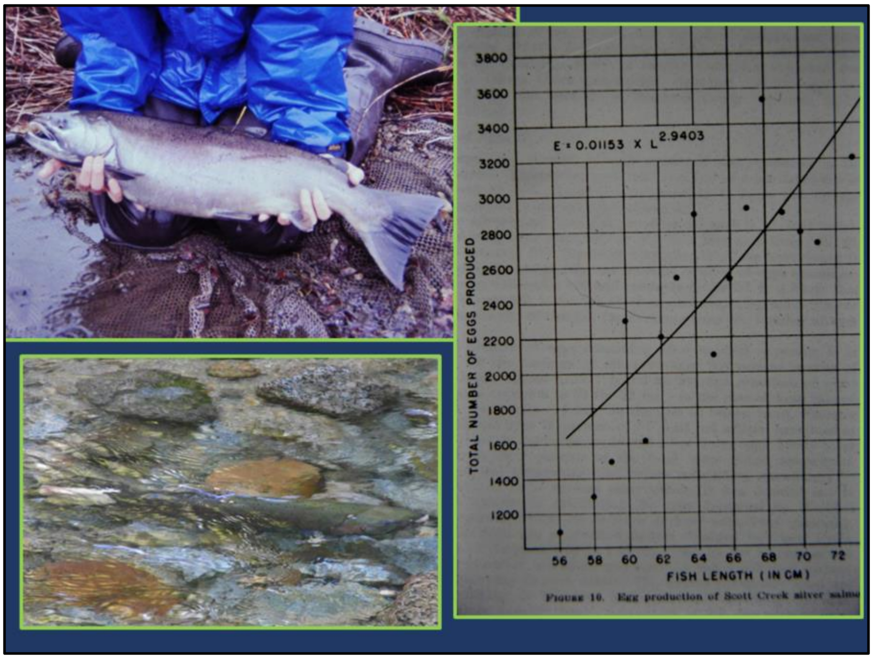
The male steelhead in the upper left spent 1 year in the ocean and has been in freshwater for an extended period, so its silver coloration has been replaced by the darker “rainbow trout” coloration.  He also has a more hooked snout for fighting with other males for access to females.  In addition this 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 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).




Rainbow trout and steelhead are the same species, but steelhead have the wandering trait. Fish that stay in freshwater (resident rainbow trout) mature at 2 to 3 years old, depending upon growth rate, and usually at a relatively small size compared to fish that go to the ocean.

Steelhead spend 1 or 2 (or more) years in freshwater, depending upon growth rate. They then undergo some shape, color and physiological changes (turning skinny and silvery, with black tips of the tail, and changing salt regulation adaptations in their gills) that will allow them to transition to, and survive in, the ocean. They usually spend 1 or 2 years in the ocean before maturing and returning to the stream they were raised in to reproduce. The potentially much higher growth rate of steelhead in the ocean, compared to fish that remain in fresh water, allows them to produce many more eggs and out reproduce the resident fish. Steelhead life style is also favored if habitat for reproductive aged and sized fish is limited in the freshwater habitat. On the other hand, if the migration to and/or from the ocean is difficult or curtailed, the fresh water resident life style is favored. This can occur if upstream adult passage is blocked or inhibited by dams, falls or other barriers, or if the stream usually dries in downstream reaches prior to the migration of juveniles to the ocean. If the ocean conditions are unfavorable, due to periodic collapses of ocean upwelling conditions that disrupt the food chain or increased predation on ocean fish, then the resident lifestyle is also favored. For example, heavy ocean harvest of Atlantic salmon off New England and Canada selected for male salmon that remained in the stream (safe from nets, but producing relatively tiny male adults). Female salmon still migrated to the ocean, because their egg production was substantially enhanced by ocean growth.

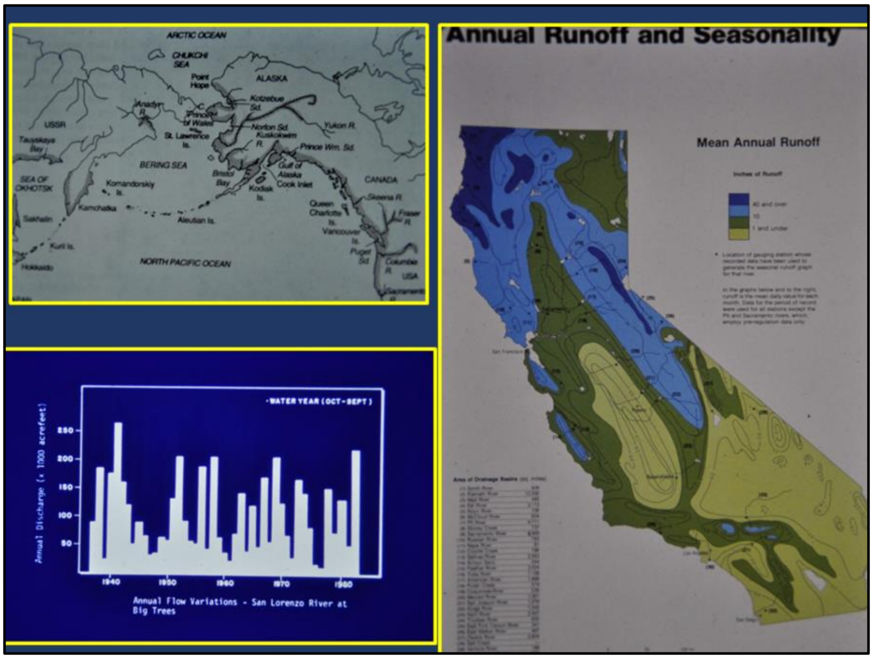
Coho males spend 1 year (a “jack”, lower left) or 2 years (upper right) in the ocean. Like steelhead they are silvery when they enter freshwater (left) and develop intense red/maroon color after time in freshwater. The older male has a very large hooked upper jaw, and the younger male a more modest hook 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.

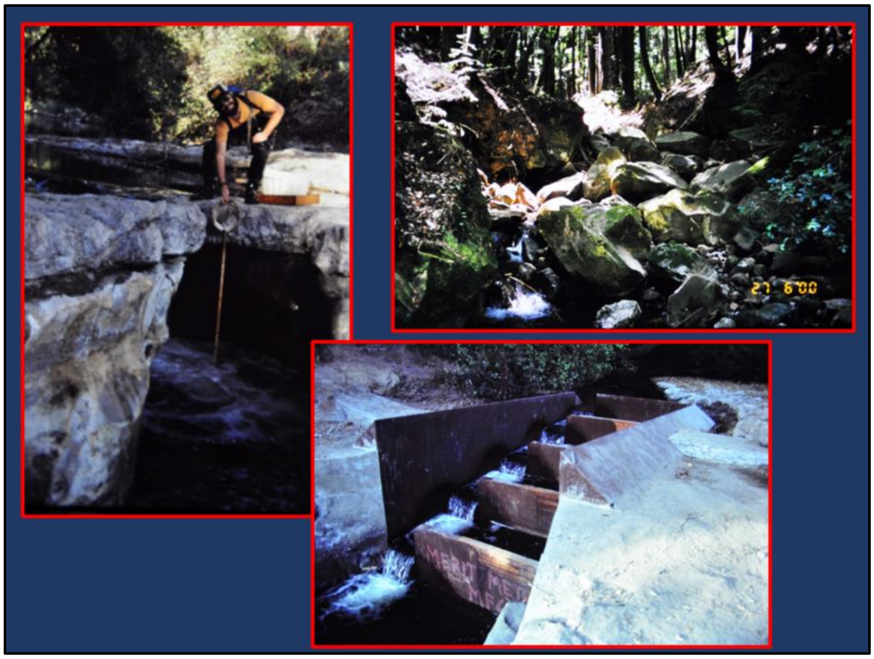
The dead coho female was found adjacent to her redd in Waddell Creek. Carcass counts are a way to index the number of coho spawners, sex ratios, and the ratio between jacks and 3 year old males. The fish on the right is a mature 2 year old female (a “jill”). These apparently do no occur in the wild, but can occur among fish raised to large size in a hatchery before release to the ocean. These 2 year old females are usually larger than wild 2 year old males, and are an important way to fill in lost or weak coho year classes that result from bad spawning/rearing years and the rigid 3 year female cycle. In addition, a portion of coho juveniles may spend an extra year in freshwater, producing 4 year old fish that help break the 3 year cycles.

Fall run Chinook (or king) salmon are present along the coast down to the Russian River and occasionally farther south. In addition, hatchery-produced fish from the Central Valley often stray, and occasionally successfully spawn, in tributaries to San Francisco Bay. The adult male in the upper photo was caught in the Guadalupe River in San Jose. These fall-run fish attempt to spawn early locally, often in September or October, before local rains usually begin. If the redds survive the early winter storms the juveniles reach smolt size (right) and emigrate in spring; they do no rear in the streams in summer and fall, and can avoid the summer conditions that may be unsuitable due to poor water quality or warm temperatures.
In the Central Valley the Chinook salmon occur as the fall run, a late-fall run, a winter run (originally spawning in early spring in the upper Sacramento River system, now above Lake Shasta), and a spring run, which enters in in late spring, over-summers in snowmelt streams and spawns in very early fall. The winter and spring runs of Chinook are listed under the Federal Endangered Species Act, because of dams and water diversions. The fall run in the Central Valley is heavily dependent upon hatchery production.



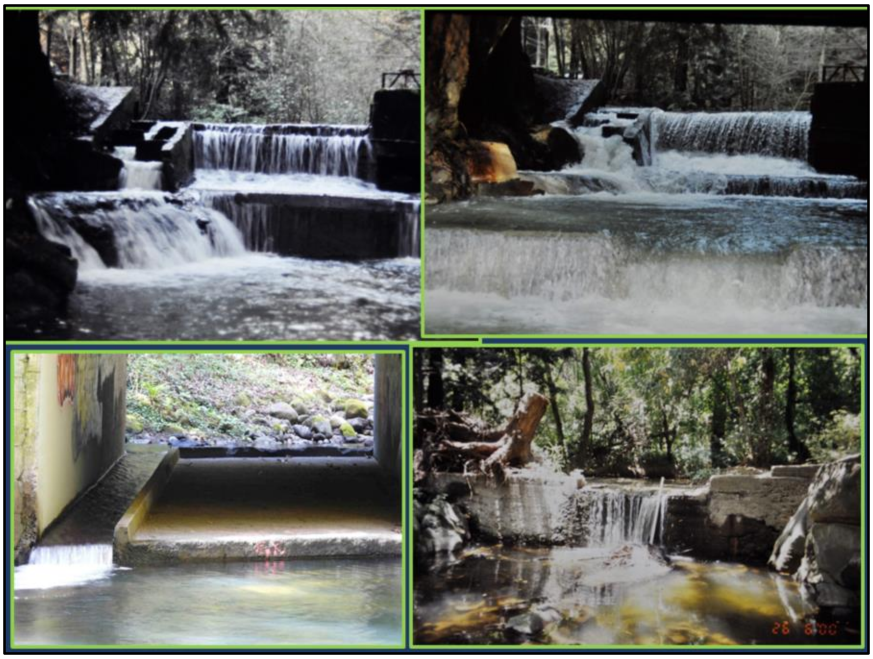

Coho salmon range from Kamchatka in Asia around and down the west coast to Santa Cruz County (the edge of the range!). Rainfall and runoff decline (right) farther south in California, and both become much more variable to the south. The rigid life cycle (1 time spawning, 3 year life cycle) of coho is 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 (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 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. The photo in the lower right is of Miller Canal east of Gilroy. This canal is often dry in summer, but is the winter and spring migration pathway for steelhead to and from Pacheco Creek; because the canal is flat and narrow it takes very little stream flow to provide winter and spring passage.



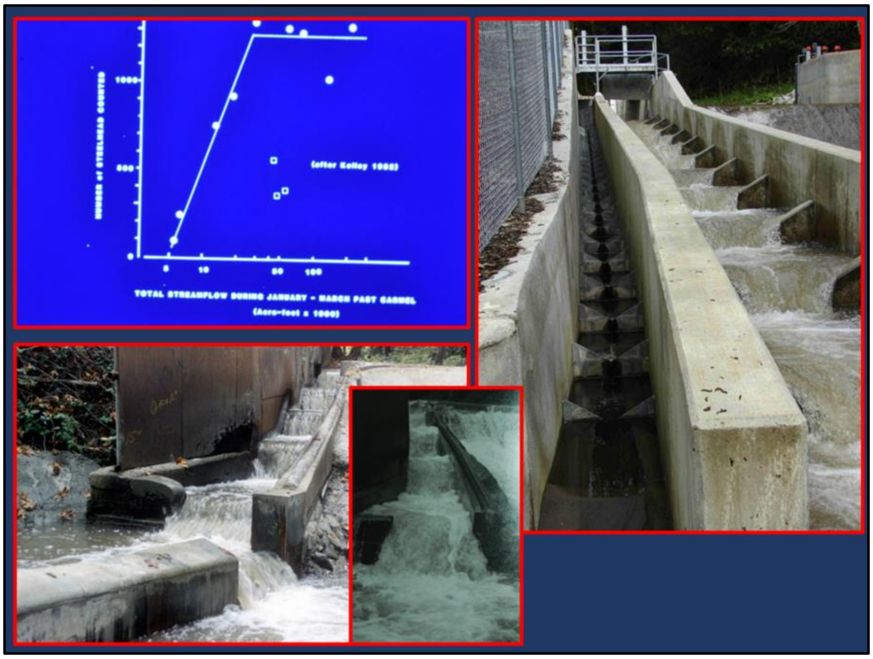
Natural barriers, like the boulder falls in the upper right often limit the upstream extent of steelhead access. Even this falls is occasionally passable during some stream flow conditions because of its stair-step arrangement. The natural falls in the upper left (Quail Hollow Falls on Zayante Creek) 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.


Man-made barriers are frequently associated with road crossings.  The box culvert in the upper left presented 2 problems for adult fish passage:  the high jump required due to channel down-cutting downstream of the culvert and velocity and depth issues through the culvert.  The adult passage issue was solved by reducing the height of the jump with weirs and fill downstream and with baffles in the culvert.  Because of large cobbles in the moderately high gradient channel, the baffles require periodic maintenance (after years of severe floods).  The culvert in the lower right is not too difficult for an adult to jump, because of a deep pool downstream; however, baffles would increase the depth and reduce velocities through the culvert.  However, current regulations require that modifications normally provide passage for all sizes of salmonids (adult steelhead, resident trout, juveniles), which would require $400,000 to create a "riffle-ramp" of fill up to culvert (even though only adult access is an issue for this site).  In the upper right a Chinook salmon has successfully jumped (3 feet)  onto this bridge apron and weir, but the 8" high curb has blocked the fish, which cannot jump from the shallow sheet flow on the apron.  The perched culvert on the lower left blocks adult access to a small tributary suitable for spawning and rearing.

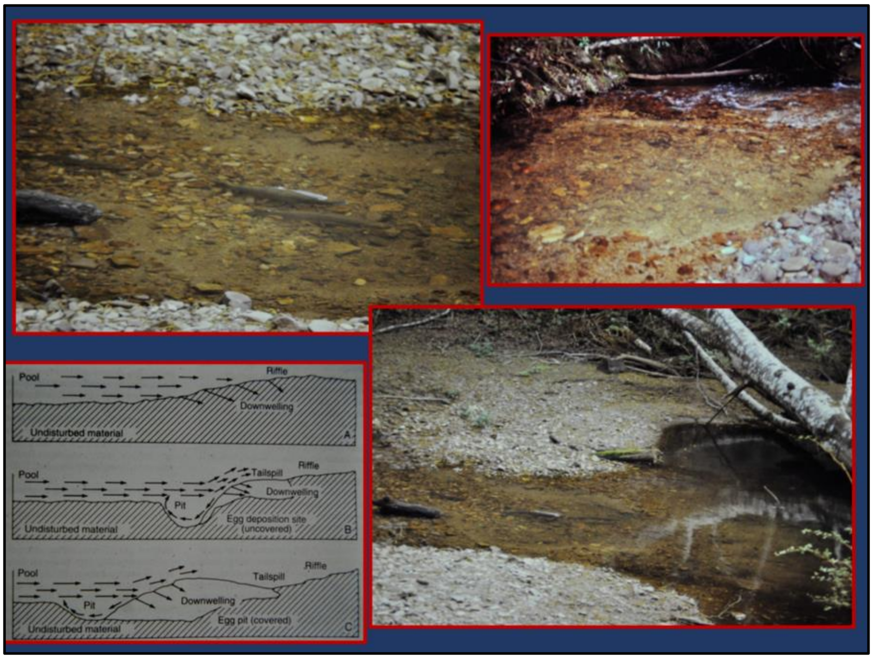


The culvert on the lower left is an example of a road culvert that presents no real passage problem for adult steelhead, under stream flow conditions that allow the fish to move upstream over numerous riffles to reach the site (the culvert is flat, concentrates low flows, and the jump is short). Adults are never observed “stacked up” at the site, even though Road Xing software said the culvert was impassable to all age classes of steelhead. Replacement of the culvert floor would have eliminated the pool and the undercut wall downstream that provides the best over-wintering habitat in this reach of stream; $400,000 would have been spent to reduce smolt production in the watershed. The unused diversion dam on the lower right was a serious impediment because the jump height was high compared to the shallow pool downstream; the barrier also blocked access to most of the stream. The barrier was removed 12 years after its removal was recommended. The diversion dam in the upper left (@ 6.5 cfs) presented 3 problems for migrating adult steelhead: the high jump (4.5+ feet) to get into the pool below the fish ladder; a difficult jump from that pool to enter the ladder; and potential turbulence in the “pool and weir” ladder at high flows. The site was a “fish watching” site because adult steelhead stacked up at the dam and made repeated jump attempts. After the facility was partially damaged on 4 January 1982, a weir was installed downstream producing 2 easily surmounted jumps rather than 1 large jump, and the jump into the ladder was improved (upper right photo). Turbulence in the ladder is still a problem at some flows (25 cfs in photo) , but fish no longer are blocked at the site, and recreational fish-watching has been eliminated.

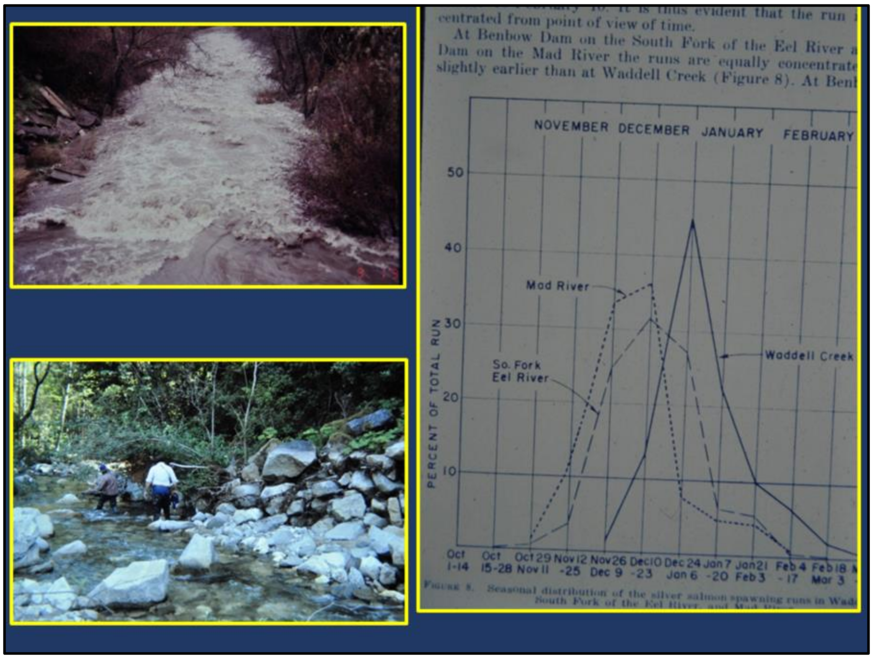
Log jams (and much of the in-channel wood) used to be regularly removed as barriers or potential barriers to fish passage.  However, they also produce pools and refuges from the high flows that severely reduce overwinter survival of juvenile fish.  The two top logjams produce valuable pools and allow adult passage under (left) or through (right) the partial jams.  They should be monitored for potential modification, but not removed.  The two lower photos are of the same large jam that formed in 1999 in an entrenched channel, and that has been a severe barrier to steelhead (and potentially coho) adult access in the majority of years (through 2013), except during extreme floods.  Modification of the jam should be conducted to open it to fish passage, while still keeping it as a high flow refuge.




Higher stream flows tend to make many barriers more passable, so in a study on the Carmel River, the number of steelhead adults counted in at the fish ladder at San Clemente Dam initially increased as cumulative stream flow in January – March increased (upper left). The number of fish leveled off above a cumulative stream flow high enough to allow most fish to pass critical riffle barriers; additional stream flow didn't affect the number of steelhead counted at San Clemente Dam. Fish ladders (lower left) used to be pool and weir designs, but now contain v-shaped baffles (right) that reduce velocities more effectively and provide pockets of calmer water over a wider range of flows. The paired ladder on the right has a high flow portion with larger pools for adult winter passage (on the right) and a separate smaller pool/smaller jump low flow ladder for juveniles at lower stream flows. Prior to 4 January 1982 (bottom, middle) the ladder at the diversion dam was steep, required a difficult jump to enter, and the top pool was short and very turbulent; fish usually required multiple attempts to surmount the ladder. After damage in the 4 January 1982 storm, the ladder was remodeled (left) by adding an additional pool at the base of the ladder, and lengthening the upper pool; this allowed adults to successfully pass within a narrower range of suitable flows compared to the modern ladder on the right. However, Juvenile steelhead abundance upstream was unchanged by the modification in 1982 and by the more recent "modern ladder", and overwintering habitat still limits smolt production upstream.




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. 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.




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.

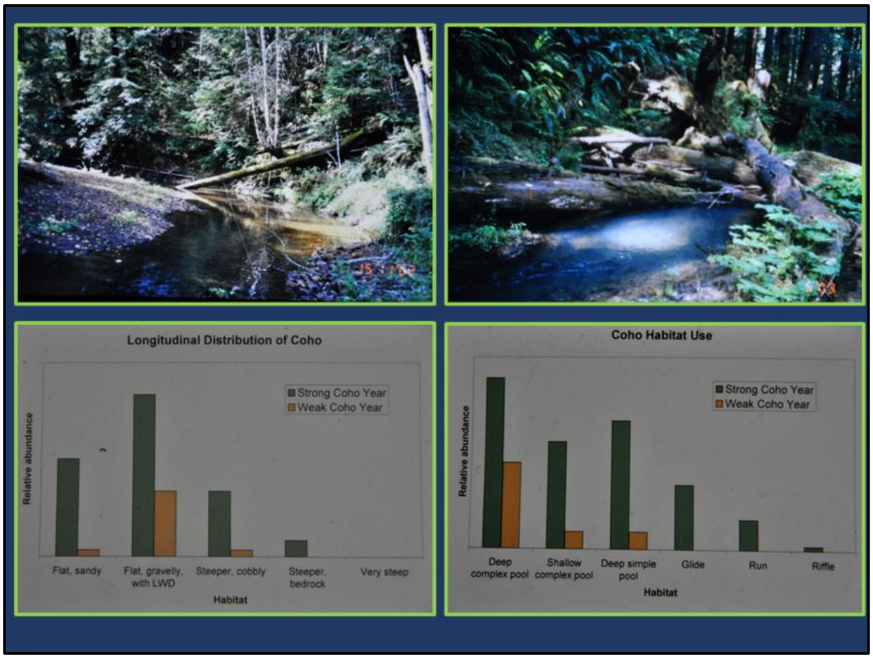
## Steelhead and Coho Standard Lengths

Scott Creek 2012

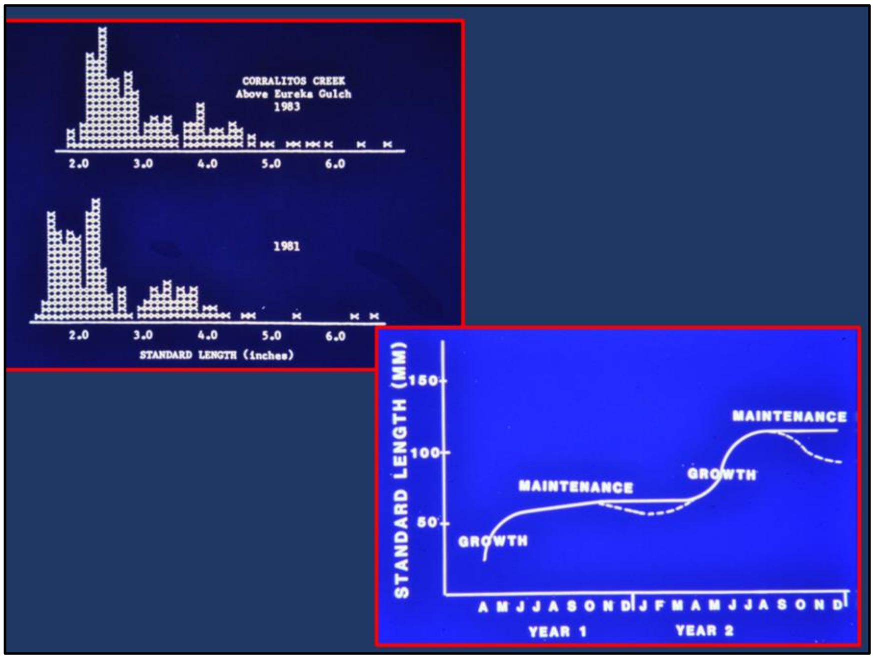
| | Sites 5,7,9 | | Mill Creek | |
|---|---|---|---|---|
| 25 – 29 | 0 | | | |
| 30 – 34 | 000 | | | |
| 35 – 39 | 000000000000000000000 | | | |
| 40 – 44 | 000000000000000000000000 | C | | |
| 45 – 49 | 0000000000000000000000000000000000000000 | CC | 0000000000 | |
| 50 – 54 | 000000000000000000000000000000000 | | 0000000000 | |
| 55 – 59 | 000000000000000000000000 | CC | 00000 | CC |
| 60 – 64 | 000000000000000 | C | 0 | CCC |
| 65 – 69 | 000 | CCCC | 0 | CCCCCCCCCCC |
| 70 – 74 | 00000 | CCCC | | CCCCCC |
| 75 – 79 | 11 | CC | | CCC |
| 80 – 84 | 1111111 | C | 11 | |
| 85 – 89 | 11 | | | |
| 90 - 94 | 1 | | | |
| 95 – 99 | 1 | | 111 | |
| 100-104 | 11 | | 1 | |
| 105-109 | 1 | | 1 | |
| 110-114 | 11 | | 11 | |
| 115-119 | 1 | | | |

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, in 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. 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.

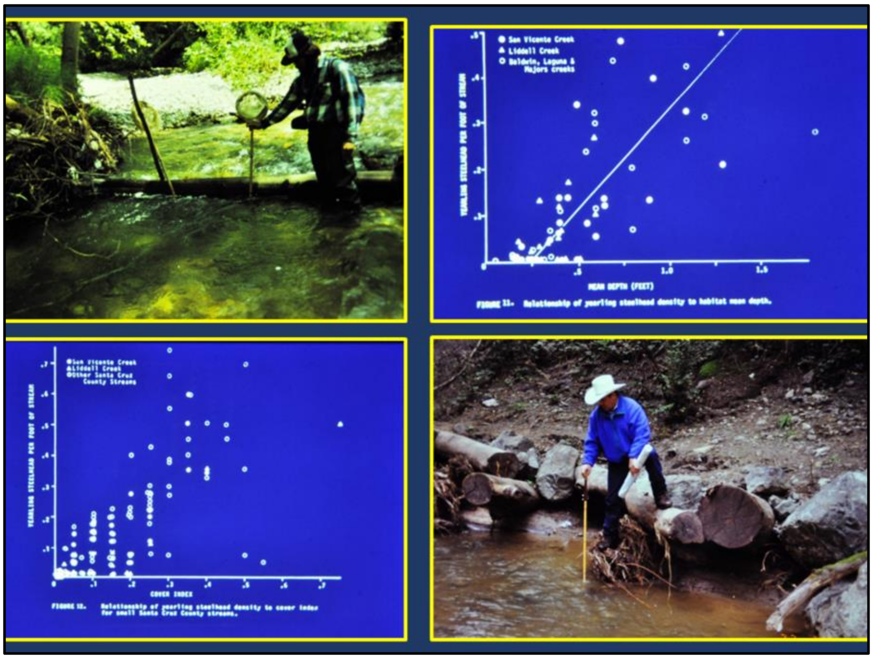
Coho (silver salmon) spawn and emerge from the gravels earlier than steelhead, so in small streams with low summer stream flows they are normally bigger than young-of-year (YOY) steelhead. Most coho emigrate to the ocean as yearlings, so older, larger coho are usually absent. Even coho that remain a second year tend to be not much larger than YOY. Steelhead in small streams usually spend a second year in the stream before emigrating to the ocean, and some may spend 3 summers in the stream; 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.  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.

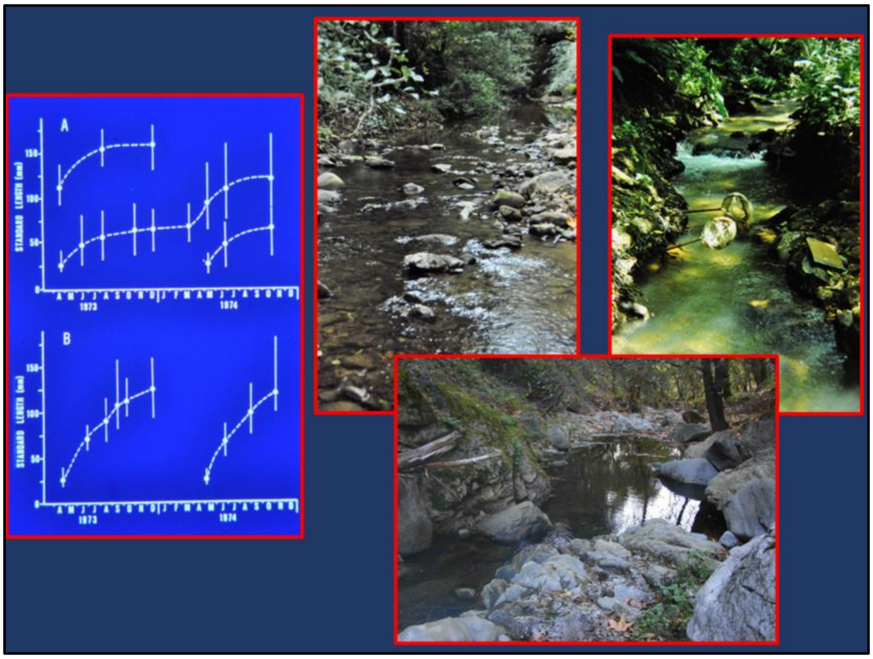



In small low flow streams steelhead usually require two years to be big enough to emigrate to the ocean, so there are two distinct size classes (and some additional larger, older fish, upper left). The yearlings are relatively rare compared to the young-of-year, because of heavily overwinter loss (major limiting factor). For these data from Corralitos Creek there was no change in abundance between a moderately dry year (1981) and a wet year (1983). However, fish were larger in the wet year because stream flow was higher for a longer period in early summer to allow more time for growth. Interestingly, the lack a difference in fish numbers in the two years occurred despite difficult adult passage at the fish ladder at a diversion dam in 1981, and very easy adult passage at the remodeled ladder in 1983; even with the more difficult passage in 1980/1981 the stream was apparently fully seeded. Growth in these small streams (right) occurs primarily in spring and very early summer, and there is usually little or no growth (and often a loss of weight) in late summer and fall (a maintenance, rather than growth period); the plateau and loss of weight is usually even greater for yearlings, because of their greater absolute food demands, and yearlings are usually skinny in the fall.

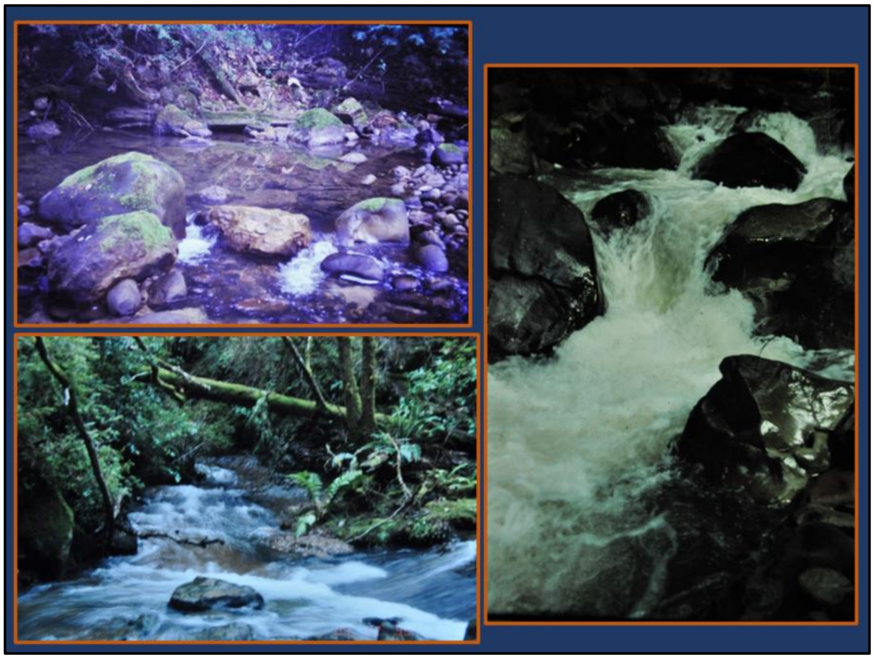



Yearling abundance in these small, low flow streams is strongly related to the combination of habitat depth (upper right) and escape cover (lower left). Both habitat features are not only preferred in summer and fall by yearling steelhead, but are also the features associated with carrying the fish over 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. Adding anchored wood (lower right) is a technique to increase escape cover and pool development.

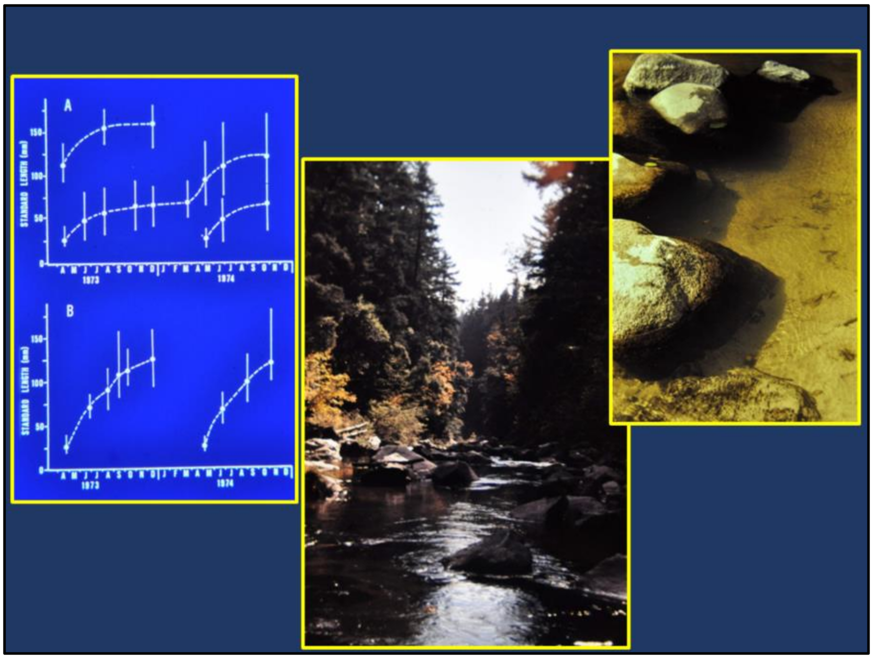
Scour at the large boulder (upper left) produced this pool on Corralitos Creek. When a flood and landslides filled the pools in this reach of the stream on 4 January 1982, subsequent storms recut the pool at the same location. The constructed back-water channel (upper right) on San Vicente Creek provides an excellent high flow refuge for overwintering coho and steelhead. The habitat usually gets little use in summer, but provides the crucial habitat required to carry the fish over the winter, when heavy mortality normally occurs. Steelhead also use loose cobbles (lower left) as escape cover in summer, and especially during winter high water. When sand and other fine sediment is abundant, these cobbles may be "embedded" or buried, so there is no underneath to provide a refuge . Embedded gravels and cobbles also provide little habitat for insects that serve as coho and steelhead food.




For steelhead in small streams 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.

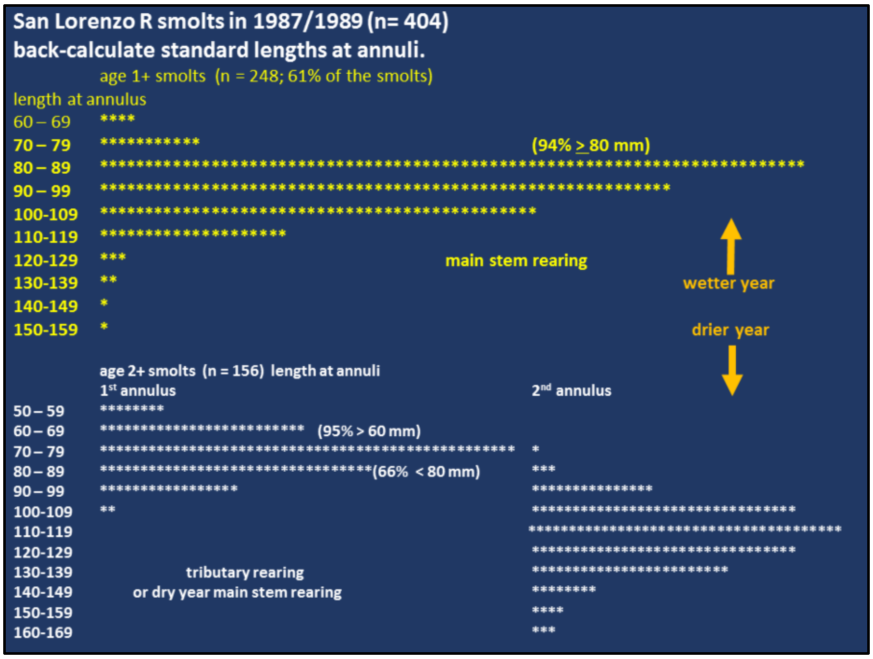


Unlike coho, which are largely restricted to complex pools in low gradient (<3 %) habitats, steelhead extend much farther upstream to areas of bedrock and boulders (left), and even very steep (6+ %) stair-step habitats.

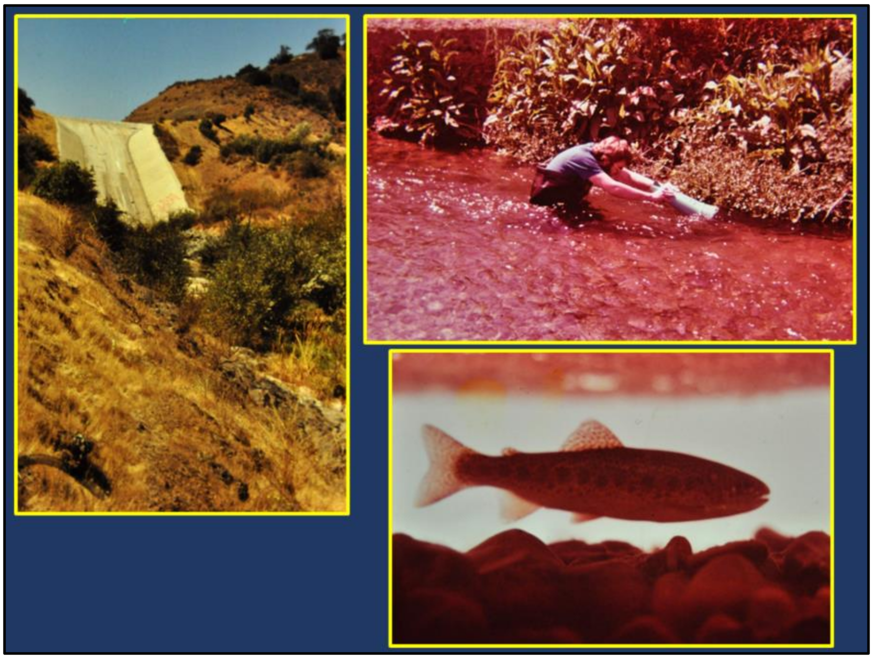



Where summer/fall stream flow is high, such below reservoirs where flow is augmented by releases for ground water percolation, steelhead are able to grow all summer and fall (B in the graph on the left), using the fast-water habitat to feed on the conveyor of drifting insects. In Santa Cruz County the 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 subwatershed; 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).

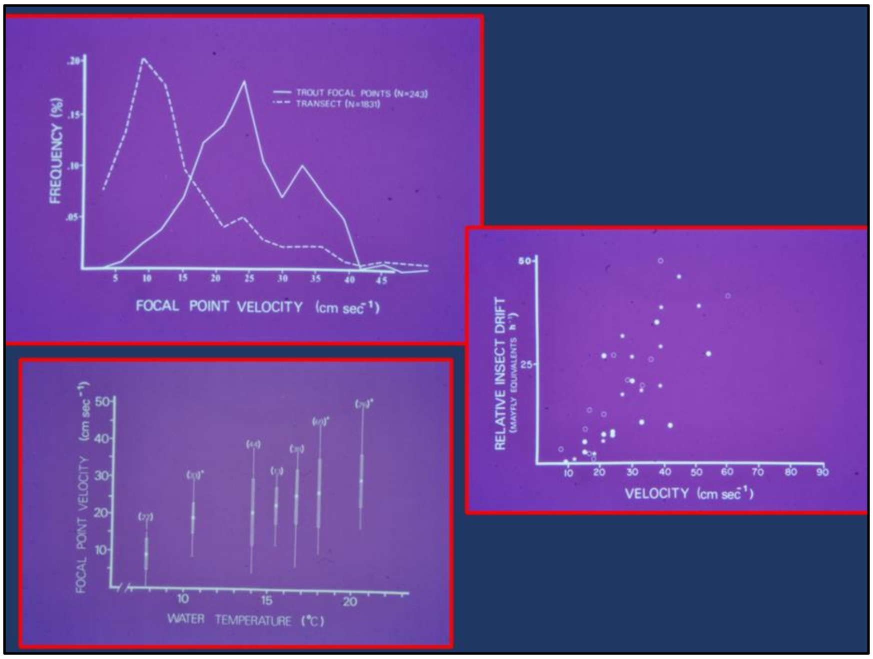
Upstream in Brookdale (left) and above Felton (right), the gradient and stream flows are less, and late summer/fall growth is less and limited to average and especially wet years. The abundant, sandy-bedded pools that dominate available habitat serve as overwintering habitat, but relatively scarce pool-rearing 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 (middle). Coho, if present, would be very scarce because 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..



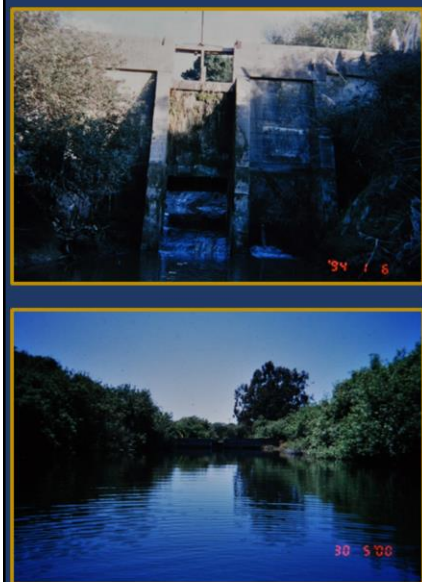

Most of the juvenile steelhead in the San Lorenzo River watershed are small young-of-year fish in tributaries and other slow growth areas. Based upon numbers of fish, many erroneously consider the tributaries to be the most important steelhead producers, and discount the warmer main stem of the San Lorenzo 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.



Where dams and reservoirs (Uvas Dam in Santa Clara County, left) 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 (right) produced fast-growing fish that were quite large by fall and smolted as yearlings.




Those fish in Uvas Creek were concentrated in the faster-water habitats compared to what was available in the stream (upper left). This was because food as drifting insects increased with increasing velocity of the habitat, with few insects available as food below 1/3 –1/2 feet / sec (right). As water temperature increased seasonally or downstream in Uvas Creek, food demands of the juvenile steelhead increased and they utilized faster microhabitats for feeding in order to meet their food needs (lower left). Larger fish, with higher absolute food demands, also used faster microhabitats. Restudies of Uvas Creek since 2005 have found the same strong dependence on fast-water feeding habitats, but fish abundance and growth have declined substantially compared to 1980 because of poorer stream substrate quality and increased canopy closure (due to the effects of development and the gradual impacts of the reservoir). Turbidity has also increased, and along with the shade), has reduced feeding efficiency.



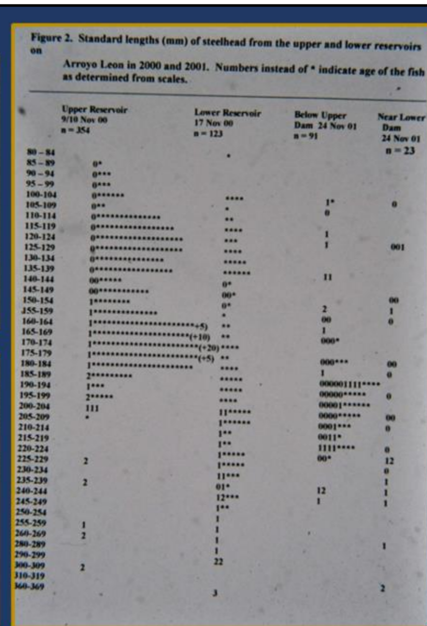
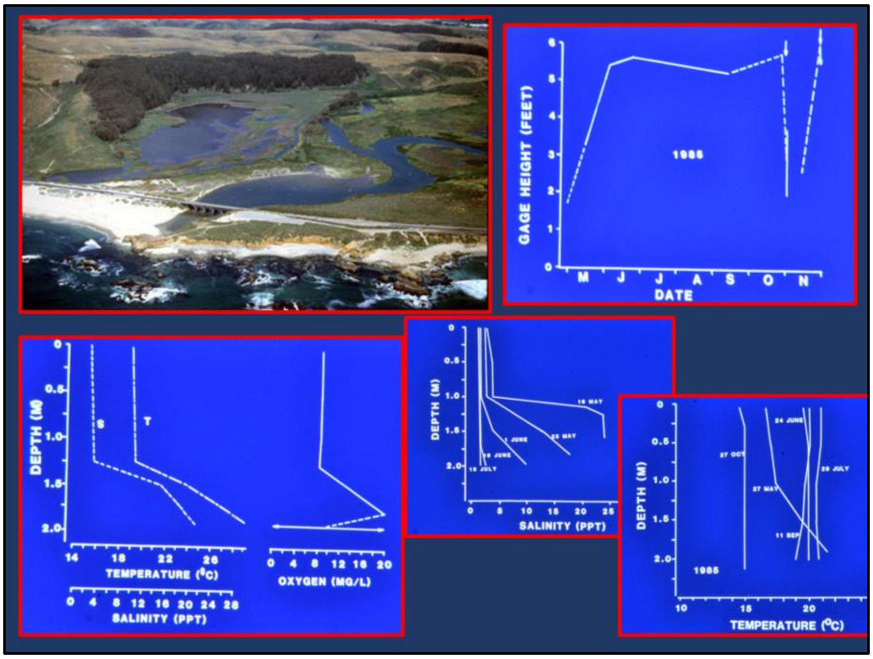



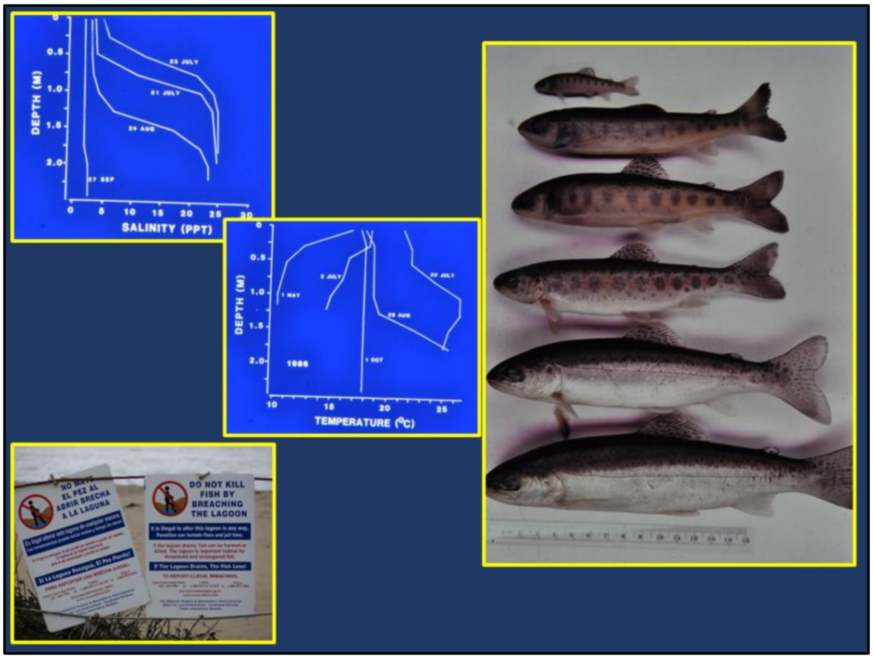
**Figure 2. Standard lengths (mm) of steelhead from the upper and lower reservoirs on Arroyo Leon in 2000 and 2001. Numbers instead of * indicate age of the fish as determined from scales.**

| | Upper Reservoir 9/10 Nov 00 n = 354 | Lower Reservoir 17 Nov 00 n = 123 | Below Upper Dam 24 Nov 01 n = 91 | Near Lower Dam 24 Nov 01 n = 23 |
|---|---|---|---|---|
| 80 – 84 | | * | | |
| 85 – 89 | 0* | | | |
| 90 – 94 | 0*** | | | |
| 95 – 99 | 0*** | | | |
| 100-104 | 0****** | **** | | |
| 105-109 | 0** | * | 1* | 0 |
| 110-114 | 0************* | ** | 0 | |
| 115-119 | 0**************** | **** | | |
| 120-124 | 0****************** | *** | 1 | |
| 125-129 | 0****************** | **** | 1 | 001 |
| 130-134 | 0************** | ***** | | |
| 135-139 | 0**************** | ****** | | |
| 140-144 | 00***** | 0* | 11 | |
| 145-149 | 00*********** | 00* | | |
| 150-154 | 1******** | 0* | | 00 |
| 155-159 | 1************** | * | 2 | 1 |
| 160-164 | 1*********************+5) | ** | 00 | 0 |
| 165-169 | 1*******************(+10) | ** | 1 | |
| 170-174 | 1**********************(+20) | **** | 000* | |
| 175-179 | 1**********************(+5) | ** | | |
| 180-184 | 1********************* | **** | 000*** | 00 |
| 185-189 | 2********* | ***** | 1 | 0 |
| 190-194 | 1*** | ***** | 000001111**** | |
| 195-199 | 2***** | **** | 00000***** | 0 |
| 200-204 | 111 | 11***** | 00001****** | |
| 205-209 | * | 1****** | 0000***** | 00 |
| 210-214 | | 1** | 0001*** | 0 |
| 215-219 | | 1** | 0011* | |
| 220-224 | | 1***** | 1111**** | 0 |
| 225-229 | 2 | 1***** | 00* | 12 |
| 230-234 | | 11*** | | 0 |
| 235-239 | 2 | 01* | | 1 |
| 240-244 | | 12*** | 12 | 1 |
| 245-249 | | 1** | 1 | 1 |
| 250-254 | | 1 | | |
| 255-259 | 1 | 1 | | |
| 260-269 | 2 | 1 | | |
| 280-289 | | 1 | | 1 |
| 290-299 | | 22 | | |
| 300-309 | 2 | | | |
| 310-319 | | | | |
| 360-369 | | 3 | | 2 |

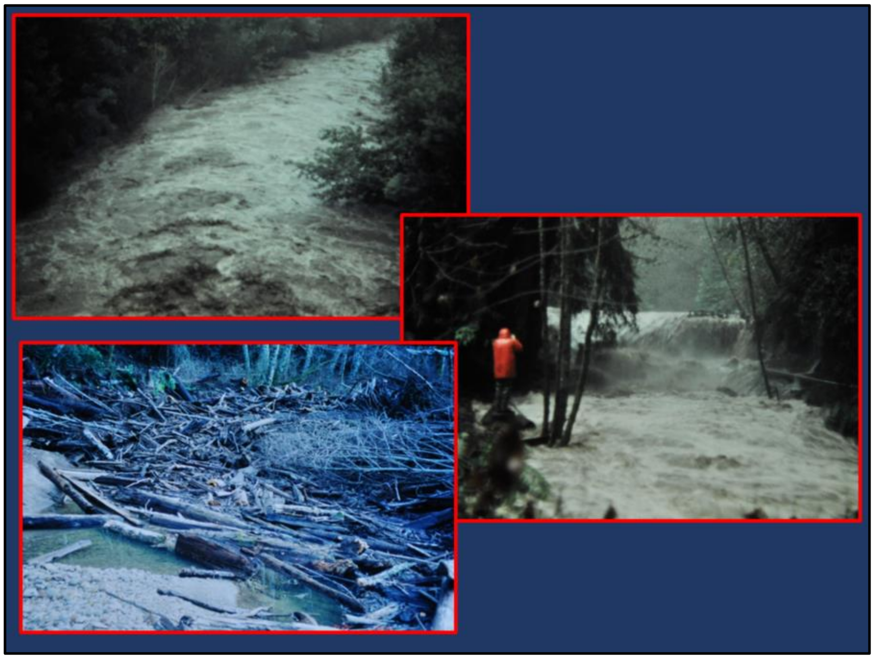
Some on-channel seasonal ponds can be important potential rearing habitat for steelhead, because they provide abundant food. The seasonal ponds on Arroyo Leon (left), near Half Moon Bay, produced abundant (an estimated 1500 fish in 2000) smolt-sized young-of-year and yearling steelhead in 2000 and 2001. The ponds were taken off line by the regulatory agencies to produce “more natural” habitat that rears few, small fish; smolt production in the watershed was probably cut by 80-90%. Similarly, use of Spring Lake, a smaller seasonal impoundment on a tributary to Uvas Creek, was discontinued.



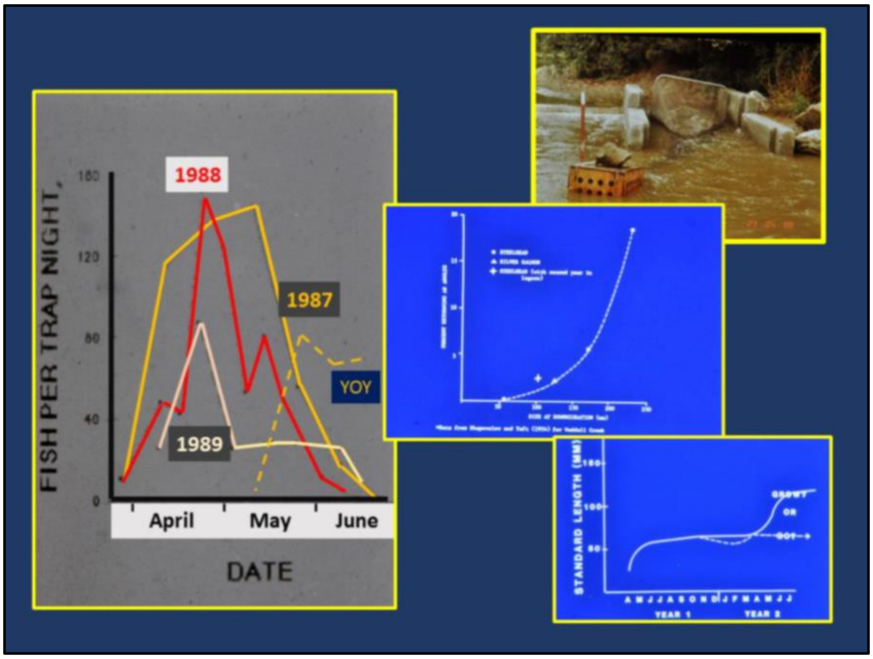

When sandbars form at the mouth of central coast streams in late spring through early summer they produce relatively deep lagoons and can flood adjacent marshes (Pescadero Creek, left top). In 1985 the habitat rapidly increased after the sandbar formed at Pescadero Creek in May (upper right; the arrows in October and November indicate artificial sandbar breaches). However, salt water 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.



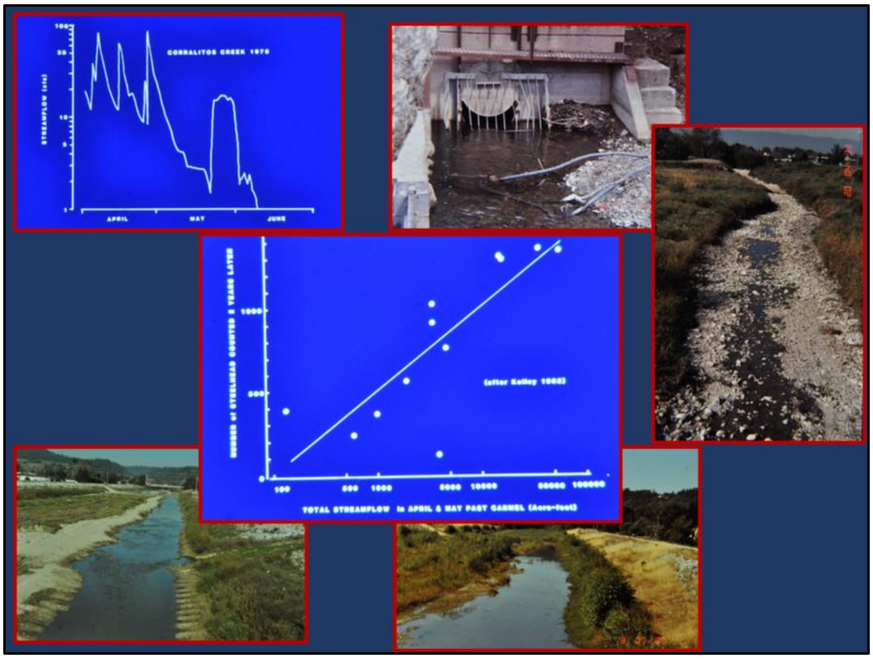

In 1986 at Pecadero the sandbar formed late (mid July) trapping abundant salt water; because stream flows were low by the time the sandbar formed, the lower salt water layer only gradually was eliminated (upper left). Water temperatures in July and August were warm because of the solar collector effect (middle), and dissolved oxygen levels were depressed for several months. The abundant steelhead grew well prior to sandbar closure and after the lagoon was converted to a mixed freshwater system, but they had slow growth during the stratified transition. However, in both years the lagoon reared 10,000 to 20,000 large smolt-sized steelhead. In the photo on the right, the top fish is a typical young-of-year steelhead upstream of the lagoon, and the next 3 fish are two-year old smolts. The young-of-year and yearling in the bottom of the photo were reared in the lagoon in summer 1985. In the drought years of 1987-1989 there was little inflow after the sandbars formed, the lagoons remained brackish and stratified for salinity, temperature and oxygen, and very few steelhead successfully reared. Since the late 1980's it has been illegal to breach lagoon sandbars, although the practice continues (lower left).



Overwintering of coho and steelhead through large winter storms (upper and middle) 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 and flood plain habitat are crucial for over-wintering. This includes such structures of flood plain trees or debris jams (left bottom) that may be over-looked as crucial habitat during surveys of the low-flow summer stream channels.



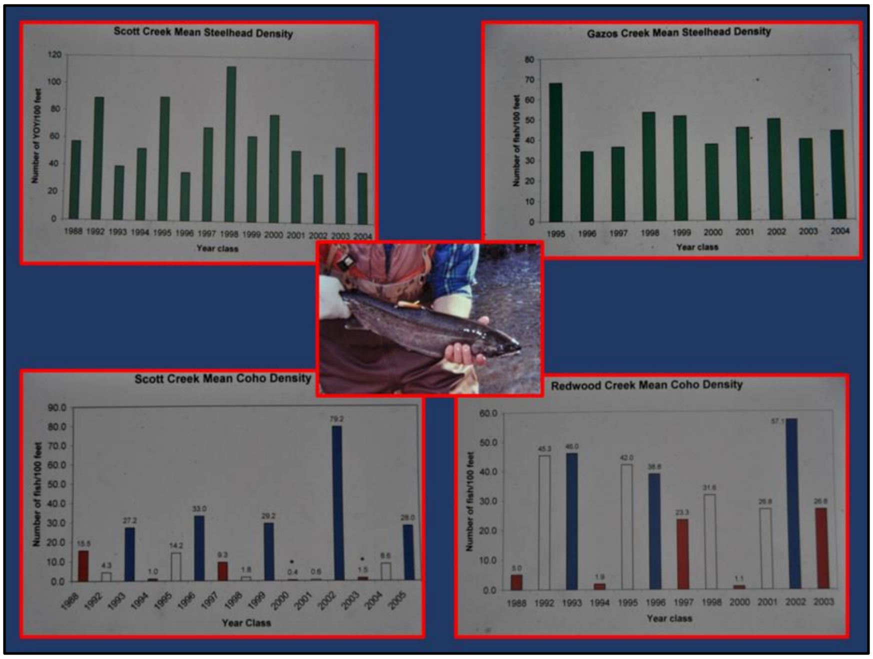

For those fish that survive winter conditions, smolt trapping (upper right) shows a counterintuitive smolt migration pattern (left). Most of the smolts do not migrate in winter when passage flows are assured, but wait until late March through May, when declining stream flows can be very problematic. 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).




In a study on the Carmel River (center) there was a direct relationship between April and May stream flow (and the passage and feeding opportunities it provided) and the number of steelhead returning 2 years later. The strong relationship shows that spring feeding and outmigration are very important population limiting factors. 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. Diversions, like the formerly-operated Nobel Avenue Diversion on Upper Penitencia Creek in San Jose, used to dry up the downstream channel by April (upper right). 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 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 open lagoon at Waddell Creek (lower left) provided little residual habitat in the 1980' and most of the 1990's for emigrating smolts. However, a flood in 1999 eroded a large meander bend upstream of Highway 1 and also produced a deep scour hole that provides feeding and brackish water for adjustment by emigrating smolts. The meander and emergent vegetation on the inside of the bend also provide a flood refuge for steelhead, coho, and endangered tidewater goby.

Throughout the central coast, steelhead and coho populations have declined substantially due to water diversions (top left), sedimentation from development, logging, and severe storms (right), and barriers to passage (lower left). However, at least for steelhead, most of those declines took place prior to the environmental laws of the 1970's. Since then, the requirements for environmental impact reports (state projects) ) and environmental impact statements (federal projects) have required mitigations of adverse impacts on new projects. The state Forest Practices Act has regulated timber operations to reduce large clear cuts, sedimentation from roads, and large-scale streamside tree removal. Environmental review (CEQA) and mitigation requirements of new water rights and streambed alteration agreements have resulted in few new diversions, no new large dams, and reduced alteration of streambeds and riparian habitats. Breaching of sandbars was illegal by the late 1980's. In general, steelhead are probably as abundant as in 1980. However, coho, with their rigid life history have gradually lost year classes due to storms impacting redds and to access problems. Coho were recently hit very hard by ocean conditions in 2005 and 2006, which affected all three year classes.




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) which boosted weak year classes in 1995, 1997, and 2004. 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.

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 2012-2017).  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.

The captive brood stock rearing and spawning has allowed significant releases of 1-year old smolts and release of some surplus brood stock produced weak juvenile production in Scott Creek 2012 (when storms destroyed redds) and relatively strong juvenile production in Scott Creek in 2013 and 2015 and Waddell Creek in 2015 (from strays).  Both streams had some juvenile coho production in 2016, despite poor ocean returns and severe March storms that destroyed redds.