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FISHERY RESOURCES OF THE REDWOOD CREEK BASIN

Richard L. Ridenhour and Terrence D. Hofstra

22 February 1994

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FISHERY RESOURCES OF THE REDWOOD CREEK BASIN

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Introduction

The Redwood Creek basin supports rather unique and valuable fishery resources. These resources have been exploited by humans, first by Native Americans and, subsequently, also by non Native American immigrants, for many centuries. Within the past 100 years, human activities have caused a substantial decline in the ability of the Redwood Creek basin to produce fish and, therefore, a decline in the populations of fish to be found within the basin. This paper reviews the characteristics of the Redwood Creek watershed that have importance to its ability to support fish populations, the species of fish found within the Redwood Creek basin, and the human activities that have contributed to the declining productivity of the Redwood Creek basin with regards to the fishery resources.

The Redwood Creek basin generally has characteristics similar to other north coastal streams of California in terms of both its aquatic habitat and its fish fauna. The mainstem of Redwood Creek is accessible to migrating fish for most of its length as there are no serious barriers in the form of falls until near the headwaters of the stream (Rogers and Hatzimanolis 1972, Anderson and Brown 1983, and Brown 1988). Excepting the ^{and Bridge Creek} ~~Prairie Creek~~ drainage which enters Redwood Creek near the mouth of Redwood Creek, ^{and Bridge Creek} ~~there are~~ no second or higher order tributary streams that are generally short and steep and provide relatively little habitat for anadromous salmonids (Best 1984 and Brown 1988). ~~Prairie Creek~~ has much more of a dendritic pattern and provides substantial fishery habitat. The stream has supported a limited variety of species of fish which is characteristic of coastal streams in this region (Table 1) (DeWitt 1964). Some species spend their lives in freshwater. Most of the fish are anadromous species that utilize the stream system for spawning and initial rearing of juveniles but growth to maturity occurs in the ocean. Several species of fish found in the creek are euryhaline (meaning that they live in brackish water) and are, therefore, found only in or near the estuary. Moyle (1976) categorized the species in coastal streams like Redwood Creek as found in the "resident trout zone" which is generally

Table 1. Fishes of Redwood Creek, Humboldt County, California.

Species	Freshwater	Anadromous	Estuarine	Reference ¹
Pacific lamprey (<u>Lampetra tridentata</u>)		X		2,3,4,5
Western brook lamprey (<u>Lampetra richardsoni</u>)	X			3
American brook lamprey (<u>Lampetra appendix</u>) ²	X			3
Cutthroat trout (<u>Oncorhynchus clarki</u>)	X	X		2,3
Steelhead or rainbow trout (<u>Oncorhynchus mykiss</u>)	X	X		2,3,4,5
Coho salmon (<u>Oncorhynchus kisutch</u>)		X		2,3,4,5,6
Chinook salmon (<u>Oncorhynchus tshawytscha</u>)		X		2,4,5,6
Eulachon (<u>Thaleichthys pacificus</u>)		X		2
Surf smelt (<u>Hypomesus pretiosus</u>)			X	5
Night smelt (<u>Spirinchus starksi</u>)				
Sacramento sucker (<u>Catostomus occidentalis</u>) ³	X			2,4,5,6
Coastrange sculpin (<u>Cottus aleuticus</u>)	X			1,3,4,5
Prickly sculpin (<u>Cottus asper</u>)	X			1,3,6
Rifle sculpin (<u>Cottus gulosus</u>)	X			
Staghorn sculpin (<u>Leptocottus armatus</u>)			X	5
Tidewater goby (<u>Eucycloobius newberryi</u>)			X	5
Three-spined stickleback (<u>Gasterosteus aculeatus</u>)	X	X		1,2,4,5,6
Pike perch (<u>Drena damalichthys vaeca</u>)				
Shiner surfperch (<u>Cymatogaster aggregata</u>)			X	5
Starry flounder (<u>Platichthys stellatus</u>)			X	5
Pacific herring (<u>Clupea harengus</u>)				

¹ 1 - Evermann and Clark 1931, 2 - DeWitt 1964, 3 - Reeves et al. 1976, 4 - Iwatsubo et al. 1976, 5 - Iwatsubo and Averett 1981, and 6 - Salamunovich 1987.

² Previously named Lethenteron lamottei.

³ Previously considered to be a distinct species - Catostomus humboldtianus.

RNP data file

Saddleback gunnel (Pholis ornata)

upstream of barriers to the migration of anadromous fish, the "anadromous lifeline zone" which is upstream to the limit of migration by anadromous species, and the "intertidal zone" which is that area of the stream influenced by tides and often contains water with some percentage of salt water from the ocean. All the anadromous species, including the anadromous lamprey have probably been utilized by Native Americans for centuries before the 19th century. The anadromous salmon and trout and the anadromous smelt have been the only species utilized by non Native Americans during the past 125 years or so.

Fishery Habitat Conditions

The Watershed

Most of the watershed is relatively narrow and straight with steep, unstable slopes, and a narrow valley (Figure 1) (CDF&G 1965b, NPS 1981, and Iwatsubo and Averett 1981). The geology of the watershed is relatively unstable and prone to slope failures (NPS 1981). Timber harvest activities, along with attendant road construction, highway construction, and grazing practices have also added to the susceptibility for erosion and slope failures within the basin (Best 1984). In this watershed, which is already prone to erosion and has been made more unstable by human activities, high flows associated with heavy winter storms often cause deposition of large quantities of earth and rock in the stream and large movements of bedload. Large storm events, such as the flooding in 1964, may cause accumulation of bedload that greatly alter the stream morphology and can take many years for the stream to transport out of the system and restore the previous morphology. Generally, the large influxes of bedload and the movement of large quantities of bedload within the stream are detrimental to the productivity of the stream for fish.

Most of the Redwood Creek watershed is or has been forested. The downstream areas near the coast and inland along the stream course were forested with coastal redwoods (Sequoia sempervirens) and associated species such as western hemlock (Tsuga heterophylla), Douglas-fir (Pseudotsuga menziesii), ^{grand} lowland fir

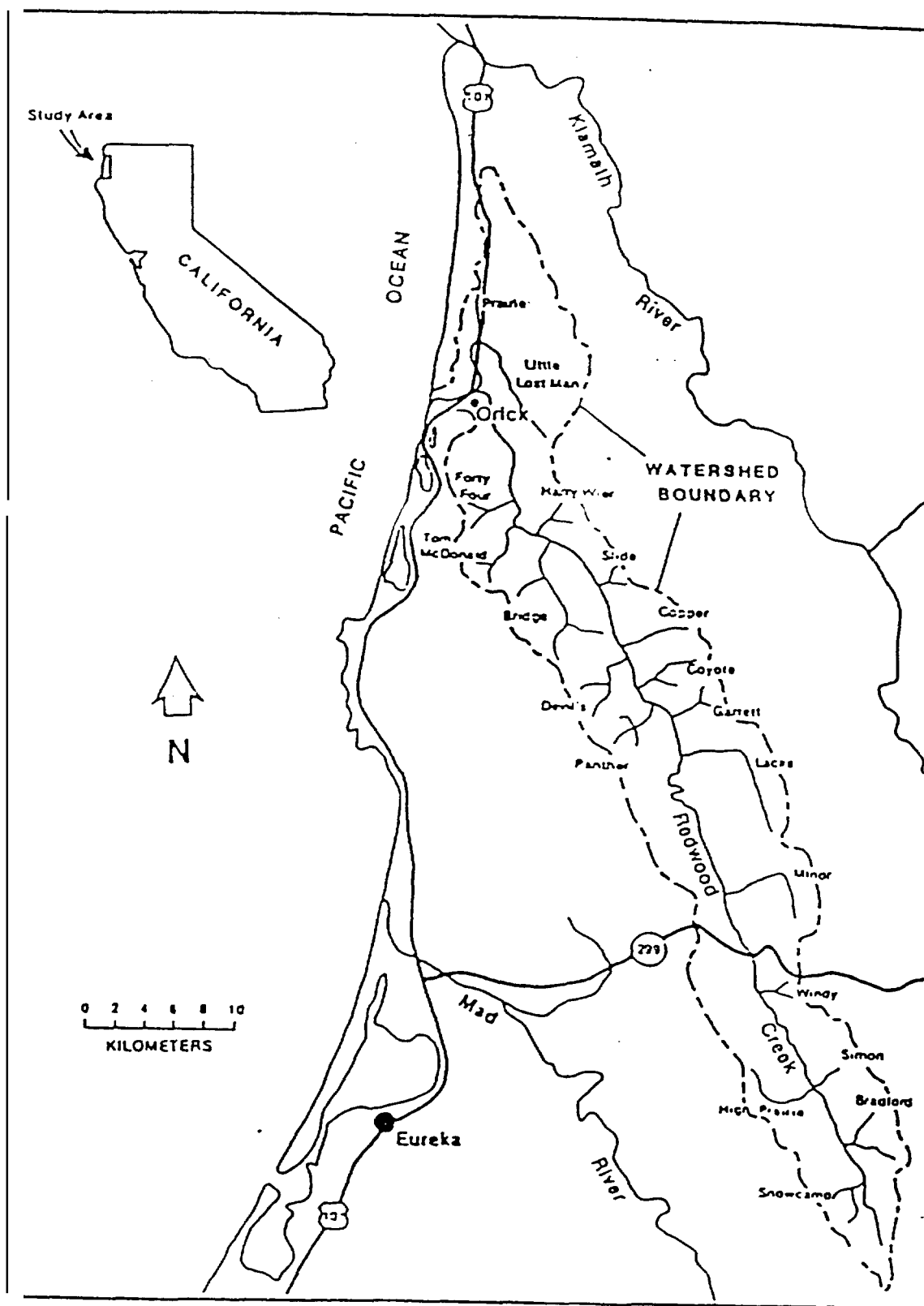


Figure 1. Redwood Creek basin, Humboldt County, California (from Brown 1988).

(Abies grandis), Sitka spruce (Picea sitchensis), western red cedar (Thuja plicata), red alder (Alnus rubra), big leaf maple (Acer macrophyllum), and willows (Salix sp.). Red alder is often the primary riparian species although any of the species of trees, along with a lush growth of shrubs including salmon berry (Rubus spectabilis), thimble berry (R. parviflorus) and salal (Gaultheria shallon), may occur in the riparian zone. Douglas-fir and mixed Douglas-fir and hardwood stands of Oregon white oak (Quercus garryana), California black oak (Quercus kelloggii), California laurel (Umbellularia californica), madrone (Arbutus menziesii), and tanoak (Lithocarpus densiflorus) with an understory of California huckleberry (Vaccinium ovatum) and ceanothus (Ceanothus sp.) begin to dominate the watershed further upstream and at higher elevations above the main stream. Red alder continues to be the dominant riparian vegetation along with big leaf maple but the streamside shrubs become less abundant. The north eastern ridgeline of the watershed is characterized by extensive open prairies some of which do extend down to the stream. The prairies are often bordered by stands of Oregon white oaks intermixed with Douglas-fir and some black oak at the higher elevations. At the highest elevations are stands of incense cedar (Libocedrus decurrens) and white fir (Abies concolor) and an understory of manzanita (Arctostaphylos sp.) and ceanothus. The vegetation pattern generally reflects the progression from the relative cool, damp coastal climate to progressively more xeric conditions further inland.

The Stream

The mainstem of Redwood Creek is nearly 60 miles (95 km) in length. The highest elevations at the headwaters are Over 5000 feet (1525 m). In the first 5 miles (8 km), the stream descends about 3000 ft (915 m) or 600 ft/mile (115 m/km). Over the next 10 miles (16 km) of stream, the drop is only about 1000 ft (305 m) or 100 ft/mile (19 m/km). From this point downstream, the gradient is much less precipitous with a drop of only about 800 ft (245 m) over the next 25 miles (40 km) or 32 ft/mile (6 m/km). The remaining 200 ft (60 m) of elevation to sea level is spread over the last 20 miles (27 km) or so at a gradient of 10 ft/mile (2.2 m/km).

The flow patterns within Redwood Creek are characterized by flows at Orick that may be 15 cfs (cubic feet per second) ($0.4 \text{ m}^3/\text{s}$) or less during the late summer season to flows in excess of 50,000 cfs ($1415 \text{ m}^3/\text{s}$) during large winter storm events (Rantz and Moore 1965, Janda et al. 1975, Ricks 1985, and Coghlan 1984). Redwood Creek is similar to other north coastal streams, including the Eel River and the Mad River, in the sense that its watershed is highly unstable and prone to land failures that introduce large amounts of materials into the stream that become part of an extremely high bedload (NPS 1981 and Ricks 1983 and 1985). The natural instability of the watershed has been greatly exacerbated by human activities within the watershed including road construction, logging, and grazing by livestock (DeWitt 1964 and Best 1984). The particularly large additions to the bedload during the 1955 and 1964 floods caused stream channel aggradation and widening in the lower flood plain. Flows within the Prairie Creek drainage are generally less affected by the storm events because it is more completely forested and, therefore, this drainage is less prone to land failures and large bedloads.

Water temperatures of Redwood Creek and its tributaries range from about 6° to 13° C (43° - 55° F) during the winter and from about 17° to 25° C (63° - 76° F) during the summer (Iwatsubo et al. 1976, Anderson and Brown 1983, and Anderson 1988). The highest water temperatures were measured in the Redwood Valley reach of the mainstem. Water temperatures in tributary streams nearer the ocean such as Harry Wier Creek, Tom McDonald Creek, and Lost Man Creek were not found to be greater than 14.5° C (58° F). Also, the ocean influence tends to moderate the water temperatures in Redwood Creek downstream of Orick. Cold pools of water have been identified in Redwood Creek in association with a sources of cool water from tributary streams or springs and deep pools with large organic debris ^{on gravel bars} possibly important to retard mixing (Keller and Hofstra 1983). ^{Orzaki 1988}

The water chemistry of Redwood Creek and its tributaries was extensively monitored in 1974 and 1975 (Iwatsubo et al. 1976). The water generally contained low levels of total dissolved solids and the conductivity was, therefore, also low. Nitrate and nitrite concentrations were generally low relative to dissolved phosphorus and considered to be limiting to growth of algae (Bradford and Iwatsubo 1978).

These conditions suggest a moderate organic productivity (FWS 1960 and Bradford and Iwatsubo 1978)

Dissolved oxygen levels were generally greater than 8.0 mg/l (or parts per million) throughout the basin (Anderson and Brown 1983), which are considered to be desirable levels for salmon and trout (Denton 1974), with levels below 7.0 mg/l only recorded twice. The water in Redwood Creek ~~tends~~ was usually alkaline with pH levels generally above 7.0 though levels were often a bit below 7.0 and, therefore, slightly acid during the winter (Iwatsubo et al. 1976). The pH ranged from about 6.5 to 8.2 which is well within the range of suitability for the species of fish found in Redwood Creek. Anderson (1988) found pH levels to range from 6.6 to 7.3 in eight tributary streams and at one mainstem station. Generally, alkaline waters are considered to be more productive than acidic waters. Water in Lost Man Creek, a tributary of Prairie Creek, tended to be a bit more acid with pH values generally a little below 7.0 throughout the year. The lower pH levels in Lost Man Creek possibly reflect the greater amount of leaf litter in the Prairie Creek system as compared with the rest of the Redwood Creek basin.

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Fish Habitat

In order to support viable populations of native fish, a stream such as Redwood Creek must provide suitable conditions for the various life history stages of the species involved (Hofstra and Harrington 1983). Thus, for those species that live their entire life in the stream, the stream must provide suitable habitats for spawning and incubation of eggs, rearing of juveniles, and maintenance of adults. The requirements for anadromous species are quite variable depending on the species and, in some cases, the race of fish involved. Clearly, anadromous fish will need access to suitable habitat to spawn and incubate their eggs, suitable habitat for their young to grow until they migrate to the ocean which may be a matter of only a few months but can be a year or more, and, for summer steelhead, suitable habitat for the adults between the time they migrate into the stream and when they are ready to spawn.

Brown (1988) found approximately 58 miles (94.5 km) of the mainstem and 50 miles (80.5 km) of the tributaries to be accessible to anadromous fish. Except for steep topography and a large falls in the upper two to three miles of the stream, the mainstem of Redwood Creek had no natural barriers to the migration of anadromous salmon and steelhead (Rogers and Hatzimanolis 1972, Anderson and Brown 1983, and Brown 1988). At times there may have been log jams that impeded movement of fish but none that would do so exist in recent years in the upper 10 miles (16 km) of the mainstem and in some of the tributaries such as Bridge Creek (Rogers and Hatzimanolis 1972 and Brown 1988). Most of the tributaries, with the exception of Prairie Creek, have access for anadromous fish impeded by barriers, such as steep gradients and waterfalls, within a relatively short distance from Redwood Creek (Anderson and Brown 1983 and Brown 1988). In some tributaries, though they have flowing water and habitat suitable for fish throughout the summer, during the dry season there may be no surface flow in the last few hundred feet before joining the mainstem. The mouth of Redwood Creek normally is closed during the summer low flow period by a sand berm resulting from the along shore drift of sand and the prevailing northwesterly direction of the ocean waves (CDF&G 1965a and Ricks 1985). This berm is often not broken by natural forces until ^{fall and} winter storm flows are sufficient to wash it out. The California Fish and Wildlife Plan identified the bar at the mouth of Redwood Creek as being a serious factor reducing the productivity of Redwood Creek by impairing the upstream migration of anadromous fish (CDF&G 1965a). Prior to the establishment of the Redwood National Park, local landowners would often breach the berm when their lands became flooded by the impounded water (Hofstra and Sacklin 1987). More recently, the Redwood National Park has managed the berm to allow controlled releases and thereby prevent flooding of adjacent lands (Hofstra 1983, Hofstra and Sacklin 1987). This barrier may delay anadromous salmonids, especially the fall runs of coho salmon and chinook salmon, from entering the stream in a timely manner.

The purpose of the controlled releases would maintain are designed to maintain the habitat and fish in the estuary, while removing water from adjacent private pastures.

*In the tributaries
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RNP making one jam
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Lost Man
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*which would promote
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Spawning Habitat

There are sufficient suitably sized gravels throughout the accessible portions of Redwood Creek and its tributaries to support large numbers of spawning salmonids. Two problems have reduced the suitability of the spawning gravels. The extensive erosion within the watershed has added large amounts of fines that cause the gravels to be cemented together (CDF&G 1965b and Chupp 1976). Cemented gravels are not selected for spawning by salmon and trout because they have difficulty digging their redds (spawning nests). Also, large amounts of fines in the gravel prevent the flow of water through the gravels as is needed for proper incubation of the eggs of salmon and trout deposited in redds in the gravel (Cordone and Kelley 1961). Without adequate flow through the gravel, the developing embryos may suffocate (Chupp 1976). Large flow events associated with rapid runoff from unvegetated portions of the watershed can cause massive movement of the gravels along the stream bed. This movement can scour out and either displace salmonid eggs so they are destroyed or bury them so deeply that the newly hatched fry cannot subsequently emerge from the gravel into the flowing stream.

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Nursery Habitat

The nursery habitat for juvenile fish in Redwood Creek is limited primarily by low flows (CDF&G 1965a and 1965b). High summer water temperatures and limited amounts of cover in the mainstem reduce the quality of the nursery habitat. High summer temperatures are particularly a problem in the Redwood Valley reach of the mainstem where they may reach as high as 25° C (76° F) (Iwatsubo et al. 1976 and Anderson 1988) which may be lethal to salmon and trout unless the fish can find pockets of cool water such as tributary or spring flows or deep pools that have cool temperatures near their bottom (Keller and Hofstra 1983). The water temperatures are, to some extent, increased by the lack of riparian vegetation ^{which occurred} either because of logging activities or because of widening of the channel during high flows and the associated massive movement of bedload materials. The warming effects resulting from logging activities are a problem primarily in the upper basin tributary streams. The lack of riparian vegetation

- or no pools + structure

associated with widening of the channel is primarily a problem in the lower mainstem. The high summer temperatures affect mainly the juveniles of steelhead trout and coho salmon since many juvenile steelhead and virtually all juvenile coho salmon remain in the stream through their first summer of life. Many of the juvenile coho salmon and steelhead utilize the cooler water in the tributary streams during the summer even though those streams often do not have surface flows into the mainstem during the late summer. Since juvenile chinook salmon in Redwood Creek tend to migrate from the stream to the estuary by early July (McKeon 1985 and Larson 1987) and ^{by fall} ~~in the ocean soon thereafter~~ if the mouth of the creek is open to the ocean, they have limited need for nursery habitat within the stream. ~~however, nursery habitat is important and needed in the estuary~~ ^(C. Hobbs 1983)

Instream cover, particularly in the mainstem, is limiting for juvenile fish. At the present time, there is relatively little large woody debris in the mainstem. This type of material is important because it provides objects under which fish can hide from predators and it deflects the current causing scouring of pools which, in turn, provide cover in the form of deep water (Keller et al. 1981 and Pitlick 1981). Boulders provide good instream cover and cause the scouring of deep pools in the upper reaches of the stream and the middle reaches of the stream between Lacks Creek and Bridge Creek. Riparian vegetation in the mainstem of Redwood Creek, and particularly below Bridge Creek, provides little cover either in the form of root wads or by causing pool formation because of the extensive bar formation resulting from the large movement of bedload. Generally, instream and riparian cover is better in the tributary streams and particularly within the Prairie Creek drainage. *Instream woody structures have been ~~put~~ ~~and~~ placed and anchored in some ^{tributaries containing} anadromous fish to restore nursery habitat.*

Food Production

The water chemistry of Redwood Creek generally indicates that the water is relatively infertile (Bradford and Iwatsubo 1978). Since salmon die after spawning, their carcasses can be an important source of organic fertilization in the stream (Warren 1988). The extensive amount of bedload movement in the stream can be detrimental to the production of aquatic invertebrates (Cordone and Kelley 1961).

Excessive amounts of fines also may reduce production of invertebrates by limiting the amount of exposed rock surfaces and preventing the invertebrates from getting under the rocks.

Fairly substantial populations of aquatic invertebrates, particularly immature insects in the freshwater and the crustacean, Corophium sp., in the embayment, are produced (Harrington 1983, Anderson 1988, and Ridenhour and Salamunovich 1993). The food habits of the various species of fish generally correspond to the availability of the types of food so that fish were found to eat primarily immature insects, and especially immature flies and gnats (Chironomidae), in the freshwater areas and crustaceans, and especially Corophium sp., in the estuary (Salamunovich 1987 and Salamunovich and Ridenhour 1990). Terrestrial invertebrates are often an important component in the diet of young salmon and trout (Salamunovich 1987 and Salamunovich and Ridenhour 1990). Most of the terrestrial insects enter the stream in the form of organisms dropping from stream side vegetation (Anderson 1988). Where this riparian vegetation has been reduced, there is a reduction in terrestrial invertebrates entering the stream relative to the drop into streams with a closed riparian canopy (Anderson 1988).

Predators

The fish in the Redwood Creek basin have been subjected to predation for time immemorial. Apart from fishing by Native Americans and, within the past nearly 150 years, by non Native Americans, there have been a wide variety of animal predators. These have included river otters (Lutra canadensis), mink (Mustela vison), raccoons (Procyon lotor), and black bear (Ursus americanus) and, at one time, grizzly bear (Ursus horribilis). Avian predators include common mergansers (Mergus merganser), ospreys (Pandion haliaetus), belted kingfishers (Ceryle torquata), great blue herons (Ardea herodias), and little green herons (Bufo striatus). Immediately around the mouth and within the estuary of Redwood Creek predators include ^{cal?}Stellar's sea lions (Eumetopias jubata) and harbor seals (Phoca vitulina) and a variety of birds including cormorants (Phalacrocorax sp.), ^{lewis}western grebes (Aechmophorus occidentalis), ~~scoters~~ gulls, (Larus sp.) and ducks such as scoters (Melanitta sp.) and scaup (Aythya sp.). As long as the habitat

mergers

remained intact and, particularly, cover in the form of deep pools, large woody debris, and an overhead riparian canopy, these natural predators did not seriously affect the viability of the fish populations. However, events that have reduced the amount of natural cover have made the fish much more vulnerable to the impacts of predation. Reductions of fish populations that have been attributed to the effects of predation can generally better be attributed to the damage to and loss of suitable habitat needed by the fish.

The Fishery Resources . .

Redwood Creek contains a fish fauna that is relatively unique at this time for the streams of California. While nonnative species have been widely introduced in most California streams both officially by fishery management agencies and unofficially by members of the general public, Redwood Creek still contains essentially only those species of fish native to this region prior to the planting of introduced species that began in the late 1800s (DeWitt 1964) (Table 1). A complete sample of fish taken from a section of Prairie Creek in September of 1951 included 699 sculpin, 144 juvenile coho salmon, 83 juvenile steelhead, 21 stickleback, 9 cutthroat trout, 3 juvenile chinook salmon (note that chinook salmon would not normally be expected to be in the stream at this time of year), and an unrecorded number of larval lampreys (DeWitt 1954 and 1964). The species of fish can be placed in one or the other of three groups: those found only within the freshwater portions of the stream, those that are anadromous meaning that they reach maturity in the Ocean and then migrate to the stream in order to spawn, and those that live in the estuary or move in and out of the estuary to feed. The habits of some of the species are such that they may be included in more than one category such as cutthroat trout which may remain as residents in freshwater throughout their life or they may migrate to the ocean and, thus, become anadromous.

have found a few 1+ in recent years
Salmon
South
Stream
Range

The anadromous salmon and steelhead are noted for their tendency to "home" meaning that they tend to return to spawn in the stream, and, in fact, often to the portion of the stream, where they were hatched. The homing habit ensures that more fish will return to spawn in habitats that were good producers of fish than in habitats that were marginal. Also, it ensures the successful reproduction of those fish that have

evolved to be genetically compatible with the characteristics of the stream such as when the stream is accessible and when the water temperatures are suitable. There may be a limited amount of straying. DeWitt (1964) suggested eulachon runs into Redwood Creek may be strays from the Klamath River. Recent returns of marked fish have indicated some straying of cutthroat trout from Stone Lagoon, located about three miles south of Redwood Creek, into the Redwood Creek estuary.

Knowledge about the current status of the fishes found in Redwood Creek is quite variable. Generally, much more is known about those species used most by humans and relatively little is known about those species that have had limited use by humans. Estimated spawning escapements of 5,000 chinook salmon, 2,000 coho salmon, and 10,000 winter steelhead as well as an indicated large run of anadromous cutthroat trout have appeared in a variety of publications (CDF&G 1965a and 1965b, Winzler and Kelly 1970, and Chupp 1976). These estimates all derive from the same source that were made using information from studies conducted on the Eel River in 1955 through 1958 by the California Department of Fish and Game and are only valid for those years (FWS 1960). It was recognized that much larger runs had previously existed and subsequent information has indicated a progressive decline (FWS 1960). Elk et al. (1966) indicated that Redwood Creek had historically supported "fair runs" of chinook and coho salmon, steelhead, and cutthroat trout as well as resident rainbow and cutthroat trout in the headwaters of the basin. More recent estimates for Prairie Creek, Boyes Creek, and May Creek were 371 chinook salmon, 833 coho salmon, 915 steelhead, and 50 cutthroat trout (NPS 1984). There have been no independent estimates of numbers of salmon and steelhead in Redwood Creek that would indicate population trends but all documented runs in other northwestern California streams have been declining and it is judged that Redwood Creek runs have done the same (Winzler and Kelly 1970 and Denton 1974). In fact, the commercial salmon landings at Eureka, California that increased until 1925 but were followed by declines through 1928 led Snyder (1931) to conclude that runs salmon runs in the Klamath River were already declining at that time. The populations of the species of less interest to humans have probably remained fairly stable although some, like the freshwater sculpins, may have declined because of less suitable habitat in the form of reduced instream cover and warmer water temperatures.

Spawning surveys
1953-1962

10 19 42 23
112

$\bar{x} = 100$ redd
 + 200 fish
 + 100 fish in river
 1000 4, 8, 13, 18, 11 300 fish
 5, 10, 15 142
 Prairie Creek spawning survey data indicates numbers of salmonids have not declined in this creek since 1983-4. Average over 7 years was about 100 chinook, 80 coho and 20 steelhead on the mainstem.

Human activities have undoubtedly had their greatest impacts on the anadromous salmon, trout, and smelt because of the changes in the habitat required for the production of these species. The limited information available suggests that the runs of anadromous salmon and steelhead have declined to approximately 10 percent of their former numbers (Denton 1974). The results of a California Department of Fish and Game survey in 1956 concluded that Redwood Creek was an excellent spawning stream for anadromous fish but that current runs were far below those that occurred 70 to 80 years ago (Chupp 1976).

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Chinook Salmon

The chinook salmon that utilize Redwood Creek are considered to be of the fall-run variety. This means that they enter the stream on their spawning run in the fall (CDF&G 1965b). The life history of chinook salmon in Prairie Creek has been outlined by Briggs (1954). They spawn in the main stream and the larger tributaries such as Prairie Creek, Tom McDonald Creek, Bridge Creek, Lacks Creek, and Minor Creek during the winter and their eggs hatch in late winter. Within the Prairie Creek basin, Briggs (1954) found chinook salmon spawning only in Prairie Creek and Lost Man Creek and he noted that Prairie Creek was an unusually small stream system to support spawning chinook salmon. The adults all die after spawning. The young emerge from the gravel in early spring and start moving to the ocean by late spring. Essentially all enter the estuary by early July (McKeon 1985 and Carson 1987) and enter the ocean any time after mid July depending upon access which might be prevented by the closure of the mouth of the stream. Since most of the juvenile fall chinook salmon migrated from the stream by July (McKeon 1985, Larson 1987, and Brown 1988), late summer and early fall stream conditions are of little consequence to the well being of populations of this race of chinook that spawns in the Redwood Creek basin. The fish remain in the ocean from one to three years or possibly more before they mature and return to their home stream to spawn. Precocious males, often called jacks, return to spawn after one summer in the ocean when they weigh about 3 or 4 lb (1.4 or 1.8 kg). Most males and the females return after two or

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indication that the Native American fisheries had any lasting negative impact on the productivity of the fish populations in Redwood Creek.

After the arrival of the immigrants in the mid 1800s, Redwood Creek became known for the quality of the fishing (Feranna & Ricks 1981). The catches of fish over the last 150 years, particularly salmon and steelhead and, possibly, eulachon, have likely reduced the populations of adult fish that return to the stream.

Sport fishing for salmon and steelhead in Redwood Creek has been popular and productive. Chinook salmon as large as 50 lb (23 kg) were not uncommon (Feranna and Ricks 1981). There was even been a limited commercial seine and aillnet fishery for salmon and steelhead in the estuary during the early 1900s (FWS 1960). Management of the fisheries was generally by regulation of the fisheries to limit the numbers of salmon and trout an individual could catch in one day, to protecting the fish on their spawning grounds, and to control the types of fishing gear that could be used. One estimate of fishing effort and success indicated that 500 angler days were spent to catch 250 salmon, 1,000 angler days were spent to catch 600 steelhead, and 2,500 angler days were spent to catch 6,000 trout (mostly juvenile steelhead caught in Prairie Creek) (FWS 1960). A more recent estimate of the magnitude and success of recreational fishing for salmon and steelhead in Redwood Creek indicated that salmon fishermen spent approximately 700 angler days to catch 150 fish per year and steelhead fishermen spent approximately 500 angler days to catch 500 fish per year (CDF&G 1965a). Another source indicated that 2,000 to 4,000 angler days resulted in a catch of 650 to 6,250 salmon and steelhead (Chupp 1976).

An unknown number of salmon produced in the Redwood Creek basin have been caught in the ocean by commercial and recreational fishermen. This fishery has been developed almost entirely since 1900. The magnitude of the ocean catch of salmon and trout has been estimated for other streams based on returns of marked fish. A ratio of four fish caught to one fish returning to the spawning ground has been often used with about 80% caught by offshore commercial fishermen, 16% caught by offshore recreational

fishermen, and 4% caught by instream recreational fishermen (Wood et al. 1983). The impact of this level of harvest on the sustained productivity of the salmon population has not been established but early reductions in runs have been attributed to commercial fishing (Chupp 1976). Since the harvest of steelhead and cutthroat trout in the ocean by either commercial or recreational fishermen is nil, the only impact of fishing on the size of the spawning escapement of these two species is the instream recreational fishery.

A general management objective for the anadromous salmon and trout resources has been to limit the legal harvest so that enough fish return to spawn in the streams within a particular watershed. Thus, enough salmon and trout should be allowed to return to spawn in the Redwood Creek basin to take full advantage of all of the naturally suitable habitat within the basin. This may mean enough fish to fully utilize all of the areas of suitable spawning gravels or it may mean enough fish to produce juveniles that would occupy all of the available rearing areas. There are two possible shortcomings of this management objective. First, there have been suggestions that adult fish in excess of the capacity of the spawning areas may be important in terms of the fertility their carcasses provided to the relatively unproductive coastal streams in the redwood region. Warren (1988) demonstrated in two tributaries of Prairie Creek that the addition of extra salmon carcasses could increase the basic productivity of the stream. Another possible effect that has not been tested is the activity a large numbers of spawners could have in terms of maintaining the quality of spawning gravels by preventing accumulation of fines and impaction. Thus, numbers of fish in excess of the capacity of the spawning and rearing areas may be important to maintaining the general productivity of the streams.

The fishery for eulachon in Redwood Creek has continued since the 1850s. However, the runs, in recent years, have been smaller and irregular (DeWitt 1964). Since no consistent data have been collected with respect to this resource or its harvest, no specific comments can be made about how it may have been affected by the fishery.

The fishery for lamprey is very limited at this time and no data are available concerning its historic or present magnitude or current status.

Poaching has contributed to the decline of the anadromous fish populations. Frequently these illegal activities are conducted on the actual spawning areas of salmon and steelhead where fish are killed and disturbed. The slimmer steelhead are particularly vulnerable to poaching during the summer when they remain in deep pools of clear water where they can be readily seen and pursued (Anderson 1993a).

Artificial Propagation

The fairly long history of fish propagation activities within the Redwood Creek basin has been outlined by Feranna and Ricks (1981). It started with establishment of a salmon egg taking station in the late 1800s. An egg collecting station was reestablished in 1928 and a temporary fish hatchery was constructed in 1929. These activities were followed by the construction of a permanent facility, Prairie Creek Fish Hatchery, by the California Department of Fish and Game in 1937 at the mouth of Lost Man Creek (Chupp 1976). This hatchery propagated chinook and coho salmon and steelhead and cutthroat trout until 1955 when the California Department of Fish and Game moved its north coast hatchery operation out of the Redwood Creek basin. The County of Humboldt subsequently took over operation of this hatchery in 1957 and operated it until 1992 at which time the hatchery was abandoned. During operation by the County of Humboldt, coho salmon continued to be reared until about 1967 when stocks had declined to the point that eggs could no longer be obtained. Chinook salmon were reared throughout the operation period but steelhead production was phased out by the County by about 1975. Salmon and steelhead eggs were frequently obtained by trapping adult fish at a weir on Prairie Creek as they were migrating to their natural spawning areas. The County of Humboldt also raised coastal cutthroat trout in the facility for stocking in selected ponds and streams generally outside the Redwood Creek drainage.

more summers in the ocean when they have reached a weight of 10 to 15 lb (4.5 to 6.8 kg) or as much as 30 or 40 lb (13.6 to 18 kg) or more.

It has been estimated that there are 69 miles of suitable chinook salmon habitat within the Redwood Creek basin with 48 miles being in the mainstem (FWS 1960, CDF&G 1965a, and Brown 1988). The best spawning areas were identified as being in Prairie Creek, the middle reach of Redwood Creek including Lacks Creek and Minor Creek, and the upper reach of Redwood Creek (FWS 1960). Redwood Creek has been noted for producing substantial numbers of large chinook salmon (Feranna and Ricks 1981). Runs returning to the creek were estimated in 1960 to be 5,000 fish (FWS 1960) with 1,000 using the upper reach, 2,000 using the middle reach and tributaries, and the remaining 2,000 using the lower reach and particularly Prairie Creek (FWS 1960). The chinook salmon spawning areas of the Redwood Creek basin were estimated to be sufficient to support 5,400 spawning fish (FWS 1960) which would mean a run of about 13,500 salmon if there were 1.5 males for every female. An order of magnitude estimate of the run in 1979 can be made based on the 20,000 juveniles estimated to be in the estuary in early July 1980 (Larson et al. 1981). If the 20,000 juveniles represented 90% of the juveniles produced by the stream, there was a 1% survival of eggs deposited by the 1979 spawning run, the females spawners produced an average of 3,000 eggs, and there were 1.5 males for every female in the run, there would have been approximately 1,850 adults in the 1979 run.

Coho Salmon

Though coho salmon and chinook salmon have a similar life history, there are some important differences. Shapovalov and Tait (1954) described the life history of coho salmon based on their studies on Waddell Creek in Santa Cruz County, California, and Briggs (1954) described the life history of coho salmon in the Prairie Creek system where he found them spawning in May Creek, Godwood Creek, Elk Prairie (Boyes) Creek, and Brown Creek as well as Prairie Creek. Coho salmon also return from the ocean to Redwood Creek in the fall. They, however, spawn primarily in Prairie Creek and its tributaries

and in the smaller tributaries of Redwood Creek (FWS 1960, CDF&G 1965b). It has been estimated there are 110 miles of suitable stream habitat for coho salmon in the Redwood Creek basin (CDF&G 1965a). Surveys in 1980 and 1981 found juvenile coho salmon in the Prairie Creek drainage (Anderson and Brown 1963 and Brown 1988) with individual fish found in Tom McDonald Creek in lower Redwood Creek, Coyote Creek, Karen Creek, and Pilchuck Creek in the middle reach of Redwood Creek (Brown 1988).

Upon hatching and emerging from the gravel in the spring, the juveniles remain in the stream for approximately a year before they migrate to the ocean in late winter and early spring. Like chinook salmon, some male coho salmon will return as jacks to spawn after one summer in the ocean. But, unlike chinook salmon, virtually all of the rest, the remaining males and all of the females, return to spawn after completing two summers in the ocean. The jack males generally weigh about 3 lb (1.4 kg) and the others weigh between 8 and 15 lb (3.6 and 6.8 kg).

The characteristic of remaining in the stream for one year means that the stream habitat must be suitable that entire time for coho salmon to reproduce successfully. In particular, the juvenile coho salmon must have cool water and ample cover. Loss of quality or quantity for either of these two stream characteristics will result in the loss of coho salmon production. Redwood Creek was identified as providing excellent habitat for coho salmon in 1951 when 9,610 juveniles were seined from Prairie Creek and its tributaries (Hallock et al. 1952). An extensive stocking program by the California Department of Fish and Game in the late 1950s and early 1960s probably increased the runs of coho in Redwood Creek as they were in other north coast streams but they were not sustained by natural reproduction when the stocking program was stopped (Denton 1974). Runs were estimated to be approximate 2,000 fish (FWS 1960). These 2,000 fish were indicated as being distributed through the basin with 600 spawning in the upper reach of Redwood Creek, 800 fish in the middle reach, and 600 fish using the lower basin (CDF&G 1965b) though Brown (1988) reported no juveniles in the upper basin and very few in the middle basin. Runs into Redwood Creek may still be 2,000 fish or more with most returning to Prairie Creek as indicated by 100 to 1,800 fish returning to the Prairie Creek Hatchery

between 1972 and 1990 (Brown et al. In press). However, the number of coho salmon returning to Prairie Creek may have been influenced by hatchery production (CDF&G 1994).

Steelhead

Steelhead, like chinook and coho salmon, grow to maturity in the ocean and return to their "home" stream to spawn. A major difference, however, is that steelhead do not necessarily die after they spawn (Shapovalov and Taft 1954). Though there is a substantial mortality caused by the rigors of migrating and spawning, as many as 15% may succeed in returning to the ocean and subsequently returning to spawn again the following season. An estimated 112 miles of suitable steelhead habitat has been identified (CDF&G 1965a). Steelhead spawn in the smaller tributaries like coho salmon but, unlike coho salmon, they utilize all accessible tributaries as well as the upper portions of the mainstem stream (FWS 1960 and CDF&G 1965b). Juvenile steelhead or rainbow trout were found throughout the Redwood Creek basin but were relatively less abundant in the Prairie Creek system where cutthroat trout and coho salmon were found (Brown 1988). Also like coho salmon, most (76%) of them remain in the stream as juveniles for approximately one year but substantial numbers do migrate to the ocean before the first summer of their life while some may remain in the stream for more than one year before migrating to the ocean (Larson 1987). In fact, some may remain in freshwater, reach maturity, and spawn without ever going to the ocean and, thus, become what are known as rainbow trout (DeWitt 1964).

There are two distinct races of steelhead that occur in the Redwood Creek basin: winter steelhead and summer steelhead. Winter steelhead typically return to their "home" stream to spawn during the winter. Summer steelhead, on the other hand, return to the stream in late spring and early summer. Runs of winter steelhead have been estimated to be 10,000 fish (CDF&G 1965a) while summer steelhead counts have been consistently less than 50 fish (Anderson 1993a and 1993b).

Winter steelhead, whose life history has been described by Shapovalov and Tait (1954) for Waddell Creek, Santa Cruz County, California, and by Briggs (1954) for Prairie Creek, spawn in late winter and early spring (CDF&G 1965b). Adult winter steelhead generally weigh between 6 and 15 lb (2.7 and 6.8 kg) though Redwood Creek has had the reputation for producing fish that weigh 15 to 20 lb (6.8 to 9 kg) (Denton 1974).

As indicated, summer steelhead return from the ocean to the stream on their spawning run in the late spring and early summer (Moyle 1976). They move upstream and generally stay in large pools through the remainder of the summer and early fall. With the winter rains, they move further upstream into the headwaters of the mainstem or tributaries where they spawn. Adult summer run steelhead generally weigh from 3 to 6 lb (1.4 to 2.7 kg).

Clearly, the habitat demands of the summer steelhead are much greater than for winter steelhead since they must have suitable conditions for the adults to survive throughout the hot, late summer and early fall. Cool water, either provided by riparian shading, cool springs, cool tributary water, or stratification of pools with the cooler water being near the bottom under less dense, warmer water on the surface, must be available. Since the adult summer steelhead are essentially living off of stored body fats during their freshwater stay, it is not necessary for the stream habitat to provide a source of food for them during this period. But, this extended stay in the stream does make them particularly vulnerable to fishing and, especially, poaching because they are both visible in the clear water of the summer and they remain essentially in one pool for the entire late summer and fall period (Anderson 1993a).

Though DeWitt (1964) did not recognize the existence of a run of summer steelhead in Redwood Creek, Redwood National Park personnel surveyed from approximately Lacks Creek to Tom McDonald Creek for this race of steelhead since 1981 (Hořtra and Harrington 1983 and Anderson 1993a and 1993b). The largest numbers observed were 44 in 1984 and 1985 but most counts have been between 10 and 20 fish with counts of only 0, 2, and 4 in 1989, 1982, and 1983, respectively. Most of the fish were observed

in pools and, particularly, deep pools with associated flows of cool tributary water (Keiler and Hoistra 1983). Clearly, the population of summer steelhead in Redwood Creek is very low and such that its future well being is tenuous at best. Anderson (1993a) concluded that "habitat degradation [lack of deep pools], poor water quality [high water temperatures], sport-fishing and poaching, and [small] population size" are the most serious problems affecting possible recovery of summer steelhead populations in Redwood Creek.

A few steelhead juveniles may stay in freshwater throughout their life rather than migrate to the ocean. When they live to maturity in freshwater they are called rainbow trout. Rainbow trout in the Redwood Creek basin are generally restricted to the headwater areas and may be found upstream of barriers to migrating anadromous fish (DeWitt 1964). These fish seldom reach a size in excess of 8 or 10 in (20 to 25 cm). There is evidence that resident rainbow trout may hybridize with resident cutthroat trout in some tributaries of Redwood Creek (Neillands 1990).

Cutthroat Trout

Like the steelhead, anadromous cutthroat trout return from the ocean to the stream in order to spawn. They typically utilize the streams in the lower portion of the Redwood Creek basin (DeWitt 1954). They do move into the smallest accessible portions of the tributaries. They generally enter the stream in the late fall and spawn during the winter. Most of the young fish return to the ocean after a year or more in fresh water and, in fact, many do not return at all but remain in freshwater where they may mature and reproduce. The fish remaining their entire life in freshwater generally stay in the smaller tributary streams above barriers to migration by most anadromous fish (DeWitt 1954 and 1964). The adult anadromous cutthroat trout generally weigh 1 or 2 lb (2.2 or 4.4 kg). Those that become freshwater residents seldom get larger than 8 to 10 in (20 to 25 cm) in length.

The run of anadromous cutthroat trout Redwood Creek has been considered to be fairly good (CDF&G 1965b) considering that this stream is near the southern limit of the range of cutthroat trout which have been found only as far south as the Eel River, approximately 50 miles south of Redwood Creek (DeWitt 1954). Surveys in 1980 and 1981 found cutthroat trout to be most abundant within Prairie Creek and its tributaries (Anderson and Brown 1983 and Brown 1988) with other individuals found only in Emerald (Harry Wier) Creek, McArthur Creek, Gunrack Creek, and High Prairie Creek (Brown 1988). Those fish found in the upstream tributaries are likely to have been resident cutthroat trout. As indicated for resident rainbow trout, there is evidence that resident cutthroat trout may hybridize with resident rainbow trout in the tributaries of Redwood Creek but not between the anadromous races of these species since there was no evidence of hybridization in fish collected from the Redwood Creek estuary (Neillands 1990).

Since the cutthroat trout are in relatively low abundance and is generally much smaller compared to steelhead and salmon, little attention has been given to them. The numbers of cutthroat trout have been estimated to be 41 in Ray Creek, 6 in Boyes Creek, and 3 in Prairie Creek (NPS 1984). Only a few fishermen might know the "trout" they have caught is a cutthroat rather than being a juvenile steelhead.

Pacific Eulachon

The eulachon is a smelt that is related to the surf smelt (Moyle and Yoshiyama 1993). This species enters the stream in the spring and spawns almost immediately in the riffle areas as far upstream as the mouth of Prairie Creek and in lower Prairie Creek. Spawning is conducted by the male fertilizing the eggs as the female lays them near the gravel bottom of the stream. The eggs tend to be sticky and adhere to the gravel where they remain until they hatch a few days later (Moyle and Yoshiyama 1993). The newly hatched larvae are essentially washed to the ocean at the whim of the currents and tidal action as they enter the estuary. The adults die shortly after spawning. These fish are between 6 and 8 in (5 and 20 cm) long

when they return to spawn. The flesh of the fish is quite oily and they can be and have been dried and burned as **candles** which is the basis for the species to be called "candle fish" by some people.

The runs of eulachon in Redwood Creek have been somewhat sporadic (DeWitt 1964); the runs were considered substantial up until the mid-1370s but smaller since then (Moyle and Yoshiyama 1993). The flood control levees and the changes the levees have made to the estuary may have made the habitat unsuitable to the eulachon but oceanic conditions may also have been an important factor affecting their abundance. (Moyle and Yoshiyama 1993). When runs have occurred, a fishery has undoubtedly been conducted on Redwood Creek for centuries by the Native Americans and has continued until recent times by both Native Americans and others. Fishing is usually conducted with dipnets

Pacific Lamprey

The Pacific lamprey, often called an "eel" and the basis for the name of the Eel River, is neither an eel nor a true fish because, for example, it does not have jaws or paired fins or even a backbone like most animals called "fish". Like the other anadromous species, it grows to maturity in the ocean and returns to spawn. They tend to return to spawn in the late winter and early spring. They make spawning nests in gravel areas of the stream by picking up and moving the gravel with their sucker-like mouth. After spawning they die. The young hatch into a larval form, called an "ammocete", which remains in the stream for three to four years, living much of the time in bottom materials composed of a mixture of sand and detritus. In this juvenile stage they eat microscopic organisms found in the water and attached to woody debris and stones. They metamorphose into the adult form after three to four years and migrate to the ocean. As adults, they use their sucker-like mouth and their teeth and tongue to attach to and eat fish. Lampreys are eel-like in shape and about 20 to 24 in (50 to 60 cm) long at maturity.

Native Americans have long caught and used lampreys as food but most non Native Americans disdain them and consider them to be pests.

Other Species

The other species of fish found in Redwood Creek are of much less interest to humans in terms of their being caught for either sport or food. Partly in consequence of this lack of human interest, virtually nothing is known about their past or present status. Some, like the freshwater sculpins and the non-anadromous brook lampreys, require similar cold, clean, well oxygenated water as do the salmon and trout. The Sacramento sucker are found in lower Redwood Creek but they cannot tolerate saline water and are not found in the estuary if it contains any salty water. The three-spined stickleback, which can be anadromous (Moyle 1976), are found in areas of slow currents and backwaters in the lower reaches of Redwood Creek and the estuary. The tidewater goby is found only in the estuary and in 1994 was designated as an endangered species. The surf smelt, staghorn sculpin, shiner surfperch, and starry flounder are all marine species that are frequently found in salt and brackish water embayments. Those species found only in the estuary are usually juveniles there to feed on such organisms as the amphipod, Corophium sp.

Human Activities and Developments Impacting the fishery Resources

Redwood Creek was judged to be severely damaged and in poor condition for the production of anadromous salmon and steelhead in 1966 (Fisk et al. 1966 and Denton 1974). Fisk et al. (1966) surveyed 84 miles of streams in the basin and determined that 64 miles were severely damaged meaning that either 70 to 100% of the bottom was covered with silt, or there was no riparian canopy, or there were no pools, or there was no shelter for the fish. Redwood Creek from Orick to its headwaters, High Prairie Creek, and lower Prairie Creek were considered severely damaged. Minor Creek and Tom McDonald Creek were considered to be moderately damaged. Lacks Creek and Bridge Creek were classified as lightly damaged. Only the middle and upper areas of Prairie Creek and the lower and upper portions of Lost Man Creek were considered to be undamaged. Fisk et al. (1966) noted that the floods of 1955, 1964, and 1965 had added large amounts of sand, silt, and gravel to the stream beds causing them to be raised and

widened so that riparian vegetation became too far removed from the live stream to provide much cover or shading.

There have been a number of human activities affecting the fish populations in Redwood Creek. Some of these activities have undoubtedly been occurring for centuries such as the Native American instream fisheries for salmon, steelhead, cutthroat trout, eulachon, and lampreys. Most of the obvious impacts have occurred since the arrival of the first non-Native Americans in the area in the 1850s. The immigrants greatly increased the harvest of the fish, they initiated agricultural activities within the basin, they greatly expanded the road system from the trails developed by the Native Americans, they began a systematic harvest of the forest resources within the basin, they implemented a program of fish propagation that included both the removal of fish stocks, usually in the form of fertilized eggs, from the basin and the stocking of races of fish species native to the basin as well as races of fish species not native to the basin, they removed water from the streams and flood plain ground water for irrigation and domestic use, and they constructed flood control projects. Most of these activities, in one way or another and to one degree or another, have had negative impacts on the production of fish in the Redwood Creek basin. Since the impacts generally have been overlapping, it is not possible to precisely assess their specific effects. It is possible, however, to make educated judgments about the effects on the fish based upon measurable impacts on the habitat and experiences in other watersheds and about which activity or activities have most seriously affected the productivity of the stream.

Fishing

Fishing has been an ongoing activity in the Redwood Creek basin for an unknown period of time. The Native Americans of the Yurok tribe established villages near the mouth of Redwood Creek and relied heavily on the fishery resources of both Redwood Creek and the adjacent ocean for food (Chupp 1976). It is reasonable to assume they caught salmon, trout, smelt, and lampreys from Redwood Creek. There is no

There is no indication that the effects of the artificial propagation program in the Redwood Creek basin were ever evaluated. It is not known whether taking of adult fish from within the basin and incubating their eggs and rearing their young for release back into Redwood Creek has improved production over levels that would have been attained by allowing the fish to spawn naturally. It is not known whether taking adult fish from within the basin and stocking their progeny outside the basin caused any reduction in subsequent spawning escapements into the Redwood Creek basin. It is not known whether the stocking of fish raised from the spawn of fish from outside the basin, such as coho salmon from the Klaskanine River in Oregon as was done in the late 1950s and early 1960s, changed the genetic composition of returning fish so they were better or worse adapted to those environmental conditions unique to the Redwood Creek basin.

Public Roads

Since the 1850s, there have been numerous roads constructed within the Redwood Creek basin. Many of these started as trails used by pack trains often following trails established long before by Native Americans. One such trail crossed the Redwood Creek basin at the south end of Redwood Valley near the confluence of Minor Creek with Redwood Creek. The Trinidad trail followed the coast north. Another trail led along the Bald Hills portion of the ridge line of the northeasterly side of the Redwood Creek watershed. These trails were developed into the first roads.

Early road construction within the basin caused minimal amounts of impact as there were limited amounts of cuts and fills associated with the road alignments. The first major projects were the construction of Highway 299 across the middle of the basin and the construction of the coastal Highway 101 which crossed the Redwood Creek floodplain at Orick and followed along virtually the entire length of Prairie Creek. The initial construction of these roads probably had relatively little long term effect on the streams in the Redwood Creek basin because there was minimal disturbance of the land form in terms of cuts and fills.

Subsequent highway improvements and construction had greater impacts. Efforts to improve the road by widening and removal of curves required more cutting and filling that resulted in greater erosion and wasting of sediments and bedload into the streams. The 1964 flood especially revealed the vulnerability of the roads by destroying large portions of Highway 299. Since 1964, there have been major improvements to Highway 299 and construction of the Park Bypass of Highway 101, where it formerly passed through Prairie Creek Redwoods State Park. There have been problems with unstable land in the Lupton Creek area along Highway 259. Though extensive efforts were made to control erosion along the Highway 101 Park Bypass, there was some serious erosion causing large sediment loads to enter portions of the Prairie Creek basin during construction (Meyer et al. 1993). The construction of Highway 101 along Prairie Creek has also resulted in some realignment of the stream and consequent loss of fishery habitat. Since one of the principal factors limiting production of salmon and trout in the Redwood Creek basin has been identified as the condition of the estuary, anticipated negative impacts of constructing the Park Bypass were mitigated by installation of a control structure in the flood control levee to allow water to flow from Redwood Creek through the South Slough (NPS 1984). Another mitigation measure was the provision of operational funds to the County of Humboldt for the operation of the Prairie Creek Hatchery.

Agriculture

One of the earliest impacts on the watershed that followed the arrival of the immigrants in the mid 1800s was the use of the range to support livestock including cattle and sheep. Overgrazing and heavily used trails probably contributed to the erosion and associated slope failures that introduced sediments into the streams. There is no good information to indicate the magnitude of these effects and, relative to other factors, they were probably small. In some situations, such as in Redwood Valley and along Prairie Creek, livestock may have caused substantial damage to the riparian vegetation leading to loss of instream cover, warming of waters, and erosion because of lost bank stability (Platts 1985). The removal of water from the stream or groundwater adjacent to the stream for irrigation in Redwood Valley and the area around Orick has reduced the summer flows of Redwood Creek. In 1970, it was estimated that, based on a 90-day

season, irrigation in the Orick area used 4.3 cfs (0.12 m³/s) and it was projected to increase to 6.1 cfs (0.17 m³/s) in 1990 and 8.5 cfs (0.24 m³/s) in 2020 (Winzler and Kelly 1970). These amounts would be a substantial proportion of the 15 cfs (0.42 m³/s) late summer flows that can occur in lower Redwood Creek. Any reduction in summer flows would cause a concomitant reduction in cover for fish and contribute to warming of the water which is already at or near lethal levels in and upstream from Redwood Valley.

Timber Harvest

Harvest of timber has been conducted within the Redwood Creek basin since the late 1800s (Janda et al. 1975 and Best 1984). Much of the timber harvest initially was limited to the coast redwoods. Harvest of redwoods was accelerated during the 1950s and especially during the early 1960s prior to the formation of Redwood National Park. Harvest of the Douglas-fir did not begin in any great amount until the 1940s but was extensive during the late 1940's through the 1980s. Best (1984) has reviewed the history of timber harvest in the Redwood Creek basin and the effects of that harvest on the watershed. Less than 6% of the original area forested by conifers had been harvested by 1948. By 1978, an estimated 76% of the total area forested with conifers had been harvested leaving only about 25% of the area originally covered by coniferous forest unlogged. Most of the uncut coniferous forest area (66%) was in the lower basin, where Prairie Creek Redwoods State Park and Redwood National Park are located, but only 15.8% of the original coniferous forest area remained unharvested in the middle basin. DeWitt (1964) noted that a number of tributaries in the lower Redwood Creek basin were in good condition but the effects of extensive timber harvest in the upper basin were readily evident by the condition of the mainstem.

Initial logging efforts were slow and labor intensive and involved chopping and hand sawing and the movement of logs by oxen teams. As mechanization became available, the speed of trees being harvested increased. Chainsaws became the fallers tool of choice, tractors and cable systems moved the logs to landings, and trucks moved along extensive road systems to haul the logs to the mill. The accelerated

harvest of timber has had an attendant increase in damage to the watershed. Part of the damage can be attributed to the removal of vegetative cover resulting in increased heating of streams and more rapid runoff of water increasing the magnitudes of floods during storm events. The California Fish and Wildlife Plan noted that a major factor reducing the productivity of Redwood Creek was the extreme range of stream flows between the summer and the winter which seriously affected the quality of the year-round habitat required by coho salmon and steelhead (CDF&G 1965a). Studies of two Prairie Creek tributaries found coho salmon and cutthroat trout in the stream with an unlogged watershed but only cutthroat trout in the stream with a logged watershed (Reeves et al. 1976). This study also found immature mayflies (Ephemeroptera) dominated the benthic fauna in the stream with the unlogged watershed while gnat (Chironomidae) larvae were most abundant in the stream of the logged watershed. Studies in a tributary stream in the middle reach of Redwood Creek found certain beetles (Psephenidae) and immature stoneflies (Nemouridae) to be the most abundant insect forms upstream where logging had occurred while gnat (Chironomidae) larvae were most abundant downstream in the area that had not been logged (Harrington 1983). Burns (1972) observed that removal of riparian vegetation can result in higher summer water temperatures and that, until revegetation recurs, timber harvest can also increase in summer flows because of reduced transpiration, higher peak flows and, therefore, greater bedload movement during periods of heavy runoff, and increased erosion and sedimentation.

The greatest damage to the stream habitat required for fish production resulting from past timber harvest practices has been identified as the increased levels of erosion resulting from those activities (Best 1984). DeWitt (1964) observed that extensive logging in redwood region watersheds often reduced the suitability of streams for fish primarily because logging has led to "increased turbidity, siltation, flooding, and creation of barriers to migration". A survey of the entire stream in 1972 noted that sliding was occurring on 50% of the slopes and there was erosion occurring along the stream except the upper two miles of the stream and where there had not been logging such as on some U. S. Forest Service lands and within the Redwood National Park (Rogers and Hatzimanolis 1972). The harvesting activities themselves have a major impact by disturbing the soil. In some cases, activities have caused compaction that

accelerates runoff and provides a poor substrate for revegetation. In other cases, the soil surface and stream flow patterns have been disturbed resulting in massive land wasting and erosion. In particular, haul roads have been the source of a majority of the sediments that cause damage to fish habitat in the streams (Calhoun and Seeley 1962). It has been estimated that about half of the sediment produced within the Redwood Creek basin has come from the failure of road fills and stream crossings and the diversion of streams at roads (Madej 1992).

The Redwood Creek watershed has been noted for being naturally quite unstable and subject to mass wasting and erosion (NPS 1981). Forest harvest activities within the basin have contributed substantially to the problem. To a significant extent, the public perception of the impacts of timber harvest activities contributed to the formation of the Redwood National Park in 1968 and its expansion in 1978. In recognition of the potential dangers past logging activities posed to park resources, the National Parks Service initiated studies to identify hazards, formulated a comprehensive watershed management plan which included correcting problems created by past logging activities on land that became part of the Park (NPS 1981). The Redwood National Park has implemented an extensive watershed rehabilitation program to rehabilitate unstable sites, particularly abandoned haul roads, that existed within the park at the time it was established in 1968 and expanded in 1978 (Holstra and Harrington 1983).

Large woody debris in streams has relatively recently become recognized as an important element of good fishery habitat (Keller et al. 1981). Until the 1960s, the value of large wood debris to fish was not appreciated and, in fact, it was a common practice of management agencies to remove woody debris from streams because it was thought to block the migration of anadromous fish. More recently, it has been found that only infrequently do large amounts of large woody debris accumulate to form log jams that actually block fish migration or cause adverse channel erosion (Keller et al. 1981). This material more often creates habitat diversity that helps the stream to form deep pools, provides cover for fish, and provides substrate for invertebrate fauna that are important as fish food. In natural forested watersheds, large wood debris accumulates from fallen trees. Large wood debris should not be removed from streams unless

it clearly is a barrier to migrating anadromous fish (Pitlick 1981). In logged watersheds where riparian vegetation is harvested, the source of large woody debris may be removed (Keller et al. 1981 and Pitlick 1981). The California Fish and Wildlife Plan noted that the condition of the Redwood Creek basin was generally in good condition in terms of accumulations of large woody debris though timber harvesting was recognized as having caused some reduction in stream productivity (CDF&G 1965a). More recently, extensive jams created from logging debris were noted in the upper 10 miles of the mainstem to the vicinity of Bradford Creek or Minon Creek (Rogers and Hatzimanolis 1972).

Mining

There have not been any developed mining activities within the Redwood Creek basin excepting that the stream course has long been a source of gravel for various human needs. Undoubtedly, the stream was the source of gravel to be placed on the first roads constructed in the basin. Road construction associated with timber harvest activities have utilized large quantities of gravel. These extractions took place primarily in Redwood Valley and in lower Redwood Creek near Orick and especially in the vicinity of the mouth of Prairie Creek. Instream operations destroy large numbers of invertebrate fauna in the immediate area of the gravel mining activity and immediately downstream where suspended sediments settle out and may smother invertebrate organisms. Generally, these impacts on the invertebrate fauna, and, therefore, any impacts of fish production, are limited unless the activity is quite extensive. Current regulations keep the mining of gravel out of the stream course which prevents the deposition of sediments and fines immediately downstream of the operation as occurred when instream operations were allowed. Another impact of the mining activity is to change the stream morphology where the extraction is occurring. Deep pools are often formed and the course of the stream may be altered. Some of these changes in the stream morphology may persist for several years after the mining activity occurred.

Pollution

The streams in the Redwood Creek basin have received pollutants in different forms. The most obvious and serious source of water pollution is the excessive turbidity associated with the extremely large bedloads found in the streams of the basin. The high levels of turbidity in the Redwood Creek basin can be attributed to the natural instability of the watershed but the human activities within the basin and timber harvest, in particular, have contributed greatly to the high levels. Cordone and Kelly (1961) and Chapman (1988) have reviewed the evidence that fish can survive high levels of turbidity but the deposition of silt on the bottom of the stream can be detrimental to both eggs incubating in the gravel and the production of aquatic invertebrates. A study of sediment impacts on incubating steelhead eggs after a single storm event that caused an unusually large deposition of sediment in Brown Creek from the Park Bypass found no measurable effects (Meyer et al. 1993). However , large numbers of oligochaete worms in some egg groups were related to low egg survival (Meyer et al. 1993). Another source of pollution associated indirectly with timber harvest is the deposition of herbicides into the streams in the basin. Herbicides have been used to release young conifers by suppressing the growth of broad leafed woody vegetation. Normal applications have not been found to cause fish mortalities but excessive levels of herbicides at times have occurred during aerial applications and these may have caused isolated damage to fish and fish food organisms. But even normal applications would, of course, kill back many of the riparian species of trees such as red alder and broadleaf maple and, thereby, affect canopy cover and the drop of terrestrial insects into the streams. No detectable levels of herbicides were found in water samples collected at nine different tributary and mainstem stations in 1974 (Janda et al. 1976). The principal source of organic pollution within the basin has been the dairies in the Orick area. This source of pollution contributes such materials as nitrates and nitrates as well as coliform bacteria that enter lower Redwood Creek primarily, because of the flood control levees, through the small tributaries such as Strawberry Creek and Sand Cache Creek in this area. Organic pollution is particularly high during the first fall rains when summer accumulations of fecal material are washed into the streams (Bradford and Iwatsubo 1978). Most of the relatively little development within the basin is concentrated in the Orick

area and probably does not contribute appreciably to storm drain types of pollution. Another potential source of organic pollution is domestic waste which is entirely treated through septic tank and drainfield systems within the Redwood Creek basin. It is doubted that domestic pollution is a serious problem within the Redwood Creek basin because of the low population density excepting in the Orick area but it undoubtedly does add some organic materials to the estuarine ecosystem. At this time, there has been no indication that pollution within the Redwood Creek basin, excepting the effects of sedimentation, has any deleterious effects on the fish populations.

Dams

There were two small, permanent dams constructed in the 1930s on Lost Man Creek to divert water to the Prairie Creek Hatchery (Brown 1988). Brown (1988) did not consider one of these dams to be a serious impediment to migrating anadromous fish but he felt the larger one could have blocked salmon since he found only steelhead and cutthroat trout juveniles upstream of it. Both of these structures were removed in about 1990.

A 130-foot high permanent dam has proposed for the Green Point site near where Highway 299 crosses Redwood Creek (CDWR 1957 and Winzler and Kelly 1970). This project, which is not being actively considered at this time, would impound approximately 5,000 af (acre feet) of water for recreation on the reservoir, improvement of natural stream habitat below the dam by releases of water, and, possibly, flood control. If built, this project would disrupt anadromous fish migrations, inundate some existing spawning areas, and create a habitat for exotic fish that could prey on juvenile salmon and steelhead.

There have been occasional small, seasonal dams within the basin such as in the Redwood Valley area and near where Highway 299 crosses the basin. These have usually been developed for recreational use rather than to divert water from the stream. Their impacts on fish populations has probably been

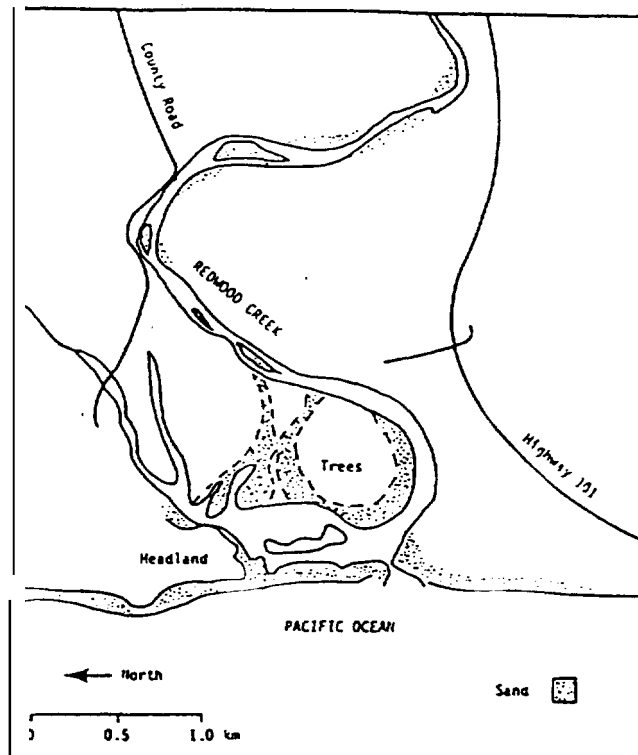
minimal. There undoubtedly has been the destruction of invertebrates where the stream bed has been disturbed by the construction activities. Since these facilities must be reconstructed each year, the impacts associated with construction disturbances would be repeated each time. The expanded surface area within the impoundment would allow greater warming of the water which would increase the temperature of the water that flows past the structure. Since the structures have been temporary and not intended to withstand high flows, they are removed by the first increased flows in the late fall or early winter and, therefore, probably do not inhibit the migration of fish which could not migrate upstream until sufficient flow is present in the mainstem.

Flood Control

Ricks (1985) has provided a complete review of the flood history, flood control efforts, and the effects of the flood control efforts on Redwood Creek. Winter floods, and the 1964 flood in particular, have caused severe property damage to the town of Orick. Though the construction of levees to provide flood protection for Orick had been previously considered, the 1964 flood brought quick attention and action on the project. Between 1966 and 1968, levees were constructed along both sides of Redwood Creek for approximately 5.1 km (3.2 mi) from near the mouth of Prairie Creek a short distance upstream from Orick to within about 100 yards of the mouth of Redwood Creek (Larson et al. 1981 and 1983, Ricks 1983 and 1985, and Hofstra and Sacklin 1987) (Figure 2). The levees were composed of coarse rock and the channel was designed to have a capacity of approximately 77,000 cfs. The project straightened the channel including the complete removal of the last major bend in the stream just upstream of the mouth. The project also resulted in the removal of all riparian vegetation from the mouth of Prairie Creek to the ocean.

The construction of the flood control levees on lower Redwood Creek destroyed much of the fish habitat in this area (Chupp 1976, Feranna and Ricks 1981, Ricks 1985, Larson et al. 1981 and 1983, Hofstra 1981 and 1983, and Hofstra and Sacklin 1987) and caused approximately 50% of the lower estuary to become filled with sediment and isolated from the stream (Ricks 1985). The straightening of the lower

1962
CONDITIONS



1978
CONDITIONS

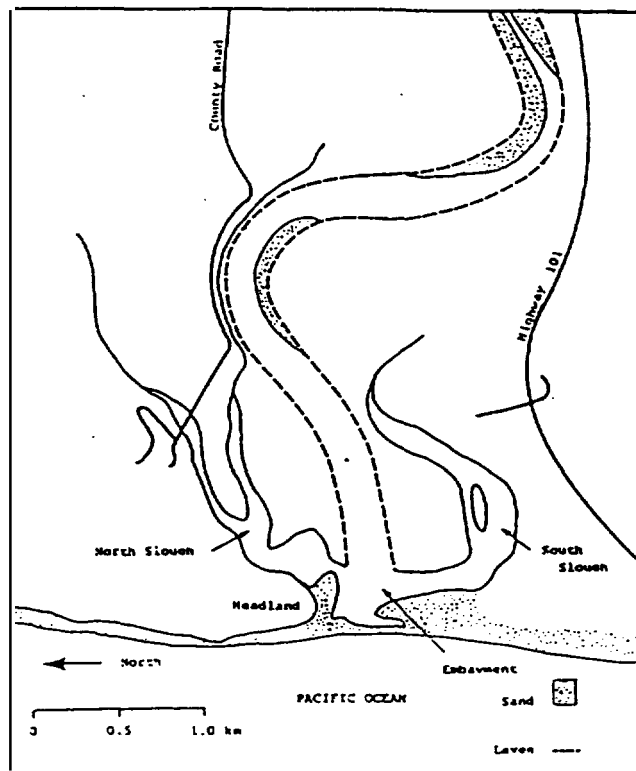


Figure 2. Redwood Creek Humboldt County, California, estuary before flood control levee construction (1962) and after flood control levee construction (1978) (from Larson et al. 1983).

portion of the stream caused the complete filling in of the large, deep (approximately 20 feet) pool at the mouth of Redwood Creek that had been a substantial and important habitat element for fish in the estuary (Ricks 1985). Another aspect of the estuary, an arm of water called the North Slough which connected to the lower estuary from the north side of Redwood Creek has subsequently become almost completely isolated from the estuary. All other pool habitat associated with scouring caused by riparian vegetation and associated with meanders was eliminated. Essentially all cover for fish, in the form of riparian vegetation or deep pools, was removed by the project in the lower 5.1 km of Redwood Creek including the estuary.

The importance of an estuary to the production of chinook salmon has been documented by Reimers (1973). That juvenile chinook salmon, as well as juvenile steelhead, still seek to use the Redwood Creek estuary has been clearly documented (McKeon 1985, Larson 1987, Larson et al. 1981 and 1983). The levees have eliminated virtually all cover needed to provide protection of juvenile salmon and trout from predators. The destruction of the deep pool near the mouth and the inaccessibility of the North Slough has eliminated areas where juvenile fish can avoid the flushing effect of a breaching of the berm that develops most summers at the mouth of Redwood Creek (Hofstra 1983 and Hofstra and Sacklin 1987). Construction of a bypass through the south levee to allow water to pass from Redwood Creek into the South Slough, formerly the last downstream meander of Redwood Creek, has been an effort to make the South Slough suitable refuge habitat for juvenile salmon and steelhead (Hofstra 1983 and Hofstra and Sacklin 1987). Immediate entry of juvenile chinook salmon and steelhead into the ocean without the opportunity for acclimation to saline water may cause lethal stress for many (Larson et al. 1981 and Larson 1987). Also, since the levees have been in place, flushing of the estuary causes a mass movement of unconsolidated sand, gravel, and sediments and attendant destruction of large quantities of invertebrates including, in particular, the burrowing amphipod, Corophium sp., that live in those materials and are important as food for juvenile salmon and steelhead (Larson 1987, Salamunovich 1987, Salamunovich and Ridenhour 1990, and Ridenhour and Salamunovich 1993).

Conclusions

Redwood Creek has been an important producer of fish, and especially salmon and steelhead (FWS 1960 and CDF&G 1965a and 1965b). The estimated populations of fish, specifically anadromous salmon and steelhead, are generally considered to be much smaller than they were historically (Chupp 1976). Counts of anadromous salmon and steelhead at Sweasey Dam on the Had River in the late 1950s and early 1960s were about 30% of the numbers in the late 1930s and early 1940s and counts at Benbow Dam on the South Fork of the Eel River in the late 1960s and early 1970s were about only about 20% of the numbers in the late 1930s and early 1940s (Denton 1974). Redwood Creek anadromous salmon and steelhead runs probably declined about the same amount during that time. Also, the estimated sizes of the runs should not be considered measures of the productive capacity or potential of the stream (Winzler and Kelly 1970). Much of the declines in the production of salmon and steelhead can be clearly attributed to the activities of humans. The ever increasing demands of an ever growing population of people are putting great stress on the ability of ecosystems to satisfy those demands without permanent damage to the character and productivity of the ecosystems. Appropriate actions can be taken to restore the productivity of the Redwood Creek basin but those actions must be initiated promptly while populations of the various species and races of fish are still available.

The magnitude of the declines of salmon and steelhead in Redwood Creek have prompted Nehlsen et al. (1991) to identify the fall chinook salmon stocks as being at moderate risk of extinction because of habitat damage and over harvest, the coho salmon and cutthroat trout stocks also to be at moderate risk of extinction because of habitat damage, and the summer steelhead stocks to be at high risk of extinction because of habitat damage and over harvest. Similarly, Higgins et al. (1992) identified the Redwood Creek chinook and coho salmon stocks to be "stocks of concern" and the summer steelhead stocks to be at a high risk of extinction.

Much of the decline in the stocks appears to have occurred within the past 50 years. Much of the decline can be attributed to human activities including harvesting, both recreational and commercial, timber harvest, road construction, hatchery practices, levee construction, and grazing practices (Higgins et al. 1992). The declines in the fish populations in north coastal streams of California, including Redwood Creek, have been attributed, in part, to natural events such as drought and oceanic El Niño events but primarily to poor land use practices such as timber harvest that have changed the streams from being "deep, tree-lined channels with frequent pools and long riffles carrying cool water" into streams that are "shallow, warm, and barren of streamside vegetation" (Denton 1974 and Higgins et al. 1992). The difficulty of trying to specifically identify the cause of declining numbers of fish was illustrated by Burns (1971) who found more variation between years in the numbers of fish (coho salmon, steelhead and cutthroat trout, and sculpins) per unit of water surface area to occur in Godwood Creek, a tributary to Prairie Creek and a stream that had an undisturbed watershed, than in streams that had logged watersheds. Burns' observations suggest that trends in numbers of fish over time must be considered when seeking to identify the factors affecting the size of fish populations.

The impacts of timber harvest on stream environments required for production of coho salmon and steelhead were not recognized as a particular problem in the early 1950s (Shapovalov and Tait 1954). But, the problems soon became noted as Calhoun and Seeley (1962), who did not look specifically at Redwood Creek, observed that "careless logging operators continue to damage priceless watersheds and to degrade important salmon and trout streams in California. Destructive practices include use of stream beds as roadways, operation of heavy equipment in streams, tractor logging on steep slopes, and removal of stream side vegetation." Fisk et al. (1966) judged that "logging activities, particularly the construction of roads and skid trails and the removal of vegetative ground cover, have been a major factor contributing to increased erosion and land slippage" in the Redwood Creek basin. Timber harvest has been a major factor that, unless appropriate precautions are taken, will continue to have adverse effects on stream habitats (Burns 1972). He suggested that impacts on the stream can be either harmful to the production of fish or, in some cases, beneficial depending on such factors as the characteristics of the stream and the

riparian vegetation, the seasonal timing of timber harvest activities, and the harvest methods used. Moyie (1976) also noted the potential for damage to fish habitat resulting from timber harvest and grazing in the riparian zone. Though many of the poor timber harvest practices identified as damaging to fishery habitats by Calhoun and Seeley (1962) and Burnis (1972) have been corrected by current timber harvest regulations, the particular fragility of the Redwood Creek basin makes even current regulations sometimes inadequate.

Construction of flood control levees along lower Redwood Creek have been judged to have particularly damaged the estuarine habitat which is important as rearing habitat for juvenile chinook salmon and, to a lesser extent, juvenile steelhead (Larson et al. 1981 and 1983 and Hofstra 1981 and 1983,). Hofstra (1981 and 1983) and Hofstra and Sacklin (1987) have outlined some ways to alleviate the effects of the negative impacts of the levees on the Redwood Creek estuary. The only action implemented has been the installation of the control structure in the south levee to allow water from Redwood Creek to flow through the South Slough.

All of the human activities identified must share the blame for the decline in the fish populations and the productivity of the Redwood Creek watershed in varying degrees (Winzler and Kelly 1970) but logging and levee construction probably have had the most serious and negative impacts on the fishery habitat within the basin. Efforts to restore the productivity of Redwood Creek and restore its fish populations must seek to correct the problems caused by poor logging practices and the levees and to prevent any further such damage to the stream ecosystem.

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