STATE OF THE FISHERIES & AQUATIC RESOURCES OF PRAIRIE CREEK

Final Report to Redwood National and State Parks for Cooperative Agreement Number P13AC00848, Task Agreement Number P14AC01284.

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Executive Summary

This report synthesizes information on fisheries and aquatic resources in the Prairie Creek sub-basin of Redwood Creek in northern California, founded on a bibliographic search of historic and current datasets, reports, theses, and publications. The annotated bibliography, which located 335 records, is appended to the report. Life histories and population status of the salmonid fishes within Prairie Creek are described, and species occurrence of non-salmonid fishes, amphibians, macroinvertebrates, and common benthic algae are listed. Habitat conditions which may limit salmonid production were assessed. Although salmon abundance is decreased from historic levels, production of juvenile salmonids in Prairie Creek is relatively stable and robust in comparison with the rest of the Redwood Creek Basin. Carrying capacity likely differs between the undisturbed upper reaches of Prairie Creek and reaches in lower creek, which are affected by legacy impacts from timber and agricultural activities. Altered sediment supply and lack of channel and floodplain structure in lower Prairie Creek appear to be the greatest stressors to salmonid production. Existing datasets on aquatic resources and environmental variables are listed, and subject areas where few data are available are identified.

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Purpose of Report

The objective of this report is to synthesize the available literature on fisheries and aquatic resources from the Prairie Creek sub-basin of Redwood Creek in Humboldt County, California, focusing in particular on salmonid fishes which are commonly the targets of restoration efforts. Non-salmonid fishes, amphibians, macroinvertebrates, and common benthic algae which inhabit the creek are listed. Life histories and population status of the salmonid fishes within Prairie Creek are described, along with a description of habitat factors which may limit their production. Available datasets on the physical/chemical template and on aquatic biota of the sub-basin are summarized, and subject areas where few data are available are identified. This report is founded on a 2015 search of historic and current datasets, reports, theses, and publications on fisheries and aquatic resources in Prairie Creek from the libraries of state and federal governments, academic institutions, and other organizations. Literature and data records from the search are contained in a companion bibliography (Metheny and Wilzbach 2016), which is appended to this report). Many early entries in the bibliography derive from holdings in the 2003 NRBIB collection of Redwood National Park. This report is not intended to represent a full watershed assessment, nor does it offer recommendations regarding management or restoration of aquatic resources. Detailed watershed assessments of the Prairie Creek sub-basin are described in The North Coast Assessment of the Redwood Creek Basin (Cannata et al. 2006) of the California Department of Fish and Wildlife, and in the Final Recovery Plan for the Southern Oregon/Northern California Coast Evolutionarily Significant Unit of Coho Salmon (National Marine Fisheries Service 2014).

Some acronyms or abbreviations used throughout this report include:
Redwood National and State Parks: RNSP
California Department of Fish and Wildlife: CDFW
National Marine Fisheries Service: NMFS
Humboldt State University: HSU
U.S. Geological Survey: USGS
U.S. Geological California Cooperative Fish and Wildlife Research Unit: USGS Coop

Note: A couple of creek names in Prairie Creek have changed. Streelow Creek was formerly named Wolf Creek, and Boyes Creek was sometimes referred to as Elk Prairie Creek in early literature.

Acknowledgements

The assistance of RNSP scientists Vicki Ozaki and David Anderson in compiling and providing access to existing studies and data, and of spatial analyst Judy Wartella in querying RNSP GIS databases and creating maps for this report is gratefully acknowledged.

Background

Prairie Creek drains 103 km^2 of the northwestern portion of the 759 km^2 Redwood Creek basin, in Humboldt County, California. The largest of the Redwood Creek tributaries, Prairie Creek enters Redwood Creek at river km 5.6 as a fourth-order stream; Redwood Creek flows into the Pacific Ocean 2.7 km west of Orick, California. Prairie Creek provides a minimum of 78.4 km of stream length accessible to anadromous fish (Table 1). The sub-basin is composed of forested terrain from approximately 8 m to 692 m elevation. Nearly all (98%) of the sub-basin is in public ownership, and managed by the Redwood National and State Parks. Drainage area, basin slope, floodplain area, and stream kilometers within each of its catchments are also listed in Table 1.

Climate and Hydrology

The regional climate of coastal northern California is characterized by mild, wet winters and cool, dry summers. Air and water temperatures are moderated by the dense canopy cover of the redwood forest and by summer fog, which extends 24 km inland from the coast. Annual air temperatures typically range from 6-16 ^{o} C, with a June mean of 15^{o}C and a January mean of 8^{o} C. Snowfall in the Prairie Creek sub-basin is rare. Over a period of record from 1937-2004, annual rainfall in Prairie Creek averaged 171 cm (Fig. 1), with most of the rainfall occurring between November and March.

Prairie Creek flows perennially, with a flow regime reflective of its winter rainfall hydrograph. Flow history of the creek can be characterized from a record of over 68 years of continuous streamflow recorded at the U.S. Geological Survey gaging station on Redwood Creek in Orick (station code 11482500). The gage is located immediately downstream of the confluence of Prairie Creek with Redwood Creek. From the 1950s to early 1970s the basin experienced several extremely large flood events (Figure 2).

From the mid-1970's through water year 2015, peak discharge has exceeded the discharge of a 5-year recurrence interval (32,000 ft^3s^{-1} or 906 m^3s^{-1}) only once, in 1997.

The recurrence interval of 1997 peak discharge was approximately 11 years. Klein and Marquette (2010) summarized available annual discharge data within catchments of the Prairie Creek sub-basin, as well as flood frequency curves for Prairie Creek above May (station PRW) and Little Lost Man Creek. The higher stormflow discharge per unit area of Little Lost Man Creek relative to Prairie Creek reflects its steeper gradient and more poorly-drained soils.

TABLE 1. Catchment area, basin slope, floodplain area, stream length, and length of reaches supporting anadromous fish in the Prairie Creek basin. Stream length is expressed as km of stream greater than Strahler order 5. Strahler stream order is based on 1-m lidar data and uses the crenulated stream network, rather than perennial streams, to define stream channels. Stream reaches supporting anadromous fishes represents a minimum stream length, as not all reaches have been surveyed. Data are from the RSNP GIS and 2012 CDFW CalFish databases.

Catchment	Drainage Area (km^2)	Basin Slope (%)	Floodplain area (km^2)	Stream length (km ≥ Strahler order 5)	Length of reaches supporting anadromy (km)
Boyes Creek	4.84	20	10.93	4.54	7.13
Brown Creek	4.73	23		3.42	3.36
Davison	1.04	20		0.86	1.85
Godwood Creek	4.64	22	62.32	3.97	4.12
Good Creek	0.59	26		0.60	
Larry Dam Creek					
Little Creek	0.83	23		0.52	6.10
Little Lost Man Creek	9.25	22	6.47	5.47	6.09
Lost Man Creek	4.72	21	6.07	21.35	13.15
May Creek	4.62	21		3.55	5.3
Middle Fork Lost Man Creek	5.78				
North Fork Lost Man Creek	5.73				
Prairie Creek Interfluve East	3.19			0.38	
Prairie Creek Interfluve West	2.54			0.02	
Prairie Creek Tributary-East	7.55			4.46	0.76
Prairie Creek Tributary-West	4.74			1.91	0.06
Prairie Creek	5.06	8	454.46	14.48	25.81
Ranch	0.48	23		0.52	
Redwood Creek Floodplain	6.82		681.90		
Skunk Cabbage Creek	6.21	19	78.50	3.37	3.96
South Fork Lost Man Creek	10.55				
Streelow Creek	7.36	19	40.87	5.05	6.76
Sweet Creek	0.98	24		0.92	
Ten Tapo Creek	1.08	22		1.06	
West Side	1.72	17		1.42	

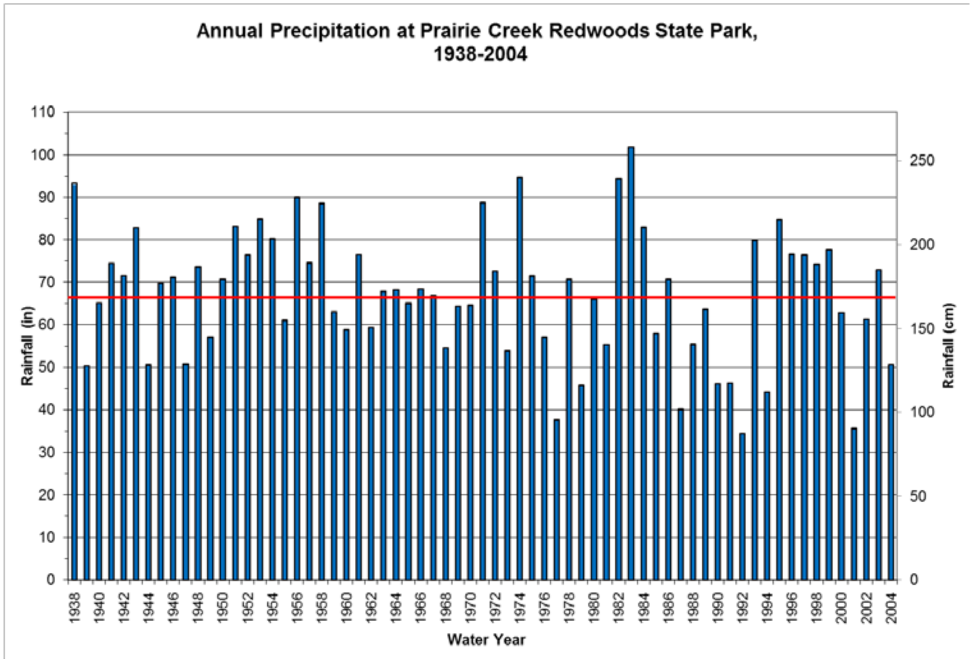

FIGURE 1. Annual rainfall at Prairie Creek Redwoods State Park during water years 1938-2004. Average rainfall over the period of record is denoted with a red line. Data from RNSP database; figure provided by V. Ozaki.

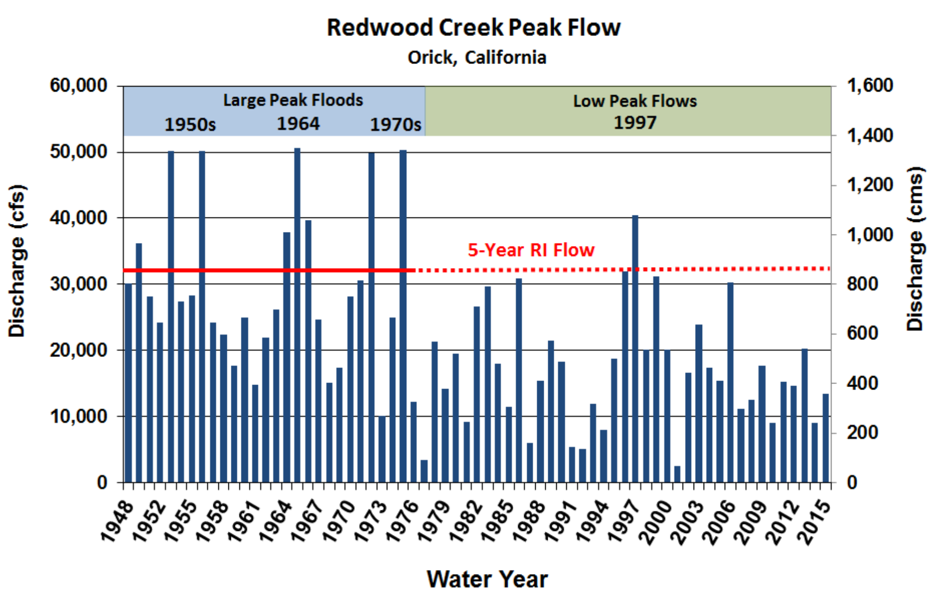

FIGURE 2. Peak flows recorded by the U.S. Geological Survey gage at Redwood Creek at Orick, California from 1948 through 2015. The 5-year recurrence flow is indicated with a red line. Flow data from 2015 are provisional and subject to revision. Figure provided by V. Ozaki, RNSP.

Geology

While most of the Redwood Creek drainage is underlain by metamorphic and sedimentary rocks of the Franciscan assemblage, a majority of the Prairie Creek watershed is underlain by weakly consolidated shallow marine and alluvial sediments known as the Prairie Creek Formation. Sediments of the Prairie Creek Formation were derived from ancestral Klamath River and estuary deposits (Cashman et al. 1995). The Prairie Creek watershed is tectonically active. The northern coastal California region is considered to have some of the highest uplift and seismic activity rates in North America. The combination of rapid uplift from tectonic subduction and compression, unstable soil types, high rainfall, and legacy effects from prior land use practices produce large sediment yields (Mount 1995).

Vegetation

The sub-basin of Prairie Creek is almost entirely (93%) vegetated in coniferous forest. Approximately 48% (47 of 98 km^2) of the forest consists of late seral (unlogged old-growth) stands of coast redwood (*Sequoia sempervirens*), Sitka spruce (*Picea sitchensis*), and Douglas-fir (*Pseudotsuga menziesii*). Remaining forest (52%) is mid-seral, most of which regenerated from old-growth forests that were harvested in the 1950s and 1960s. Much of the second-growth is dominated by Douglas-fir (Teraoka 2012), which was aerially seeded at high densities following logging. The distribution of old-growth and second-growth forest is given in Table 2.

Vegetative composition of riparian forests, which connect upland forests with adjacent aquatic ecosystems, is particularly important to stream biota because it affects stream water temperature, bank stabilization, and supplies to the stream channel of large woody debris, nutrients, detrital material, and invertebrate prey for fish and other stream predators. Keyes and Teraoka (2014) found differences in structure and composition of overstory and understory riparian stands between paired old-growth and second-growth stands in Lost and Little Lost Man creeks. Redwood was the dominant overstory tree in old-growth riparian areas, while second-growth was dominated by red alder (*Alnus rubra*), Douglas-fir, and redwood. Understory species were similar in both forests, but understory species differed in importance values (sum of relative frequency and cover, divided by 2) between old-growth and second-growth stands. Redwood sorrel (*Oxalis oregano*) and western white trillium (*Trillium ovatum*) had higher importance values in old-growth, and red huckleberry (*Vaccinium parvifolium)*, wood fern (*Dryopteris* spp.), and sedges *Carex* spp. had higher importance values in second-growth.

Emergent wetland vegetation and forested/shrub wetland vegetation in Prairie Creek were surveyed and classified as part of a U.S. Fish and Wildlife Service Floodplain and National Wetland Inventory conducted (Fig. 3). Wetlands and floodplain habitat are most extensive in Skunk Cabbage Creek and Prairie Creek near its mouth. As expected, the floodplain broadens and increases in areas the creek increases in size from headwaters to mouth (Table 1).

Table 2. Areal coverage of old-growth and harvested forest within catchments of the Prairie Creek sub-basin. Data are from the RSNP GIS database.

Catchment	Old-Growth (km^2)	Harvested (km^2)
Boyes	1.26	3.11
Brown	4.45	0.06
Davison	0.00	1.04
Godwood	4.60	0.03
Good	0.59	0.00
Little	0.77	0.06
Little Lost Man	8.22	0.97
Lost Man	7.58	23.73
May	0.02	4.30
Prairie Creek Interfluve East	2.16	0.61
Prairie Creek Interfluve West	1.16	1.24
Prairie Creek Tributary-East	5.19	2.14
Prairie Creek Tributary-West	3.08	1.62
Prairie Creek	2.46	0.13
Skunk Cabbage	2.57	0.49
Streelow	0.52	3.56
Sweet	0.86	6.79
Ten Taypo	1.05	0.12
West Side	0.45	1.26

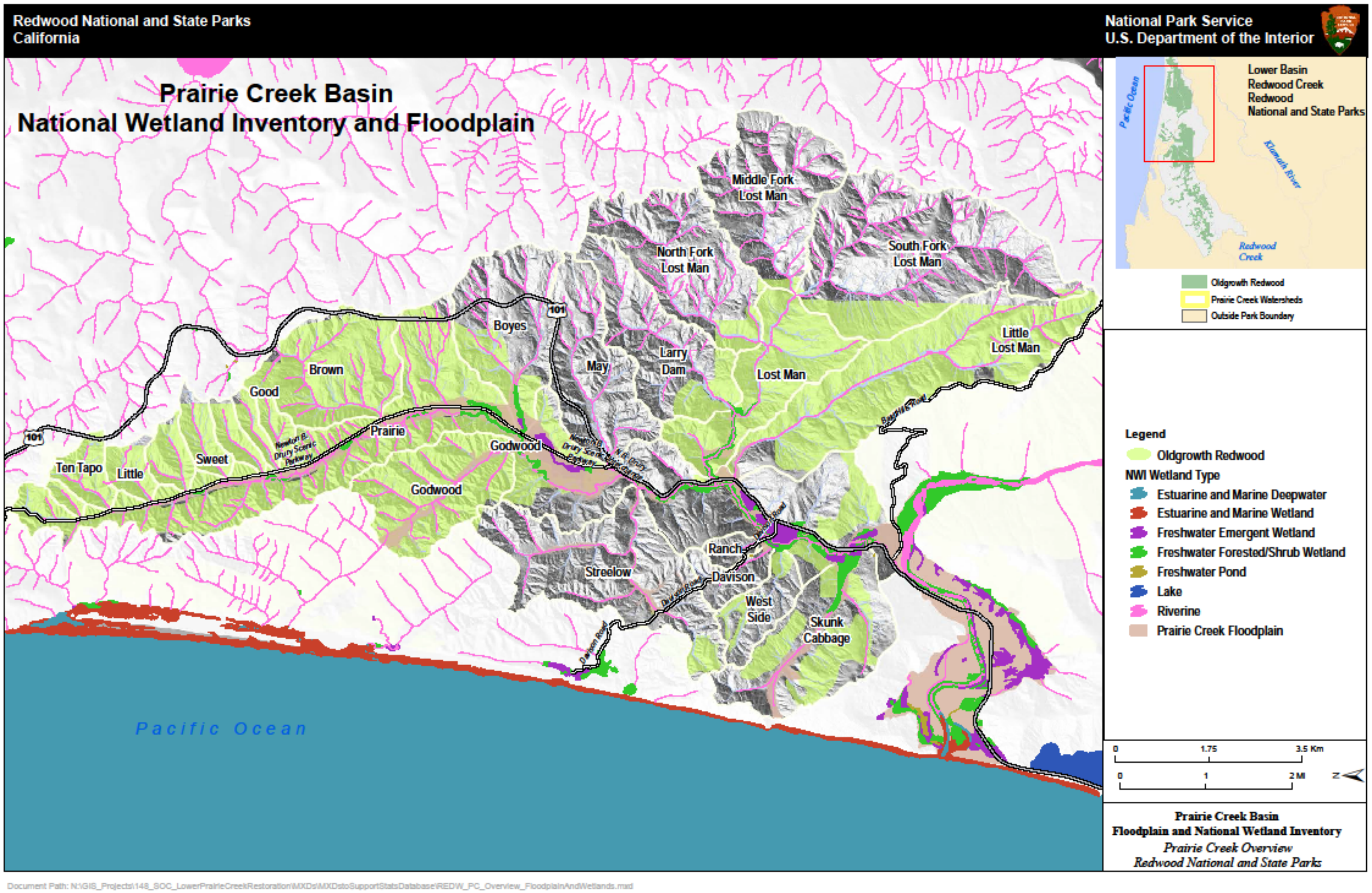

Figure 3. Distribution of wetland types and floodplain in Prairie Creek, based on a National Wildlife Inventory. Map created by J. Wartella from RNSP GIS database.

Land Use History

Land Development, Timber harvest, and Park Management.

- Euro-American settlement of northwest California coast began with the discovery of gold in the Gold Bluffs in 1851, and resulted in the large-scale displacement of indigenous peoples who had inhabited redwood forests of the region for over 3,000 years. While gold mining operations were short-lived, commercial logging of old-growth redwoods to supply building needs of the settlers boomed. Between 1880 and the early 1900's, hundreds of hectares of virgin redwoods were cleared. Mounting concern over the loss of the ancient trees was reflected in the establishment in 1918 of the Save the Redwoods League, which aimed to preserve redwood forests through land purchase. The League and the State of California together purchased thousands of acres of old-growth redwood stands adjoining Prairie Creek in the upper part of the watershed. Prairie Creek State Park was created in 1923 with an initial donation of 65 hectares from a landowner to the League; through subsequent acquisitions, the Park now encompasses 5,339 hectares of virgin redwood forest.

While the lands within State Park boundaries have been protected from logging since the establishment of the park, logging and extensive road-building continued on private lands in lower Prairie Creek, particularly during the 1950s through the early 1970s (Fig. 3). The last timber harvest occurred in 1977, in the Skunk Cabbage drainage. Road and landing construction were unregulated, and large areas of forest were clearcut by tractor yarding during the 1950s to early 1970s, prior to implementation of the State of California Forest Practice Rules in 1975. Establishment by Congress of Redwood National Park in 1968 secured some of the few remaining stands of uncut redwoods in the Prairie Creek watershed. Logging practices in upland and riparian areas during the 1950s to 1970s exacerbated high natural rates of erosion; further loss of riparian redwoods, along with widespread erosion and sedimentation of the creek, were experienced during large floods in 1955 and 1964. Redwood National Park boundaries were expanded by Congress in 1978, with the addition of 19 hectares from largely logged-over portions of Redwood Creek and the lower Prairie Creek watershed.

Since 1978, the Park has removed approximately 114 km of abandoned logging roads within the Prairie Creek sub-basin (Fig. 4), and has revegetated previously logged areas. Not including skid roads, approximately 140 km of existing road remain within the Prairie Creek sub-basin; road density by catchment averages 1.67 $km \cdot km^2$. While 40% of the roads were estimated to be sited in areas of high landslide potential (Cannata et al. 2006), historically active landslide features account for less than 1.5% of the basin area. Restoration efforts are ongoing. Since 1994, the National Park Service and the California Department of Parks and Recreation have jointly managed Redwood National and State Parks[MAW1].

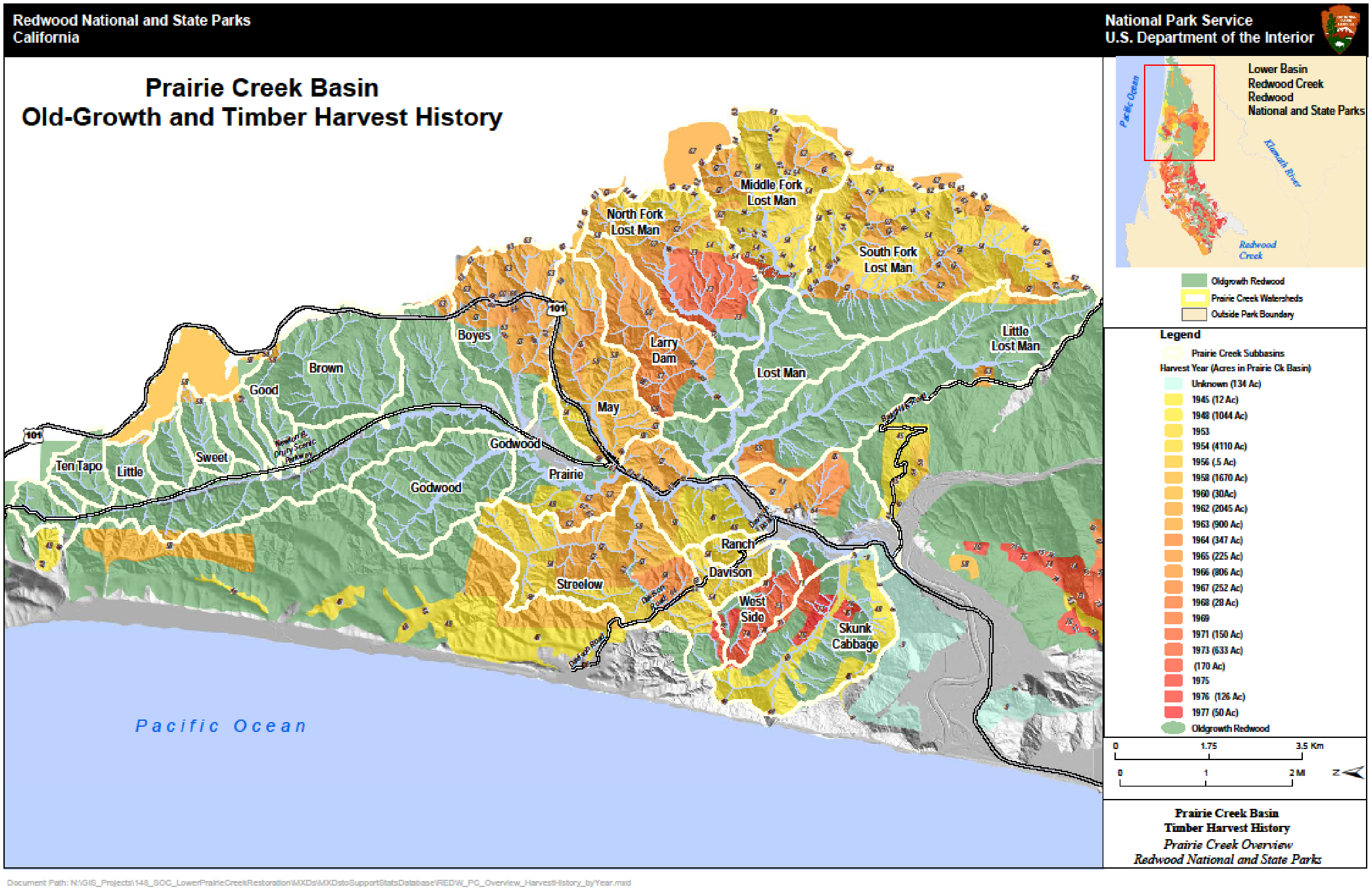

FIGURE 4. Timber harvest history within the Prairie Creek sub-basin. Map created by J. Wartella from RNSP GIS database.

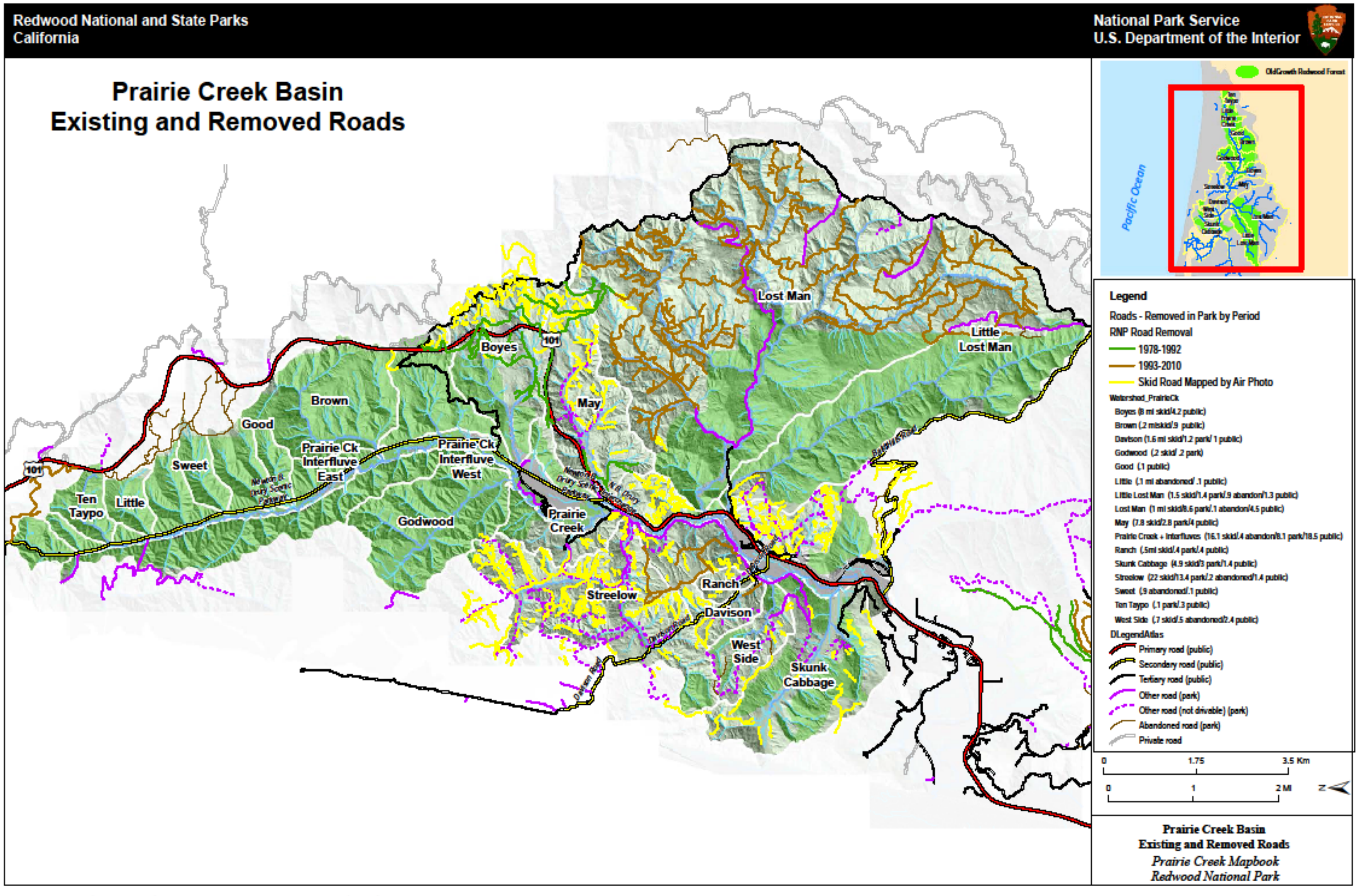

Figure 5. Existing and removed roads in the Prairie Creek Basin. Map created by J. Wartella from RNSP GIS database.

Channel and Floodplain Alteration.

- The floodplain, riparian, and channel structure of Prairie Creek, particularly in lower reaches, were substantially altered in association with dairy operations and other agricultural activities, logging operations, and construction of a small number of private residences prior to acquisition of landholdings by RNSP (Ferrana and Ricks 1981, RSNP 1996). Wetlands were filled, riparian vegetation was cleared, the stream channel was diked, and logjams were removed from the creek to reduce flooding. In some instances, logjams were removed with dynamite. The 40-ha Davison Ranch, a former dairy ranch in operation for close to a century, was acquired by the park in 1991. The A- and B- Mills were logging mills and log decks used in large-scale timber harvest operations in the Prairie Creek valley. The B- Mill, adjacent to the Davison Ranch, was acquired and removed by the park in 1991. Save the Redwoods League acquired the 51-ha A- Mill property in 2013, and has initiated a project to restore ecological integrity of the creek and wetland areas at the site. Approximately 187 ha of the lower Prairie Creek watershed remains in private ownership, and is used in part for livestock grazing.

In an early winter storm in October 1989, erosion of soils which were exposed during construction of the Highway 101 Prairie Creek bypass delivered large amounts of fine sediments to Brown, Boyes, and May creeks. Sediments were subsequently transported into the mainstem of Prairie Creek. The storm transported 30 times the amount of sediment than storms of a similar magnitude that occurred later that year (Klein 1995). Impacts on aquatic biota and on channel structure are detailed in the aquatic resources and habitat assessment sections (Sediment Supply and Hydrologic Function) of this report.

Prairie Creek Hatchery.

- The Prairie Creek Hatchery operated between 1927- 1992. Hatchery operations began with the establishment of a temporary tent facility on Prairie Creek (Van Kirk 1994). A permanent facility was erected in 1936 by the California Department of Fish and Game Hatchery to improve sport and commercial fishing in the area, particularly for Cutthroat Trout. The Department believed that Prairie Creek had the greatest potential to supply Cutthroat Trout eggs. During early years of operation, several log jams and other obstructions were removed from the creek which were believed to be problematic for fish passage. Among the hatchery fish planted in Prairie Creek were 4,395 Atlantic Salmon (*Salmo salar*), which are native to the North Atlantic Ocean basin. Humboldt County assumed control of the hatchery operation in 1962. Located on Lost Man Creek close to its confluence with Prairie Creek, the primary trapping site was a weir and fish ladder located at the hatchery, with a secondary weir and trap in mainstem Prairie Creek, approximately 200 m upstream. A dam was built 0.5 km upstream in Lost Man Creek as a water source for the hatchery, and abandoned in 1955 when it filled with sediment. The dam was replaced by another dam closer to the Hatchery, which is no longer operational. The upper dam, which was a partial barrier to migrating salmon, particularly Chinook Salmon, was removed by Redwood National Park in August 1989. Removal of the dam increased salmonid spawning access and use of 2.9 km of upstream habitat in the creek (Ozaki and Anderson 1993). Relative percent of live adult salmonids, carcasses and redds nearly doubled upstream of the dam site following dam removal.

The Prairie Creek Hatchery ceased operations in 1992. During its operation, it both received eggs and broodstock and supplied fish from several locations outside of the Redwood Creek Basin. Eggs and broodstock of Coho Salmon, for example, were received from the Trask, Klaskanine, and Sandy River in Oregon, the Skaggit and Soos rivers in Washington, and the Trinity and Noyo rivers in California. Cutthroat Trout broodstock were obtained from the Alsea River in Oregon. During 1990-91, plantings of hatchery fish in Prairie and Lost Man creeks included 52,000 Chinook Salmon, 109,835 Coho Salmon, 65,985 Steelhead, and 260 Cutthroat Trout (Yarbrough 1991). The genetic effects on wild stocks of salmon and steelhead through introgression with non-native strains and from domestication are unknown.

Aquatic Resources

Prairie Creek supports 4 species of salmonid fishes: Chinook Salmon (*Oncorhynchus twshawtyscha*), Coho Salmon (*O. kisutch*), Coastal Rainbow Trout (*O. mykiss* ssp. *irideus*), and Coastal Cutthroat Trout (*O. clarki* spp. *clarki*), all of which are native to western North America. Small numbers of Chum Salmon (*O.* keta) occasionally stray into Prairie Creek, but are not common. Pink Salmon (*O. gorbuscha*) have also been observed (Smedley 1952). Anadromous forms of Coastal Rainbow Trout are referred to as steelhead. Steelhead and Coastal Cutthroat Trout are known to hybridize within the creek (Neillands 1994). A brief synopsis of the life history and population status of each salmonid species follows below a listing of other aquatic taxa inhabiting the creek.

Non-Salmonid Fishes

Non-salmonid fishes present in the Prairie Creek watershed include: Threespine Stickleback (Gasterosteidae: *Gasterosteus aculeatus*), Sacramento Sucker (Catostomidae: *Catostomus occidentalis*), Prickly Sculpin (Cottidae: *Cottus asper*), Coast Range Sculpin (Cottidae: *C. aleuticus*), Pacific Lamprey (Petromyzontidae: *Lampetra tridentata*), and Pacific Brook Lamprey (Petromyzontidae: *L. richardsoni*). Two Eulachon (*Thaleichthys pacificus*), a small anadromous fish of the eastern Pacific Ocean, were captured in 2015 in a rotary screw trap at the mouth of Prairie Creek for the first time in the trap's operation. Populations of this fish are considered by the U.S. Fish and Wildlife Service as likely extirpated (http://www.nmfs.noaa.gov/pr/species/fish/pacificeulachon.htm) in Redwood Creek, and individuals had not been observed since the 1970s. The last large run of Eulachon occurred in 1967 (VanKirk 1994). Eulachon in the southern distinct population segment (which includes Washington, Oregon, and California) are listed as threatened under the Endangered Species Act (ESA).

All of the fish species present in Prairie Creek are native to the region. The distribution of the anadromous Pacific Lamprey coincides with the North American distribution of Pacific salmon and steelhead. As is the case for salmon, runs in North Coast streams of California are much smaller than they were historically, based on living memories of tribal subsistence fishers. Population sizes of adult lamprey are poorly understood and not formally monitored. Tribal fishers have reported consistently low runs since the mid 1980s; declines in adult abundance of Pacific Lamprey in the Mad-Redwood Creek system are estimated to be in the range of 50-70% (Goodman and Reid 2012). The fish, however, is believed to currently occupy most historical anadromous habitat in the region downstream of impassable dams. Small numbers of adult Pacific Lamprey, and hundreds of lamprey ammocoetes have been routinely captured in smolt trap at the mouth of Prairie Creek (Table 3). Pacific Lamprey co-occur with the non-parasitic Brook Lamprey in Prairie Creek.

TABLE 3. Annual abundance of non-salmonid fishes captured by the smolt trap operated above the confluence of Prairie Creek with Redwood Creek, averaged from 2011-2013. Data are from Sparkman et al. (2015).

Species Captured	**3-yr Average Catch**
Prickly Sculpin	1,588
Coast Range Sculpin	2,252
Sucker	239
Three-Spined Stickleback	1,658
Adult Pacific Lamprey	27
Lamprey Ammocoetes	625
Brook Lamprey	48

Amphibians

Amphibians that have been collected from Prairie Creek include 4 salamanders and 5 frogs (Table 4). With the exception of the American Bullfrog, all amphibian species are native to the region. The American Bullfrog is native to the eastern and Midwestern United States and southeast Canada, was introduced to California in the 1920's by commercial frog farmers, and has now become established.

Three species, the Pacific Coastal Salamander (formerly the Pacific Giant Salamander), Tailed Frog, and Southern Torrent Salamander, are common throughout perennial streams in the watershed. Larval and paedomorphs (sexually mature animals with larval morphology) of the Pacific Coastal Salamander are strictly aquatic, and are benthic predators often found under cobble-sized substrate. They may account for as much as 99% of the predator biomass in small streams throughout the Pacific Northwest. Only the larval stage of the Tailed Frog are aquatic. Specialized folds that create suction, and a ventrally placed mouth, allow the tadpole to cling to underwater rock surfaces, where it feeds as a scraper on attached periphyton. Tailed Frogs are unique among temperate frogs in being specifically adapted to fast-flowing and cold water habitats. Adults of the small, secretive Southern Torrent Salamander occur both within small streams and streamside; larvae are aquatic, and found on the streambed in coarse gravel. The salamander feeds on small insects and spiders, and is preyed upon by the Pacific Coastal Salamander. The Southern Torrent Salamander has the lowest desiccation tolerance of all North American salamanders, and exhibits temperature stress at temperatures above 17 C.

None of the native amphibian taxa found in Prairie Creek are federally or state listed as threatened or endangered. The Southern Torrent Salamander, Red-Legged frog, and Foothill Yellow-legged Frog, however, are considered Species of Special Concern by the California Department of Fish and Wildlife.

The Pacific Giant Salamander, Tailed Frog, and Southern Torrent Salamander have been found to be more abundant in streams bordered by late seral forest than in streams bordered by second-growth forest (Ashton et al. 2006). Welsh and Oliver (1999) reported that their densities were lower in streams impacted by sediment delivery from the 1989 bypass incident than in control streams, but that density differences had disappeared 6 years later. Madej et al. (2006) found that stream reaches in undisturbed redwood forests within the Redwood Creek basin had significantly higher biomass and density of tailed frogs than streams in watersheds with various degrees of road removal work.

TABLE 4. Scientific and common names of amphibians collected from Prairie Creek. Records derive from data of the USGS Coop and CDFW from upper (above Boyes Creek) and lower (above confluence with Redwood Creek), and studies by Ashton et al. (2006) and Welsh and Oliver (1999).

Scientific Name	**Common Name**
Order Caudata	Salamanders
Dicamptodontidae	Giant Salamanders
Dicamptodon tenebrosus	Coastal Giant Salamander
Plethodontidae	Lungless Salamanders
Ensatina eschscholtzii	Ensatina
Rhyacotritonidae	Torrent Salamanders
Rhyacotriton variegatus	Southern Torrent Salamander
Salamandridae	Newts
Taricha granulosa	Rough-skinned Newt
Order Anura	Frogs
Bufonidae	True Toads
Anaxyrus boreas	Western Toad
Leiopelmatidae	Tail-wagging Frogs
Ascaphus truei	Coastal Tailed Frog
Ranidae	Brown Frogs
Rana aurora	Northern Red-legged Frog
Rana boylii	Foothill Yellow-legged Frog
Lithobates catesbeianus	American Bull Frog

Macroinvertebrates

Benthic and drifting macroinvertebrates (invertebrates > 0.5 mm at maturity) from Prairie Creek have been sampled and described in several reports and theses. These include Averett and Iwatsubo (1995), Madej et al. (2006), Dinger (2010, 2012) and Humboldt State University theses, e.g., Anderson (1988), Kvam (1988) Strange (1989), Meyer and Haux (1995), Beesley (2006), and Gonzales (2006). In addition, RNSP sampled benthic macroinvertebrates in the Lost Man Creek drainage (North Fork, Lost Man above North Fork, Larry Damm Creek, Lost Man below North Fork, and Lost Man at Larry Damm Creek) in 2007 to monitor impacts associated with road removal.

Studies were conducted with differing objectives, and with differing degrees of taxonomic resolution. Invertebrates sampled in the Redwood Creek drainage by the U.S. Geological Survey in 1973-1975 (Averett and Iwatsubo 1995) and collections by Anderson were intended as general descriptors of aquatic resources and habitats within Redwood National Park. Madej and co-authors compared abundance and diversity of benthic macroinvertebrates and other aquatic organisms between 2004-2005 and the

1970s (reported by Iwatsubo et al. (1975) and others, to assess the impact on stream health of over 30 years of extensive watershed restoration. Kvam developed keys for identification of genera of Chironomidae (Order Diptera, Insecta) from invertebrate samples previously collected as part of a program to monitor effects of construction of the Highway 101 bypass. Meyer and Haux (1995) also reported on invertebrate impacts from the bypass construction. Beesley estimated annual production for one genus of mayfly in Prairie, Boyes, and Streelow creeks, and Gonzales reported on diet and invertebrate prey consumption of juvenile Coho Salmon.

Invertebrate studies differ in the level of taxonomic resolution sought according to study objectives. A combined list of insect and non-insect invertebrate taxa that have been collected and identified from the above-referenced studies of Anderson, Kvam, Madej and co-authors, Strange, and RNSP is given in Tables 5 and 6. Invertebrate prey items found by Gonzales to be important in the diets of juvenile Coho Salmon included larval and adult Diptera, and the Oligochaeta. Amphipods contributed substantially to their diets in Streelow Creek, but not in other streams where amphipods do not appear to be present or abundant. Differences in amphipod distribution among Prairie Creek tributaries potentially result from differences in water buffer variables (e.g., calcium concentration, alkalinity, and water hardness).

Efforts to relate assemblage structure of benthic macroinvertebrates to adverse effects from influx of sediments from road construction or removal, or to improved physical conditions following watershed restoration in Prairie Creek, have not been greatly successful. Using bioassessment metrics of an Index of Biological Integrity (IBI) that was developed for southern California, Madej et al. (2006) were unable to find clear trends in macroinvertebrate metrics between the 1970s and 2000s, and found high variability in macroinvertebrate composition between seasons and years, and among sites. The most pristine sites did not have the highest IBI ratings. An IBI specific to the northern coastal California, where timber harvest is a major stressor, has been developed subsequent to their analysis (available at www.waterboards.ca.gov/swamp), and may be more appropriate. However, use of a multi-metric rapid assessment approach to analyze temporal changes in macroinvertebrate composition, based on coarse levels of taxonomic resolution and distinguishing only among a small number of categories of biological condition (very poor to very good) , is likely to reveal only large-scale changes in assemblage structure. Bioassessment protocols, as is standard for most invertebrate-based IBI's, are developed from samples of riffle habitat only, and thus do not reflect assemblage structure within pools or in association with large woody debris. The ability to detect loss or addition of single species sensitive to disturbances such as sedimentation likely require a different type of analysis. Samples collected by RNSP, which were enumerated and identified by J. Lee (2007), to detect impacts from road removal restoration on invertebrates in the Lost Man Creek drainage also did not reveal substantial differences in IBI scores among sampling locations affected and unaffected by road removal. North Fork Lost Man Creek was ranked as very good (NorCal IBI score=88 out of 100), other sites except Lost Man Creek at Larry Damm were ranked as good (IBI scores ranged from 68-71), and Lost Man at Larry Damm received a ranking of fair (IBI score = 59). Results from sampling in selected sites in Prairie Creek by the NPS Klamath Network Inventory and Monitoring Group Results of the Northern California Coastal IBIs suggested that the streams of REDW are all at least in good condition, with some sites in the very good category. The application of the EPA threshold of —52‖ to indicate impairment (<52: unimpaired; ≥52 impaired) from Stoddard et al. (2005) showed that no sites within RNSP were impaired based on macroinvertebrate assessment. Benthic invertebrates, monitored from 1985-1992, did not appear to be adversely affected from construction of the Highway 101 bypass construction (Meyer and Haux 1995).

Although differences in annual production of the mayfly genus studied by Beesley (2006) were slight and variability of the estimates was unknown, the pattern of production magnitude generally fit the pattern of perceived disturbance among the three streams she studied. Production was highest in Prairie Creek, considered the least disturbed of the sites, and lowest in Boyes Creek, where disturbance was most recent.

None of the aquatic invertebrates sampled in Prairie Creek are known to be non-native. The highly invasive and exotic New Zealand mud snail has been detected in the Redwood Creek estuary, but a recent survey did not detect New Zealand mud snails in Prairie Creek (Ward and Sepulveda 2012). The mud snail, like other mollusks, depends on calcium availability, as $CaCO_3$ is necessary for shell deposition and growth. Low alkalinity and water hardness in Prairie Creek may discourage or limit colonization of the snail.

TABLE 5. Aquatic insect taxa collected from Prairie Creek and its tributaries. Only streams from which taxa have been collected are listed. Data are compiled from Anderson (1988), Kvam (1988), Strange (1989), Madej et al. (2006), and RSNP (2007).

TAXON	**Prairie**	**Brown**	**Boyes**	**Lost Man**	**Little Lost Man**	**Streelow**
COLEOPTERA						
AMPHIZOIDAE						x
ANTHICIDAE				x		
CIRCULIONIDAE	x					x
DYTISCIDAE	x				x	x
Oreodytes sp.	x			x		

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
ELMIDAE	x				x	x
Ampomixis dispar	x			x		
Heterlimnius koebelei	x			x		
Lara sp.	x			x		
Narpus concolor	x			x		
Optioservus sp.	x			x		
Ordobrevia nubifera	x			x		
Zaitzevia parvula	x			x		
GYRINIDAE						x
HALIPLIDAE					x	
Brychius sp.				x		
Haliplus sp.				x		
HYDRAENIDAE						x
Ochthebius sp.	x					
HYDROPHILIDAE	x					x
Tropisternus sp.				x		
PSPHENIDAE					x	
Eubrianax edwardsi	x			x		
PTILLIDAE	x					
PTILODACTYLIDAE						
Anchytarsus sp.				x		
DIPTERA						
BLEPHARICERIDAE						
Philorus californicus				x		
CERATOPOGONIDAE						x
Bezzia sp.	x					
Atrichopogon sp.	x					
CHIRONOMIDAE	x				x	x
Subfamily Chironominae						
Tribe Chironomini						
Polypedilum sp.	x			x		
Tribe Tanytarsini						
Rheotanytarsus sp.	x			x		
Stempellina sp.	x			x		

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
Stempellinella sp.	x			x		
Subfamily Orthocladinae						
Heterotanytarsus sp.	x			x		
Krenosmittia sp.	x			x		
Lopescladius sp.				x		
Subfamily Podonominae						
Tribe Boreochlini						
Boreochlus sp.				x		
Subfamily Tanypodinae	x			x		
CULICIDAE						
Anopheles sp.	x					
DIXIDAE	x				x	x
Dixa sp.	x					
DOLICHOPIDAE	x					
EMPIDIDAE						x
Chelifera sp.	x			x		
EPHYDRIDAE	x				x	x
MUSCIDAE				x		
PETECORHYNCHIDAE						
Glutops sp.	x					
PSYCHODIDAE	x				x	
Maruina lanceolata	x			x		
Pericoma sp.	x			x		
PTYCHOPTERIDAE						
Ptychoptera sp.	x			x		
SIMULIIDAE	x				x	x
Prosimulium sp.				x		
Simulium sp.	x			x		
STRATIOMYIDAE						
Allognosta sp.	x			x		
Myxosargus sp.						
TABANIDAE				x		
Tabanus sp.						
TIPULIDAE				x		

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
Antocha monticola	x			x		
Dicranota sp.	x			x		
Hexatoma sp.	x					
EPHEMEROPTERA						
AMELETIDAE	x			x		
Ameletus sp.	x	x			x	x
BAETIDAE	x			x		
Baetis	x	x			x	
EPHEMERELLIDAE				x		
Attenella margarita				x		
Caudatella heterocaudata	x					
Ephemerlla inermis	x			x		
Ephemerlla infrequens	x					
Drunella coloradensis	x			x		
Drunella doddsi	x					
Drunella grandis	x					
Drunella spinifera				x		
Serratella levis	x			x		
Serratella teresa	x			x		
Serratella tibialis	x			x		
Timpanoga hecuba	x				x	x
HEPTAGENIIDAE	x			x		
Cingymula sp.	x			x		
Epeorus albertae	x			x		
Epeorus longimanus	x			x		
Heptagenia sp.	x			x		
Ironodes sp.	x	x		x		
Rithrogena sp.	x				x	x
LEPTOPHLEBIIDAE	x		x	x		x
Paraleptophlebia	x	x			x	x
SIPHLONURIDAE						
TRICORYTHIDAE						
Tricorythodes sp.						
HEMIPTERA						

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
CORIXIDAE	x					
Sigara vandekeyi						x
GERRIDAE				x		
Gerris sp.						x
VELIIDAE	x					x
LEPIDOPTERA						
	x					
MEGALOPTERA						
CORYDALIDAE	x			x		
Orohermes crepusculus						
SIALIDAE	x			x		
Sialus sp.	x					
ODONATA						
GOMPHIDAE	x			x		
Gomphus sp.						
PLECOPTERA						x
CAPNIIDAE	x			x		
Capnia sp.	x			x		
Paracapnia angulata	x				x	x
CHLOROPERLIDAE	x			x		
Paraperla frontalis	x			x		
Suwalia sp.	x					x
LEUCTRIDAE	x				x	x
NEMOURIDAE	x			x		
Zapada cinctipes	x			x		
Zapada oregonensis	x				x	x
PELTOPLERIDAE	x			x		
Yoroperla brevis	x				x	x
PERLIDAE	x			x		
Calineuria californica	x			x		
Hesperoperla pacifica						
PERLODIDAE	x			x		
Cultus sp.	x			x		
Isoperla sp.	x			x		

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
Kogotus nonus	x				x	
PTERONARYCIDAE	x			x		
Pteronarcys californica						
TRICOPTERA	x				x	x
BRACHYCENTRIDAE	x			x		
Micrasema onisca	x				x	x
CALAMOCERATIDAE	x			x		
Heteroplectron californicum	x				x	x
GLOSSOMATIDAE	x			x		
Agapetus taho	x			x		
Glossosoma sp.	x				x	x
HYDROPSYCHIDAE				x		
Arctopsyche grandis	x			x		
Hydropsyche sp.	x					
Parapsyche sp.	x				x	
HYDROPTILIDAE				x		
Hydroptila sp.	x			x		
Ochrotrichia sp.	x			x		
Palaeagepetus nearcticus					x	
LEPIDOSTOMATIDAE	x			x		
Lepidostoma sp.	x				x	x
LIMNEPHILIDAE	x			x		
Apatania sorex	x			x		
Dicosmoecus gilvipes	x			x		
Ecclisomyia conspersa	x			x		
Hydatophylax hesperus	x			x		
Neophylax rickeri				x		
Onocosmoecus sp.	x					
PHILOPOTAMIDAE	x			x		
Wormaldia sp.						
PSYCHOMYIIDAE	x					
Psychomyia lumina	x					x
POLYCENTROPIDAE	x			x		
Polycentropus sp.	x				x	x

TAXON	Prairie	Brown	Boyes	Lost Man	Little Lost Man	Streelow
RHYACOPHILIDAE	x			x		
Rhyacophila spp.						
SERICOSOMATIDAE	x			x		
Gumaga griseola						
UENOIDAE	x			x		
Farula sp.						

TABLE 6. Non-insect aquatic invertebrates collected from Prairie Creek or its tributaries. Only streams from which taxa were collected are listed. Data are compiled from Anderson (1988), Kvam (1988), Strange (1989), and Madej et al. (2006).

TAXON	Prairie	Lost Man	Little Lost Man	Streelow
ANNELIDA				
C. HIRUDINEA	x			
C. OLIGOCHAETA	x	x		
C. ADENOPHOREA				
O. Rhabditida	x			
ARTHROPODA				
C. ARACHNIDA				
O. Acari	x		x	x
SubOrder Hydracarina	x	x		
C. COLLEMBOLA	x		x	x
C. CRUSTACEA				
O. Amphipoda				
F. Gammaridae	x		x	x
Anisogammarus confervicolus	x	x		
O. ISOPODA	x		x	x
F. Asellidae				
Asellus sp.	x			
MOLLUSCA				
C. GASTROPODA				
F. Hydrobiidae				

TAXON	Prairie	Lost Man	Little Lost Man	Streelow
Amnicola sp.	x			
F. Physidae				
Physa sp.	x	x		
F. Planorbidae				
Gyraulus sp.	x	x		
F. Pleuroceridae				
Juga sp.		x		
C. PELECYPODA				
F. Sphaeridae				
Sphaerium corneum	x	x		

Algal Assemblages

Benthic algae, along with nonliving organic carbon from a variety of sources, represent the primary energy source at the base of riverine food webs. Photosynthetic activity of benthic algae provides oxygen for aerobic organisms in the ecosystem, and the carbon fixed by algae through photosynthesis provides food resources for herbivorous invertebrates and fishes. Benthic algae remove nutrients from the water column, attenuate the current and stabilize sediments, and provide habitat for other organisms. Composition of benthic algae is often used in rapid bioassessment protocols as a water quality indicator in California's surface water ambient monitoring program (SWAMP). Madej et al. (2006) compared rates of periphyton accrual on artificial substrates between 1973-1975 and 2004-2005 in Little Lost Man and Lost Man creeks (and other sites in Redwood Creek) as a means of assessing changes in stream health following extensive watershed restoration.

Few taxonomic descriptions of benthic algae in Prairie Creek are available. Iwatsubo et al. (1976) described the summer periphyton composition in 1974 and 1975 close to the mouths of Little Lost Man and Lost Man creeks, and reported both a greater taxonomic richness and overall abundance in Little Lost Man than in Lost Man Creek. Both streams were dominated by diatoms (algal division Bacillariophyta), with *Achnanthes lanceolata and Achnanthes spp.*, *Cocconeis placentula,* and *Synedra amphicephala* occurring in largest numbers. Occurrence of filamentous blue green algae (division Cyanobacteria) and green algae (division Chlorophyta) was low in both streams. In mid-summer of 1975, however, the unicellular green alga *Chlamydomonas sp.* was abundant.

Madej et al. (2006) found a decrease in periphyton growth rates at sites throughout the Redwood Creek basin, including Prairie Creek, in 2004 and 2005 in comparison with periphyton growth in the early 1970s, which they attributed to an increase in riparian canopy cover. Periphyton growth did not differ between years in level of watershed disturbance or extent of road removal.

Salmonid Fishes

Data on salmonid fishes in Prairie Creek come from many sources, including monitoring data and reports of RSNP and CDFW, studies, theses, and class reports of the USGS Coop and Humboldt State University, and consultants. Based on the 2012 CalFish database, the minimum stream length within each catchment known to support anadromous salmon is given in Table 1, and the distribution of Coho Salmon, Chinook Salmon, and steelhead within Prairie Creek is shown in Fig. 6. Stream lengths are listed as a minimum as not all stream reaches have been surveyed. The Prairie Creek sub-basin supports most of the Coho Salmon and Cutthroat Trout in Redwood Creek (Sparkman et al. 2014). While steelhead are the most widely distributed salmonid in the Redwood Creek basin, Coho Salmon outnumber steelhead and commonly outnumber Chinook Salmon in Prairie Creek. For example, during the 2013-2014 spawning season, CDFW estimated a total of 538 Coho Salmon, 151 Chinook Salmon, and 57 steelhead redds within Prairie Creek (Ricker et al. 2014).

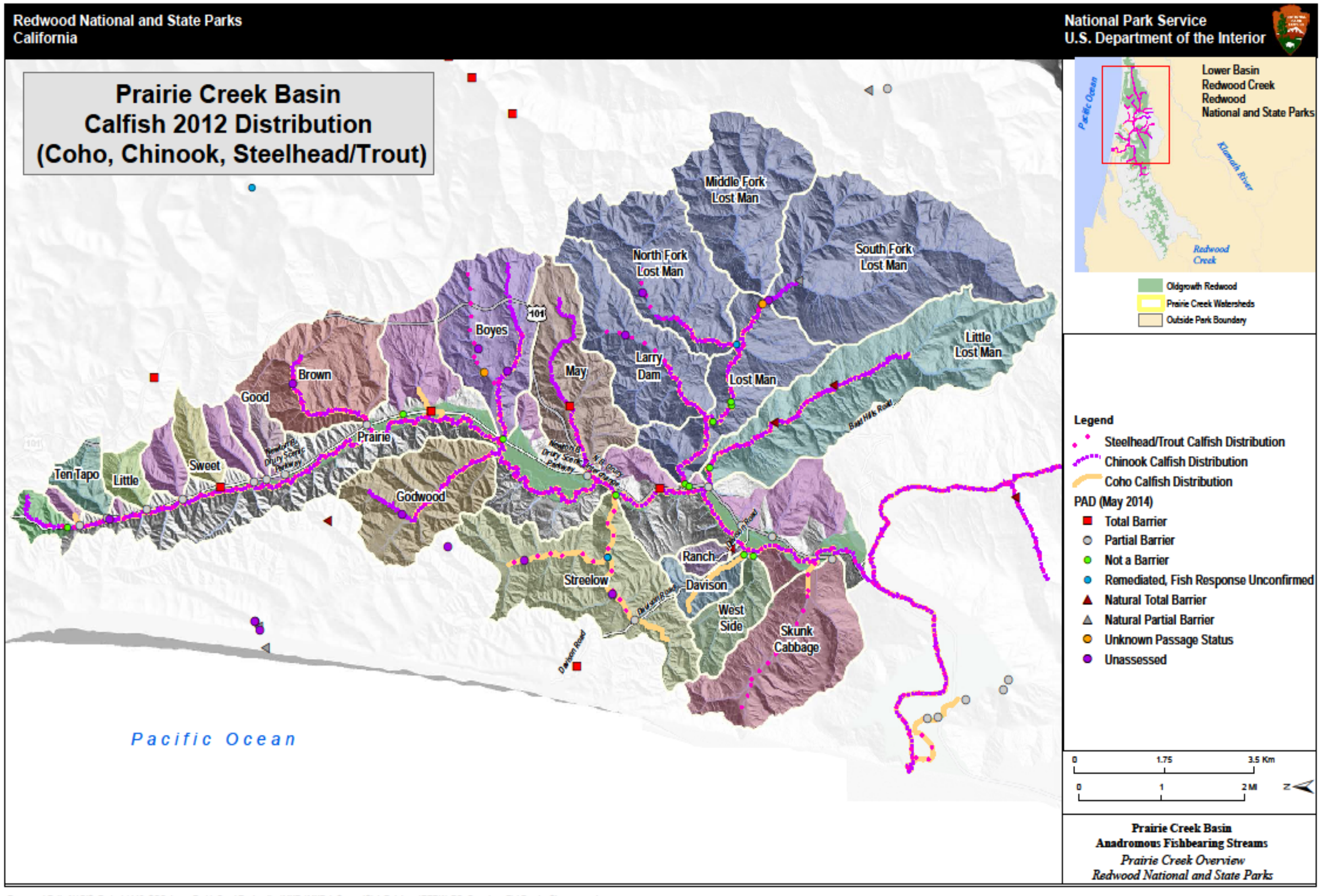

Figure 6. Distribution of Coho Salmon, Chinook Salmon, and steelhead/trout within the Prairie Creek basin, based on the 2012 Calfish database. Map created by J. Wartella, RNSP.

Chinook Salmon. - The largest of the anadromous Pacific salmon (mature fish reaching lengths of 1 m or more), Chinook Salmon typically spend 2-4 years or more at sea, and migrate as adults from the ocean into the freshwater rivers of their birth in order to mate. Like other Pacific salmon, the fish are semelparous, i.e., dying after spawning once. Adult Chinook Salmon returning to Prairie Creek to spawn are usually in their 3rd - 5th year and are fall-run. Precocious males, referred to as jacks, may return to the creek to spawn after only one summer in the ocean, at a weight of about 1.4-1.8 kg (Ridenhour and Hofstra 1994). Upstream passage during late spring and summer months is prevented by low stream flows and sand bar closure of the Redwood Creek mouth. Freshwater entry is usually coincident with the first heavy fall rains, with most of the individuals comprising the first main run often entering Prairie Creek during the first two weeks in November. The run usually continues through the end of December or early January. Briggs (1953) noted that the distribution of spawning by Chinook Salmon within the mainstem and larger tributaries of Prairie Creek reflects its preference for areas of comparatively greater flow. Prairie Creek, he observed, is an unusually small stream to support spawning by Chinook Salmon.

Juvenile Chinook Salmon in Prairie Creek are predominantly ocean-type rather than stream-type, with individuals migrating to the estuary as smolts within the first 3-6 months of life. Small numbers of juveniles, however, have been found to reside in Prairie Creek for 1-2 years before migrating. The peak smolt migration typically occurs in April and May. Chinook Salmon smolts from Prairie Creek enter the estuary earlier than do smolts from Redwood Creek upstream of Prairie Creek, and at a smaller size (Sparkman et al. 2015). This suggests a need for Prairie Creek Chinook Salmon to continue rearing in lower Redwood Creek and estuary to reach a size that increases marine survival. Impairment of lower Redwood Creek and the estuary from sedimentation, channelization, sparse accumulations of LWD, and altered riparian composition likely reduces the number of adult Chinook Salmon returning to spawn in Prairie Creek, because of reduced growth and survival of smolts.

Chinook Salmon in Prairie Creek are included in the California Coastal Chinook Salmon Evolutionary Significant Unit (ESU), which is federally listed as threatened under the Endangered Species Act. The listing reflects concern over greatly depressed population sizes relative to historical abundance. Early records of adult Chinook Salmon in Prairie Creek are sparse. Based on carcass and redd counts, McCormick (1954) estimated a spawning population of 400-555 fish in Prairie Creek above the hatchery, and 30 fish in Lost Man Creek. In 1960, approximately 2,000 adults were estimated to return to Prairie Creek and lower Redwood Creek based on returns to the Eel River [(USFWS 1960), cited in Ridenhour and Hofstra (1994)]. Duffy (2011) compiled escapement estimates between 1999-2008 for Chinook Salmon derived from Area-Under-the-Curve (AUC) analysis of live fish observations, and reported a high value of 710 fish in 2002, and a low of 38 fish in 2008. Estimates of redd and smolt abundances of Chinook Salmon from 2011-2014 are shown in Figure 1. Lack of complete correspondence in abundances among years between adults (indexed here by redds) and smolts may be attributable to the effect of spring storm events on survival of emergent fry. For both adults and smolts, abundances were exceptionally high in 2013. Based on records from the USGS gaging station on Redwood Creek at Orick extending from 1911-2014, spring flows during 2013 were less than 50 percent of the means of monthly discharge. During 2011, a year in which smolt abundance was low despite a high abundance of redds, flows were substantially higher than the long-term mean during March and April (e.g. mean Mar discharge = 1930 cfs; Mar 2011 discharge = 3,931 cfs).

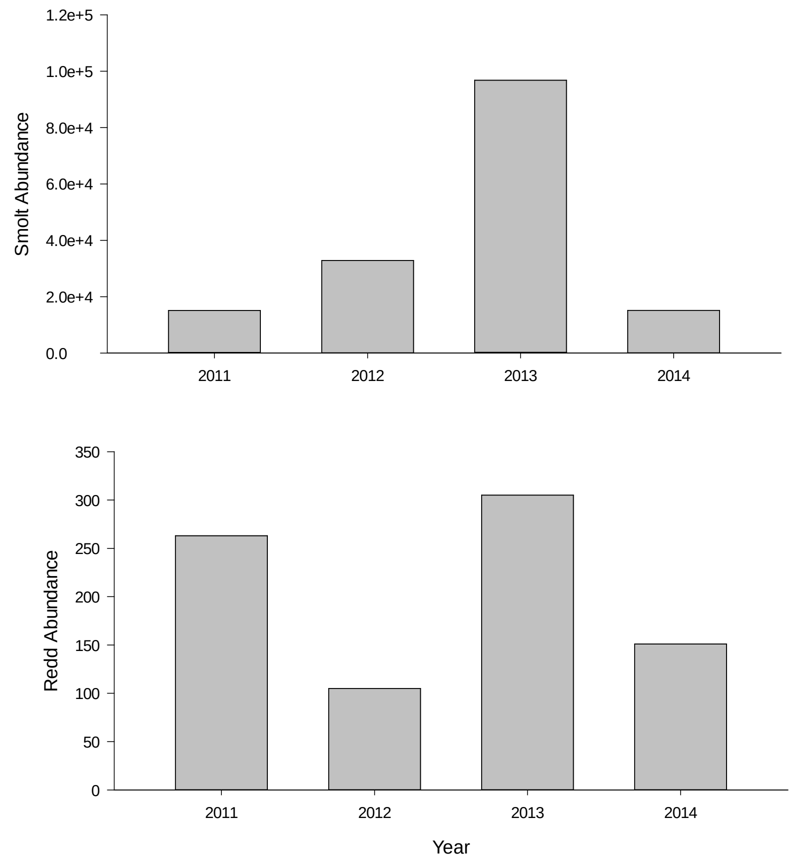

FIGURE 7. Estimates of smolt (upper) and total redd (lower) abundances of Chinook Salmon in Prairie Creek, 2011 – 2014. Data are from Sparkman et al. (2015) and Ricker et al. (2015 a, b, c, d). Redd construction was monitored over a spawning period extending between the 5-6 mo. period of spawning migration (November and March or April), and is identified by the calendar year in which monitoring ceases. For example, the estimate of redd abundance in 2014 spans the time period between November 2013 through April 2014. Smolt abundance was estimated from trapping operations conducted during the major downstream migration period, generally between March and August of a calendar year.

Spawning of Chinook Salmon usually occurs in reaches with gradients of 0.2-1%, in water 0.3-0.9 m deep over substrate dominated by large pebble/small cobble (25-76 mm diameter) (Flosi et al. 1998). During years of higher flows, spawning can occur in upper basin tributaries 2-3 m wide. During years of low flow, spawning occurs in the lower mainstem of Prairie Creek. After emergence, fry are found in quiet water, close to cover structures. Juveniles tend to feed in faster water than is used by Coho Salmon.

Coho Salmon. – Coho Salmon are anadromous and semelparous. Adults return to their stream of origin to spawn and die, usually at three years of age although some precocious males, referred to as jacks, may return as 2-yr old spawners. In Prairie Creek, the run timing of adults (November – February) overlaps with that of Chinook Salmon. Spawning habitat for Coho Salmon is in water with an average velocity of 60 cm/s, with a minimum depth of 0.12-0.18 m, in gravel and small pebble substrate (e.g., Briggs 1953, Regnart 1991, Mull and Wilzbach 2007). Juvenile Coho Salmon in California typically rear in freshwater for one year, before migrating to the ocean as smolts. Several studies in Prairie Creek and other small streams in northern California, a 2-yr freshwater life history have been documented (Bell and Duffy 2007, Ransom 2007, and Moore 2014). Ransom found that the incidence of this life history varied between 0-30% among regional streams and annually over three years of study, with peak winter streamflow best explaining the amount of extended rearing. The largest proportions of 2+ Coho Salmon were observed during summer, following the winter with the mildest streamflows. Neither density nor average size of fish showed clear relationships with extended rearing. The peak in timing of smolt migration in Prairie Creek occurs in April and May.

Coho Salmon in Prairie Creek are within the Southern Oregon/Northern California Coasts ESU, which is federally listed as threatened under the Endangered Species Act. Populations within this ESU have experienced dramatic declines in abundance from historical levels, and for many populations the trend in abundance continues to be downward (National Marine Fisheries Service [NMFS] 2014). The Redwood Creek population is considered by NMFS to be at a high risk of extinction, with lack of floodplain and channel structure, and impaired estuarine/mainstem function regarded as the key stresses limiting the population. However, Prairie Creek is a stronghold for Coho Salmon, and produces most of the Coho Salmon (and Cutthroat Trout) within the basin (Brown 1988). Prairie Creek provides lower gradient habitat and cooler water temperatures than are present elsewhere in basin, and offers much more habitat in nearly pristine condition. Coho Salmon are distributed throughout the Prairie Creek watershed (Anderson 1988). Williams et al. (2006) rated all of the named and unnamed tributaries and mainstem reaches of the creek as having high intrinsic potential to support Coho Salmon.

Coho Salmon spawner surveys have been conducted since 1991, although differences in methodologies and monitoring locations have made trend analysis difficult. First surveys were in response to concerns over the 101 bypass (1990-1998) episode. Surveys were continued by the USGS Coop (1998-2008), then by CDFW (2009-present). Adult surveys extend as well to Chinook Salmon and steelhead, although the entire steelhead spawning season is not covered.

Estimates of smolt abundances have been made by the California USGS Coop from 1998-2011, generally in the mid to upper portions of the basin (above the confluence of Streelow Creek), and are summarized in a report prepared by Duffy (2012). Smolt abundance has been monitored since 2011 by CDFW in collaboration with the USGS Coop in the lowermost section of Prairie Creek to provide an estimate at the sub-basin level. Data are summarized in Sparkman et al. (2015). Spawner surveys have been conducted by CDFW since 2009 in randomly selected and index reaches to also provide sub-basin scale estimates of escapement (Ricker et al. 2014 a, b, c, d and Ricker 2010). During the period between the winters of 1998/1999 through 2011/2012, spawning density of Coho Salmon averaged 19-20 fish/km. Relative abundances of adult Coho Salmon and Chinook Salmon, estimated from live fish observations using area-under-the-curve analysis, varied among years (Figure 2), with Coho Salmon tending to outnumber Chinook Salmon from 2005 onward. Coho Salmon apparently outnumbered Chinook Salmon earlier as well, as Briggs (1949) reported that Coho Salmon were six times as abundant as Chinook Salmon in Prairie Creek. During 2011-2014, the annual estimate of 1+ Coho Salmon emigrating past the downstream migrant trap in lower Prairie Creek averaged 17,804 individuals (SD=6,530), a majority (86%) of which were classified as smolts. With 78.44 km of accessible habitat, this would result in an approximate smolt production of 227 1+ smolts per kilometer.

The earliest record of juvenile abundance of Coho Salmon in Prairie Creek may come from Briggs (1949), who reported counts of 61-171 fish from an approximately 300 m reach of Prairie Creek. Hallock et al. (1952) seined 9,610 juvenile Coho Salmon from Boyes Creek and an unnamed tributary of Prairie Creek in 1951 as part of a fingerling marking program. Estimates of juvenile abundance of Coho Salmon in Prairie Creek over the period 1999-2011, based on a modified Hankin and Reeves (1988) sampling methodology in 2-6 km reaches of Boyes, Streelow, and Upper Prairie (above Brown) creeks), ranged between 2,393 (2001) and 8,664 (2003) individuals (Duffy 2012). Summer density of juvenile Coho Salmon was greater in Boyes Creek (0.77 individuals/m^2) than in Upper Prairie (0.33 fish/m^2) or Streelow (0.38/m^2) creeks. Using a 2-pass snorkeling methodology in pools distributed throughout the Prairie Creek watershed, Drobny (2016) estimated a juvenile density of Coho Salmon in late summer 2014 to be 0.52 fish/m2 (SD=0.38, SE = 0.03, n = 159). Briggs (1949) reported a density of juvenile Coho Salmon in Prairie Creek of 0.19 to 0.52 fish/m.

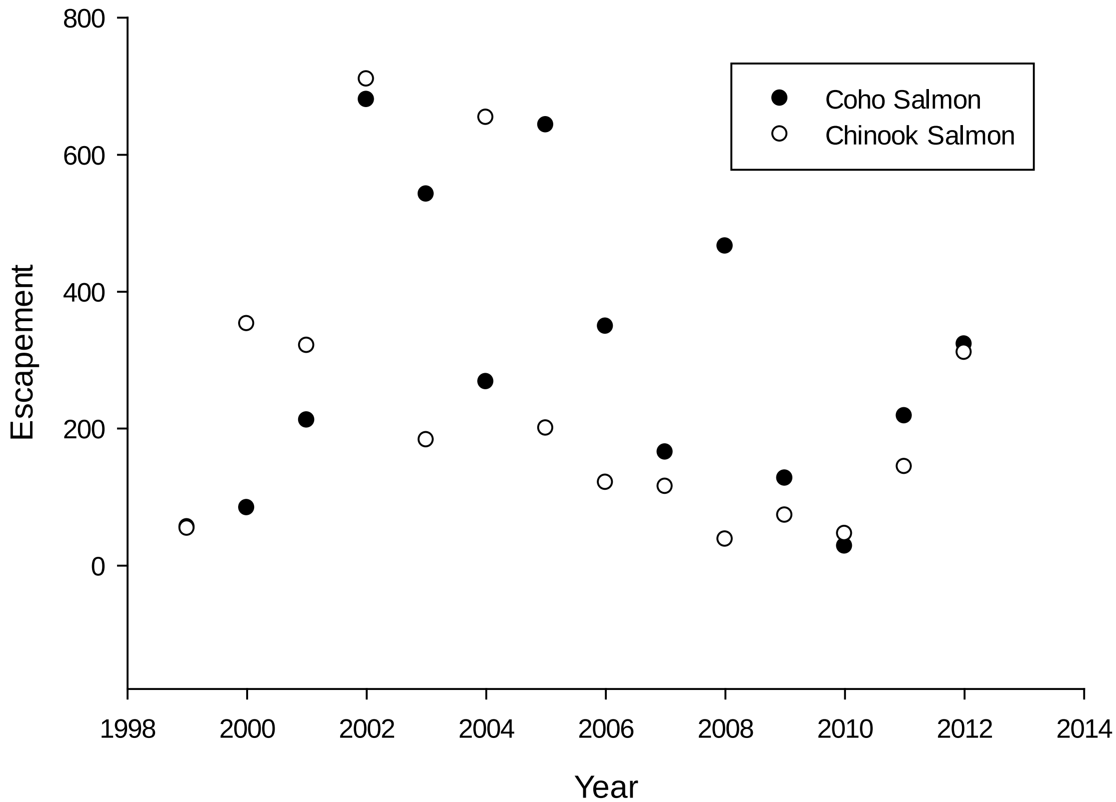

FIGURE 8. Estimated escapement of Coho Salmon and Chinook Salmon to Prairie Creek from spawning seasons 1998/1999 through 2011/2012. Data are from Duffy (2012).

Emergent fry of Coho Salmon are found along quiet water margins, in side channels, backwater, and dammed pools. During higher flows and cold water temps, juveniles move to slow, deep pools, beaver ponds, or to side channels and backwater pools off the main stream, and seek cover under rocks or in cover structures. In summer, juveniles use primary pools or backwater eddies in association with tree roots or LWD or undercut banks (Flosi et al. 1998). In Prairie Creek, most juveniles are in deep pools during summer, and in alcoves or backwaters during winter (Bell 2001, Bell and Duffy 2007).

Steelhead. – Steelhead are the anadromous form of the Rainbow Trout (*Oncorhynchus mykiss*), which may also exist in nonanadromous form, with individuals residing in freshwater for the duration of their lives. The percentage of non-anadromous residents, and the amount of gene flow between resident and anadromous forms in Prairie Creek or the Redwood Creek basin has not been studied. Unlike other Pacific salmonids, steelhead exhibit iteroparous reproduction, i.e. they can spawn more than one time. Repeated spawning is more common in female than in male steelhead. In common with steelhead from many coastal streams of northern California and the Pacific Northwest, Prairie Creek steelhead belong to the fall or winter run type. Diminishing numbers of summer-run steelhead are found in the mainstem of Redwood Creek. Adults enter freshwater from the ocean with well-developed gonads in late fall and winter, and spawn shortly thereafter, usually between February and April. Juvenile steelhead normally smolt and enter the ocean at 1-2 years, with April and May the peak months for downstream migration of juveniles. Sparkman et al. (2015) reported that during the years 2011-2014, most steelhead in Prairie Creek smolted at 1 year; 2+ fish averaged 23% of the steelhead smolt population each year. The majority of steelhead spend 2 years in the ocean before their first spawning. A small number of "half-pounder" steelhead have been captured at downstream migrant traps (Sparkman et al 2014), but this life history is not prevalent in Prairie Creek, or Redwood Creek. Instances of repeat spawning have been observed in marked steelhead from Prairie Creek (Poxon 2012), but the frequency of repeat spawning has not been described from the basin.

Steelhead in Prairie Creek are within the Northern California Distinct Population Segment (DPS) which is federally listed as threatened under the Endangered Species Act. Few historical estimates (pre-1960s) of steelhead abundance are available. Relative to 1930s dam counts from the Eel and Mad rivers in Humboldt County, current population abundances within the ESU are low and continuing to trend downward. Steelhead numbers in Prairie Creek were enhanced by hatchery production beginning in the 1930's, when steelhead from the Sacramento River were introduced via the hatchery to supplement the sport fishery. Between 1972 and 1980, yearly production averaged 78,988 fish. The hatchery continued to produce steelhead until it closed in 1992. Trapping records for adult steelhead from 1972-1973 through 1982-1983 from the weir on Lost Man Creek, at the site of the hatchery, ranged from 5 fish (in 1974-1975) to 104 fish (1976-1977). Annual escapement of steelhead to Prairie Creek, estimated from redd observations, ranged from 0-67 from 1998/1999 through 2012/2013. Annual production of steelhead smolts from Prairie Creek averaged 7,059 during 2011-2014, representing approximately 16% of the total smolt population abundance in the Redwood Creek basin.

Although steelhead are the most widely distributed salmonid in the Redwood Creek Basin (Anderson 1988), the species is outnumbered by Coho Salmon and Cutthroat Trout in the Prairie Creek watershed. Distribution within the basin has been documented in mainstem Prairie Creek and tributaries including Godwood, Streelow, Boyes, Lost Man Creek and tributary Larry Damm Creek, Little Lost Man Creek. Most spawning occurs in the mainstem of Prairie Creek or in Lost Man Creek. Spawning requirements of steelhead are similar to those for Coho Salmon: preferred gravel size is dominated by gravel and small pebbles. Young of year are found in shallow riffles, and the heads of pools and runs during summer, and feed in faster water than do juvenile Coho Salmon. In winter, they are found along stream margins or pools with cover during winter, where they are likely to enter interstitial habitat within the substrate at temperatures below 4^{o} C. Yearling and older steelhead are found in in riffles or runs with wood or boulder cover in summer or in cool water pools with extensive cover. In winter, steelhead use backwater pools, secondary channel pools, and pocket water (Flosi et al. 1998).

Cutthroat Trout. – The Coastal Cutthroat Trout includes anadromous and non-anadromous life history forms. Tussing (2006) found both life history forms in headwater and lower reaches of Prairie Creek. The nonmigratory form includes fish that reside in small streams and headwater tributaries through their lives, where they grow more slowly and are smaller at maturity than are the anadromous fish. In anadromous forms, juveniles migrate from freshwater natal areas in late winter and spring to feed in estuarine or nearshore marine environments during the summer. Freshwater rearing prior to their initial seaward migration is typically two to three years. Unlike other anadromous salmonids, the Coastal Cutthroat Trout does not overwinter in the ocean. The fish return to freshwater in the winter to feed, seek refuge, or spawn, sometimes returning again to seawater in the spring. Cutthroat Trout typically spawn in small tributaries and headwater streams from December through June, with peak spawning in February. Peak emergence of fry occurs in mid-April. Rearing requirements of Cutthroat Trout are similar to those of steelhead, although the morphology of Cutthroat Trout is somewhat less specialized for fast water rearing (Hawkins and Quinn 1996). Peak months of downstream juvenile migration are in April and May.

A status review of Coastal Cutthroat Trout in Washington, Oregon, and California by the National Marine Fisheries Service in 1999 concluded that insufficient evidence exists to demonstrate that Coastal Cutthroat Trout are at a significant risk of extinction. At the same time, they concluded that "there is insufficient evidence to demonstrate that Coastal Cutthroat Trout are *not* at significant risk of extinction". Anecdotal reports compiled by Van Kirk (1994) suggest that sea-run Coastal Cutthroat Trout were very abundant in the Prairie Creek watershed during the late 1800's and into the early 1900's; their numbers have since declined considerably. They were determined to be overfished by sport anglers by 1925 (Van Kirk 1994), and populations declined further in response to habitat degradation during the 1950s to 1960s (Gerstung 1996). More recently, Duffy and Bjorkstedt (2009) reported that northern California Cutthroat Trout populations appear to be stable.

The Prairie Creek sub-basin supports nearly all of the Cutthroat Trout production in the Redwood Creek Basin, and they are found in nearly all Prairie Creek tributaries.

One of the earliest surveys of Cutthroat Trout in Prairie Creek was by DeWitt in 1954. Neillands (1984) found evidence of recent hybridization between steelhead and Cutthroat Trout based on gel electrophoresis; overall extent of hybridization using current genetic technologies has not established. Baumsteiger et al. (2005) cautioned that field crews commonly misidentify hybrids between these two species from visual field identification, particularly in juvenile fish.

The average population abundance of juvenile Coastal Cutthroat Trout moving past the trap in lower Prairie Creek from 2010 – 2015 (Fig. 9) was 5,782 (SD = 1595; SEM = 713 (Sparkman et al. 2015). Approximately half of these were classified as smolts; few were parr.

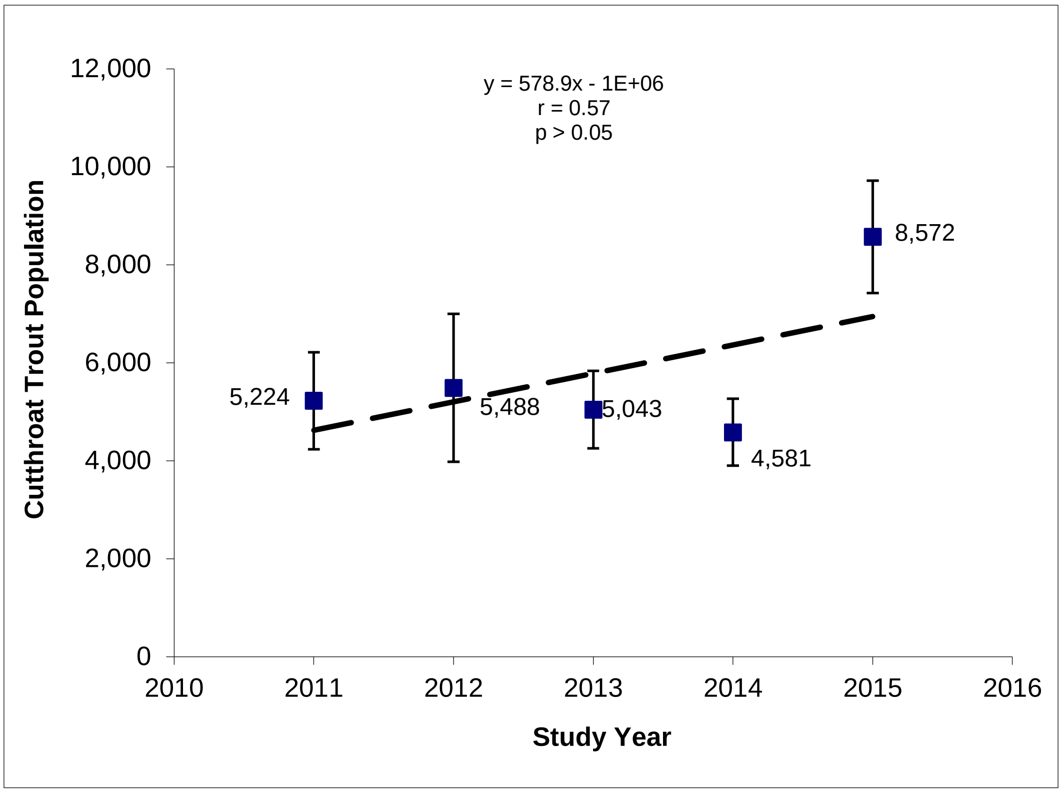

FIGURE 9. Estimates of Cutthroat Trout population abundance in Prairie Creek from 2011-2015. Error bars represent 95% confidence intervals. From Sparkman et al. (2015).

Salmonid Habitat Condition and Potential Limits to Production

Salmonid requirements in freshwater, at the beginning and end of anadromous life cycles, and throughout the life of resident fish, include: 1) an adequate supply of cool, clean water; 2) free access to migrate up and down their natal streams; 3) clean gravel suitable for successful spawning; 4) a food supply sufficient to enable growth; and 5) protective cover to escape predators and ambush prey, as well as velocity refuges during high flows.

Salmonid production will be limited if any of the above requirements are not met. Specific requirements vary among species and life history types, and needs may change seasonally, by life stage and the presence of other biota. For example, spawning requirements may not be met when high winter stream flows wash away nests or when gravels are silted. This is potentially more problematic for Chinook Salmon and Coho Salmon, which spawn near the beginning of the winter storm season, than for steelhead, which spawn later. Juvenile steelhead feed in faster water than do Coho Salmon and are likely to rely to a greater extent on drifting invertebrates as a food source; optimal pool-riffle ratios would not be the same for these two fishes. Coho Salmon are limited by stream gradient, as steeper streams lack the abundant, deep pools that these require.

Salmonid requirements in freshwater are provided by diverse physical, chemical, and biological conditions and the geomorphic (e.g. water and sediment transport) and ecological processes (e.g. primary and secondary production which determine food availability) associated with them. Stressors represent alterations in these conditions or processes which affect population abundance or viability. In the Recovery Plan for Coho Salmon in the southern Oregon/northern California ESU (2014), the National Marine Fisheries Service (NMFS) categorized potential stressors affecting various life-stage of Coho Salmon as lack of floodplain and channel structure, impaired estuary/mainstem function, impaired water quality degraded riparian forest, altered sediment supply or hydrologic function, barriers, adverse fishery and collecting-related effects, and adverse hatchery-related effects. The National Marine Fisheries Service (2014) also identified threats that cause or contribute to the stresses that are affecting Coho Salmon. For the Redwood Creek Basin, these included: climate change; existing roads; diking of lower Redwood Creek; grazing & agricultural practices in lower Prairie Creek; and invasive/non-native species. Findings for Coho Salmon are generally applicable to other anadromous Pacific salmon, and particularly for other salmonids with extended freshwater residence (i.e. steelhead and Coastal Cutthroat Trout).

The Prairie Creek sub-basin differs substantially in physical setting and in past and current land uses from the Redwood Creek drainage situated above the Prairie Creek confluence. For example, because of its lower gradient, broader floodplain, and coastal temperature regime, Prairie Creek offers a higher intrinsic potential to support production of Coho Salmon than does the middle and upper reaches of Redwood Creek. Thus, the NMFS ranking of stressors from the Redwood Creek Basin (NMFS 2014) is broadly applicable to Prairie Creek only below the Prairie Creek confluence (i.e., the population status of Coho Salmon in Prairie Creek is also impacted by degradation of lower Redwood Creek and the estuary). A subjective ranking by the report author of the severity of stresses affecting each life stage of the Prairie Creek population of Coho Salmon is offered in Table 7, founded on evaluation of available literature. While the literature suggests that oceanic conditions more strongly drive annual variability in population abundance of Coho Salmon and other anadromous Pacific salmon than does the freshwater environment (e.g., Gallagher et al. 2012), freshwater conditions are nonetheless critical in providing population resilience necessary to buffer against fluctuations in ocean survival.

Within Prairie Creek, and not considering impaired functionality of the Redwood Creek estuarine or lower river, population abundance of Coho Salmon is likely to be influenced through density-dependent growth and survival operating at the juvenile life stage (i.e., rather than egg, fry, or smolt life stages). Several studies have detected density-dependence in these population processes in Prairie Creek (e.g., Bjorkstedt et al. (2001) for density-dependent growth; Drobny (2016) for density-dependent overwinter survival) and elsewhere. Limiting resources are expected to vary seasonally and with discharge. During summer, constraints on prey availability and habitat volume imposed by low flows may be a bottleneck to growth and survival; during winters with frequent or high-intensity storms, availability of slow-water refugia and opportunities for feeding may be in short supply. Curiously, while Drobny detected density-dependence in overwinter survival of juvenile Coho Salmon, survival was not found to be affected by large, woody debris, cover, or pool depth. His study, however, was conducted in a water year in which the peak flow did not exceed bankfull discharge (i.e., recurrence interval of storm events was < 1.5 yr), and velocity refugia may not have been limiting.

Effect of seasonal limitations in resource supply interact; resource shortages in one season should not be construed as more limiting or important to population growth than bottlenecks during another season. For example, numerous studies in Prairie Creek and elsewhere in the Pacific Northwest have documented that over-winter survival of anadromous salmonids is positively correlated with body size. The ability to reach a large body size is critically dependent on resource availability in early summer, when Gonzales (2006) found salmonid growth to be most rapid. In recent years, overwinter survival estimates of juvenile Coho Salmon have been higher in Prairie Creek (Moore 2014, Sparkman et al. 2015, Wilzbach et al. 2016) than in other streams within the region, such as Mill Creek in Del Norte County. In comparison with Freshwater Creek, fewer juvenile Coho Salmon exhibited an early (fall) migration from Prairie Creek in fall of 2013 or 2014 (e.g., 2% of tagged fish in 2013 v. 30% in nearby Freshwater Creek (Rebeneck et al. 2015)), perhaps reflecting more favorable habitat conditions.

General stability in the production of juvenile Coho Salmon in Prairie Creek over the last decade of monitoring (Duffy 2011, Sparkman et al. 2014) suggests that the population is likely to be at or close to the carrying capacity of the creek, that is, the maximum, equilibrium population size that can be indefinitely supported in a given environment. However, carrying capacity likely differs between the pristine, old-growth upper reaches of Prairie Creek, and reaches in lower Prairie Creek which are affected by legacy impacts from timber harvest and road construction, and by past and current effects to riparian and floodplain functioning from grazing or other agricultural activities. Among tributaries, remaining impacts from prior land use most evidenced in Streelow Creek. Here, continued input of sediments from untreated source areas and persistence of legacy sediment loadings have resulted in loss of available habitat, and perhaps a reduced food supply and reduced foraging efficiency for fish. In the lower mainstem of Prairie Creek, carrying capacity of the stream to support aquatic production is likely to have been reduced as a result of historic removal of riparian vegetation, diking and ditching of the channel, and clearing of in-channel large, woody debris. Altered sediment supply and lack of channel and floodplain structure from legacy land uses in lower Prairie Creek appear to be the greatest stressors to salmonid production in the Prairie Creek Basin. These were conservatively ranked as medium-level stresses. A more detailed description of the status of each of the components affecting salmonid habitat condition (e.g., channel structure, water quality, etc.) follows.

Although the stressor occurs outside the Prairie Creek watershed, functioning of the lower mainstem of Redwood and its estuary cannot be dismissed as a critical factor limiting production of anadromous fishes in Prairie Creek. Loss of the floodplain connection in the lower river, and the large reduction in volume and impairment of water quality in the estuary are particularly problematic for juvenile Chinook Salmon and steelhead, which have been found to leave Prairie Creek earlier and at a smaller size than elsewhere in Redwood Creek. These fishes need to achieve greater growth in lower mainstem and estuary to improve probability of survival in the ocean.

TABLE 7. Subjective ranking by author of the severity of stresses affecting life stages of the Prairie Creek population of Coho Salmon, based on evaluation of available literature and patterned after the template of stressors from NMFS (2014). Table does not include operation of stressors in lower Redwood Creek or the Redwood Creek Estuary.

Stresses		Egg	Fry	Juvenile[1]	Smolt	Adult	Overall Stress Rank
1	Lack of floodplain and channel structure[1]	Low	Low	Medium	Low	Low	Low
2	Impaired water quality	Low	Low	Low	Low	Low	Low
3	Degraded riparian forest condition	-	Low	Low	Low	Low	Low
4	Altered sediment supply[1]	Medium	Medium	Medium	Low	Low	Medium
5	Increased biological interactions or disease	Low	Low	Low	Low	Low	Low
6	Altered hydrologic function	Low	Low	Low	Low	Low	Low
7	Adverse fishery- and collection-related effects	-	-	Low	Low	Low	Low
8	Barriers	-	Low	Low	Low	Low	Low
9	Adverse hatchery-related effects	Low	Low	Low	Low	Low	Low

[1] Key limiting stresses and limited life stage.

Floodplain and Channel Structure

The pristine, upper watershed of Prairie Creek offers some of the highest quality salmonid habitat within coastal northern California. Tributaries in the most heavily disturbed catchments (Streelow, May, Larry Damm, and North, Middle, and South Forks of Lost Man Creek, Fig. 4) and in the lower mainstem of Prairie Creek likely offer reduced carrying capacity to support salmonid fishes. Sites still recovering from legacy impacts are expected to provide increasing habitat quality with time and/or appropriate management activities.

Indicators of the status of channel structure relative to its capacity to support salmonid populations and a diverse aquatic biota include the median substrate particle size (D50), spacing and depth of pools, large woody debris frequency, and development of alcoves, side-channel, and off-channel (floodplain) habitat. Each of these components is briefly reviewed.

Substrate particle size.

– Particle sizes of streambed substrate in Prairie Creek reflect underlying bedrock and stream gradient. Hillslopes are predominantly underlain by unconsolidated to weakly consolidated silts, sands, and gravels, and much of the stream length in the Prairie Creek watershed has a relatively gentle gradient (approximately 40%of stream length ≤ 4% gradient; 84% of stream length ≤ 25% gradient) (Klein 1999, Cannata et al. 2006). Streambed substrate consists largely of sands, fine gravel, and pebble (Janda et al. 1975, cited in Cannata et al. 2006). Lisle (1989 found that median particle size in Prairie Creek equaled 21.5-25.5 mm, with a majority of its surface material falling within the preferred range of sizes used by spawning salmon (80% was between 10 and 100 mm). Madej et al. (2006) reported a range in median particle sizes at several locations in Prairie Creek study sites from 18 mm (Godwood Creek) – 147 mm (Little Lost Man Creek at gage). Seney and Weinberg (2016, in prep.) found that the dominant substrate in Prairie Creek near Elk Meadow is cobble, while Prairie Creek from the confluence of Lost Man Creek to the confluence with Redwood Creek is gravel and sand.

Klein (1999) reported results of 9 years of monitoring by RNSP and others of physical conditions in Prairie Creek associated with the Highway 101 bypass construction. Streambed surfaces in streams affected by the 1989 bypass erosion event were extensively covered with silt, and fine sediments infiltrated into the substrate, potentially affecting egg survival in salmon redds. Most of the silt was flushed downstream during the first runoff season in water year 1990; some of the material may have infiltrated into coarse gravels farther downstream in Prairie Creek. Tracking of subsurface fines in Prairie Creek was discontinued in 1995.

Embeddedness, which describes the percent of cobbles or gravel at a pool tailout which are covered with fine sediments, is commonly used as an indicator of increased sediment supply. High embeddedness reduces intra-gravel water flow, which may result in suffocation of salmon eggs or developing embryos, and reduces substrate complexity for benthic organisms. NMFS (2014) established rankings of stream habitat suitability with respect to embeddedness as: Very Good (low embeddedness): ≤ 25%; Good: 25-30%; Fair: 30-45%; and Poor: >45%. Cannata et al. (2006) found the best ratings to be in May, Godwood, and a site in upper Prairie Creek, and the lowest ratings in Brown and Boyes creeks. RSNP measured substrate embeddedness at six reaches in Prairie Creek in fall 2015 (Seney and Weinberg, in prep.). Embeddedness was observed to be somewhat higher at sites: South of Davison Bridge, South of Lost Man Creek, and South of 101 Bridge [all with scores of 3.0] than at reaches north and south of the campground, where scores were 2.5 and 2.7.

Pool Spacing.
- Salmonid and other vertebrate consumers require a diversity of erosional (riffles, runs) and depositional (pool) habitat types for various life history stages, and species differ in optimal ratios of habitat types within life stage categories. Coho Salmon parr, for example, have a higher requirement for pools and slow velocity water than do steelhead parr, which rear in higher velocity waters. Pool spacing is often expressed as a ratio of the number of bankfull channel widths per pool. In undisturbed forested streams of the Pacific Northwest, the frequency of pools is controlled by channel slope, type, and width, and by loading of large, woody debris (LWD) (Montgomery et al. 1995). Pool spacing in steep, step-pool channels is independent of large woody debris. However, mean pool spacing in pool-riffle, plane-bed, and forced pool-riffle channel reaches decreases as the supply of large woody debris increases, from greater than 13 channel widths per pool to less than 1 channel width per pool. Values of 2-7 channel widths per pool are typical in streams of the northern California coast. In pool-riffle and plane bed reach types, pieces of large wood have been found to force the formation of approximately 40% of the pools. Reaches flowing through previously logged forests tend to have lower loading of large woody debris and consequently fewer pools than reaches in pristine forests.

CDFW considers pools composing 40% or more of stream length as a desirable standard for anadromous fish habitat (Flosi et al. 1998). NMFS (2014) ranked streams with pool frequency > 50 % by length, and > 35% by area, as very good for recovering Coho Salmon. Several reaches in the Prairie Creek sub-basin fail to attain these standards. Cannata et al. (2006) reported a channel width:pool ratio of 5:1 in a sample of 10 reaches within the Prairie Creek sub-basin, with pools comprising an average of 27% of stream length. The lowest percentage of pools was found in Boyes Creek (19%), and the highest was found in a reach of Lost Man Creek (47%). Pool spacing was not notably greater in pristine reaches (Godwood and Prairie above Brown Creek, with 26 and 20%

pools by length, respectively) than in more disturbed locations. Lack of correspondence of pool spacing with disturbance suggest that single numeric targets, without consideration of the suite of factors affecting pool formation (e.g. channel width, slope, type) may not be meaningful in Prairie Creek.

Pool Depth. - The amount of deep pool habitat is a commonly used indicator in watershed assessments, as deep pools provide year round habitat for rearing juvenile salmonids such as Coho Salmon, and are important holding areas for adult salmonids during spawning migrations. Landscape disturbance can cause loss of deep pools and limit fisheries productivity. Low gradient reaches may be particularly sensitive to pool filling and accumulation of fines from an increased sediment supply. Residual pool depth is likely to be negatively correlated with stream gradient and stream size, and positively correlated with watershed area. Based on an Environmental Decision Management Support model, lack of deep pools was the habitat factor most often identified as limiting to salmonid production in Prairie Creek in the CDFW Assessment of the Redwood Creek Basin (Cannata et al. 2006). This conclusion, however, is not fully consistent with fisheries data.

Target values used in the watershed assessment of pool condition of anadromous salmonid habitat in North Coast California streams were pools with maximum depth of from 0.61-0.76 m for 1st and 2nd order streams, 0.91 m for 3rd order streams, and >1.22 m deep for 4th order streams. Pools were often below target values for depth in Prairie Creek. Mean maximum depth for pools was 0.55 m for 1st and 2nd order streams, and 0.82 m for Prairie Creek. Results of summer habitat surveys conducted in association with fish sampling in Prairie Creek above Brown Creek, Streelow, and Boyes creeks during 1998-2004 were summarized by Duffy (2012). Despite finding the shallowest pool depths and lowest pool volume in Boyes Creek, densities of Coho Salmon were also greatest there. Duffy attributed this to the concentrating effect of pools at low flow, but expression of fish abundance as density (numbers per unit area) already corrects for area.

Large Woody Debris. – Large woody debris (LWD) plays important structural and functional roles in lotic ecosystems. It affects channel morphology through the formation of pools and stabilizes the channel, affects sediment routing through the formation of depositional sites, retards the export of organic matter and strongly affects carbon cycling, and provides habitat and cover for fishes and invertebrates. Past timber harvest degraded riparian forests in Prairie Creek, decreasing the number of large conifers and reducing the potential for recruitment into the channel of a supply of slowly-decomposing wood. Early settlers cleared wood from streams to facilitate movement of logs and prevent formation of log jams. Hatchery records indicate that fishery managers also cleared wood from the creek to ensure fish passage (Van Kirk 1994). Loss of wood from Prairie Creek, as elsewhere, reduced habitat complexity for aquatic biota. Keller et al. (1985) found that nearly all the pools in the upper reaches of Prairie Creek are either directly formed by large, woody debris or are influenced by it; in the lower reaches, approximately 50% of the pools are influenced by large organic debris.

Loading of large wood to streams naturally decreases as stream size increases (Bilby and Ward 1991), thus it is not clear the extent to which the reduced amount of large wood in lower Prairie relative to upper reaches in Prairie Creek reflects legacy impacts or natural processes. For example, Bilby and Liken (1980) found that 75% of organic matter stock was stored in LWD in 1st-order streams, 58% was stored in 2nd-order streams, and only 20% was stored in 3-rd order streams in a New Hampshire watershed. Target values established by NMFS (2014) for assessing floodplain and channel structure using LWD as an indicator of habitat suitability for Coho Salmon were adjusted for channel size, such that habitats ranked as good included 54-84 pieces of wood/mi in channels with a wetted width of < 20 ft, 37-64 pieces in channels 20-30 ft wide, and 34-60 pieces in channels > 30 ft wide. Key pieces of LWD (with a minimum diameter of 60 cm and a minimum length of 10 m) per 100 m should number 2-3 in a 'good' habitat, and exceed 3 pieces in a 'very good' habitat. The biological basis for these targets is not clear. Solazzi et al. (2000) and others showed that adding wood to historically cleared streams on the Oregon coast increased over-winter survival of juvenile Coho Salmon, but the precise quantities and volumes of wood required for maximum salmonid production are not well understood.

Surveys of LWD in Prairie Creek include unpublished surveys for RNP by: 1) Klein and Kramer above Streelow Creek; 2) a 2015 survey by the USGS Coop (Deibner-Hanson) in the mainstem from the confluence with Redwood Creek to the causeway, in Streelow Creek to the 1st large tributary confluence, in Godwood Creek from the confluence with Prairie Creek upstream 1.5 km, and May Creek, from the Prairie Creek confluence to the Highway 101 culvert; and 3) a 2015 survey by Seney and Weinberg extending from the mouth of Prairie Creek to its confluence with Lost Man Creek and from just south of the Prairie Creek Redwoods State Park Visitor Center to 1.5 miles north of the visitor center. A thesis in preparation by Deibner-Hanson will also include LWD survey data from mainstem reaches, paired with reach-specific movement and overwinter survival of juvenile Coho Salmon.

Data from Deibner-Hanson suggest limitations in the NMFS targets for LWD (Fig.10). Number of key pieces, sized as XX in the figure, would place pristine upper Prairie Creek only in the good rather than very good category, at 2.6 key pieces/100 m; key pieces in the lower reach (0.97/100m) are not abundant enough to rank the reach as good. Lower Prairie Creek has more total pieces of LWD/km than does Upper Prairie Creek, but a lower total volume of wood (Fig. 11), suggesting that more of its wood is smaller in size and likely to include a larger component of red alder and other riparian hardwoods. Choice of the metric used to characterize LWD (e.g. density or volume) matters, as the most appropriate metric will vary with the ecosystem role of LWD that one is interested in assessing. Density (no. of pieces) of LWD/km of channel length would be expected to correlate with density of salmonids/km. The positive effect of LWD density on salmonid density is mediated through increased pool frequency and cover that protects fish from predation or displacement at high flows. Carbon cycling (wood processing) and growth or condition of salmonids may correlate better with volume of LWD of channel, inventoried by tree species, than with density of LWD. The basis of this correlation would be processing of the LWD by hyphomycete fungi and gouging shredder invertebrates. Tree species matter in carbon cycling, as carbon cycling and use by shredding invertebrates follows the same trajectory as litter of the same tree species: alder and maple leaves and wood decompose slowly; conifers, oak, and bay are processed slowly.

FIGURE 10. Tallied large woody debris pieces per kilometer by size class in Prairie Creek, Humboldt County, California during summer 2015. The first letter indicates the diameter size class; the second indicates length. Diameter size class abbreviations are as follows: S = Small (10-15 cm), M = Medium (15-30 cm), B = Big (30-60 cm), X = Extra Large (>60 cm). Length size classes are: S = Small (1-3 m), M = Medium (3-6 m), B = Big (6-15 m), X = Extra Large (>15 m). The "impaired" watershed contains the lower 7.8 km of main stem Prairie Creek which was managed for timber harvest until the late 1970's. The "unimpaired" watershed contains the uppermost 13.7 km of pristine Prairie Creek which lacks commercial logging history. Data and figure are from Deibner-Hanson.

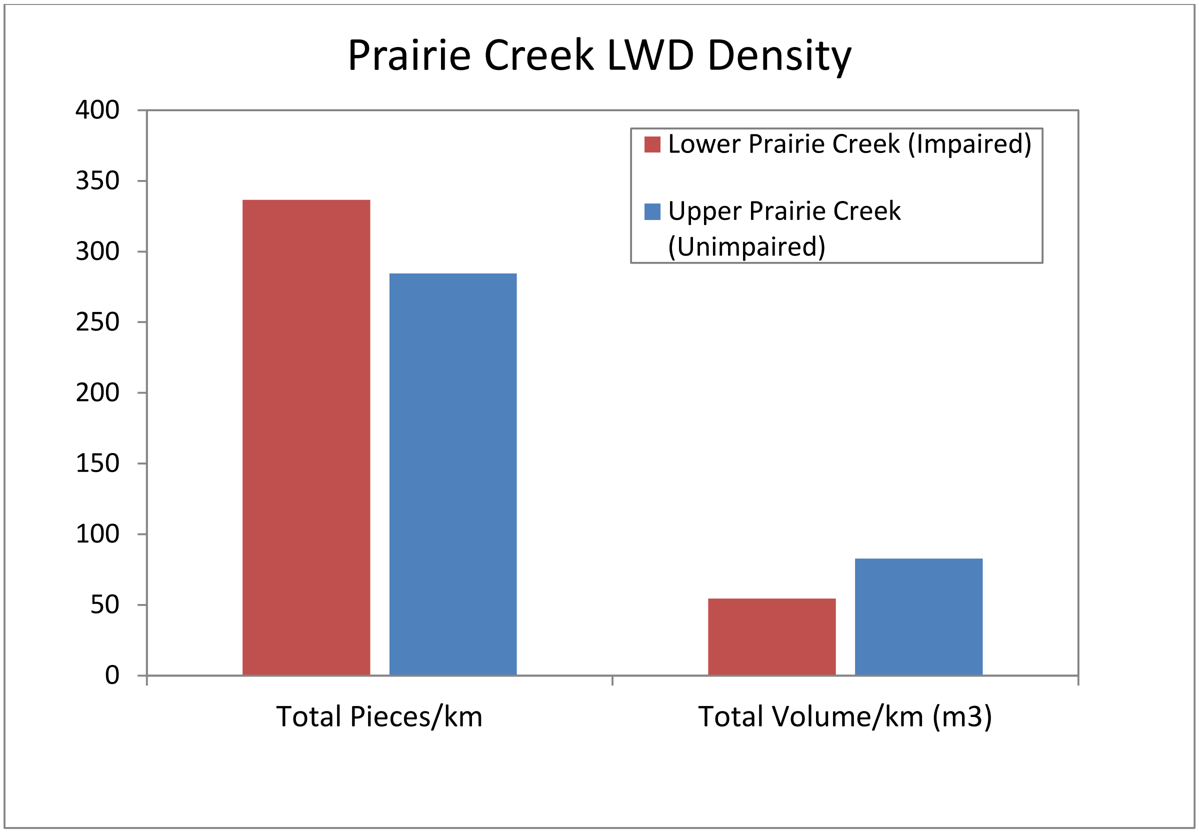

FIGURE 11. Large woody (LWD) debris densities in total pieces and total volume from LWD surveys in Prairie Creek, Humboldt County, California, summer 2015. The "impaired" watershed contains the lower 7.8 km of main stem Prairie Creek which was managed for timber harvest until the 1970s. The "unimpaired" watershed contains the uppermost 13.7 km of pristine Prairie Creek which lacks commercial logging history. Data and figure are from Deibner-Hanson.

Floodplain Connectivity. - Overwinter survival and rearing success of juvenile salmonids is strongly dependent on provisioning of complex, slow water habitats, including alcoves, side-channels, backwaters, sloughs, and beaver ponds from unconstrained reaches in low-gradient streams such as Prairie Creek. Bell (2001) compared habitat fidelity and survival of juvenile Coho Salmon rearing in alcoves versus main channel pools and other habitats of the Prairie headwaters, and found higher survival in alcoves during a winter of high flows. Riparian clearing, and ditching and diking of lower Prairie Creek in association with agricultural and timber harvest activities reduced hydrological connectivity between the channel and floodplain, and legacy effects remain.

NMFS (2014) used professional judgement rather than numeric indicators of floodplain connectivity in assessing stresses to habitat suitability for recovering Coho Salmon in Redwood Creek. A separate assessment of Prairie Creek is not available.

Differences among catchments in floodplain area within Prairie Creek (Table 1), based on the National Wetland Inventory, suggest that the potential for complex side-or off-channel rearing available for overwintering juvenile salmon is variable. The detailed vegetation map of the lower Prairie Creek floodplain prepared in 2015 by Seney and Weinberg (Fig.12) evidences legacy and current effects of grazing and other land uses, particularly in the presence of non-native species and man-made structure.

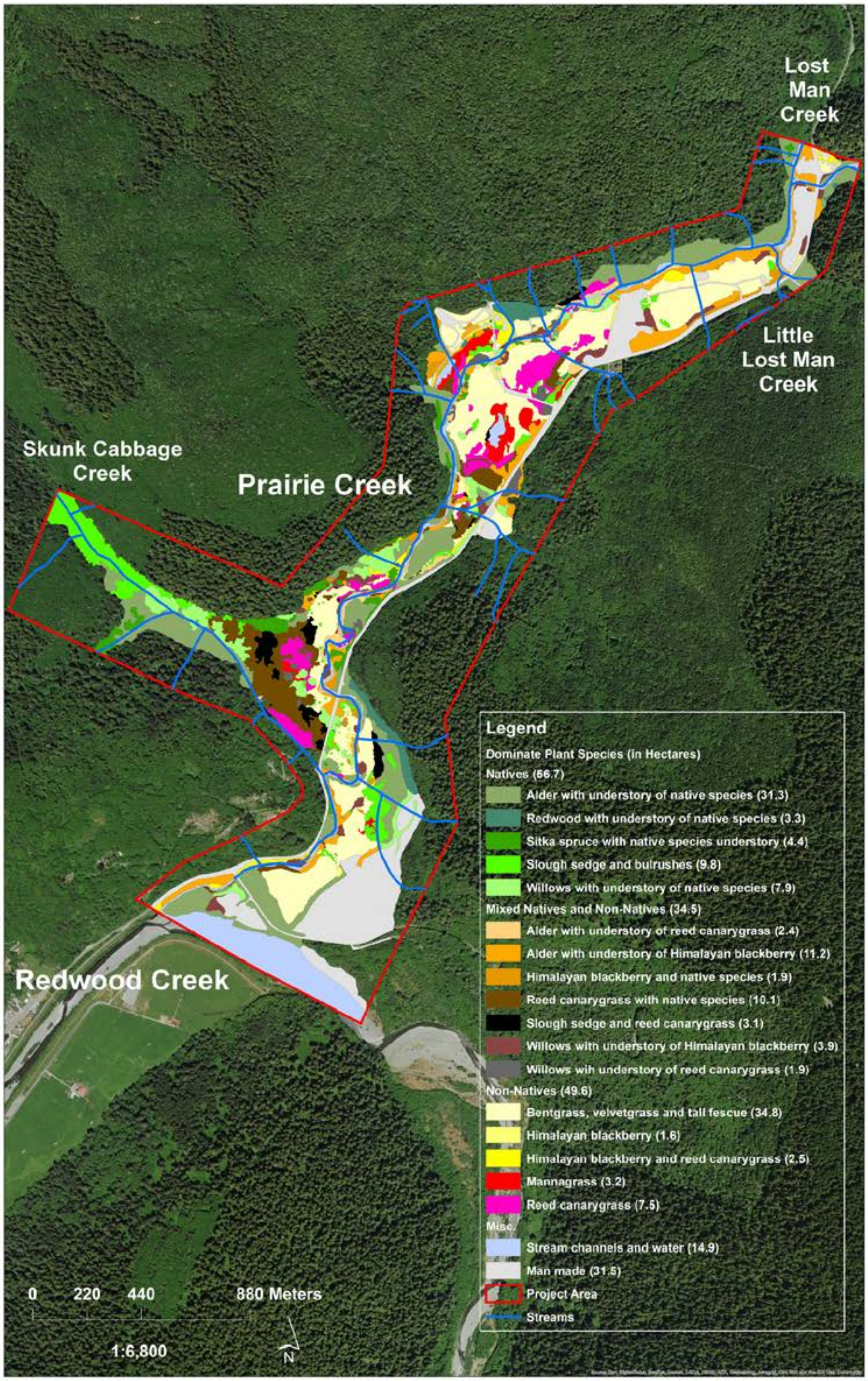

FIGURE 12. Vegetation map of the lower Prairie Creek floodplain. Survey and map from Seney and Weinberg (2015).

Water Quality

Parameters considered here include water temperature, dissolved oxygen concentration, and pH and alkalinity. Turbidity is discussed under Sediment Supply and Hydrological Function. Water quality targets are specified by the California North Coast Regional Water Quality Control Board for the Redwood Creek Hydrologic Unit or generally for freshwaters with designated beneficial uses for cold water. Water quality objectives may be accessed online at: http://www.waterboards.ca.gov/northcoast/water_issues/programs/basin_plan/083105-bp/04_water_quality_objectives.pdf. Nutrient concentrations are not generally included in water quality assessment by NMFS or the Water Board, but may strongly affect aquatic productivity. In contrast to streams impacted by agricultural activity or urbanization, where nutrients may be present in excess, the nutrient-poor water in Prairie Creek may play a role in limiting aquatic primary production. Overall water quality in Prairie Creek is excellent.

Temperature.

- Temperature is a master environmental variable in stream ecosystems. Ecosystem processes, including decomposition, primary production, community respiration, and nutrient cycling, are all temperature dependent. Most stream organisms are ectothermic; their metabolism, growth, life cycles and overall productivities of populations are all temperature dependent. Elevated water temperature, which may result from water diversion, alteration of the streambed and banks, removal of riparian vegetation, and other human activities, is one of the most widespread and greatest stresses facing listed salmonid species.

In a review of laboratory and field studies of temperature effects on salmonid fishes in the Pacific Northwest (Region 10), USEPA (1999) concluded that temperatures of approximately 22-24° C limit salmonid distribution generally, and they designated 16 ° C as the seven-day average of the daily maximum temperatures (7-DADM or MWMT) temperature that should not be exceeded in areas designated as core rearing locations (USEPA 2003). Temperature needs of differing life stages of steelhead, Coho Salmon, and Chinook Salmon are summarized in Carter (2005).

Although Redwood Creek is listed as temperature impaired under section 303(f) of the Clean Water Act and high summer water temperature is believed to limit the distribution of juvenile Coho Salmon in the mainstem Redwood Creek (Madej et al (2006), water temperature in Prairie Creek is largely fully suitable throughout the year to support production of salmonid and other cold water fishes (Fig. 13). However, Prairie, Lost Man and Little Lost Man creeks exceeded an MWMT of 16 ˚C. in some years prior to 2007.

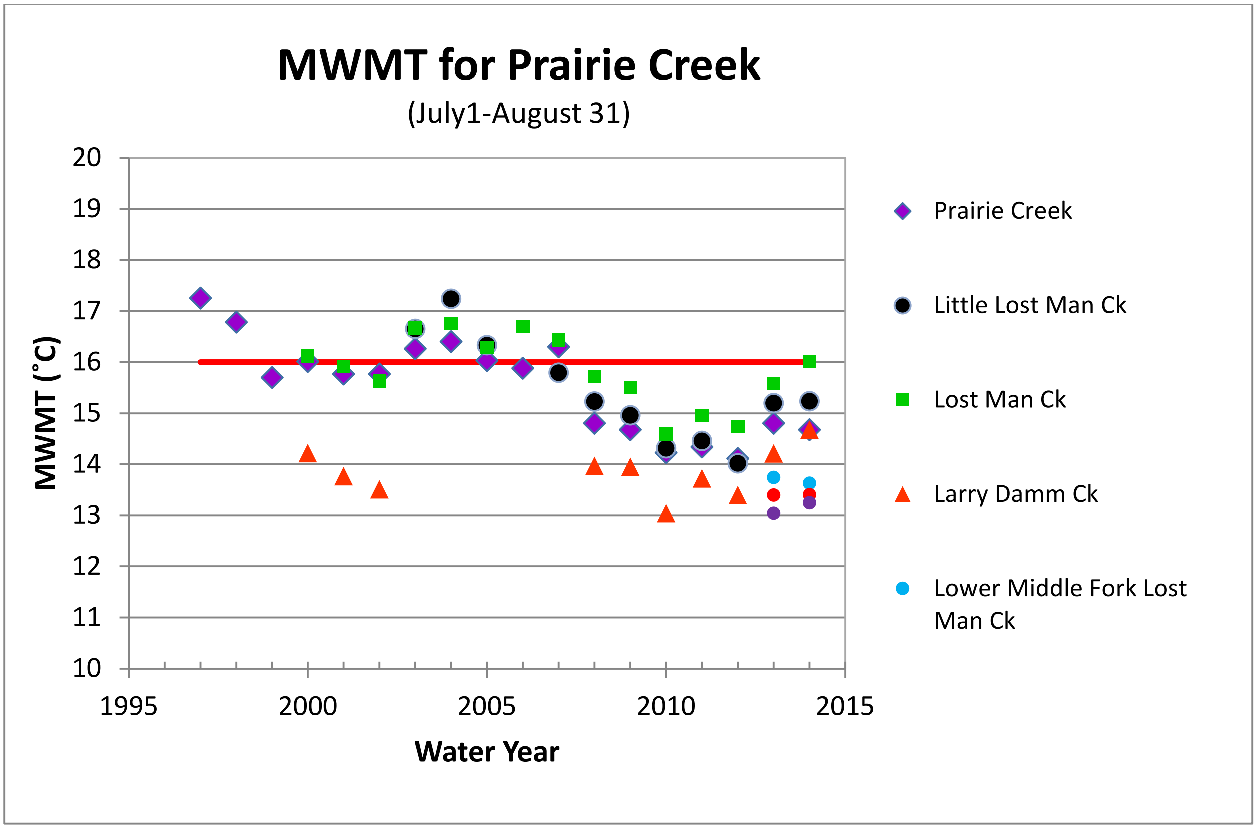

FIGURE 13. Maximum weekly maximum temperature in the Prairie Creek sub-basin, Jul 1-Aug 31, 1997-2015. Figure prepared by V. Ozaki from RNSP database.

Stream temperature has been continuously monitored during summer months (Jun-Sept) by RNSP at a number of sites since the 1997, and annual reports with temperature statistics from Jul 1- Aug 1, the period with the warmest temperatures, have been compiled for each station (Table 8; data available on request from RNSP). Two of the sites (Prairie at Wolf Creek Bridge and Little Lost Man) are in pristine locations; other monitoring sites are in watersheds impacted by past land use.

TABLE 8. Monitoring locations of summer water and air temperature in Prairie Creek by RSNP, and years of record.

Location	Years	Medium Monitored
Prairie Creek at Wolf Creek Bridge	1997-2014	Water, Air
Lost Man Creek at the Hatchery	2000-2014	Water
Larry Damm Creek	2000-2002, 2008-2014	Water
Lost Man Creek Lower Middle Fork	2013-2014	Water
Lost Man Creek Upper Middle Fork	2013-2014	Water
Lost Man Creek South Fork	2013-2014	Water
Little Lost Man Creek at gaging station	2003-2014	Water, Air

Numerous other studies conducted in Prairie Creek since the 1970s have included some temperature data, but temperature has not been routinely monitored throughout the year. Beesley (2006) reported an annual degree-day accumulation (i.e. the summation of daily mean temperatures above 0° C) of 3473 degrees in Prairie Creek during the 1999 water year. Degree-day accumulation is ecologically relevant to stream biota as it affects life cycle timing in many organisms and voltinism (the number of generations per year) in invertebrates. Salmonid egg development and emergence from redds is related to accumulated water temperature, with fry emergence beginning at approximately 700 degree-days (Sparkman 2003). Among invertebrates, most mayflies require 2000+ degree-days to complete one generation from egg to adult. If the required number of generations are not provided within a year, two or more years will be required to complete a generation. Invertebrate taxa with more rapid turnover provide more continuously available prey for fish and amphibian predators.

Dissolved Oxygen (DO). -
An adequate concentration of dissolved oxygen in stream water is essential to the respiratory metabolism of most aquatic organisms. The water quality objective for dissolved oxygen is 6.0 mg/L. During critical salmon spawning and egg incubation periods, the objective is increased to 9.0 mg/L, to maintain adequate intra-gravel oxygen for developing embryos. Intra-gravel oxygen concentrations are typically around 3 mg/L lower than water column measurements (US EPA 1998); thus a water column DO reading of 9.0 mg/L would correspond to an intra-gravel oxygen concentration of 6.0 mg/L. Life-stage and species-specific requirements for dissolved oxygen for Chinook Salmon, Coho Salmon, and steelhead were provided by Carter (2005b).

Low dissolved oxygen concentration is not problematic in Prairie Creek. Mean summer concentrations in 2014 at 4 stations (Prairie above Wolf Creek bridge, May, Streelow, and Skunk Cabbage) measured by RSNP all exceeded the objective. Woods (1980) reported that the weekly mean of intra-gravel oxygen in Little Lost Man Creek from June-November 1974 averaged 9.6 mg/L. In a previously logged section of a tributary to Lost Man Creek during the same time period, the weekly mean concentration of intra-gravel oxygen was 6.6 mg/L. Intra-gravel oxygen concentration following input of sediments from the highway 101 bypass project following a 1989 storm did not differ between stream reaches upstream of and below the sediment input (Roelofs and Sparkman 1999).

pH and Alkalinity. -
The solubility and biological availability of nutrients and heavy metals is affected by pH, which also affects many cellular processes of aquatic organisms. The water quality objective established in 2011 by the California North Coastal Regional Water Quality Board for pH ranges from 6.5-8.5. Alkalinity measures the capacity of water to absorb hydrogen ions, buffering changes in pH. Buffering

capacity is primarily due to the presence of bicarbonate and carbonate ions, and is usually measured as mg/L of calcium carbonate. Alkalinity is frequently positively correlated with stream productivity and with taxonomic richness. Water with alkalinity less than 20 mg/L has little capacity to buffer acidic inputs and has been often found to support a greatly reduced diversity of aquatic organisms, particularly of mollusks and crustaceans. The fairly low alkalinity of Prairie Creek water may make it more resistant to invasion by the exotic New Zealand mudsnail.

During summer 2014, RNSP reported mean pH values at 4 sites in Prairie Creek (Prairie above Wolf Creek Bridge, mouth of May Creek, mouth of Streelow Creek, and Skunk Cabbage Creek) of 7.2, 7.1, 6.8, and 5.9, respectively, from continuous water quality monitors recording hourly measurements. The pH of Skunk Cabbage Creek was below the criterion value; values from the other sites are in compliance and consistent with previous measurements of pH. Anderson (1988), for example, reported pH values of 6.7, 6.8, and 7.0 for Prairie, Wolf (Streelow), and Little Lost Man creeks, respectively. Bradford and Iwatsubo (1978) found that pH was higher (7.5) in the dry than in the wet season (6.8). Alkalinity has been measured in Prairie Creek infrequently. Anderson (1988) reported values ranging from 16-22 mg $CaCO_3$/L at the same sites mentioned above. At 5 sites on mainstem Prairie extending from above Ten Taypo Creek to the confluence with Redwood Creek, alkalinity ranged from 30-37 mg $CaCO_3$/L and jumped to 64 m mg $CaCO_3$/L below the confluence with Redwood (Mushet 1990).

Sediment Supply and Hydrologic Function

Functioning of a stream ecosystem depends on a balance of instream structure such as large wood or boulders, transport capacity, and sediment supply (Yarnell et al. 2006). Diverse benthic communities and successful spawning of salmonid fishes cannot be supported without a sufficient influx of sediment particles to provide heterogeneous streambed substrate, or without the flushing downstream of sediments present in excess. Alteration in the quantity, composition, or timing of sediment supply from land use activities such as timber harvest or road construction may be manifest in the suspended load or in deposited sediments stored within the channel. An increase in the suspended load of fine sediments increases turbidity, reducing light penetration for photosynthesis of aquatic plants and foraging efficiency and growth of visually feeding consumers. Suspended sediments may also abrade gill or soft tissues of vertebrate and invertebrate consumers, and scour benthic surfaces. Turbidity can have positive effects on fish by reducing predation risk. Deposition of sediments which are not transported downstream in the suspended load disturbs stream communities by smothering benthic invertebrates and redds of fishes, and reducing the primary production that fuels the food web. Increases in deposited sediments can substantially affect channel morphology through filling of pools and channel widening, burying large, woody debris, and severing the channel connection with riparian or floodplain areas. Adverse effects of increased sediment supply on channel form and aquatic biota may be particularly persistent in low-gradient streams, where streams may have sufficient power to transport sediments only during infrequent, high magnitude flows.

Indicators of altered sediment supply, and rankings established by NMFS (2014) for assessing the degree to which Coho Salmon in the southern Oregon/northern California ESA are stressed by altered sediment supply include, among other indicators, percent embeddedness and turbidity. For turbidity, expressed as numbers of hours per year exceeding 25 FNUs, rankings of stream habitat suitability are: Very Good: <120; Good: 120-360; Fair: 361-720; and Poor: >720. Inconsistencies exist in the literature with respect to the threshold of impacts to salmonids; some recent work suggest that these target values may be too conservative (e.g., White and Harvey 2007, Harvey and Railsback 2009). Measurements of turbidity in Prairie Creek are presented here; substrate embeddedness data are discussed in the section on substrate particle size.

The Redwood Creek basin was listed on California's Clean Water Act Section 303(d) beginning in 1992 as sediment impaired. High sediment loads and the level of sedimentation in the basin was judged to exceed existing criteria for supporting its coldwater fishery, and a TMDL (total minimum daily load) which established instream numeric targets was completed in 1998 to address sediment supply problems. The TMDL for Redwood Creek acknowledged differences in the severity of sediment impairment between Prairie Creek and the rest of the Redwood Creek basin. The TMDL sediment load analysis demonstrated that most sediment inputs came from logging and road building; and Prairie Creek has had less human disturbance than the rest of Redwood Creek. For this reason, the TMDL used Little Lost Man Creek to establish reference conditions for sediment in an undisturbed setting.

RNSP began operating gaging stations in Prairie Creek in 1990 to assess the impacts and persistence of fine sediment eroded into Prairie Creek from the highway 101 bypass construction project, and later to assess impacts from road removal projects, especially in Lost Man Creek. Gaging stations provide continuous stage and turbidity data, monitor stream discharge and collect suspended sediments using automated pumping samplers controlled by turbidity threshold sampling. At present, RNSP operates three long-term gaging stations at Little Lost Man Creek (pristine), Lost Man Creek at the Hatchery (logged and most roads recently removed) and Prairie above Boyes Creek (pristine).

Klein (1999) summarized results of 9-yrs of physical monitoring of control and impacted stream reaches to assess impacts and their persistence associated with the Prairie Creek bypass construction. Suspended sediment flux varied primarily as a function of the magnitude of winter stormflows. Subsequent to a large spike in sediment transport during the October 1989 storm, suspended sediment discharge measured at gaging stations settled down to levels which varied more with peak flow than with degree of sedimentation from the bypass, except in Boyes Creek. In Boyes Creek, unit suspended sediment flux was over ten times higher than at Prairie Creek below Brown Creek in 1996. That same year, total suspended sediment yield from Boyes Creek comprised 85% of that passing Prairie Creek above May Creek, while Boyes Creek comprises only about 13% of the contributing drainage area. This was attributed by Klein to historic timber harvest in Boyes Creek, but bypass erosion, both from the October, 1989, storm and later erosion events, may also have contributed significantly to the high suspended sediment discharges continuing in Boyes Creek. Biological impacts from bypass erosion were summarized by Meyer and Haux (1995). Degraded gravel quality in subsurface spawning gravels in Prairie Creek, particularly downstream from Boyes Creek, may have had an adverse effect on salmon egg survival in water year 1990.

Findings from 2003 – 2011 monitoring of erosion and turbidity in associated with road removal projects in Lost Man Creek were summarized by Klein (2012). Excavations of stream crossings contributed large amounts of sediment on occasion, but contributions decreased rapidly over time. suspended sediment yields and peak storm turbidities varied directly and linearly with treatment intensity. The road work, which was completed in 2010, is expected to reduce suspended loads and turbidities over coming years. Legacy and natural erosion and delivery are likely to continue indefinitely on an episodic basis.

Klein and Marquette (2010) presented annual suspended sediment yield data, in tons/square mile, from water years 1990-2011 among catchments in Prairie Creek. The high yield at Lost Man Creek in 2011 evidences the road removal and legacy and natural erosion mentioned above. Recent among-catchment data on chronic turbidity levels within Prairie Creek, as numbers of hours per year exceeding 25 FNU, have not been reported, and thus catchments cannot be ranked according to NMFS criteria for this metric.

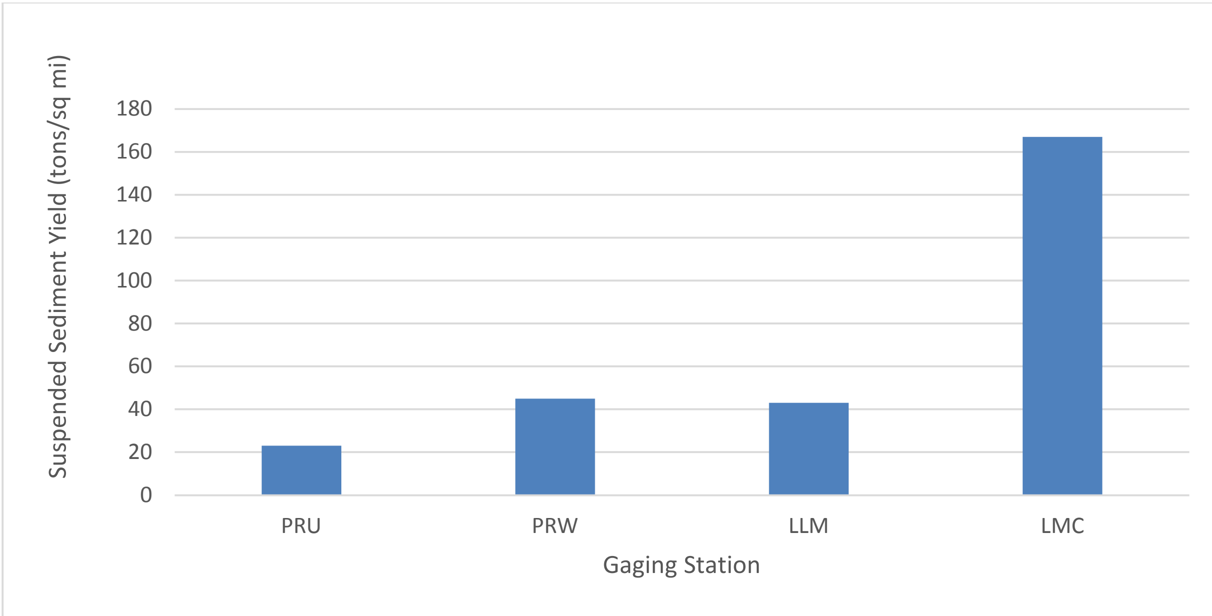

FIGURE 14. Annual sediment yield in water year 2011 at gages on Prairie Creek above Brown Creek (PRU), Prairie Creek above May Creek (PRW), Little Lost Man Creek (LLM), and Lost Man Creek at Hatchery site. Data are from Klein and Marquette (2010).

Hydrological function in Prairie Creek is not impaired by dams or large diversions. The state park campground at Elk Prairie and NPS housing and a fire cache within the national park boundaries are supplied with small amounts of water from wells. The extent to which hydrologic function may have been altered or recovered from previous timber harvest or floodplain alteration is not known. Road density can be a useful indicator of altered hydrologic function, as road density affects speed of delivery, path by which water is routed to stream, and peak flows from storm events. Overall road density in Prairie Creek (1. 67 km/km^2, or 1.04 mi/mi^2) place it in a very good category using NMFS (2014) targets. (VG < 1.6 mi/mi^2; G 1.6-2.5; F >2.5-3; P >3.

Riparian Vegetation

The riparian zone bordering a stream interacts with the channel and strongly affects structure and functioning of aquatic ecosystems. Riparian vegetation affects the amount of direct sunlight reaching the stream, which in turn affects water temperature and aquatic productivity. Its supplies inputs of litter and terrestrial invertebrates important in supporting aquatic food webs, and large woody debris important in creating habitat complexity. Riparian vegetation also protects streambank from erosion, intercepts sediments and nutrient runoff, and moderates discharge during storm events.

Among the attributes of riparian conditions included in watershed assessment protocols by CDFW (2012) and NMFS (2014) are the percentage of canopy shading provided to the stream, and the relative percentage of riparian trees that are composed of conifer and hardwood. A target of ≥ 80% canopy shading in streams supporting anadromous salmonids was established to reduce direct sunlight from warming water (Flosi et al. 1998). The importance of sunlight in fueling the food web, however, is overlooked in this assessment. Riparian composition affects the potential for LWD recruitment, as streams flowing through stands of mature conifer tend to have larger amounts of wood with larger average piece size than do streams with younger riparian stands dominated by smaller deciduous species. The former are favored because larger wood plays a larger role in pool formation, is less likely to move downstream, and it decomposes more slowly. Deciduous species, however, provide a greater amount of allochthonous inputs and terrestrial invertebrates. The latter can contribute significantly to salmonid production. NMFS (2014) ranked streams with >40% open + hardwood riparian vegetation as poor, and streams with < 20% open + hardwood vegetation as very good.

From a survey of 10 sites in the Prairie Creek subbasin, Cannata et al. (2006) concluded that riparian canopy density was suitable for shading stream reaches. Canopy density exceeded 80% in all but 1 previously harvested site on Lost Man Creek and two sites in Prairie Creek above Boyes Creek. Compared to Godwood Creek and an uncut reach of Brown creeks (70% coniferous), the percentage of riparian conifer was lower at sites in Lost Man, May, and Boyes creeks (<10%), all of which were harvested for timber in the 1950s-1960s. Madej et al. (2006) also presented data on riparian shading at several sites in Prairie Creek; they found that shading ranged from 89% (Little Lost Man at bridge) to 100% (Godwood Creek).

Biological Interactions and Disease

Effects of biological interactions, such as competition or predation, in structuring aquatic communities in Prairie Creek have received little attention. Strong biological interactions and diseases can limit recovery of some at-risk populations; these situations have been most commonly observed in settings greatly impaired from human-induced environmental alteration in hydrology, water quality, or habitat, or from intentional or accidental introductions of exotic species. Such is not the case for Prairie Creek, are not expected to represent a stressor. Drobny (2016) did not find an effect of small or large size classes of trout on density of juvenile Coho Salmon. Duffy et al. (2011) found that among free-swimming fish predators (Prickly Sculpin, steelhead, Cutthroat Trout, and

Coho Salmon), only Cutthroat Trout were observed with salmonid fry in their stomach. However, they appeared to rely more heavily on insect prey than on salmonid fry. All four predator species took juvenile salmonids with much greater frequency when confined in downstream migrant traps than in stream habitats.

Disease, particularly from myxozoan parasites, have caused significant mortality in juvenile salmonids in the nearby Klamath River in the last decade, but fish disease has not been problematic in Prairie Creek.

Passage Barriers

Barriers blocking fish migration have been identified a stress limiting salmonid recovery (NMFS 2014). Some barriers to migration are natural, such as waterfalls or debris jams. Other barriers to migration are man-made, such as dams and culverts. These barriers can be partial or complete, depending on flows and the species/life stage of fish attempting to pass the barrier. Prairie Creek stream surveys from the 1950's-1970's showed concern over debris accumulations formed from logging debris (CDFG 1952, 1961, 1962, 1966, 1975, 1976). Today, barriers are of less concern to the persistence of Prairie Creek salmonids, as most have been treated or recommended for non-action. In 2007, Ross Taylor Associates assessed stream crossings in the Prairie Creek watershed. The results of this survey, as well as locations and descriptions of barriers are available in the California Department of Fish and Wildlife Passage Assessment Database (PAD). The PAD is available online as an interactive map at https://nrm.dfg.ca.gov/PAD/. Prairie Creek barriers and known distributions of anadromous salmon from the PAD are shown in Figure 6. There are undersized culverts on tributaries just off mainstem Prairie Creek, and a collapsed Humboldt crossing on May Creek. An impassable log jam 2 km upstream of the bridge at the Lost Man Creek Picnic Area sets an upper limit to salmon spawning and rearing in Lost Man Creek except in years of high flows. This log jam has been in place at least since 1980 (D. Anderson, personal communication), and is considered a natural log barrier. Park policy is to leave natural barriers in place, as their formation is a natural process.

Fishery and Collecting-related Effects

Fishing is illegal within RSNP, which manages 98% of the Prairie Creek sub-basin, and scientific collection is permitted and heavily regulated by the state and federal government. As NMFS (2014) concluded for the Redwood Creek basin in its entirety, fishing and collection-related activities pose a low stress to juveniles, smolts, and adult Coho Salmon, based on population status relative to depensation and estimates of the fishing exploitation rate. Historic commercial and recreational overharvest of salmon undoubtedly contributed to the declines now observed in salmon abundance throughout the Pacific Northwest.

Hatchery-related Effects

Continuing impacts to aquatic biota from the historic operation of the Prairie Creek Hatchery are unknown, but likely to be low. Detection of domestication selection in contemporary populations would be difficult as more than 20 years have passed (and 7 or so generations of fish) since hatchery operations ceased. Wild adaptation is believed to be attained relatively rapidly following return to a wild condition (with no hatchery) (A. Kinziger, personal communication). While the impact of out-of-basin sources on genetic structure can be detected, the literature has shown that the stocking must have been very extensive before effects are realized. Most transplanted fish fail to become established.

Summary of Existing Data and Data Gaps

Table 9 summarizes existing datasets on fisheries and aquatic resources and relevant environmental variables in the Prairie Creek basin, identifies the location and years of data collection or measurement, the responsible agencies or organizations, and authors or appropriate contacts of reports, publications, or datasets.

TABLE 9. Existing datasets of physical/chemical variables and fisheries and aquatic resources in the Prairie Creek sub-basin of Redwood Creek, California through 2015. NWS=National Weather Service; RNP=Redwood National Park; USGS=U.S. Geological Survey; CDFW=California Department of Fish and Wildlife; USGS Coop = California Cooperative Fish and Wildlife Research Unit; PCFWWA=Pacific Coast Fish, Wildlife, and Wetlands Restoration Association; HSU=Humboldt State University.

Variable	**Location**	**Years**	**Agency/ Organization**	**Author or Contact**
Air Temperature	Prairie Creek State Park	1938-2004	NWS	
Precipitation	Prairie Creek State Park	1938-2004	NWS, RNP	
Streamflow	above Boyes Creek	2004-2015	RNP	Klein (retired), Ozaki
	at Wolf Creek bridge	1991-2012	RNP	Klein (retired), Ozaki
	Upper Prairie Creek	1990-2011	RNP	Klein (retired), Ozaki
	Little Lost Man	1975-2015	USGS, RNP	Klein (retired), Ozaki
	Lost Man Creek at Hatchery	2003-2015		Klein (retired), Ozaki
	Redwood Creek at Orick	1948-2015	USGS	http://waterdata.usgs.gov/nwis/uv/?site_no=11482500&agency_cd=USGS
Turbidity, Suspended Sediments	Prairie Creek Stations	2003-2015	RNP	Klein (retired), Ozaki
Water Temperature and Water Chemistry	mouth of Prairie Creek: trap operation	2011-2015	CDFW	Sparkman
	Various, summer only	1997-2015	RNP	Ozaki
	Various, GRTS	Every 3 yrs beginning	RNP Klamath	Dinger

Variable	Location	Years	Agency/ Organization	Author or Contact
	sampling design	2012	Inventory and Monitoring Network	
Substrate size	area impacted by 101 bypass	1990-1999, and sporadic	RNP	Klein (retired)
Large Wood	below Streelow	2015	RNP, USGS Coop	Seney, Ozaki Deibner-Hansen
Large Wood	above Streelow		RNP, NMFS	Klein (retired), Kramer
Barriers	barriers associated with the Newton Drury Parkway Highway 101 culverts Basin-wide	2009 2004 1980-81	Ross Taylor Associates HSU RNP	Ross Taylor Associates Lang Brown
Wetland Vegetation	USGS Orick Quadrangle	2010 2015	USFWS	National Wetlands Inventory Seney: wetlands assessment using CRAM methodology; final report in preparation
Aquatic Invertebrates	various locations	Sporadic	USGS, RNP,USGS Coop, HSU	several authors; see text
Algal Assemblages	near Lost Man Creek	1974, 2004	USGS	Iwatsubo, Madej
Amphibians	direct sampling	Sporadic	RSL_USFS	Ashton et al., Welsh

Variable	Location	Years	Agency/ Organization	Author or Contact
				and Oliver
Amphibians and non-salmonid fishes	bycatch of fish collections	Various	RNP, CDFW, USGS Coop	Anderson, Sparkman, Duffy (retired), Wilzbach
Salmonid Fishes:				
Outmigrant smolts	near Streelow Creek	1992-1994	PCFWWA	Farro
	above Streelow Creek	1995-1998	PCFWWA, HSU	Klatte, Roelofs (retired)
	above Streelow Creek	1998-2008	USGS Coop	Duffy (retired), HSU student theses
(Outmigrant smolts)	mouth of Prairie Creek	2011-2015	CDFW, USGS Coop	Sparkman
Juvenile Abundance	Prairie, Boyes, Streelow Creeks	1998-2010	RNP USGS Coop	Anderson Duffy (retired), several HSU student theses
	Prairie Creek Basin	2014	USGS Coop	Wilzbach, Drobny thesis
Adult Spawner Index	Lost Man Creek	1991-1998	RNP	Anderson, Haux
Adult Escapement	above Streelow Creek	1995-1998	PCFWWA, HSU	Klatte, Roelofs (retired)
	above Streelow Creek	1998-2008	USGS Coop	Duffy (retired)
	basin-wide sample	2008-2015	CDFW	Ricker

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Queries of the bibliographic compilation of aquatic resources in Prairie Creek revealed that far more information is available for some taxa and subjects than others. Not surprisingly, 514 records mentioned fish; of these, 507 items pertained to salmon, and 404 specifically mentioned Coho Salmon. Amphibians were mentioned in 60 records, and invertebrates were mentioned in 54 records. Algae were mentioned in only 17 items. The extensive monitoring effort associated with the Highway 101 bypass construction and 1989 sediment spill was referenced in 96 items. A search on sediment yielded 175 items, while a search on riparian returned 51 items. Taxa and areas for which data or scientific understanding are sparse are described below, but this listing should not be construed as all-inclusive.

Salmonid and other Fishes. - While a great deal of effort has been expended monitoring and studying salmonid fish populations in Prairie Creek, holes still remain in scientific understanding of the linkages between salmonid production and physical and chemical conditions of their environment. Linkages may be revealed through trend analysis as monitoring efforts continue; increased use of experimental research and modelling approaches would potentially advance understanding more quickly.

Studies and monitoring efforts in Prairie Creek are biased toward Coho Salmon, likely reflecting the focus of available grant funds. Our understanding of other listed salmon and trout is more limited. Steelhead and Cutthroat Trout populations, because of their longer freshwater residence, are highly sensitive to freshwater conditions and are useful indicators of watershed recovery.

Population parameters have not been equally monitored. Monitoring of juvenile salmonid abundance in summer, prevalent in the 1990's and early 2000s through use of the Hankin-Reeves approach, was abandoned as investigators became persuaded that population bottlenecks occurred primarily in winter. Recent studies in Prairie Creek do not support this view. For the same reason, survival has been estimated more often has fish growth. Both are vital population processes.

Among fishery scientists, limitations to production of salmonid fishes are commonly assumed to derive from physical or chemical features of the environment (e.g. LWD, suspended sediment loads, etc.). The strong possibility that availability of food resources is limiting to growth, and the manner in which this interacts with habitat elements, has not been well studied. Salmonid production is a product of fish biomass (density) and growth, and is often more strongly influenced by high growth rates than by dense populations (Warren 1971). Even when physical habitat and water quality are favorable for growth, high growth rates require abundant food resources. Similarly, freshwater survival is often assumed to vary primarily with the availability of velocity refugia. The contribution of predation, and the manner in which predation risk varies with habitat elements, has not received attention in Prairie Creek.

Spatially, salmonids have been studied more frequently in the upper, more pristine reaches of Prairie Creek than in lower reaches of the creek. Understanding of the extent to which juvenile salmonids rear or merely move through the lower river is limited, as is understanding of resource availability and limitations.

Studies on non-salmonid fishes have been largely limited to enumerating the bycatch of trap or seining collections targeted at salmonid fishes.

Amphibians. - Species such as the Pacific Giant Salamander, Tailed Frog, and Southern Torrent Salamander are useful indicators of watershed recovery, as these are associated with late seral forests. Periodic monitoring of amphibian assemblage structure, which has been previously directly censused only sporadically, would allow trend analysis. Studies in Washington have shown promise in the use of *e*-DNA to detect presence/absence of amphibians without disruption to stream substrate; this approach could be considered in Prairie Creek.

Invertebrates. - Use of invertebrates as indicators of habitat quality in Prairie Creek has not yielded great insight, perhaps because the rapid bioassessment protocols which have been used are able to detect only fairly coarse differences in community composition among sites differing in degree of disturbance. Taxonomic identity of species and genera occurring in Prairie Creek is well established. Few data exist on the relative importance of different taxa or groupings in the diets of vertebrate consumers. Should the New Zealand Mud Snail become established in Prairie Creek, its potential for rapidly disrupting invertebrate community structure and alter food web dynamics is high. Periodic monitoring of benthic invertebrates should be a high priority.

Ecosystem Dynamics. – Most studies of aquatic resources in Prairie Creek have been directed at the level of individual populations for vertebrates, or assemblage structure for invertebrates and, to a lesser extent, amphibians. Very few data are available to assess structure and functioning of the stream ecosystem as a whole. Basal resources for stream food webs are provided through primary production and detrital decomposition – measurement of these rates would suggest the capability of the Prairie Creek ecosystem to support a diverse food web. Comparison of gross primary to community respiration would indicate the relative importance of autorophic (produced within the channel) versus allochthonous (produced outside the channel) sources of energy. Measurement of nutrient spiraling (the downstream cycling of nutrients among stream biota and the water column) assesses the efficiency of a stream ecosystem in mineralizing inputs of organic carbon, which affects water quality locally and downstream. Secondary production of inverts and fishes are also important ecosystem-level functions for which data in Prairie Creek are limited.

The Physical/Chemical Template. – Stream nutrient data are spare in Prairie Creek, perhaps because of an understanding that Prairie Creek waters, like those in other forested streams in the Pacific Northwest, are infertile; excessive nutrient concentrations that may harm aquatic biota are not present. However, there is a possibility that a shortage of nutrients may limit algal production, with cascading effects through the trophic web. This possibility should be explored.

Although some data are available on the composition of riparian vegetation within the watershed, data on the amount and spatial patterning of incident light over stream channels appears to be absent. This information would be useful for establishing targets for riparian management to enhance aquatic productivity. Importance of light in affecting energy available to support stream biota has often been undervalued.

Data are not available on the distribution and supply of groundwater to Prairie Creek. The groundwater supply affects stream water temperature and local streamwater chemistry. Many studies have documented the reliance of salmonid fishes on groundwater for key habitat needs, and in many cases where ambient temperatures are stressful, for their very survival.

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Appendix A. Fisheries and Aquatic Resources of Prairie: An Annotated Bibliography