EAGLE LAKE RAINBOW TROUT
Oncorhynchus mykiss aquilarum (Snyder)

Status: High Concern. The Eagle Lake rainbow trout (ELRT) does not exist as a self-sustaining wild population because of dependence on hatchery propagation. Habitat degradation and the presence of alien brook trout in Pine Creek, the ELRT's principal spawning grounds, along with continued reliance on hatchery production to maintain the ELRT population will make it increasingly difficult to re-establish a wild population.

Description: This subspecies is similar to other rainbow trout in gross morphology (see Moyle 2002), but differs slightly in meristic counts, especially in having finer scales than coastal rainbow trout. It is also distinctive in possessing 58 chromosomes, rather than the 60 typical of other rainbow trout (Busack et al. 1980).

Taxonomic Relationships: Snyder (1917) described this trout as a subspecies of rainbow trout, *Salmo gairdneri aquilarum.* However, Hubbs and Miller (1948) examined Snyder's specimens and concluded that ELRT were derived from hybridization between native Lahontan cutthroat trout (presumed to have occupied Eagle Lake prehistorically) and introduced rainbow trout. Miller (1950) later retracted the hybridization theory. Needham and Gard (1959) then suggested that ELRT were descended from introduced or immigrant rainbow trout from the Feather or Pit River drainages. Behnke (1965, 1972) proposed a redband-rainbow hybrid origin, although redband trout are now considered to be rainbow trout subspecies. Busack et al. (1980), in an extensive electrophoretic, karyotypic and meristic analysis, suggested that ELRT were derived either from immigration or an unrecorded introduction of a rainbow trout with 58 chromosomes. The distinctive morphology, ecology, and physiology of this form all point to ELRT being derived from natural colonization from the Sacramento River drainage. Behnke and Tomelleri (2002) speculated that Lahontan cutthroat trout were the original inhabitants of Eagle Lake but that they disappeared during the Pleistocene during an extended period of drought. During a wetter period, rainbow trout managed to invade through an unspecified headwater connection (Behnke and Tomelleri 2002). Recent genetic studies (ALFP DNA techniques) suggest that the closest relatives of ELRT are rainbow trout from the Feather River (M. Stephens 2007, Simmons 2011). Given the relatively recent volcanism and resulting uplift and mountain building in the vicinity of Lassen National Park (near the headwaters of the Feather River), it is plausible that historic wetted connectivity existed between the Feather River and Pine Creek, Eagle Lake's main tributary (R. Bloom, CDFW, pers. comm. 2012).

Life History: Eagle Lake rainbow trout are late maturing (usually in their third year for females) and were historically long-lived, up to 11 years (McAfee 1966). Trout older than five years are rare in the lake today, although individuals as old as 8-9 years have been caught (CDFW, unpublished data). Historically, the trout spawned primarily in Pine Creek, which flows into the lake on the western shore and, presumably, on occasion, in the much smaller Papoose and Merrill creeks, which feed the southern end of Eagle Lake. Upstream migrations took place in response to snowmelt-fed high flows in March, April, or May. In the Pine Creek drainage, principal spawning areas were presumably gravel-bottomed, spring-fed creeks, such as Bogard Spring Creek, and headwaters in meadows, especially Stephens Meadows, about 45 km from the lake. In the past, it is likely that the trout spent at least their first 1-2 years of life in these stream habitats before migrating to the lake, much like coastal steelhead. However, it is possible some became stream-resident, while retaining the capability of producing migratory progeny, similar to steelhead and other lake-dwelling trout populations, such as Goose Lake redband trout (Moyle 2002). In recent years, progeny of adults transported to the upper basin have been found to be as old as four years. It is also possible that ELRT spawned successfully in the lower reaches of Pine Creek, with fry washing into the lake. In 2010 and 2011, 26 (21 male and 5 female) and 150 adult spawners (60 male and 40 female PIT tagged fish, along with 50 others), respectively, were released above the weir in lower Pine Creek in April. In June, fry (30-40 mm TL) were collected from the trap downstream (P. Divine CDFW, pers. comm. 2012). It is not known if these fish can survive in the lake.

Yearling ELRT from hatchery plantings grew to about 40 cm by the end of their first year in the lake, 45-55 cm in the third, and up to 60 cm in the fifth year (McAfee 1966). These fish could (at least in the past) apparently reach 3-4 kg and 65-70 cm FL (McAfee 1966). Data from the last 10 years shows that mature females produce an average of 3,300 eggs (Crystal Lake Hatchery, CDFW, unpublished data, 2009). Rapid growth is the result of abundant forage in Eagle Lake, combined with a delay in maturity until 2-3 years of age. This latter trait has made them highly desirable as a hatchery fish (Dean and Chappell 2005).

The life history of these fish has been significantly altered because access to spawning grounds in Pine Creek has been obstructed since the late 1950s. As fish move up Pine Creek in the spring, they are trapped at a permanent weir installed by CDFW and artificially spawned. The fertilized eggs are then taken to Crystal Lake and Darrah Springs hatcheries where they are hatched and the young reared for 14-18 months. The first generation fish that originate from parents captured in the trap are planted in Eagle Lake at 30-40 cm FL (CDFW, unpubl. data). 160,000-180,000 fish are planted in the lake each year; about half in the fall near the mouth of Pine Creek, in the vicinity of Spaulding, and the other half are planted in the spring in the south basin. In addition, between 5,000 and 10,000 1+kg ‘bonus’ fish have been planted each year for the sport fishery. Progeny of the fish captured in the Pine Creek trap are also reared in other hatcheries in California and planted widely in reservoirs (Carmona-Catot et al. 2011).

All trapped fish are marked in order to prevent sibling crosses (reduce inbreeding), avoid using fish that have been more than one generation in the hatchery, and to select for longer-lived fish to compensate for longevity reductions that may have been caused by past hatchery practices (R. L. Elliott, CDFW, pers. comm. 1998). Currently (beginning in 2001), no ELRT are planted that have been more than one generation in the hatchery (P. Divine, CDFW, pers. comm. 2012). Formerly, a hatchery program for rearing ELRT was maintained at Mt. Shasta Hatchery by using wild-caught fish as brood stock for one generation. The progeny of these fish were originally planted widely in reservoirs of the state and used as a source for brood stock in other hatcheries in California, as well as elsewhere in the western U.S. Eagle Lake rainbow trout are prized because of their delayed maturity, rapid growth and longevity. As noted, all fish reared in hatcheries for planting in Eagle Lake are first generation ELRT from the Pine Creek trap, although fish from hatchery broodstock were planted in combination with first generation fish from the Pine Creek trap into Eagle Lake in the past (P. Divine, CDFW, pers. comm. 2009).

Despite this long (60+ year) history of hatchery selection, there is evidence that ELRT can still spawn successfully in Pine Creek. Fish that were trucked to the upper reaches of Pine Creek in the 2000s produced young which survived and grew for two years. A thorough survey of Bogard Spring Creek revealed the presence of at least 170 ELRT in 2007, with most fish lengths between 105 and 150 mm FL; in 2008, only 25 ELRT were captured with lengths between 130-165 mm FL, while 34 ELRT were captured in 2009 (Figure 1; Carmona-Catot et al. 2010, 2011). These fish survived and grew despite the presence of about 5,300 brook trout in the same reach of stream in which they were found (see management section below for details). There is some evidence that two year old fish will try to migrate downstream to the lake during periods of high spring flow (P. Moyle, unpublished observations, 2006). In spring, 2009, an ELRT was captured in Pine Creek at 800 meters downstream from the confluence with Bogard Spring Creek. This fish was fin clipped in September, 2008 in Bogard Spring Creek (Moyle and Carmona, unpublished data). In 2011, a single male ELRT managed to migrate the entire distance from the weir to the upstream spawning areas (T. Pustejovsky, pers. comm. 2011).

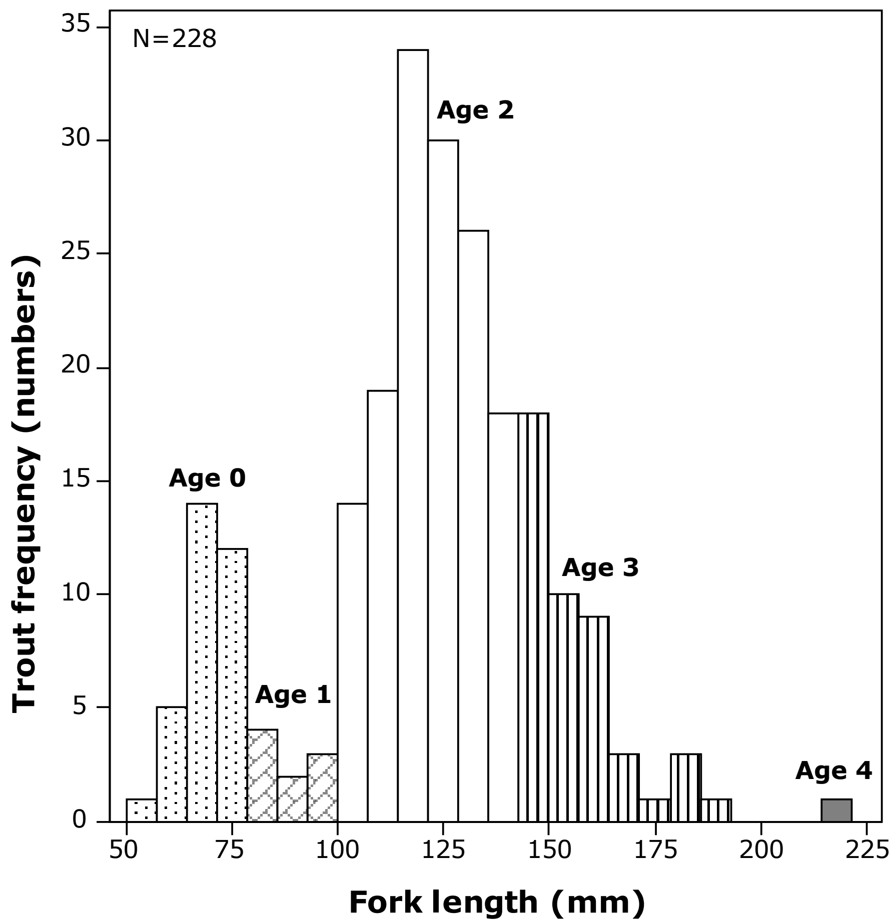

Figure 1. Fork lengths and ages of Eagle Lake rainbow trout in Bogard Spring Creek sampled in 2007, 2008, and 2009. Age distributions are inferred from scales of 71 fish. From Carmona-Catot et al. (2011).

The diet of ELRT varies with age and season. Newly planted trout in their first year in the lake feed mainly on zooplankton, including *Daphnia* spp. and *Leptodora kindti*, as well as on benthic invertebrates, especially leeches and amphipods. By August, most of the trout switch to feeding on young-of-year tui chubs (King 1963, Moyle 2002, Eagles-Smith 2006).

Habitat Requirements: Eagle Lake rainbow trout spend most of their life in Eagle Lake, a large (24 km long by 3-4 km wide), highly alkaline lake. The lake consists of three basins: two of them average 5-6 m deep in most years, but drop to 2-3 m during severe drought and the third averages 10-20 m, with a maximum depth of about 30 m. The shallow basins are uniform in their limnology and water temperatures may exceed 20°C in the summer. The deep basin stratifies so, in late summer, most of the trout are in the deeper, cooler water of this basin. Otherwise, they are found throughout the lake. Currently (2012-13) the lake is at near record low levels, so the upper basins are only about 2-3 m deep. How this has affected the ELRT population in the lake is not known.

During the summer, upper Pine Creek is a cold, spring-fed stream, flowing at .03-0.14 m^3/s through meadows and open forest, with modest gradients. Bogard Spring Creek is also a spring-fed creek, with flows of 0.01-0.02 m^3/s. The meadow streams have deep pools and glides with deeply undercut banks, providing abundant cover for trout. The Pine Creek watershed is described in detail by Pustejovsky (2007). Unfortunately, the trout present today in the Pine Creek watershed are almost entirely alien brook trout in high densities (Carmona-Catot et al. 2010).

Environmental tolerances of ELRT are high for a trout. In Eagle Lake, they live in highly alkaline water (pH 8.4-9.6), in which dissolved oxygen is usually at or close to saturation (except in the hypolimnion of the south basin during months of thermal stratification). They have been observed foraging in shallow water at temperatures of 22-23°C but generally retreat to deeper, cooler areas (<20°C) as lake temperatures increase. The requirements of spawners and juveniles in streams have not been well studied but are presumably similar to those of other rainbow trout (see Moyle 2002).

Distribution: Eagle Lake rainbow trout are endemic to Eagle Lake, Lassen County, and its main tributary, Pine Creek. They have been planted in numerous waters throughout California, where they are maintained from hatchery stocks originating from trout captured at the weir and fish trap at the mouth of Pine Creek. In the past, hatchery trout have been exported to other states and to Canada. It is unlikely that naturally reproducing populations of genetically 'pure' Eagle Lake trout are present in any of these planted waters, although supporting data are largely absent.

Trends in Abundance: Naturally-spawned ELRT were once abundant in the lake. According to Purdy (1988), "In the spring months of the 1870s and 1880s, when trout were spawning, huge quantities were being caught. It was not unusual to hear that wagon loads of trout, some weighing as much as 600 pounds, were being brought into Susanville where they were sold at local markets for twenty-five cents a pound (p. 14)." This exploitation occurred at the same time as extensive logging in the drainage, heavy grazing of the basin's meadows, and the first construction of railroad grades and roads across meadows and streams, all of which altered stream hydrology and morphology. When the ELRT was described by Snyder (1917), he noted its numbers were low. Although commercial fishing for trout was banned in California in 1917, ELRT populations remained low, presumably because of the poor condition of Pine Creek and the establishment of predatory largemouth bass and brown bullheads in the lake. By 1931, trout were scarce in the lake and Pine Creek (Snyder 1940).

During the 1930s, trout populations were further stressed as lake levels dropped dramatically when diversion of water through Bly Tunnel combined with prolonged drought to reduce spawning access to Pine Creek. In 1939, biologists with the Lassen National Forest expressed concern over impoundments further reducing flows of drought-stricken Pine Creek (Pustjevoksy 2007). Meanwhile, logging, railroad construction, and other human alterations to the basin further degraded the Pine Creek watershed. Fortunately, high alkalinities brought on by dropping lake levels also eliminated bass from the lake, although bullheads persisted into the 1970s. Even with the return of wetter conditions, the trout population showed little sign of recovery. In 1949 and 1950, CDFW collected 35 and 75 adult ELRT, respectively, from the mouth of Pine Creek, spawning them for hatchery rearing (Dean and Chappell 2005). The 258 progeny from the 1949 fish were planted in Pine Creek, where brook trout had recently become established, but probably did not survive. The spawning of fish in 1950 was more successful and the hatchery-reared progeny were planted in the embayment at the mouth of Pine Creek. From 1951-1958, some artificial propagation also took place, although the records are not clear as to how many fish were produced (Dean and Chappell 2005). Prior to hatchery propagation, trout presumably persisted only because occasional wet years permitted successful spawning despite degraded stream channels and the presence of brook trout in the spawning reaches of Pine Creek (McAffee 1966). It is possible that these actions by CDFW biologists prevented extinction of ELRT although, based on recent genetic evidence, a small component of the population may have been able to migrate upstream during larger flow events until all access to upstream areas was blocked in 1995 (Carmona-Catot et al. 2011).

In 1959, an egg taking station was built at the mouth of Pine Creek, including a wooden weir/dam to block upstream passage of most fish (Dean and Chappell 2005). Regular trapping operations began in 1959, when 16 trout were captured and spawned; in the next five years the numbers captured varied from 45 to 391 (McAfee 1966). From 1959 through 1994, a few trout were able to make it over the barrier during wet years, allowing some potential for natural spawning (Pustejovsky 2007, Moyle, unpublished data). It is unknown, however, if spawning was successful, if progeny survived in degraded stream habitats and in the presence of abundant brook trout, or if any outmigrants during this period were able to return to the lake.

In 1995, the weir was rebuilt to more effectively prevent erosion and prevent upstream movement of all ELRT (Pustjevoksy 2007), based on the assumption that adults migrating up Pine Creek would become stranded as the lower portions of Pine Creek dried and would be lost to the lake population and recreational fishery. The spawning of ELRT then became entirely under human control. At present, eggs and milt are stripped from the fish at the egg taking station. The embryos are then transported to Crystal Lake Hatchery, from where they are distributed to other hatcheries across California (Carmona-Catot et al. 2011). To provide fish for planting, hundreds of trout are trapped each year and between 1 and 6 million fertilized eggs per year are taken for hatchery rearing. Thus, in 2009, 1,737 females were spawned, producing 5,985,880 eggs for the hatchery while, in 2008, the take was 2,757,420 eggs, and, in 2007, 1,113,980 eggs (P. Divine, CDFW, pers. comm. 2009). It should be noted that the passage of California Assembly Bill 7 (AB-7) in 2005 required the CDFW to increase production of native trout forms in hatcheries, thus the incremental increase in egg take from 2007-2009. The egg quotas are developed every year by CDFW hatchery personnel in order to achieve the broodstock hatchery and statewide goals (Carmona-Catot et al. 2011). There is no recent evidence (although no studies have been performed) of natural reproduction contributing to the lake population; the fish captured by anglers usually show signs of a year or more in a hatchery environment, mainly fins with distorted fin rays or missing and/or eroded fins. The trap was modified in 2012 in order to allow passage of adults, a significant stride toward restoring some level of natural reproduction in the population (P. Divine, CDFW, pers. comm. 2012). The CDFW stocked ca. 1,000 "half pound" fish in Pine Creek intermittently prior to 2006, ostensibly for the purpose of experimentally reducing brook trout abundance through predation (Dean and Chappell 2005). However, no studies were conducted to confirm that this practice had the desired effect. Subsequent sampling suggests that few of these fish persisted for long in the creek (Carmona-Catot et al. 2011).

Actual population size of trout in Eagle Lake has not been studied but it is presumably dependent on the stocking allotments every year. Creel censuses indicate that catch per hour from 1983 through 2007 ranged from 0.2 to 0.6, with a mean of 0.3, while average length of fish caught increased over the years (Carmona-Catot et al. 2011). The number of mature females captured at the trap while migrating and spawned by the CDFW ranged from ca. 600 to 1,700, although no estimates were made of size of the entire spawning run.

Genetic studies provide some insights into minimum population sizes in the lake. Carmona-Catot et al. (2011) found individuals in the lake population had an $F_{IS,}$ or inbreeding value, of 0.064, significantly higher than zero, although no genetic evidence of a bottleneck was detected. The effective population size (size of breeding population) was estimated at 1,125 fish, with a confidence interval from 151-∞, indicating in all years there was a fairly large population contributing to reproduction. Given the presumed small number of fish used to establish the original hatchery-based population, it is interesting that no genetic bottleneck was detected. The original bottleneck could have been masked by the number of generations that have passed since the bottleneck and/or efforts of the hatchery breeding program to maximize genetic diversity (by breeding as many individuals as possible), as seen in the population's now high effective population size. It is also possible that the population left in the lake in the 1950s was larger than trapping efforts on Pine Creek indicated and multiple years of naturally-spawned fish contributed to the initial hatchery stock. The slight, if significant, F_{IS} value is still something of concern and worth monitoring, although it is comparable to levels found in other lake-stream systems in the region such as Goose Lake (Simmons 2011).

Overall, the population appears to be stable because it is maintained by hatchery production, which may be selecting against fish capable of reproducing naturally. For example, Chilcote et al. (2011) show that wild populations of three species of anadromous salmonids from the Pacific Northwest have greatly reduced ability to remain self-sustaining when fish of hatchery origin are also present. There is ample evidence that hatchery rearing has an impact on the genetics and behavior of fish released into the wild, affecting their ability to persist (e.g., Waples 1999, Araki et al. 2007, 2008, Kostow 2008). Recent evidence suggests that fitness reductions may not just be limited to fish raised in the hatchery but, instead, continues into subsequent generations (Araki et al. 2009).

Nature and Degree of Threats: The greatest historical cause of the near-extinction of ELRT has been the degradation of the Pine Creek watershed and the establishment of brook trout in historic spawning and rearing areas. The watershed was severely altered as the combined result of logging, grazing, diversions, and railroad and road building among other threats (Carmona-Catot et al. 2011). These factors do not operate independently but, instead, must be viewed in aggregate, along with other less pressing threats (Table 1), as cumulative and synergistic watershed impacts.

	Rating	Explanation
Major dams	n/a	
Agriculture	Low	Bly Tunnel was built to divert water for agriculture but was fully closed in 2012
Grazing	Medium	This was a major historic cause of degradation to the watershed but recent actions have substantially reduced impacts from grazing
Rural residential	Low	Septic tank effluents and ground water removal may be an ongoing threat; many septic issues resolved with recent construction of waste water treatment plants; however, diversion of water to evaporation ponds may negatively affect lake levels
Urbanization	n/a	
Instream mining	n/a	
Mining	n/a	
Transportation	Medium	Culverts (now fixed) have been past barriers to migration but roads continue to affect Pine Creek and lake (sedimentation, etc.)
Logging	Medium	Major activity in watershed
Fire	Low	Has potential to negatively impact entire Eagle Lake basin, especially with risk of more frequent and severe fires
Estuary alteration	n/a	
Recreation	Low	Recreation is a major human use of the basin; impacts (other than the recreational fishery) to ELRT are unknown
Harvest	Medium	Major impact in past; trophy fishery drives management; current fishing regulations in place to manage harvest rates
Hatcheries	Medium	Almost all fish have been produced in hatcheries for 60+ years; however, ELRT hatchery operations currently focus on minimizing artificial selection processes; hatchery diseases a possible threat
Alien species	High	Brook trout dominance in Pine Creek watershed is a major barrier to restoration and establishment of self-sustaining wild ELRT population; alien diseases are a possible threat

Table 1. Major anthropogenic factors limiting, or potentially limiting, viability of populations of Eagle Lake rainbow trout in California. Factors were rated on a five-level ordinal scale where a factor rated "critical" could push a species to extinction in 3 generations or 10 years, whichever is less; a factor rated "high" could push the species to extinction in 10 generations or 50 years whichever is less; a factor rated "medium" is unlikely to drive a species to extinction by itself but contributes to increased extinction risk; a factor rated "low" may reduce populations but extinction is unlikely as a result. A factor rated "n/a" has no known negative impact. Certainty of these judgments is high. See methods section for descriptions of the factors and explanation of the rating protocol.

Agriculture. In the past, Eagle Lake was viewed as a potential source of water for the otherwise arid agricultural region around Susanville and the Honey Lake Basin. This resulted in the construction of Bly Tunnel, which was completed in 1923, to send Eagle Lake water into

Willow Creek for use in crop irrigation. This project largely failed to deliver the water promised. During the 1930s, lake levels dropped as the result of diversion of water through the tunnel in combination with a severe, prolonged drought. Although it was blocked off with a concrete plug in 1986, the tunnel continued to passively leak, through an eight-inch bypass pipe in the plug, 0.034 cubic m/s (1.2 cubic ft/s) of Eagle Lake water into Willow Creek for downstream water right holders. Due to lack of surface flow diversion, some questions remained as to whether the water was coming directly from Eagle Lake or was, instead, percolating from groundwater into the tunnel. Water chemistry analysis revealed that most of the leakage was Eagle Lake water because of its unique chemical similarity to water sampled directly from Eagle Lake (Moyle et al. 1991). Based upon a position paper issued by the California Department of Fish and Wildlife to the State Water Resources Control Board in late 2011, the Bureau of Land Management, who administers the lands surrounding Bly Tunnel, closed the pipe in Feburary, 2012, thus eliminating direct discharge of Eagle Lake water via Bly Tunnel.

Grazing. Livestock grazing in the Eagle Lake basin started in the mid-1800s and was unregulated until 1905. Past grazing impacts to the Pine Creek watershed were substantial but are now greatly reduced because of improved grazing management (Pustejovsky 2007; Carmona-Catot et al. 2011). However, the legacy effects of past grazing continue, especially in the lower 40 km of Pine Creek, where the streambed has down cut and become enlarged in places, much of the riparian vegetation has been removed, and riparian meadows have presumably become drier, making them more likely to be invaded by sagebrush and similar xeric vegetation. Although stream flow records are lacking, it is likely that Pine Creek flows have also become more intermittent during summer, with spring flows decreasing more rapidly after snowmelt. At present, the lower creek (below Highway 44) usually stops flowing in late May or early June. The legacy effects of past grazing practices may have contributed to this altered hydrological regime; however, habitat conditions in recent years have been steadily improving (Pustejovsky 2007).

Rural residential. Eagle Lake has a number of residential tracts on its shores that depend on groundwater pumping (connected to lake levels) for water supplies. Although the potential connection between aquifer pumping and lake levels is poorly understood, the impacts may be substantial (especially during drought periods). Leakage of septic tank effluents into the lake is also a potential problem. This was resolved in 2007 at Spaulding Tract, with the development of a waste water treatment facility. Waste water is now diverted to evaporation ponds in Spalding Tract, Stones Landing, and South Shore campgrounds, which may result in significant loss of ground water in the basin, potentially exacerbating low lake levels during drought periods.

Transportation. Past road and railroad building to support historic and ongoing logging activities (see below) negatively affected habitat conditions and fish passage in Pine Creek. Culverts created barriers to upstream fish migration and road or railroad crossings created constriction points which may have altered stream hydrology. Wet road crossings contributed to stream bank erosion and sediment input. The more recent construction of State Highway 44, parallel to the railroad, forced Pine Creek through several culverts. The combination of culverts and channelized stream created a nearly-impassible velocity barrier for spawning ELRT. All potential barriers created by roads or other infrastructure have been removed or modified in lower Pine Creek. In spring, 2011, ELRT migration to the perennial sections of Pine Creek was verified through the use of PIT tags.

An additional concern is that part of the spring flow of Bogard Spring Creek is being diverted to provide water for a rest stop facility on Highway 44, reducing already minimal flow in this small, but important, tributary to Pine Creek.

Logging. Timber harvesting officially began in the Lassen National Forest in 1909, although the highest production took place in the 1970s and 1980s. The direct effects of timber harvest on stream habitats and flows may have been minimal because of the rapid infiltration capacity of the volcanic soils of the region, which reduces erosion rates (Platts and Jensen 1991). However, the roads constructed to facilitate logging were (and generally still are) very erosion-prone. Railroad lines were constructed across the Pine Creek drainage in the 1930s and 1940s to support logging activities, which restricted instream flows and led to channelized streambeds. Timber harvest is still very active in the area and the road networks utilized to support logging may serve as source inputs of sediments into streams.

Fire. Fires are common in the dry, heavily altered forests of the Eagle Lake watershed. The effects of fire on Pine Creek and its fishes have not been documented but the potential exists for severe damage to the upper watershed, with subsequent erosion, and perhaps direct mortality of fish in small streams. Historical photos (and surveys documenting stand densities and sizes) of the area show open stands of large conifers, with little understory or ladder fuels prior to fire suppression and logging in the basin (P. Divine, CDFW, pers. comm. 2012). Current forest conditions are quite different, with increased stand densities and widespread growth of firs which are not well adapted to fire and serve as ladder fuels (J. Weaver, CDFW, unpublished observations, 2012). This change in forest structure may increase the risk of high intensity, catastrophic fires, especially when coupled with predicted climate change outcomes, which may have dramatic impacts on riparian habitats and stream hydrodynamics in the Eagle Lake basin.

Recreation. The major use of Eagle Lake and its watershed is increasingly for recreation, much of which is focused on the widely popular recreational fishery ELRT support. The impacts from recreational angling, other than from harvest, which is closely regulated, are minimal. Other recreational impacts may include off-road vehicle use.

Harvest. As noted, in the 19th century, ELRT were once heavily exploited by a commercial fishery, which probably contributed to their initial decline. Since the 1950s, however, demand to support the lake sport fishery has been the principal reason its population has been maintained. However, a high percentage of the trout produced are planted in places other than Eagle Lake and the actual carrying capacity of the lake for rainbow trout is not known. It is possible that planting fewer fish would result in higher survival rates and more rapid growth rates. If a run becomes re-established in Pine Creek, the trout fishery in the creek will have to be managed in ways that do not negatively affect recruitment to the lake. In 2012 and 2013, the number of ELRT stocked into Eagle Lake was reduced by 20,000 to improve quality/condition of ELRT in the lake (P. Divine, CDFW, pers. comm. 2013).

Hatcheries. Eagle Lake rainbow trout are, at present, most likely completely dependent on hatchery production for survival (Moyle 2002). Prior to the1950s, they presumably persisted only because occasional wet years permitted access to upstream spawning areas through degraded stream channels and because ELRT were exceptionally long-lived for rainbow trout. A potentially negative outcome of hatchery reliance is that fish are being selected for survival in the early life history stages in a hatchery environment, rather than in the wild, perhaps for early spawning (as has happened in steelhead, Araki et al. 2007). In addition, fish may have been directly selected for large sizes for planting the lake (Carmona-Catot et al. 2011). However, sizes of angler-caught fish appear to be fairly static or slightly increasing over time (Figure 2).

Eggs taken from spawned fish at the Pine Creek Trap are sent to several hatcheries for rearing and then stocking into recreational waters. Crystal Lake Hatchery and Darrah Springs Hatchery rear fish to stock back into Eagle Lake. Darrah Springs also has a broodstock select program and rear these selected fish for 1.5 to 2 years. They are then transferred to Mt. Shasta Hatchery where they are used for production broodstock for statewide hatchery programs.

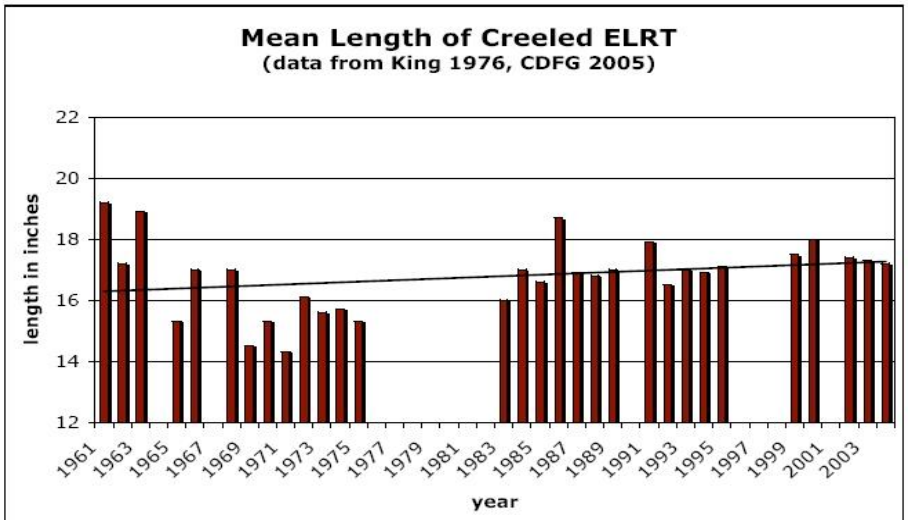

Figure 2. Mean lengths of Eagle Lake rainbow trout caught by anglers, 1961-2005 (from Pustejovsky 2007).

Genetic changes to ELRT have likely occurred as the result of continued hatchery selection, which may reduce the ability of trout planted in the lake to spawn naturally and produce young that can survive in streams or retain the predisposition to outmigrate back to the lake. Complete dependence on hatcheries for maintaining the species is undesirable because survival of the species then becomes dependent on vagaries of hatchery funding and management. Survival is further threatened by disease in hatcheries, loss of adaptation for life in the wild, loss of life history diversity, and potential inbreeding. Hatchery impacts may be particularly detrimental to a species with notable longevity (e.g., possibly eliminating the adaptation of ELRT toward a 10+ year life span, which has likely served as a buffer against extended periods of drought and periodic lack of access to spawning grounds). National Marine Fisheries Service guidelines indicate that a salmonid population dependent on hatchery production cannot be regarded as viable in the long-term (McElhany et al. 2000), a policy supported by recent studies (e.g., Chilocote et al. 2011).

The Pine Creek Coordinated Resource Management and Planning (CRMP) group (Pustejovsky 2007) has functioned over the past 25 years and is focused on restoration actions to provide for natural spawning of ELRT in Pine Creek. These efforts, if carried out completely, will result in a stream again capable of supporting a self-sustaining, wild population of ELRT. While hatchery production to sustain the trophy fishery has historically been regarded as a higher priority than re-establishment of a wild population (Dean and Chappell 2005), management shifts in recent years are increasingly focused on restoring a wild population, which is likely to happen only if brook trout are eliminated from Pine Creek so high production of ELRT juveniles can be assured (P. Divine, CDFW, pers. comm. 2012).

Another threat to the survival of ELRT is exotic disease, which could be introduced in hatcheries or into the lake by hatchery-reared fish, potentially severely affecting the lake's ELRT population (and possibly other fishes). However, hatchery protocols require routine examination of fish and water quality to reduce the threat of disease and ELRT are reared at two separate facilities to provide a redundant system, in the event that disease outbreak affects one or the other hatchery (P. Divine, CDFG, pers. comm. 2013).

Alien species. Many different species have been introduced into Eagle Lake in the past but none have persisted because of the lake's alkalinity. Nonetheless, because of Eagle Lake's large size and accessibility, it is possible that other species will be introduced illegally and, eventually, one may succeed, perhaps altering the ecology of the lake. Ironically, introduced species are most likely to become a problem if lake levels rise and alkalinity decreases, as happened in the early 1900s, when largemouth bass and brown bullhead became abundant in the lake. The only alien species that persists in the drainage is brook trout, which is abundant in upper Pine Creek. Predation and competition by brook trout in Pine Creek may prevent reestablishment of ELRT, so a program to eliminate this species from the watershed is needed and is currently in the planning stages (J. Weaver, CDFW, pers. comm. 2013). The high densities and biomass of brook trout in upper Pine Creek indicates good capacity for rearing ELRT in large numbers in the absence of brook trout (Carmona-Catot et al 2010, 2011), with the potential for contributing wild fish back into the lake population.

Effects of Climate Change: Climate change is likely to have two major impacts on the Eagle Lake watershed: decreased stream flows and changing lake conditions. Reduced snowpack in the mountains surrounding the Pine Creek watershed will presumably reduce the output of springs that feed Pine Creek. The magnitude of this effect, however, will depend on the timing and amount of rain and snowfall and how well meadows are managed to increase their ability to retain water and release it during summer months. Reduced inflow into the lake could potentially increase alkalinities to lethal levels for trout although, if average precipitation remains roughly the same, the lake should maintain itself. Unfortunately, the lake is now (2013) at near-record low levels and has been so for several years, so changing water chemistry is an increasing concern. Surface temperatures of the lake could potentially increase 2-3°C but, presumably, a cold water refuge for trout will continue to exist in the deepest basin of the lake. If climate change produces extended droughts that dry Pine Creek early or for longer periods of time, resulting in increased lake alkalinity and temperatures, ELRT could be driven to extinction in its native range, relegating it to a hatchery fish. Fires, coupled with predicted climate change outcomes, may become more frequent and catastrophic, especially in the dry headwaters of the basin and may interfere with ongoing and planned restoration efforts in the Pine Creek watershed. For these reasons, Moyle et al. (2013) scored the species as "critically vulnerable" to climate change and threatened with extinction by 2100 without human intervention.

Status Determination Score = 2.1 - High Concern (see Methods section Table 2). While this score reflects improved understanding of ELRT genetics, the subspecies is likely to experience further genetic change and become a semi-domestic hatchery fish if actions to restore a naturally spawning population are not implemented. Genetic degradation may occur because continued hatchery selection is likely to select against the ability of ELRT to maintain a natural life history. Stochastic events such as elimination of hatchery or lake stocks through a disease epidemic, severe drought, illegal introductions of invasive species, parasites, or other factors put ELRT at high risk in its native habitat given that they are endemic to only one watershed. Remarkable progress has been made in restoring stream habitats and natural spawning in the past 5-10 years but continued restoration is needed, particularly regarding the elimination of brook trout from the Pine Creek watershed.

A petition for federal listing as a threatened species was rejected by the USFWS in 1994 (Federal Register 60 (151) 401: 49-40150, August 7, 1994). A similar petition was rejected by the California State Fish and Game Commission in 2004. In both cases, the reason given for not listing was insufficient information. However, the USFWS issued a 90-day finding in 2012 (Federal Register 77 (172) 54548-54553, September 5, 2012), indicating listing may be warranted and is currently performing a 12-month review to gather additional information and make a status determination. The ELRT is regarded as a Species of Special Concern by the California Department of Fish and Wildlife and as an R5 Sensitive Species by the U.S. Forest Service. The American Fisheries Society lists it as Threatened, while NatureServe lists it as "Critically Imperiled" (Jelks et al. 2008). Eagle Lake is a designated Heritage Trout Water (one which supports a fishery for native trout forms in their historic range), managed under CDFW's Heritage and Wild Trout Program.

Listing under either federal or state ESA, while potentially justifiable, is not desirable because so much progress is being made toward their conservation and management. Listing could inhibit the ability of agencies or local conservation groups to efficiently implement restoration tasks by increasing permitting delays or disallowing certain activities intended to benefit the species. Nevertheless, it is important to underscore the need to connect habitat restoration with re-establishment of a wild population, provide additional incentives to eradicate brook trout, and continue to address other stressors.

Metric	Score	Justification
Area occupied	1	Endemic to a single watershed
Estimated adult abundance	4	Includes hatchery fish
Intervention dependence	1	Persistence depends on trapping fish for hatchery spawning and rearing and restocking lake annually
Tolerance	4	One of most tolerant, long-lived forms of rainbow trout
Genetic risk	3	Although operated to maximize diversity and minimize artificial selection processes, hatchery rearing has presumably altered genetics; possible selection against longevity and fitness in the wild is of concern; accidental hybridization in hatcheries possible
Climate change	1	Reduced stream flows or increased alkalinity of lake could further impact population; lake already at very low levels
Anthropogenic threats	2	See Table 1
Average	2.3	16/7
Certainty (1-4)	4	Well documented

Table 2. Metrics for determining the status of Eagle Lake rainbow trout, where 1 is a major negative factor contributing to status, 5 is factor with no or positive effects on status, and 2-4 are intermediate values. See methods section for further explanation.

Management Recommendations: The management of ELRT is an ideal opportunity to institute principles of adaptive management, where management actions are treated as experiments to inform future management (Carmona-Catot et al. 2011). The first step in the adaptive management process is to continue efforts to restore a wild, naturally-spawning population, rather than relying on maximizing egg 'take' for hatchery reproduction and maintenance of the recreational fishery. Substantial take of eggs to meet hatchery goals and targets can likely take place even if 10-20% of the adult fish are diverted for natural spawning and for experimental migration studies. A plan is currently being developed to guide management of the Pine Creek trap to allow for increased numbers of ELRT to migrate through the trap via the fish-way constructed in 2012 (P. Divine, CDFW, pers. comm. 2012). Additionally, CDFW, in collaboration with the CRMP, is currently (as of 2013) engaged in drafting a conservation strategy for ELRT, much of which will focus on restoration actions in the Pine Creek watershed, including a subcomponent addressing strategies to eradicate brook trout, along with options for enhancing spawning success and improving natural recruitment of ELRT in Pine Creek (J. Weaver, CDFW, pers. comm. 2013). These recent developments indicate that natural spawning and recruitment of wild stocks into the population have been identified as priorities for the recovery and management of ELRT.

As studies are developed and actions identified, three basic questions should be considered:

1: Can ELRT successfully migrate upstream from the lake in most years and successfully spawn?

2: Does re-establishment of a self-sustaining population of ELRT require complete eradication of brook trout from Pine Creek?

3: Can progeny from natural spawning return to the lake and contribute to the fishery?

Given that ELRT have undergone more than 60 years of artificial selection for reproduction and survival under hatchery conditions for a significant part of their life cycle, it is imperative to reverse that process as soon as possible. This underlying issue has long been recognized and was one of the justifications for the formation of the CRMP group in 1987, followed by many projects on Pine Creek to improve flow and remove passage barriers (Pustejovsky 2007). In order to implement adaptive management and begin the process of restoring natural spawning of ELRT, it is likely that a program of experimental release of adults above the Pine Creek weir and possible trapping and trucking of juveniles downstream past low-flow portions of the creek will be necessary. Recent research demonstrated that trapping and trucking may be a viable option for helping to recreate a naturally reproducing ELRT population; the study suggested that if spawners are allowed to migrate upstream naturally early in the season, they could successfully spawn and perhaps emigrate back to the lake (with trap and truck assistance as needed) following spawning (Carmona-Catot et al. 2010, 2011). The costs of this type of alternative management would presumably be comparable to costs of rearing hatchery fish but with fewer genetic consequences (e.g., Waples 1999, Araki et al. 2007, Kostow 2008).

Evidence exists that ELRT, at least during wet years, can migrate to the upper reaches of Pine Creek and spawn successfully. In the 1980s, a few juvenile rainbow trout were found below Stephens Meadow, suggesting adults made it over the weir, migrated upstream and successfully spawned (Moyle, unpublished data). In 1999-2005, biologists from CDFW, USFS and UC Davis placed radio transmitters in a small number of adult fish, which were then released above the weir (L. Thompson, UC Davis, pers. comm.). In 1999, one of these fish apparently made it to the Pine Creek headwaters, as its transmitter was recovered in Bogard Springs Creek, a tributary to Pine Creek above Highway 44 (T. Pustejovsky, pers. comm.). From 2002-2006, CDFW biologists released about 500 unspawned trout from the fish trap into Pine creek above Highway 44. In September, 2006, a crew from UC Davis, CDFW, and the USFS sampled Pine Creek to document the presences of ELRT (Carmona-Catot et al. 2011). They found evidence that ELRT had spawned successfully in the creek in the past two years because small numbers of juvenile rainbow trout were found at several locations in Pine Creek. About 100 m of Bogard Spring Creek were electrofished and 10 juvenile rainbow trout (76-90 mm FL) were captured, along with about 170 brook trout of varying sizes. Presumably, the rainbow trout were YOY or yearlings. The rainbow trout tended to be in faster water than brook trout, in reaches with deep overhanging cover. The UC Davis crew also found 3-4 small rainbows in Pine Creek, below the Bogard Spring Creek confluence, as well as a couple of rainbow trout in the 145 mm range in a creek filled with brook trout of all sizes, speckled dace, Lahontan redside, and Tahoe sucker. Curiously, several large trout from the lake that had been planted in the spring were still surviving in the pool below the culvert under Highway 44. Likewise, three spawners were found alive in a culvert about 5 km below the highway, in a largely dry section (no surface flow), along with a rainbow trout that was 142 mm SL. In 2007, at least 10 large ELRT (40-50 cm FL) were found downstream from the gauging station weir on Pine Creek (G. Carmona-Catot, pers. comm.). Successful spawning and migration was observed in 2010 and 2011, with juveniles reaching the trap and one tagged adult migrating from the weir to upper Pine Creek (T. Pustejovsky, pers. comm.).

From 2007-2012, Bogard Spring Creek was electrofished to remove brook trout to determine if spawning success of transplanted adult rainbow trout could be improved and to assess whether a three-pass electrofishing removal can successfully depress brook trout populations. In 2007, 4,887 brook trout were removed from the 2.5 km long creek (ca. 2,000 fish /km), which is remarkable considering the creek is less than 1 meter wide for all of its length and mostly less than 40 cm deep. During 2007, 170 juvenile ELRT were captured and returned to the creek; most fish were under 150mm FL, which indicates that they were not hatchery fish planted in the stream by CDFW at larger sizes (Carmona-Catot et al. 2010). Similar results were obtained in following years, along with evidence of a greatly diminished brook trout population. This evidence strongly indicates that a wild spawning population of ELRT can be reestablished, especially if brook trout populations are largely eliminated (Carmona-Catot et al. 2011).

As noted, major efforts have been undertaken in recent decades to fix passage problems and address habitat restoration needs in Pine Creek through the CRMP process (Pustejovsky 2007). As a result, sections of the creek have been fenced to exclude livestock, off-stream watering stations have been provided, an impassible culvert under Highway 44 has been replaced with a passable one, and a structure to divert water from Pine Creek near the Bogard Campground has been removed (and the meadow fenced). However, the meadows along lower Pine Creek and Bogard Spring Creek are still grazed by cattle, potentially affecting instream habitats and reducing the capacity for meadows to store and slowly release water into streams.

Elements of an adaptive management strategy for ELRT should include:

- Develop a management plan that is flexible enough to be adapted to changing conditions. A basic assumption of such a management plan should be that both hatchery-based and wild spawning populations will be maintained, as mutual insurance policies. As noted, CDFW, in collaboration with the CRMP, is currently (2013) drafting a conservation strategy for ELRT, which should provide the framework for future management. The

CDFW is also in the process of developing a genetics management plan for ELRT (P. Divine, CDFW, pers. comm. 2013), which should be incorporated into a broader conservation strategy.

- Continue efforts to ensure that restoration of a wild, naturally-spawning ELRT population remains a high priority.
- Develop an eradication strategy for brook trout in Pine Creek using either piscicides or other means (e.g., installation of artificial barriers and manual removal via electrofishing). If piscicides are proposed, a thorough investigation of the aquatic insect and herpetofauna of the watershed should be conducted in order to determine potential impacts of piscicides on their populations. Adaptive management and experimentation will be at the core of eradication efforts, particularly if piscicides are not employed, and successful removal of all brook trout from the Pine Creek drainage will likely be a costly, challenging and lengthy process. Nonetheless, CDFW recognizes the importance of this key step in the long-term conservation of ELRT and funding and resources are being allocated within the Department to enable focused, long-term, on-the-ground field work to benefit ELRT and other native trout forms across the state; installation of one or more barriers and experimental manual removal of brook trout in Bogard Springs Creek is slated to begin in October, 2013 (P. Divine and J. Weaver, CDFW, pers. comm. 2013).
- Finalize and implement plans to allow adult ELRT passage above the now modified Pine Creek trap as soon as spring snow-melt flows allow, in order to maximize potential for natural migration and spawning. Continue and expand upon existing instream movement monitoring studies (e.g., PIT tagging, radio telemetry) and incorporate assessments of passage improvement using these technologies, where applicable.
- Depending on water year type, develop plans to establish trapping and trucking operations for both adults (if natural migration of adults released above the weir does not occur) and out-migrating juveniles until there are signs the population is self-sustaining.
- Continue habitat improvements in the Pine Creek watershed with the goal of improving the quantity and duration of flow, following the recommendations in Pustejovsky (2007). Continue improvements in grazing practices and other activities that may affect stream habitat conditions.
- Increase flows in Bogard Spring Creek by eliminating the diversion that provides water to the rest station on Highway 44.
- Develop a comprehensive monitoring plan to assess habitat conditions, brook trout abundance, adult ELRT instream movement, spawning success, and juvenile ELRT abundance and outmigration success.
- Determine the feasibility of using Papoose Creek for establishment of a small spawning population.
- Conduct a thorough study of the survival and growth of trout planted in Eagle Lake to determine its actual carrying capacity for ELRT. Planting of trout in the lake (150,000+ per year) is based on maintaining catches of at least 0.4 fish per hour (Dean and Chappell 2005), rather than on biological constraints. It is possible that planting fewer trout may improve trophy angling.

Figure 3: Distribution of Eagle Lake rainbow trout, *Oncorhynchus mykiss aquilarum*, in California (native range only).