Inter-relationships between the spawning migration of Eagle Lake rainbow trout, streamflow, snowpack, and air temperature

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Abstract

Pine Creek has historically provided critical spawning and rearing habitat for Eagle Lake rainbow trout (ELRT, *Oncorhynchus mykiss aquilarum*). Over the past 100+ years modifications of Pine Creek watershed (e.g., overgrazing, timber harvest, passage barriers, culverts) decoupled the ELRT from its stream habitat. Introduced brook trout (*Salvelinus fontinalis*) now dominate historic rearing areas in the upper watershed. Passage barriers were constructed on Eagle Lake tributaries to prevent ELRT from spawning in degraded habitat, denying the ELRT access beyond the first kilometer of stream. Since 1950 the lake fishery has been maintained by artificial spawning. Offspring are reared in hatcheries and released into Eagle Lake. Since 1987 changes in grazing management, reconstruction of culverts, and other conservation projects have resulted in marked improvement of habitat, although ELRT have been not allowed to attempt their natural spawning migration. Their ability to migrate has been questioned, and concerns led to a petition for listing under the federal Endangered Species Act. We report on a long term study to track the spring migration of ELRT spawners in Pine Creek. We tracked the upstream migration of ELRT spawners from the mouth of Pine Creek. We then related ELRT spawner migration to stream flow and snowpack, and related flows to snowpack and air temperature. It is possible to predict ELRT migration distance from flow, duration of flow, or from snowpack. The relationships between migration distance and flow, and migration distance and snowpack in the upper watershed were weak. However, sample sizes were small, due to the limited number of years in which fish have been tracked, and the cessation of operation of the flow gages. The positive relationships between migration distance and seasonal average daily mean streamflow, and between streamflow and snowpack are particularly interesting in light of climate predictions for California. By the end of this century snowpack is likely to be reduced 65-97% in the elevation range of Pine Creek. The creek is likely to flow more during the winter, due to winter rain events, and to have lower summer baseflows. It is possible that ELRT spawners might shift to a strategy of earlier migration, moving upstream to areas of perennial summer flow during winter rain events. However, the fish currently lack the opportunity to experience and adapt to flow changes that are likely to occur with climate change.

Introduction and Problem Statement

Pine Creek is the main tributary of Eagle Lake, in northeastern California (Figure 1). The creek is 63 km long and is at an elevation of approximately 1,750 m. The creek alternates its path through low gradient mountain meadows and higher gradient reaches in pine/aspen forest. It is an intermittent stream; only upper 11 km of creek has perennial flow. In spring there are high flows from snowmelt. The creek is fed by approximately 21 springs which sustain flows in the headwaters during summer. The native fish species present in the upper Pine Creek watershed are: Lahontan redside (*Richardsonius egregius*), rainbow trout (*Oncorhynchus mykiss*), Tahoe sucker (*Catostomus tahoensis*), and speckled dace (*Rhinichthys osculus*).

Pine Creek has historically provided critical spawning and rearing habitat for Eagle Lake rainbow trout (ELRT, *Oncorhynchus mykiss aquilarum*). The ELRT sub-species is considered by the California Department of Fish & Game to be a Species of Special Concern, a Wild trout, and a Heritage trout (Pustejovsky 2007). The United States Forest Service (USFS) has rated the ELRT as an R5 sensitive species. There have been two petitions for listing of ELRT under the federal Endangered Species Act which have increased interest in the management of ELRT and the potential of the sub-species to persist without human intervention.

Over the past 100+ years modifications of Pine Creek watershed (e.g., overgrazing, road construction, timber harvest, passage barriers, highway and railway culverts) decoupled the ELRT from its stream habitat. The 1940 introduction of brook trout (*Salvelinus fontinalis*) led to competition for habitat in the upper watershed. Since 1952 the fishery has been maintained by artificial spawning, after fish are trapped at the mouth of Pine Creek. Offspring are reared in hatcheries and released into Eagle Lake (CDFG 2005). Beginning in 1959 passage barriers were constructed at the mouth of the Eagle Lake tributaries to prevent ELRT from spawning in degraded habitat, culminating in a permanent velocity barrier structure (Figure 2). Barriers were also placed on other Eagle Lake tributaries (Pustejovsky 2007). Since 1987 the Pine Creek Coordinated Resource Management Planning Group (CRMP) has lead changes in grazing management, reconstruction of culverts, and other conservation projects that have resulted in marked improvement of habitat in the Pine Creek watershed, but ELRT have been prevented from attempting their natural spawning migration by the velocity barrier (Young 1989, Platts and Jensen 1991, NRST 1999, Pustejovsky 2007).

One of the stated goals of the Pine Creek CRMP has been to restore the ELRT fishery in upper Pine Creek, which could logically be defined as a successful and repeatable natural spawning migration of ELRT, and spawning and juvenile rearing of ELRT in upper Pine Creek. After years of restoration efforts in the Pine Creek watershed, there still remain several uncertainties relating to ELRT. A key question is, are ELRT able to migrate to the headwaters of Pine Creek and its tributary Bogard Spring Creek?

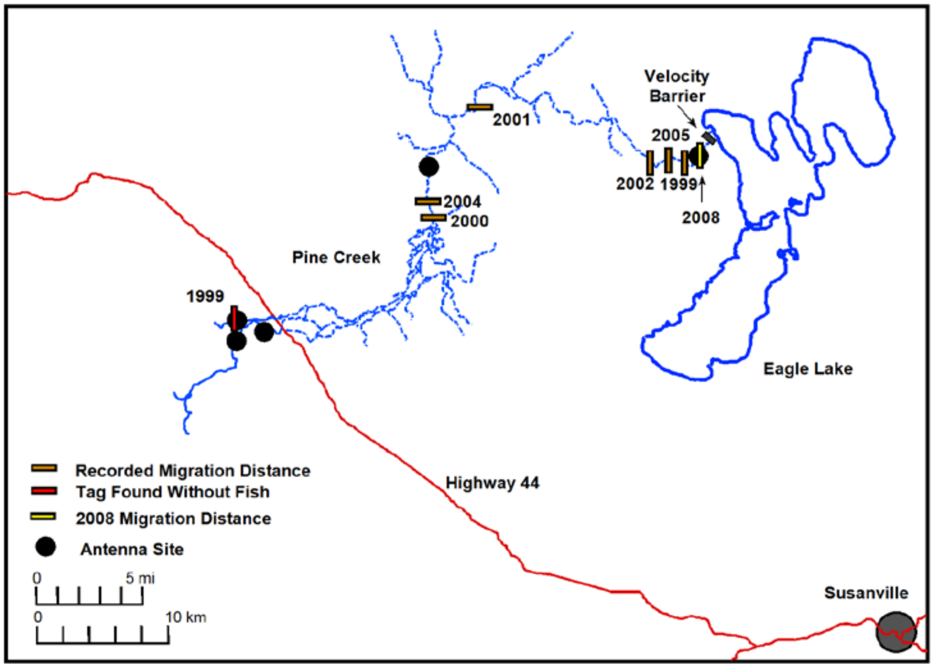

Figure 1. Map of Eagle Lake and Pine Creek, showing passive integrated transponder antenna sites (2008) and maximum distance that rainbow trout spawners migrated in each year. Note: Migration distances indicated by marks are approximate; marks were shifted to avoid overlap. Accurate distances are given in Table 1.

Figure 2. Velocity barrier operating on Pine Creek during spring snowmelt.

Objectives

The overall goal of the ongoing Pine Creek project is to test whether the numerous watershed restoration activities conducted in the Pine Creek watershed have provided conditions under which a proportion of ELRT can complete their natural life cycle, including migration, spawning, and rearing.

In addition, stakeholders have expressed interest in being better able to predict years in which ELRT are more likely to complete their spawning migration, potentially using snowpack data collected prior to the onset of the migration to predict flows. This would allow some fish to be prioritized for migration, rather than hatchery production, in “good migration” years. Alternatively, managers could avoid “wasting” fish by having them attempt to migrate in years with poor potential for success.

The main objectives of the current study were to:

1. Track the upstream migration of ELRT spawners from the mouth of Pine Creek.

2. Relate ELRT spawner migration to environmental factors such as flow volume and duration, snowpack, and air temperature.

We also considered the potential impacts of climate change on the ELRT spawning migration, including effects on the volume, timing, or duration of Pine Creek flows.

Procedure

Historical tagging and tracking of fish

The spawning migration of ELRT in Pine Creek has been studied for several years using radio-tracking, by members of the Pine Creek CRMP group including the California Department of Fish and Game (CDFG), Eagle Lake Ranger District, Susanville Indian Rancheria, and UC Cooperative Extension. We obtained data from historical tracking studies from the literature (Pustejovsky 2007) and from USFS staff (Eagle Lake Ranger District). ELRT were implanted with radio tags for a total of six years between 1999 and 2005; no fish were tagged in 2003. Tracking was done on foot, and via truck and snowmobile. In 2004, and possibly other years, one stationary antenna/receiver unit was operated 1 km upstream of Corbin Crossing, approximately 11 km upstream from the mouth of the creek.

Tagging and tracking for this study

During radio-tagging procedures female spawners were often so ripe that their skeins had broken, eggs were loose inside the body cavity and escaped through the tag incision. In addition the body wall of the ventral abdomen was so thin (e.g., 3 mm) that it was difficult to suture the incision in a lasting fashion. In 2006, based on the results of prior radio-tracking studies, the Pine

Creek CRMP decided to switch to tracking the migration of ELRT spawners using a new tagging method, passive integrated transponder (PIT) tags.

Movement of fish may be detected as they swim past a stationary PIT antenna loop placed across the river. The advantages of using PIT tags are that they are much smaller than radio tags (12 – 32 mm; 1/2” – 1 ¼” long), PIT tags can be injected subcutaneously, and the surgery procedure is faster than radio tagging. Fish behavior should be less affected by the PIT tagging procedure than with surgical implantation of a radio tag into the body cavity with a trailing wire antenna. Each PIT tag has a unique code, so each tagged fish is individually identified. Because the tags do not have to contain a battery, but get their charge from passing through the charged antennas loop, the tags last the life of the fish.

In 2006 we conducted a pilot PIT tagging study (Thompson et al. 2006). We tagged 36 ELRT that had arrived at the velocity barrier (Spalding fish trap) near the mouth of Pine Creek. Each fish was captured by netting from the tanks in the fish hatchery structure at the velocity barrier. Each fish was transferred to a cooler containing carbon dioxide anesthetic. The anesthetic solution was produced by adding 27 g $NaCO_3$ (sodium bicarbonate) and 10 mL glacial acetic acid to 10 L water (Peake 1998). Swimming capabilities and opercular movement were monitored. Once the fish reached stage 4 anesthesia (total loss of swimming motion with weak opercular movement) it was removed from the cooler and placed on a measuring board to have its length measured, then in a padded V-shaped surgery tray to be tagged. The measuring board, surgery tray, and researchers’ hands were kept wet to minimize stress to fish.

We used 32 mm long half duplex PIT tags (Allflex, 860010-001 ISO RFID PIT Needle assy – sterile 32mm HDX; RI-TRP-RR2B), each supplied in an injection needle in a sterile package (Figure 3). Tags were injected subcutaneously on the left side about 3 cm (1.2”) from the dorsal line, near the posterior end of the dorsal fin. A handheld stainless steel injection gun was used to inject the tag in a posterior to anterior direction so that the posterior end of the tag was 1 cm (2.5”) from the injection site. A drop of Nexaband® veterinary glue was used to seal the injection site. In order to make possible visible detection of marked fish, we also tagged each fish with either a yellow or mauve Floy® tag, on the right side near the back of the dorsal fin. Following tagging each fish was allowed to recover in a cooler of stream water with an oxygen aerator, then released upstream of the velocity barrier. However, since this was a pilot study there was only one PIT antenna installed, upstream of Highway 44, so it was not possible to detect whether some ELRT had moved upstream, but not as far as this point. Data from 2006 are not considered in further analyses.

Figure 3. PIT tag (32 mm; 1.3”) shown with a dime coin for size comparison.

In 2007, we intended to expand on the PIT tagging pilot study of 2006, by releasing PIT tagged ELRT just upstream of the fish trap and monitoring their upstream migration using channel spanning PIT antennas. However, low flows in Pine Creek and resulting hatchery priorities precluded the availability of ELRT spawners for this part of the study (Thompson et al. 2007).

Based on prior radio-tracking studies, we anticipated that even if ELRT spawners were released into Pine Creek just upstream of the fish trap, few fish would make it all the way to the upper watershed (i.e., to the area with perennial flow upstream of Highway 44). In order to test the ability of ELRT spawners to successfully spawn we transported a group of fish to the upper watershed to spawn. On 30 March 2007 we PIT tagged these fish in order to monitor whether they attempted to swim downstream to Eagle Lake after spawning, following the same protocol as in 2006. The ELRT were transported by truck, in coolers with aerators. Sixteen ELRT were released in upper Pine Creek, upstream of Highway 44. Fish were carried to the stream in coolers, and released upstream of a PIT antenna so that we could detect whether fish attempted to swim downstream to the lake immediately after release. Prior to the fish transfer we installed three PIT antennas along the length of Pine Creek. We installed PIT antennas with a Texas Instruments receiver at Rankin "Heights" (km 3) and Logan Springs (km 24). Each of these antennas was approximately 10 m wide and 1.5 m high (30' X 4.5') and was constructed of a single loop of 8 gage wire. We installed a smaller PIT antenna with an Allflex receiver at the McKenzie Meadow site on the mainstem of Pine Creek, just upstream of Highway 44 Bridge (km 32). The antenna was 3 m wide and 0.9 m high (9' X 2') and spanned the channel. Each antenna was powered by two deep cycle marine batteries and recorded data onto a handheld Palm m130 datalogger with an SD memory card. All antennas were manufactured by Mauro Engineering, Mount Shasta, CA. We made approximately weekly visits to the McKenzie Meadow and Logan Springs PIT antenna sites to substitute charged batteries, and to check for fish detections. The Rankin Heights site was almost dry by the time we transported spawners to the upper watershed, so this antenna was not operated in 2007. We walked along sections of Pine Creek and Bogard Spring Creek on 30 March 2007 to monitor the condition of the spawners immediately after release. We also walked along the creeks on 5-6 April, 2-3 May, and 29-31 May to check for the presence of spawners and redds.

In 2008 we PIT tagged 20 ELRT spawners at the velocity barrier and released them upstream. We followed the same tagging protocol as in 2006. The migration was tracked with 5 stationary PIT antennas placed along the length of Pine Creek (Figure 1).
With the exception of the antenna near Highway 44, all receivers units used in 2008 were manufactured by Oregon RFID®. Each of these antennas was approximately 10 m wide and 1.5 m high (30' X 4.5') and was constructed of a single loop of 8 gage wire. All 5 PIT antennas were operating and potential fish movement was tracked during the period of streamflow. We continued to operate the antennas in the zone of perennial flow throughout the summer and fall of 2008.

Following the 2008 field season we were advised by CDFG that we should not plan to tag or track ELRT spawners in spring 2009 because all available fish would be needed for the hatchery program. Accordingly, no ELRT were tagged or released upstream of the trap to attempt their spawning migration in 2009.

Flow data

We required flow data for comparison with rainbow trout migration distances. Historical water flow data were available from the United States Geological Survey (USGS) for three gaging stations in the Pine Creek watershed, one in the upstream zone of perennial flow, a lower site near the creek mouth, and one small tributary (Figure 4). The upper USGS gage had annual discharge data from 1951-1961, and annual peak streamflow data from 1951-1978 (USGS 10359250 PINE C NR WESTWOOD CA; Latitude 40°34'26", Longitude 121°06'18"; NAD27; Lassen County, California, Hydrologic Unit 18080003; Drainage area: 24.8 square miles; http://nwis.waterdata.usgs.gov/nwis/nwisman/?site_no=10359250&agency_cd=USGS. The lower USGS gage had annual discharge data from 1961-1982, and annual peak streamflow data from 1961-1982 (USGS 10359300 PINE C NR SUSANVILLE CA; Latitude 40°39'54", Longitude 120°47'25"; NAD27; Lassen County, California, Hydrologic Unit 18080003; Drainage area: 226 square miles; http://nwis.waterdata.usgs.gov/nwis?program=nwisman&site_no=10359300&agency_cd=USGS). The tributary gage had annual peak streamflow data from 1971-1980 (USGS 10359290 PINE C TRIB NR SUSANVILLE CA; Latitude 40°43'44", Longitude 120°52'44", NAD27; Lassen County, California, Hydrologic Unit 18080003; Drainage area: 4.70 square miles; http://nwis.waterdata.usgs.gov/nwis/nwisman/?site_no=10359290&agency_cd=USGS).

The California Department of Water Resources (DWR) operated a surface water site near the mouth of Pine Creek continuously from 1976-2004 (Pine Creek at Eagle Lake near Susanville; Station Number G31140; Site Type - Surface Water; Latitude 40 degrees, 39 minutes, 55.6 seconds; Longitude 120 degrees, 47 minutes, 26.8 seconds; Datum NAD83; http://www.water.ca.gov/waterdatalibrary/docs/Hydstra/index.cfm?site=G31140). This site has a continuous series of flow daily mean data from 1978-2003. An expanded version of this data set, for the period 1976-2003, was obtained directly from DWR (John Clements, DWR).

Combined data for the lower Pine Creek gage (USGS 10359300) and the DWR gage were used by Karen Vandersall (USFS, Eagle Lake Ranger District) to calculate duration of flow and annual mean daily streamflow for 1961-2004, with the exception of 1967 and 1969.

Snowpack data

Snowpack data were collected by the USFS at two sites in the Pine Creek watershed from 2002 – 2008, with the intention of correlating these data with longer data sets (1940-2008) for two nearby USGS sites in the Susan River watershed (Figure 4). The upper Pine Creek site (Stephens Meadow) was paired with the Silver Lake site, and the lower Pine Creek site (Pine Creek Valley) was paired with the Norvel Flat site, for April water content data.

We used the USGS data for our analyses in order to have snowpack data for all years in which fish migration was observed. We used the Silver Lake data set because we were most interested in the snowpack in the upper Pine Creek watershed, which would contribute to streamflow along the entire length of the creek. The linear regression between the Stephens Meadow and Silver Lake snowpack data sets was $y = 0.754x - 2.516$, $r^2 = 0.92$, n=7.

Air temperature data

Air temperature data were available from the Western Regional Climate Center for a RAWS (Remote Automated Weather Stations, operated by the US Department of the Forest Service and Bureau of Land Management) site in the upper Pine Creek watershed near where Highway 44 crosses Pine Creek (Bogard Ranger Station, http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?caCBOG) (Figure 4). Monthly mean air temperature was available from 1992-2008. This data set had some gaps in many years, and was relatively recent. In order to be able to correlate air temperature with earlier flow and snowpack data we compared the Bogard RAWS site with two nearby COOP (Cooperative Observer Program, coordinated by NOAA, National Weather Service) sites:
Susanville Municipal Airport (http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8702) and Hat Creek PH 1 (043824, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca3824) which both had monthly mean air temperature data for 1961-2000. The Bogard Ranger Station site was more closely correlated with the Hat Creek site ($y = 1.07x – 5.10$,
$r^2 = 0.98$; Figure 5), with temperatures at Bogard Ranger Station being approximately 5^{o}C lower than Hat Creek PH 1. We used this relationship to estimate monthly mean air temperature for Bogard Ranger Station (upper Pine Creek).

Data analyses

There were sufficient temporal overlaps in our data sets for us to compare fish migration distances with flow and snowpack, and to relate flow to snowpack and air temperature (Figure 6). We used simple linear regression for these comparisons (Neter, Wasserman, and Kutner 1990), with all calculations and graphics done in Excel®. We plotted the maximum distance migrated by a rainbow trout in a given year against flow for years in which the data sets overlapped. In some years daily mean flow data were available from DWR, but since these data were not available after 2003 (Figure 7) we relied on data for annual average daily mean streamflow and duration of flow. We also plotted the maximum distance migrated by a rainbow trout in a given year against April snowpack for years in which the data sets overlapped. We recognize that our sample sizes for the fish migration data are very small, but we have chosen to present the trend lines and regression equations for the relationships, since these are the only sources of this information for this fish sub-species. It is our hope that the presentation of these results will encourage more collection of fish migration data in future years in order to expand this data set.

We then examined the relationships between seasonal average mean daily streamflow and snowpack, and duration of flow and snowpack. We considered whether seasonal average mean daily streamflow and the residuals from the regression of streamflow on snowpack were related to mean April air temperature, to see whether the addition of temperature data to our models could improve our predictions.

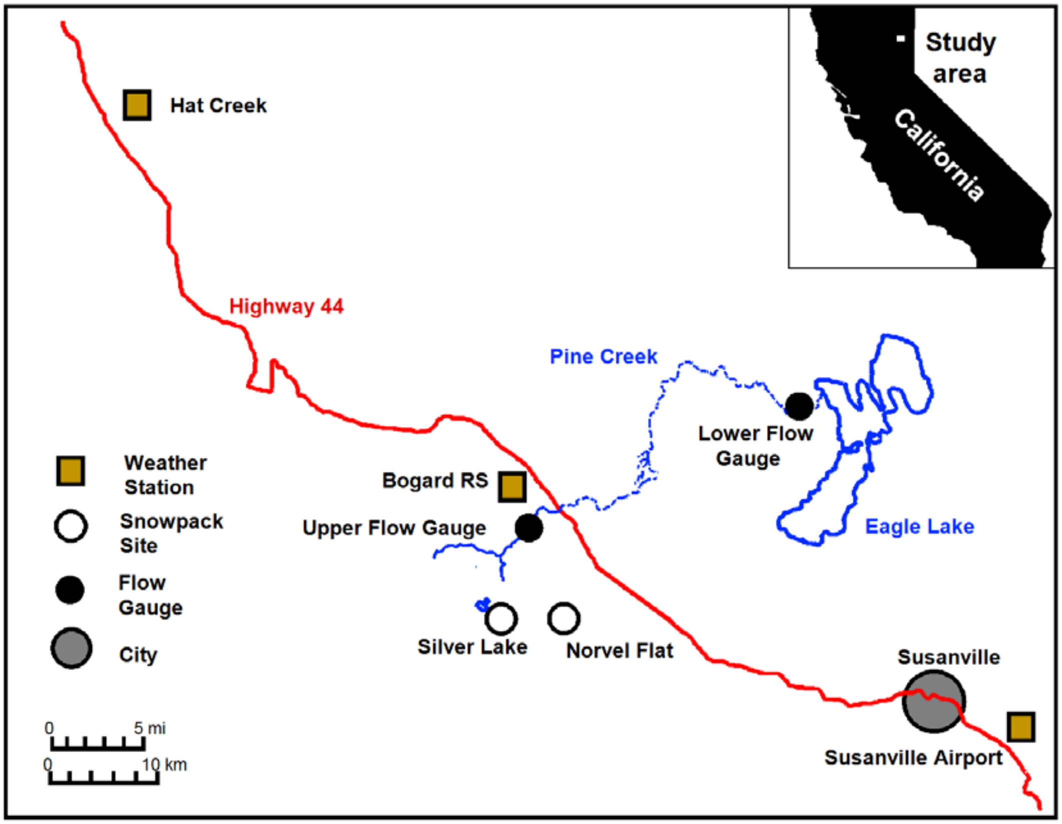

Figure 4. Locations of flow gages, snowpack and temperature data sites.

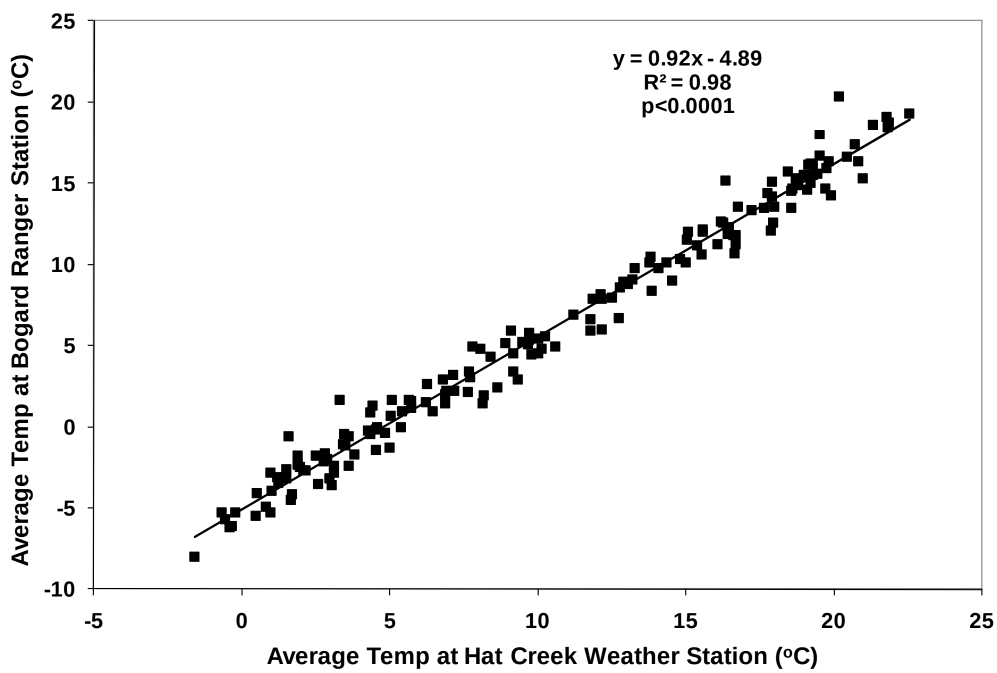

Figure 5. Comparison of mean monthly air temperature at Bogard Ranger Station RAWS site and Hat Creek PH 1 COOP site, from 1992-2008. n=170.

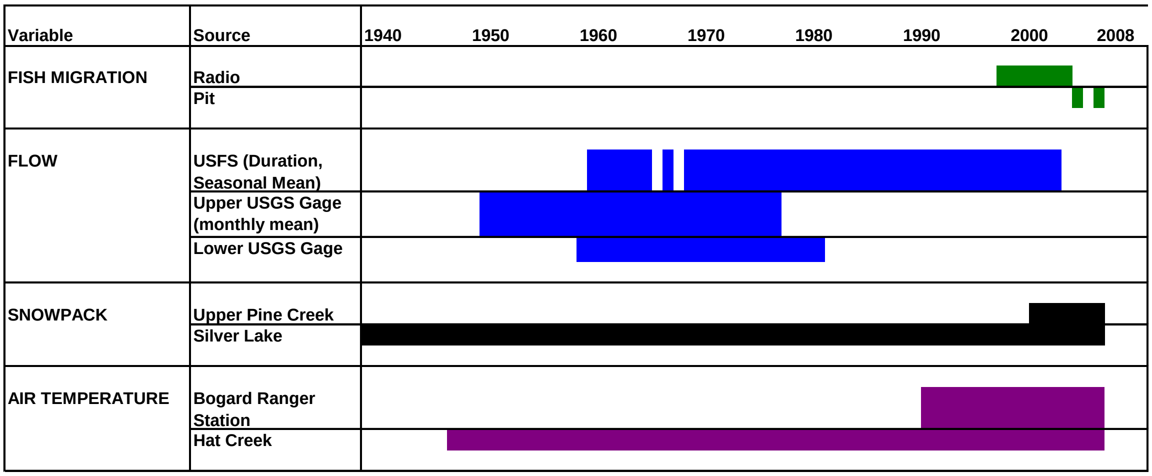

Figure 6. Overlaps in migration, flow, snowpack and temperature data from various sources.

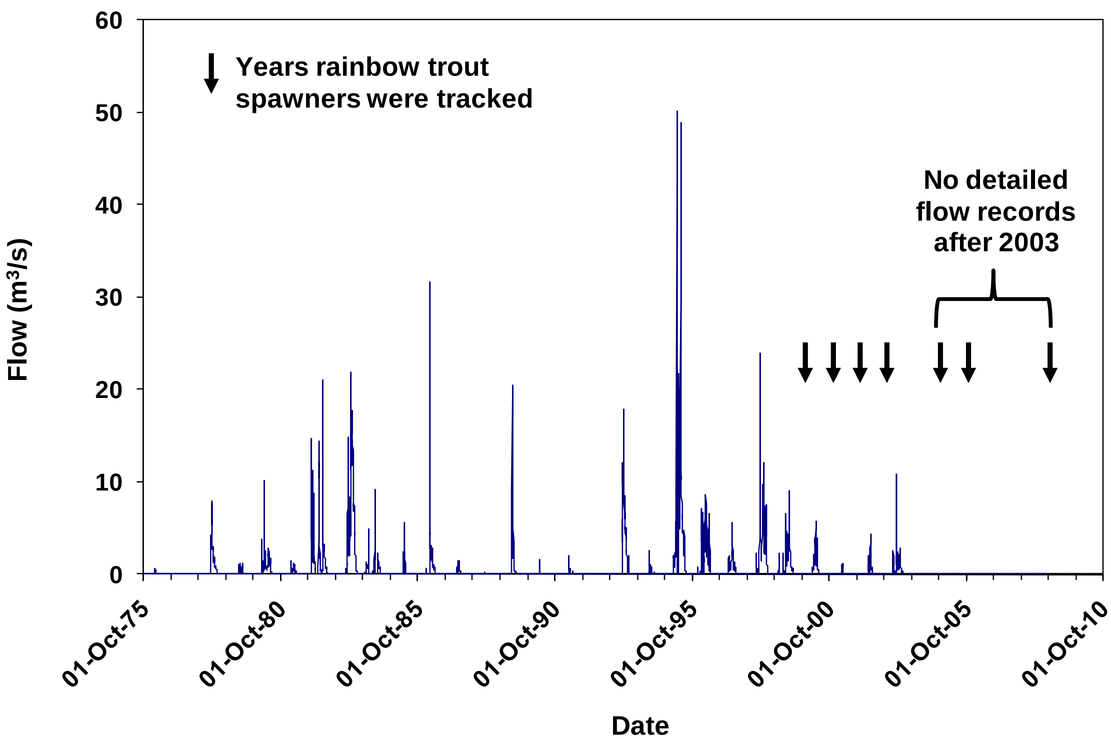

Figure 7. Mean daily streamflow for DWR gage G31140, near the mouth of Pine Creek, and years in which rainbow trout spawner migration was tracked. Flow data courtesy of John Clements, DWR.

Results

Historical tagging and tracking of ELRT involved up to 53 fish in a given year (Table 1). Tagging commenced between late March and late April, depending on the timing of runoff, and the decision by management agencies that flows were sufficient to allow fish a reasonable chance of successful migration.

Table 1. Numbers of ELRT tagged and tracked during their spawning migration, tag type, number of fish released, start and end date of tagging episodes, tracking end date, and maximum distance migrated upstream by at least one fish.

Year	Tag type	Number of fish tagged	Tagging start date	Tagging end date	Tracking end date	Maximum distance (km)
1999	Radio					5 (35)
2000	Radio	53	3/20/00	3/31/00		27
2001	Radio	20	3/23/01	3/27/01		21
2002	Radio	20	3/28/02	4/1/02		3
2003	-	0	-	-	-	-
2004	Radio (coil or whip)	30	3/23/04	3/30/04	4/20/04	27
2005	Radio	10	4/6/05	4/6/05	4/22/05	5
2006	PIT	36	4/21/06	4/21/06	-	-
2007	PIT	16	3/30/07	3/30/07	-	-
2008	PIT	20	4/05/08	4/05/08		3

In 2007 all of the ELRT that were PIT tagged, transferred, and released in the upper Pine Creek watershed were subsequently observed swimming in the creek. Two female ELRT were observed actively digging redds, and 4 redds were observed, as well as a number of less substantial "practice redds".

Maximum distances migrated by ELRT fall into three clusters: approximately 3 km, 25 km, and 35 km upstream (Table 1, Figure 1). In 2008 the furthest distance upstream that ELRT were detected was at the first PIT antenna, 3 km upstream from the mouth of the creek. Three fish reached this point but were never detected at the next antenna, 25 km upstream from the creek mouth. In prior years of tracking the maximum distance migrated by ELRT ranged from 3 to 35 km. In 1999, a radio-tag was found 35 km upstream, along the streambank of Bogard Spring Creek, a small tributary of Pine Creek. No carcass was present, but we consider it likely that the tag arrived at that point in the fish, and remained on the bank after the fish was eaten by a predator, or died naturally and was eaten by scavengers. In that same year the maximum distance reached by other tagged fish was 3 km.

There was a positive correlation between the maximum distance migrated by ELRT and annual mean daily streamflow (Figure 8). There was also a positive correlation between the maximum distance migrated by ELRT and the duration of streamflow (Figure 9). Both these predictive variables explained the same amount of variance in distance migrated.

There was a positive correlation between the maximum distance migrated by ELRT and snowpack in the upper Pine Creek watershed, represented by the Silver Lake site, although less variance was explained than for either of the flow variables (Figure 10). The correlation between maximum distance migrated by ELRT and snowpack in the lower Pine Creek watershed, represented by the Norvel Flat site, was negative, although this correlation was somewhat weaker (Figure 11).

Given the positive relationships between migration distance and flow, and between migration distance and snowpack in the upper Pine Creek watershed, we tested whether flow variables were related to snowpack in the upper watershed. Seasonal average daily mean streamflow was positively correlated with snowpack in the upper watershed (Figure 12), with 62% of variance explained. Duration of flow was also positively correlated with snowpack in the upper watershed (Figure 13), although snowpack explained only 20% of the variance in this relationship.

Seasonal average daily mean streamflow was negatively related to average April air temperature in the upper Pine Creek watershed (Figure 14).

The residuals from the regression of seasonal average daily mean flow on April snowpack were uncorrelated with average April air temperature in the upper Pine Creek watershed (Figure 15), indicating that temperature data on a monthly scale did not improve the prediction of flow.

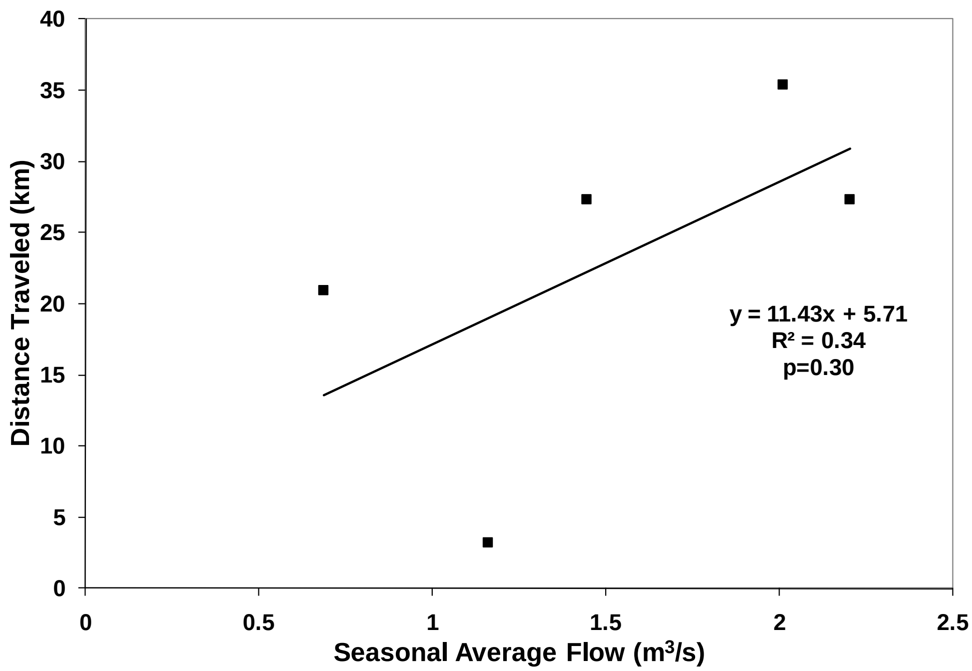

Figure 8. Maximum distance that a rainbow trout migrated upstream plotted against annual mean daily streamflow. Data for 1999-2002, 2004; n, n=5.

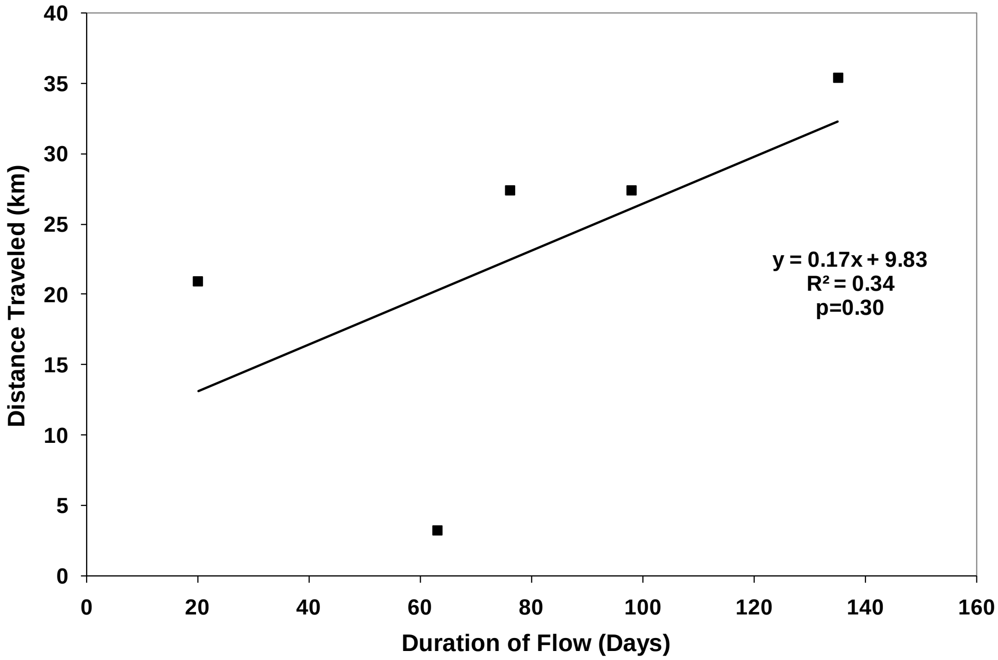

Figure 9. Maximum distance that a rainbow trout migrated upstream plotted against duration of streamflow for that year. Data for 1999-2002, 2004; n, n=5.

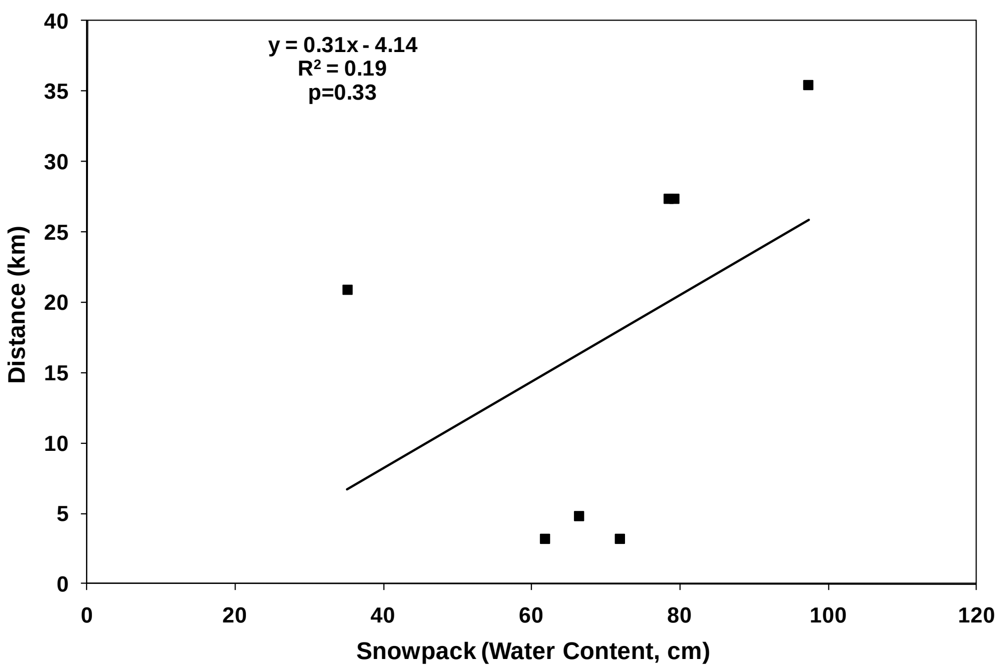

Figure 10. Maximum distance that a rainbow trout migrated upstream plotted against April snowpack in the upper Pine Creek watershed (data from Silver Lake site in Susan River watershed). Data for 1999-2002, 2004-2005, 2008, n=7.

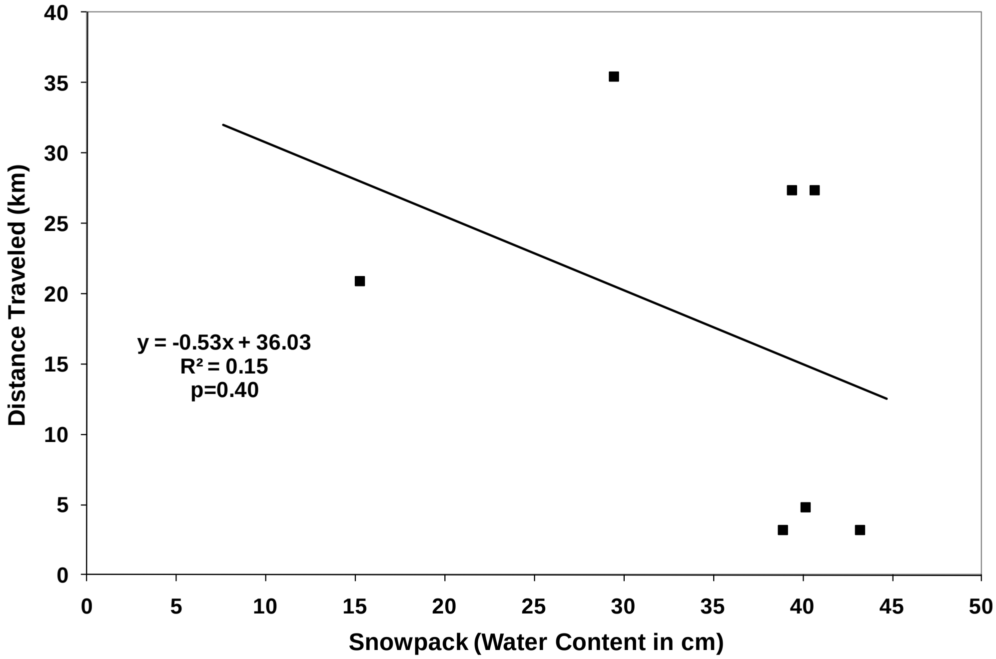

Figure 11. Maximum distance that a rainbow trout migrated upstream plotted against April snowpack in the lower Pine Creek watershed (data from Norvel Flat site in Susan River watershed). Data for 1999-2002, 2004-2005, 2008, n=7.

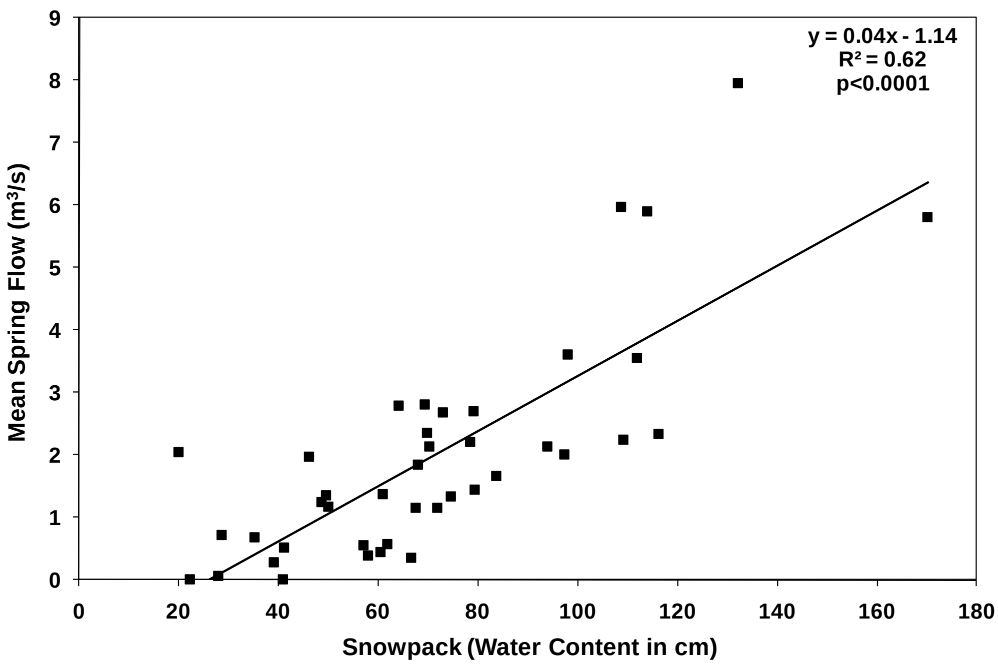

Figure 12. Seasonal average daily mean streamflow plotted against April snowpack in the upper Pine Creek watershed (data from Silver Lake site in Susan River watershed). Data for 1961-1966, 1968, 1970-1981, 1983-2004, n=41. Flow data were not collected in 1967 and 1969, or after 2004. Snowpack data were not available for April 1982.

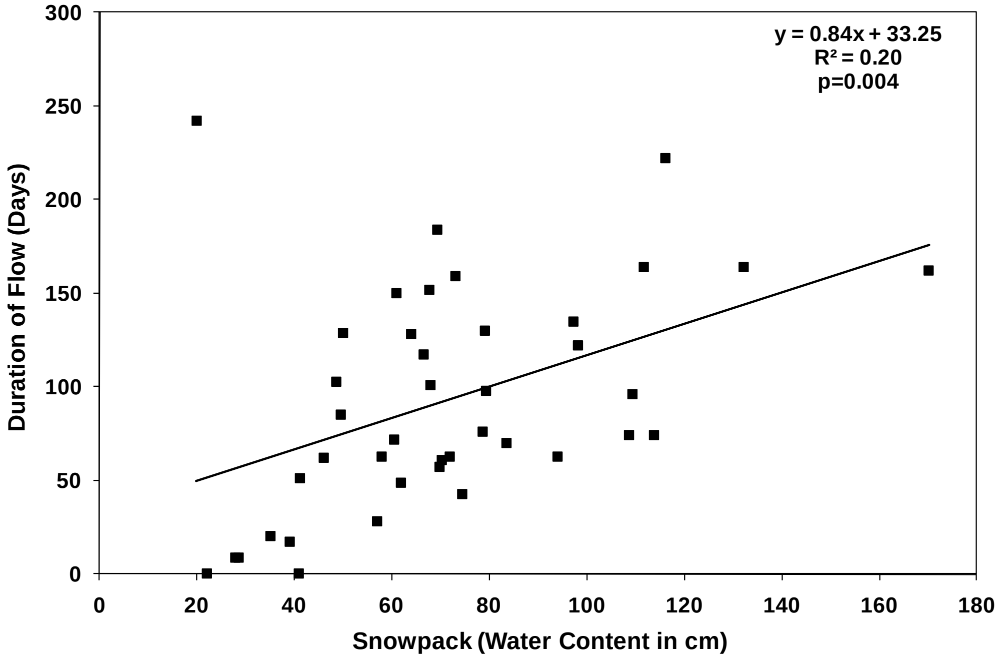

Figure 13. Duration of annual streamflow plotted against April snowpack in the upper Pine Creek watershed (data from Silver Lake site in Susan River watershed). Data for 1961-1966, 1968, 1970-1981, 1983-2004, n=41. Flow data were not collected in 1967 and 1969, or after 2004. Snowpack data were not available for April 1982.

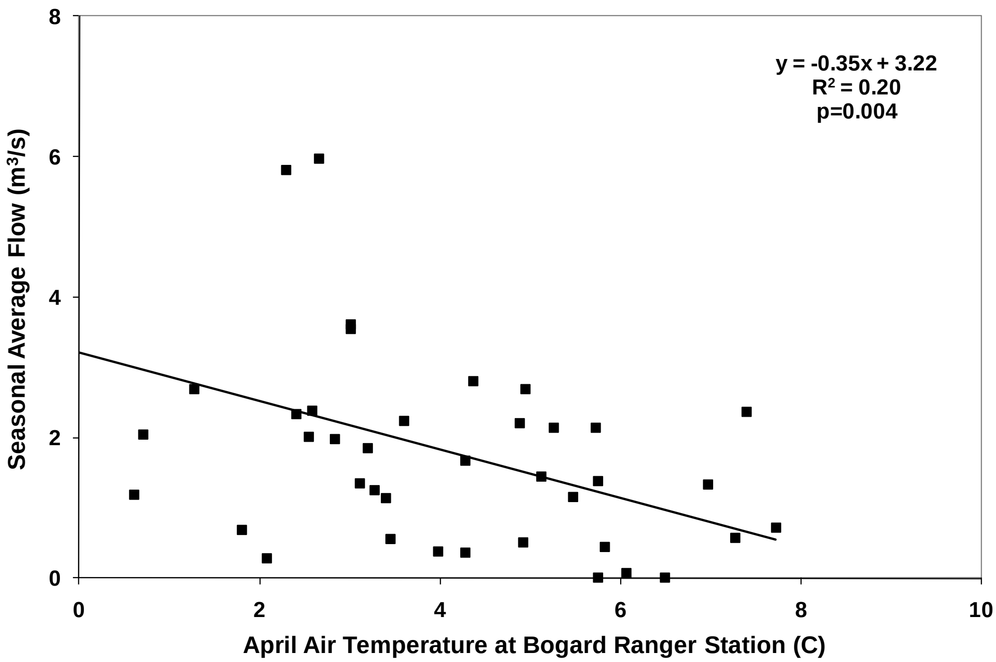

Figure 14. Seasonal average daily mean streamflow plotted against average April air temperature in the upper Pine Creek watershed (data estimated for Bogard Ranger Station COOP site). Data for 1961-1966, 1968, 1970-1994, 1997-2004, n=40. Flow data were not collected in 1967 and 1969, or after 2004.Air temperature data were not available for 1995 and 1996.

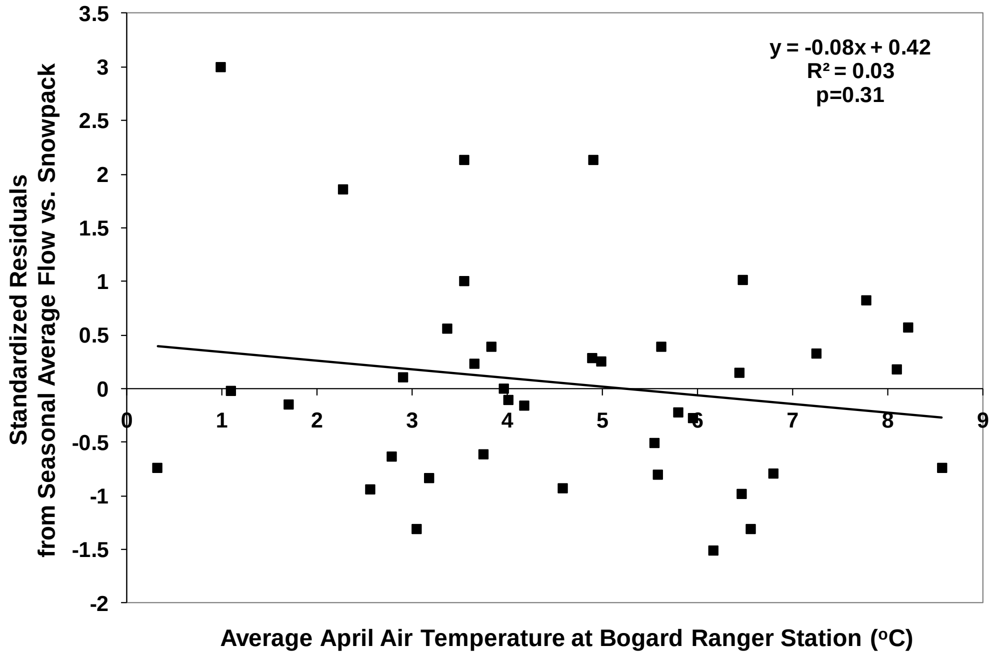

Figure 15. Residuals from regression of seasonal average daily mean streamflow vs. snowpack, plotted against average April air temperature in the upper Pine Creek watershed (data estimated for Bogard Ranger Station COOP site). Data for 1961-1966, 1968, 1970-1981, 1983-1994, 1997-2004, n=39. Flow data were not collected in 1967 and 1969. Snowpack data were not available for April 1982. Air temperature data were not available for 1995 and 1996.

Conclusions

Migration

With the probable exception of one fish, tagged Eagle Lake rainbow trout have not migrated successfully during 7 years of tracking. Historically, a migration of this distance must have been within the capacity of some ELRT in some years in order for the stock to persist. Rainbow trout in other watersheds are known to move long distances (e.g., 26 - 60 km) during migrations to spawning habitat (Meka et al. 2003, Venman and Dedual 2005). It is possible that ELRT were not able to migrate successfully in all years, depending on the water year type and snowmelt pattern. Before the population became hatchery-supported the fish were known to live to as old as 11 years (Moyle 2002), which would have allowed a mature fish to have had several years in which it could potentially migrate.

It is possible that flows during the years in which ELRT were tagged and tracked were not conducive to successful migration. The flow time series for the DWR gage (Figure 7) shows that the peak flows during the years in which fish tracking has been conducted were relatively low. In spite of the drought in the early 1990's, there were eight years in the 20-year period from 1979-

1998 in which peak flows exceeded 10 m^3/s, a level not observed during any of the years of fish tracking. Flows in 2003 were in this higher range, but fish were not tracked.

The observation of ripe female ELRT at the trap suggests that there may have been genetic selection for fish to be ripe at km 1, at the fish trap at the velocity barrier, not 35 km upstream, in the zone of perennial flow. For the past half century a fish needed to be ripe at the trap in order to be spawned and to have its genetics contribute to future generations. Fish that were not yet ripe at the time they reached the trap would be left to wait in the holding pens inside the trap facility. In recent years females have been ripe at the start of the run, whereas historically a fish would have needed to remain less ripe for the duration of the migration, which potentially could have taken several weeks as fish moved up the gradually thawing stream. Shifts in migration and spawning timing have been observed in other watersheds in connection with hatchery practices. For example, the migration timing of Columbia River steelhead (*O. mykiss*, sea-run rainbow trout) and coho salmon (*O. kisutch*) was shifted to occur earlier in the season through selection by hatchery programs that preferentially spawned the earliest arriving spawners (reviewed in Robards and Quinn 2002).

Spawning

In 2007 we transported and released sixteen ELRT spawners to the upper Pine Creek watershed and confirmed that they are able to exhibit natural spawning behavior such as digging redds. Some transported spawners were observed in the upper watershed as late as May. Thus, if significant numbers of ELRT are eventually successful in migrating to the upper watersheds it is likely that they will also spawn successfully.

Model predictions for migration and flow

It is possible to predict migration distance from flow, duration of flow, or from snowpack. The relationships between migration distance and flow, and migration distance and snowpack in the upper watershed were weak. However, sample sizes were small, due to the limited number of years in which fish have been tracked, and the cessation of operation of the flow gages. Nevertheless, the trends were in the expected direction. Additional years of fish tracking, as well as resumption of operation of a flow gage, would improve the sample size and potentially increase the predictive power of the models.

It is possible to predict seasonal average daily mean streamflow from April snowpack. The model relating seasonal average daily mean streamflow to snowpack had greater predictive power than the migration-snowpack relationship, and the relationship was also in the expected positive direction. Duration of flow was also positively related to snowpack, although much less variance was explained by the model. Thus, duration of flow can also be predicted from snowpack, but with very little accuracy.

Mean April air temperature in the upper watershed can also be used to predict seasonal average daily mean streamflow. However, temperature explained only 20% of the variance in flow, whereas snowpack explained 62%.

Climate change

The positive relationships between migration distance and seasonal average daily mean streamflow, and between streamflow and snowpack are particularly interesting in light of climate predictions for California. The Pine Creek watershed is at an elevation of approximately 1,750 m. Hayhoe et al. (2004) produced down-scaled climate change models for California, using climate data from the period from 1961-1990, and predicting future temperatures and precipitation for the period 2070-2099. They used two different climate models to run two scenarios, one which assumed that greenhouse gas concentrations would increase substantially (A1fi), and one which assumed that concentrations would level off by the end of the century (B1). In both scenarios it was predicted that winter temperatures would increase, and that winter precipitation would shift from snow to rain. Under the lower emission scenario, April snowpack would be reduced 65-87% in the elevation range of Pine Creek. Under the higher emission scenario the reduction would be from 95-97%. As a result, in either scenario the creek would be likely to flow more during the winter, due to winter rain events, but flows from snowmelt during the spring season would be lower (Maurer and Duffy 2005, Maurer 2007). More recent work by Cayan et al. (2008) corroborates the predictions of reductions in snowpack in the Sierra Nevada mountains, particularly in the lower elevation northern part of the range. Given the positive relationship between migration distance and snowpack, decreased snowpack in future years may reduce the proportion of years in which ELRT could successfully migrate during the snowmelt period.

Changes in the timing of snowmelt dominated streamflow have already been observed in the western United States, although they cannot yet be statistically attributed to anthropogenic forcing of climate change (Maurer et al. 2007). Such changes may already be occurring in Pine Creek, although the lack of recent flow data makes this difficult to determine. It is possible that ELRT spawners might shift to an early migration strategy, moving upstream to areas of perennial summer flow during winter rain events. However, the fish currently lack the opportunity to experience and adapt to flow changes that are likely to occur with climate change.

Future efforts in this watershed would be improved by reinstatement of a permanent flow gaging station. Currently there is a lack of federal funds for operation of gaging stations, and some uncertainty about which entities could be responsible for operating one of the decommissioned gaging stations. The installation of a water level logger (e.g., Solinst Level Logger®) in one of the old gages, plus calibration of the logger to measured stream flows across a range of flows, would provide flow data for future comparison with snowpack and fish migration data.

More detailed temperature data, including daily maximum data for the months of February through May, might improve our understanding fish migration success. It may be possible to relate heat wave temperature spikes to daily flow changes across the spring season, and to relate flow changes to the daily movements of individual fish. However, daily temperature data would not be available to managers in advance to use as a predictive tool in any given year. In order for ELRT to have the maximum opportunity to migrate successfully, using the entire timeframe of spring flows, the decision to allow fish to migrate must involve a commitment made early in the season. This decision could be made on a yearly basis, dependent on snowpack. Alternatively, ELRT could be given the opportunity to migrate every year, regardless of snowpack, in order to allow the stock the fullest opportunity to adapt to changes in regional climate, and to emerging flow patterns.

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