Consequences of Climate Change for Mountain Lakes and Native Cutthroat Trout.

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Introduction and background

Climate change will have drastic effects on inland aquatic systems of the western United States (Hauer et al. 1997, Poff et al. 2002, Christensen et al. 2004, Isaak et al. 2010). Previous studies of climate change and salmonids (hereafter referred to as trout) in river systems suggest these populations are susceptible to multiple aspects of a changing climate, including increased temperatures, wildfire, and more variable precipitation patterns (Rieman et al. 2007; Williams et al. 2009; Isaak et al. 2010; Wenger et al. 2011) . Trout are keystone species (Simon and Townsend 2003, Baxter et al. 2004, Benjamin et al. 2011) in many mountain streams and lakes and could also serve as sentinels for climate change given their preference for coldwater habitats (Jonsson and Jonsson 2009, McCullough et al. 2009, Wenger et al. 2011). These ecologically important fishes are also economically important owing to the recreational resources they provide.


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However, native trout are in peril (Dunham et al. 2004), a pattern specifically exhibited by cutthroat trout (*Oncorhynchus clarkii*), a group made up of 14 subspecies most of which have been petitioned for listing under the Endangered Species Act (ESA; Behnke 2002). Within the Sothern Rocky Mountains (SRM) one cutthroat trout is listed as threatened by the ESA (greenback cutthroat trout *O. c. stomias*; Behnke 2002). However, all cutthroat trout are found in only fractions of their former range and are subjects of extensive management actions to conserve the remaining populations of these ecologically and economically important fishes (e.g., Shepard et al. 2005, Alves et al. 2008, Gresswell 2011, Vinson et al. 2011, Hirsch et al. 2013). Therefore, the predicted truncation of suitable habitat for cutthroat trout in streams and rivers owing to climate warming, changes in precipitation, and shifts in disturbance regimes must be incorporated into these management strategies to maximize their effectiveness.

Western native trout also inhabit mountain lake systems, but these habitats have been neglected in assessing climate change consequences for trout. Mountain lakes and streams form networks which provide native fishes with a diverse array of habitats. While many reservoir systems are primarily inhabited by non-native fishes, headwater systems including mountain lakes are important to the conservation of native species (Dunham et al. 2004). These mountain lake-stream networks are likely of greater importance than streams alone, because lake-stream networks may promote a wide variety of life history patterns, a trait which is crucial for successful conservation of fishes in the face of a changing climate (Schindler et al. 2010). Owing to the small network fragments and high elevations to which some imperiled trout are currently restricted, warming from climate change might be a lesser threat than reduced habitat type and size (Roberts et al. 2013). For example, Colorado River cutthroat trout (*O. c. pleuriticus*; CRCT) in the SRM are largely restricted to high elevation (>1700m) streams of small extent (median length 5.9 km), and yet lakes contain 20% of populations known to be genetically pure (Hirsch et al. 2006; Young 2008). Given the unique qualities of these lake-stream networks they likely provide refuges for cutthroat trout populations from climate change stressors, and therefore increase their resiliency. For example, lakes are likely to have more stable temperature regimes than streams, and are largely protected from stream disturbances like fire, debris flow, drying, and freezing. However, very little is known about the life history patterns of inland cutthroat trout in mountain lakes, and the potential changes in abiotic conditions related to climate change that may affect them such as surface temperatures and ice-free periods. The goals of this research project are to 1) predict how changing climatic conditions will influence the thermal regimes of mountain lake-stream networks in the SRM and specifically Colorado, and 2) to measure the life-history movements of cutthroat trout in relation to these thermal regimes.

We amended our initial research objectives to leverage funds from the USGS and Dr. Roberts' new position at the USGS Fort Collins Science Center as a Mendenhall Post-doctoral fellow, and included an expanded field component to address the second goal of this research. Our overall research objectives are:

1) Predict current lake temperatures, hindcast past trends, and develop a set of eco-physiological metrics to assess the ecological consequences of changes to lake thermal regimes for cutthroat trout

2) Project future lake thermal conditions using lake temperature models and downscaled climate projections, and

3) Determine the potential for mountain lake-stream networks to serve as refuges from climate change impacts to native cutthroat trout via lake-stream movements.

The first two objectives required gathering existing data sources of lake temperature while the third involved field investigations of spring-fall cutthroat trout movement patterns within two mountain lake-stream networks.

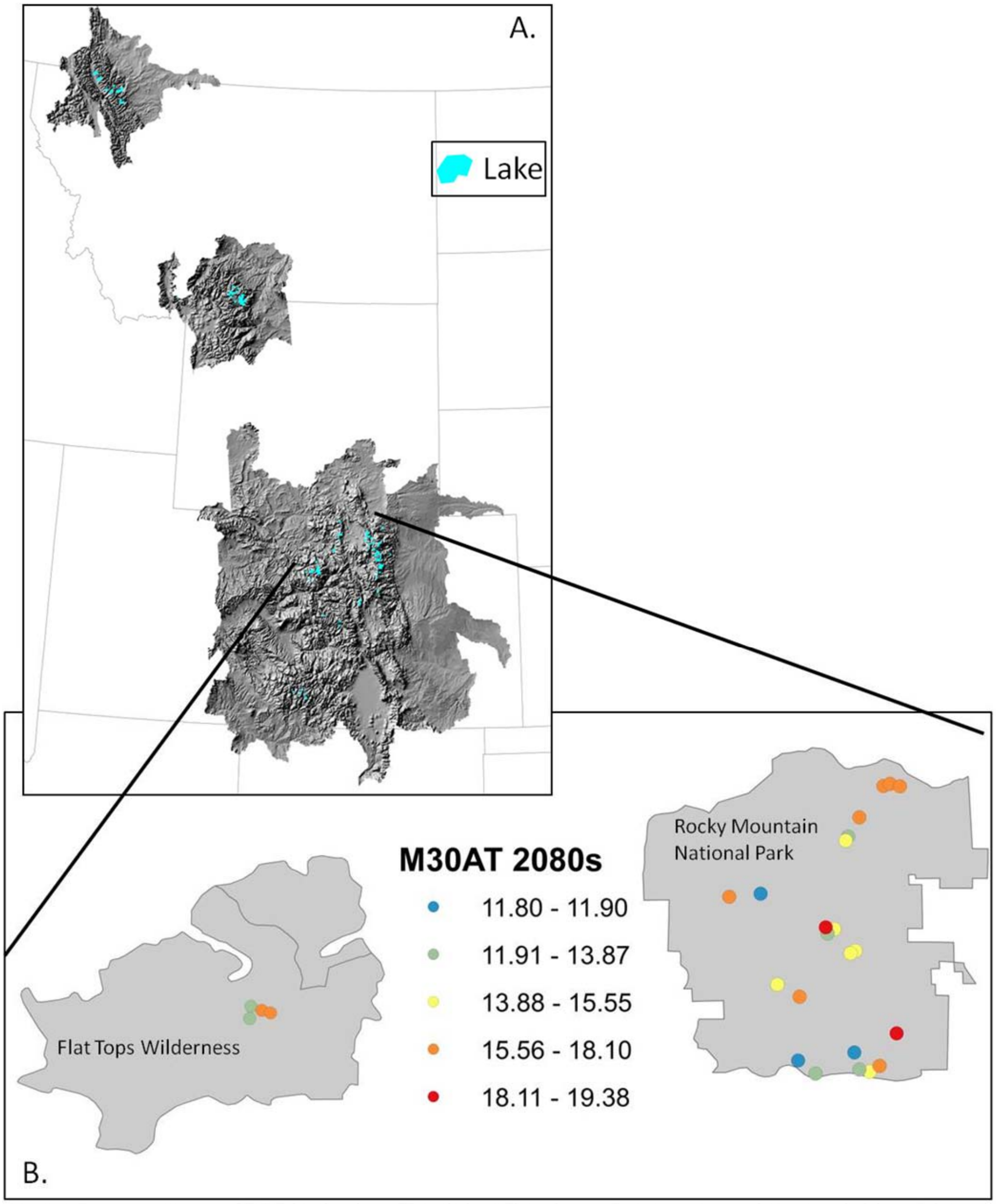

Figure 1. Locations of 144 high elevation lakes that have temperature data available within the Rocky Mountains (A). Predictions of future M30AT for 26 lakes with continuous temperature data within the Southern Rocky Mountains (B).

Objective 1-Current/past lake temperatures and eco-physiological metrics

Methods

We collected existing lake temperature data from 144 lakes in the Rocky Mountains distributed from central Colorado to northern Montana (Figure 1A). However, many of these are only point temperature measurements taken intermittently or only once during the ice-free season. Continuous records of temperature were available for only 26 lakes, and the majority of these records are from lakes in Rocky Mountain National Park (RMNP; Table 1). These continuous records range in duration from 2 to 15 years, providing a unique dataset to examine the current and future influence changing climatic conditions may have on thermal conditions of mountain lake systems in the SRM and particularly north-central Colorado. We also acquired air temperature records from the SNOTEL network which were used to create water temperature models of daily mean temperature values. In addition to these previously collected data we also deployed temperature loggers into three new lake systems. These additions include three buoy strings with loggers at every meter of depth (Sky Pond, Clinton Gulch Reservoir, and Fryingpan Lake #3) and one that measures surface temperature (Fryingpan Lake #2).

Our initial summary and quality check of all the lake temperature data, which totaled 911 years of data at 144 locations (mean: 6.3 years per location). Only the 26 lakes with continuous data had records suitable for our analysis. We calculated important thermal metrics for each of these lakes including annual Maximum 30-day Mean Average Temperature (M30AT; the average temperature for the warmest 30 days of the summer). We also created predictive models of mean daily temperature for each lake.

Table 1. Locations and site characteristics of the 26 lakes with continuous records of lake surface temperature. Adjusted correlation coefficient for non-linear logistic regression models (Mohseni et al. 1999) fit using mean weekly air temperature from the closet SNOTEL monitoring station. The entire record of SNOTEL mean weekly air temperatures (~1989-2013) was also used with these models to calculate the current Maximum 30-day Mean Average Temperature (M30AT).

Lake	Latitude	Longitude	Elevation (m)	R^2	M30AT current
Adams Lake	40.18366911	-105.7177532	3413	0.53	15.29
Arrowhead Lake	40.38055303	-105.7620367	3408	0.48	9.06
Bear Lake	40.31319877	-105.6502156	2915	0.65	11.62
Big Cow Lake	39.94546919	-107.2312062	3463	0.79	10.32
Bluebird Lake	40.19321462	-105.6514884	3338	0.60	12.78
Boundary Lake	40.16820829	-105.6972265	3316	0.35	11.48
Caddis Lake	40.44798035	-105.6588359	3277	0.64	11.01
Crystal Lake	40.47064988	-105.6455505	3495	0.69	11.93
Dream Lake	40.31022062	-105.6559065	2931	0.67	16.21
Fern Lake	40.33877742	-105.6751028	2907	0.65	14.74
Gem Lake	39.94537071	-107.2171228	3426	0.74	11.17
Jewel Lake	39.9420382	-107.2057796	3412	0.82	10.67
Lake Husted	40.51000843	-105.6093375	3384	0.75	15.03
Lake Louise	40.50757939	-105.6171881	3378	0.89	10.77
Lake Nanita	40.25900664	-105.7160674	3270	0.51	16.42
Little Cow Lake	39.94476168	-107.2328569	3467	0.77	10.54
Lost Lake	40.50719592	-105.5975919	3250	0.72	16.29
Lower Hutcheson Lake	40.17052113	-105.6334083	3323	0.58	14.11
Odessa Lake	40.33352349	-105.683044	2931	0.63	12.48
Pear Lake	40.17737783	-105.6216796	3229	0.79	15.63
Pettingell Lake	40.27328296	-105.7423296	3213	0.87	15.15
Sandbeach Lake	40.21582826	-105.601547	3148	0.74	18.68
Spruce Lake	40.34082701	-105.6850603	2947	0.66	18.98
Timber Lake	40.37689783	-105.7990317	3370	0.75	14.58
Upper Hutcheson Lake	40.17305842	-105.645435	3413	0.49	13.25
Ypsilon Lake	40.44315432	-105.6615008	3233	0.67	13.94

These models were created using a non-linear logistic regression approach (Mohseni et al. 1999). We used mean weekly air temperature from the closest SNOTEL site to predict mean daily surface lake temperature (see Figure 2 for an example of the shape of this relationship). We combined this model with the past air temperature observations at the closest SNOTEL site to examine past trends in lake surface temperature.

Results

Using our model to predict mean daily surface lake temperature from mean weekly air temperature, we then calculated the average M30AT for each lake. On average, these models accounted for 67% of the variation in the observed temperatures for these 26 lakes (R^2=0.67; Table 1). The mean current M30AT for these lakes was 13.54°C (SE=0.52), indicating that lake surface temperatures during the warmest 30 days of the summer averaged 13.5°C. To interpret

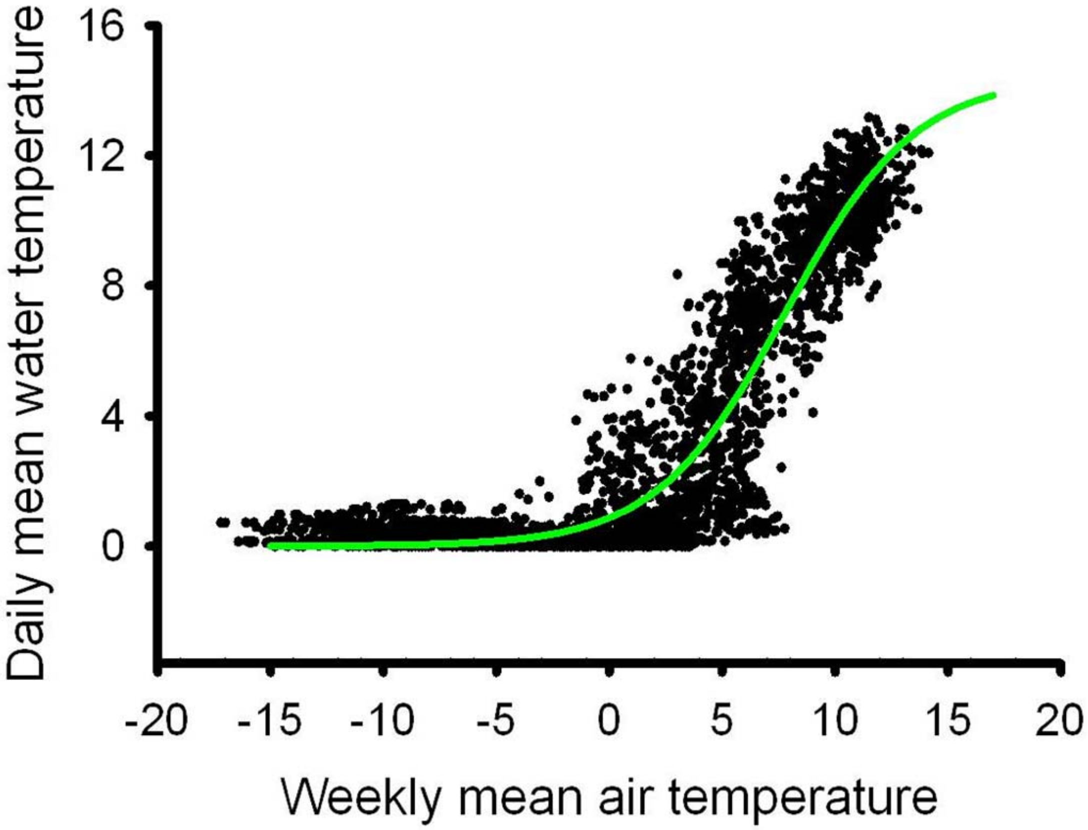

Figure 2. Relationship between mean weekly air temperature at the nearest SNOTEL site and surface water temperature at Lake Louise in Rocky Mountain National Park . The green line shows the non-linear logistic equation fit (R^2=0.89) to these data and was used to predict past and future surface water temperature.

these thermal results we used the Eco-physiological states from Roberts et al. (2013) that represent potential recruitment and growth for cutthroat trout populations (Table 2).

Table 2. Eco-physiological states for the warmest 30 days of daily mean temperatures (after Roberts et al. 2013).

Node name	Definition	States
Mean summer stream temperature (M30AT)	The warmest 30-day mean of the average daily water temperature, used to evaluate recruitment and growth	No recruitment: <8.0°C Low recruitment: 8.0-9.0°C Optimal growth and recruitment: 9.1-18.0°C Declining growth: 18.1-19.9°C Low or no growth: ≥20.0°C

Using these states no lakes are in the 'very low or no recruitment' at cold temperatures (<8.0°C) or 'low or no growth' states at temperatures that are warmer than the optimum for cutthroat trout (≥20°C). The majority of these lakes (88%; 23/26) are considered optimal for growth and recruitment (9.1-18.0°C) whereas 4% (1/26) fall into the 'low recruitment' state (8.0-9.0°C) and 8% (2/26) are in the 'declining growth' category (18.1-19.9°C). These predictions indicate that thermal conditions for most of these lakes are ideal for cutthroat trout populations. However, in some warming could reduce epilimnetic habitat quality for cutthroat trout. Despite the high elevation of these lakes only one currently has colder than optimal thermal conditions. We had good model fit for the non-linear regression created from these data, but there is some variation among the 26 lakes.

Objective 2-Project future lake thermal conditions using lake temperature models and regional downscaled climate projections

Methods

Using the model we created to predict mean daily lake surface water temperature from mean weekly air temperature, we projected future thermal conditions for all 26 lakes using regionally downscaled climate projections. The spatial resolution for these climate projections is 15 km gridded cells, and the predictions are available for short-term (2035-2045) and long-term (2075-2085) time horizons. We used output from the GENMOM climate model under the A2 emission (assuming a medium-to-high emissions future) scenario (Hostetler et al. 2011). These future air temperatures were summarized into weekly mean temperatures and used as input to our non-linear lake surface temperature model to predict potential future thermal conditions. In addition to calculating M30ATs for each lake we produced three other thermal metrics. These include mean annual water temperature (average of mean daily surface temperature for each year), mean summer temperature (average of mean daily surface temperature for June-August for each year), and potential ice-free days (number of days with a mean daily surface temperature ≥4°C for each year). We used the annual predictions of these metrics to calculate the change per decade for each of the 26 lakes.

Results

Using the a summary of mean annual surface lake temperature, mean summer lake surface temperature and the number of days ≥ 4 °C annually (an index of the ice-free season) we found warming trends extending towards the end of this century (Table 3). Mean annual lake surface temperature is predicted to increase at a rate of 0.19°C/decade (SE=0.01) while mean summer temperature increases by 0.42 °C/decade (SE=0.03). The increases in summer mean temperature are similar to 0.60 °C/decade reported in recent reviews of lake surface temperatures worldwide (Schneider and Hook 2010).

Table 3. Results of lake surface temperature model predictions. Temperature metrics were calculated using the fitted non-linear models of mean daily lake surface temperature and mean weekly air temperature from climate models (Hostetler et al. 2011).

Lake	Change per decade			M30AT 2080s
	Mean summer	Mean annual	Ice free days	
Adams Lake	0.45	0.17	3.3	16.05
Arrowhead Lake	0.47	0.16	5.1	11.99
Bear Lake	0.23	0.17	5.4	11.81
Big Cow Lake	0.63	0.2	4.9	14.81
Bluebird Lake	0.28	0.12	3.2	13.18
Boundary Lake	0.23	0.11	3.3	11.75
Caddis Lake	0.44	0.18	5.8	12.67
Crystal Lake	0.39	0.18	5	13.03
Dream Lake	0.38	0.23	5.4	16.56
Fern Lake	0.3	0.21	5.5	14.98
Gem Lake	0.73	0.23	5.3	15.55
Jewel Lake	0.82	0.25	6	16.31
Lake Husted	0.42	0.22	5.4	15.82
Lake Louise	0.49	0.24	6.8	13.11
Lake Nanita	0.36	0.22	4.9	16.84
Little Cow Lake	0.76	0.23	5.4	15.91
Lost Lake	0.41	0.28	5.2	16.92
Lower Hutcheson Lake	0.35	0.13	2.6	14.73
Odessa Lake	0.28	0.18	5.2	12.79
Pear Lake	0.27	0.13	3.2	15.87
Pettingell Lake	0.16	0.2	4.6	15.2
Sandbeach Lake	0.32	0.16	3.3	18.96
Spruce Lake	0.4	0.25	4.9	19.38
Timber Lake	0.53	0.19	4.2	16.61
Upper Hutcheson Lake	0.34	0.11	2.5	13.87
Ypsilon Lake	0.47	0.21	5.1	15.36

The number of ice-free days increases at a rate of 4.7 days/decade (SE=0.22). To assess how these changes may influence the thermal suitability of these habitats for cutthroat trout we also calculated the M30AT from the 2075-2085 predictions, which averaged 15.0°C (SE=0.40; Figure 1B) for these lakes in this long-term time horizon. Among these 26 lakes 92% are considered ‘optimal for growth and recruitment’ and 8% are considered to be in the ‘declining growth’ category. Given the role of water temperature as a “master variable” in aquatic systems that controls processes such as algal, invertebrate, and vertebrate physiology along with the potential for cumulative and threshold effects at various trophic levels (Weidman et al. 2014), specifically fish growth and survival (e.g., Coleman and Fausch 2007), these predicted changes to thermal regimes are likely to have important implications for mountain lake systems in the SRM. The change in ice-free days of about 5 days per decade seems especially significant, particularly when compared to observed patterns in ice forming and breakup dates which suggest the total number of ice-free days on average increased by 1.23 days per decade through the 1990’s (Magnuson et al. 2000).

Objective 3-Determine the potential for mountain lake-stream networks to serve as refuges from climate change impacts via lake-stream movements

Methods

Through an extensive process of searching the CRCT conservation team database and interacting with local Colorado Parks and Wildlife biologists we selected two sites to investigate

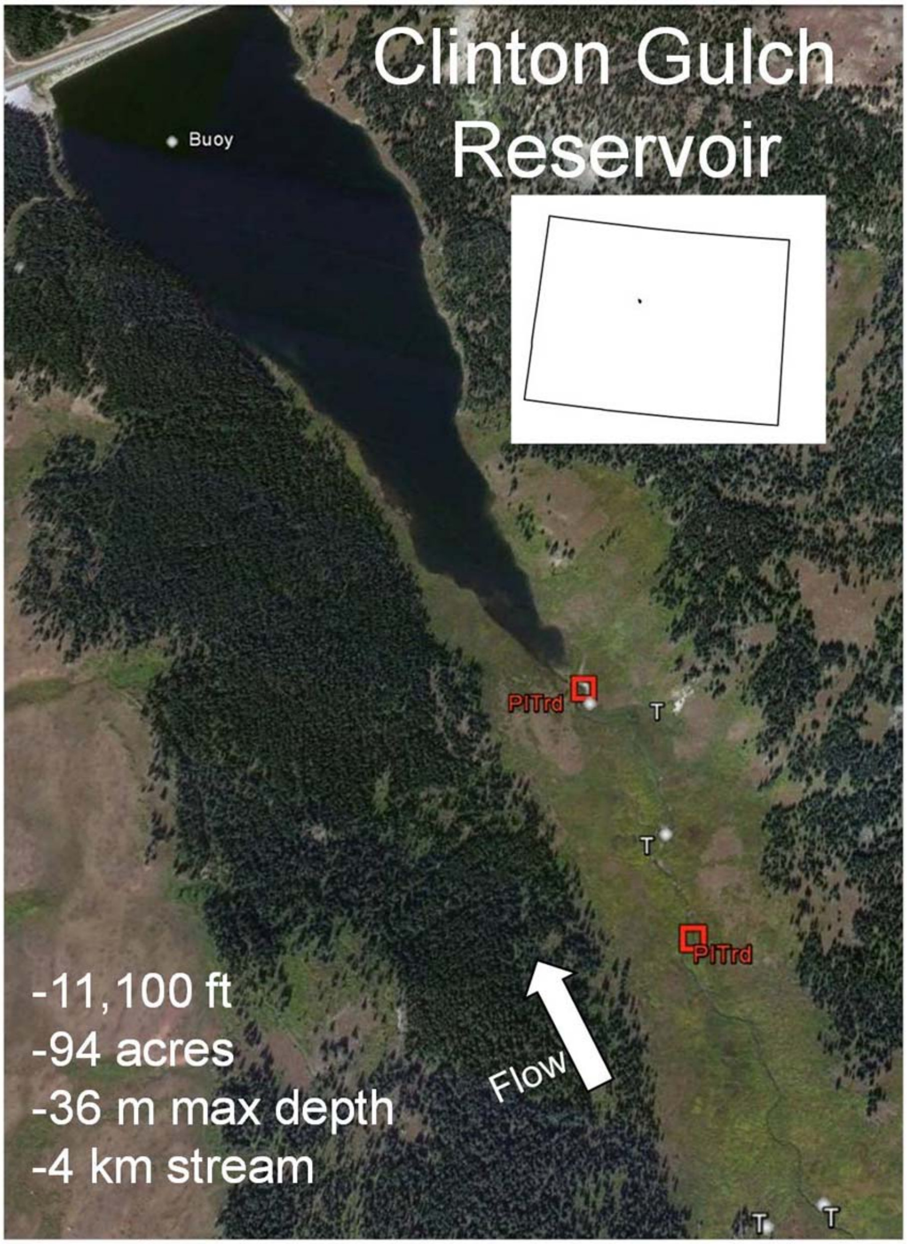

Figure 3. Clinton Gulch Reservoir, the location of PIT tag antenna s (PITrd) and the abiotic sensor array (Buoy; T=temperature logger).

the movements of cutthroat trout within mountain lake-stream networks. These sites include Clinton Gulch Reservoir (CG; Figure 3) and the upper Fryingpan Lakes (Figure 4). Our

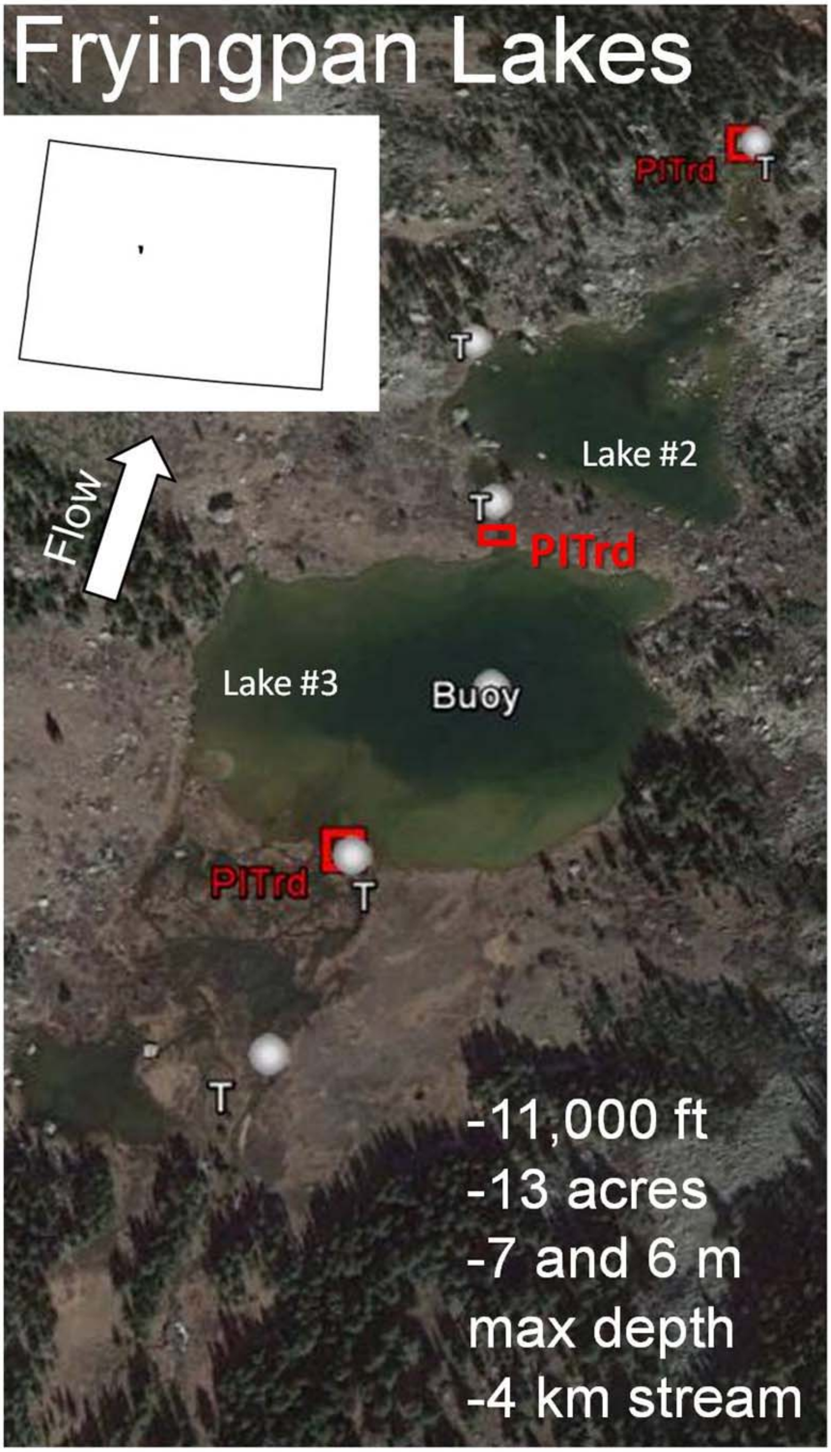

Figure 4. Upper Fryingpan Lakes, location of PIT tag antennas (PITrd) and the abiotic sensor array (Buoy; T=temperature logger).

investigation of these movement patterns used PIT (Passive Integrated Transponder) tag technology which included two sizes of tags (12 and 23mm HDX; half duplex), a mobile backpack reader, and stationary paired antennas readers. Cutthroat trout were sampled using backpack electrofishing, gillnets set for short periods, and hook-and-line sampling. We also deployed a suite of logger sensors at 1-m _intervals of depth to continuously record water temperature, and thermal stratification (see below). These data were recorded starting late spring 2013 and all devices were removed in the fall of 2014.

Results

We sampled and PIT tagged a total of 634 cutthroat trout from Clinton Gulch Reservoir (N=371) and the Fryingpan Lakes (N=263). Ease of access was the primary factor which

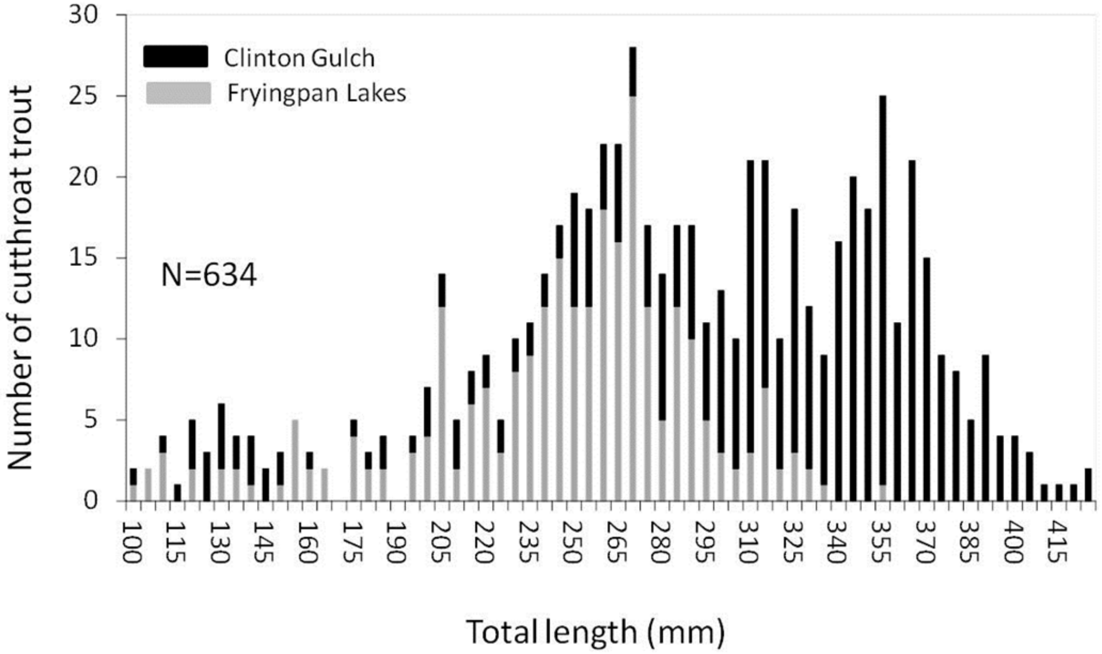

Figure 5. Cutthroat trout length frequency distribution for Clinton Gulch (N=371) and Fryingpan Lakes (N=263).

resulted in more fish being tagged at CG. The size structure of all the fish tagged showed that cutthroat trout are larger in Clinton Gulch. However, we were able to PIT tag a representative cross-section of all size classes (Figure 5).

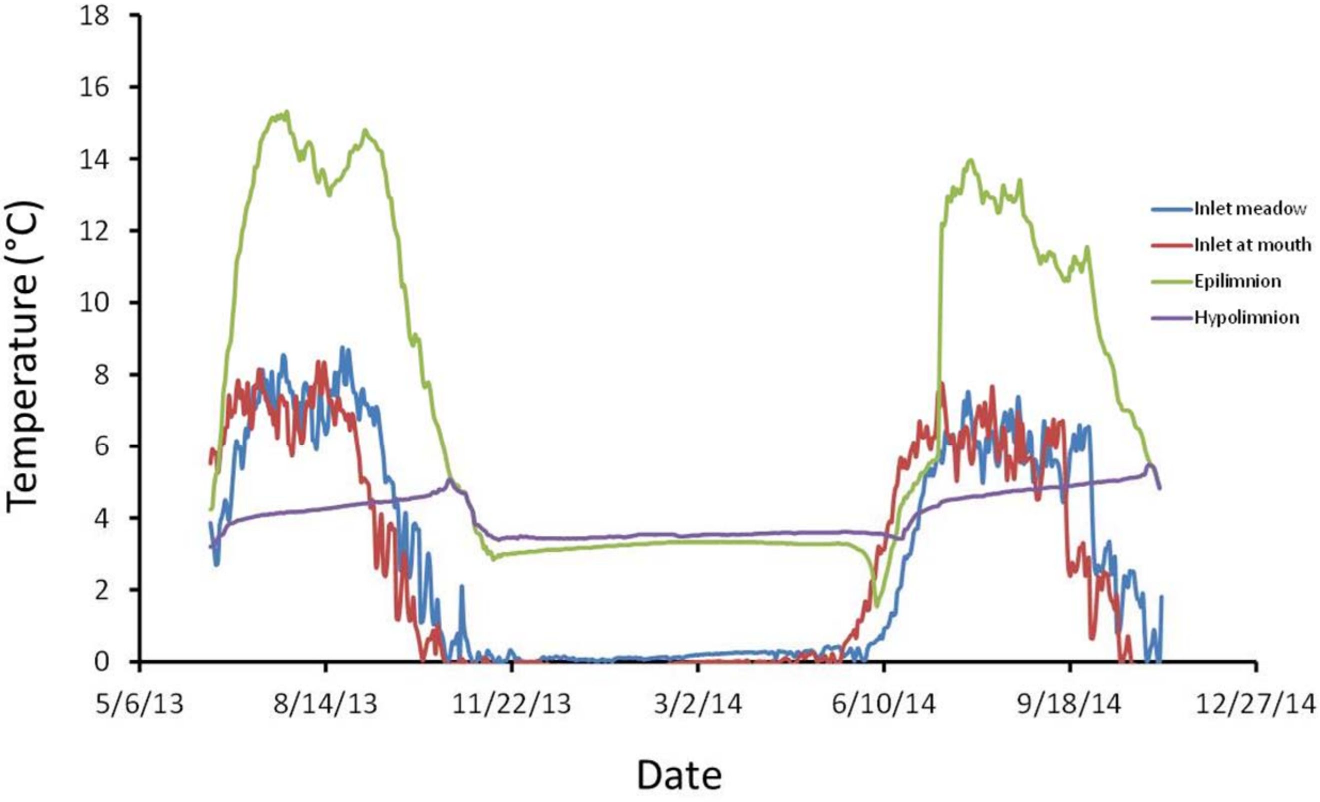

Figure 6. Thermal characteristics for Clinton Gulch Reservoir and Clinton Creek.

Multiple PIT tag antenna readers, each with paired antennas for directionality, were set up at each study site. At CG we deployed two antenna readers located in the inlet stream since water is let out of the reservoir only through a bottom release structure. One CG reader was ~25 m upstream of the inlet mouth of Clinton Creek, whereas the second reader was located ~0.6 km upstream above a meadow. In addition, we deployed three temperature loggers in Clinton Creek and one temperature/pressure logger to measure stream depth and estimate discharge. We also deployed a buoy at the deepest point in the Clinton Gulch Reservoir (37 m) with a temperature logger every meter and one temperature/dissolved oxygen logger 2 m from the bottom (Figure

3). In addition we took point measures of the vertical thermal profile along a longitudinal profile from the deepest point to the Clinton Creek inlet of the reservoir using a mini-CTD (Conductivity, Temperature, and Depth) device. These thermal profile transects were collected weekly beginning in late August 2013. Results from these data show that there are distinct

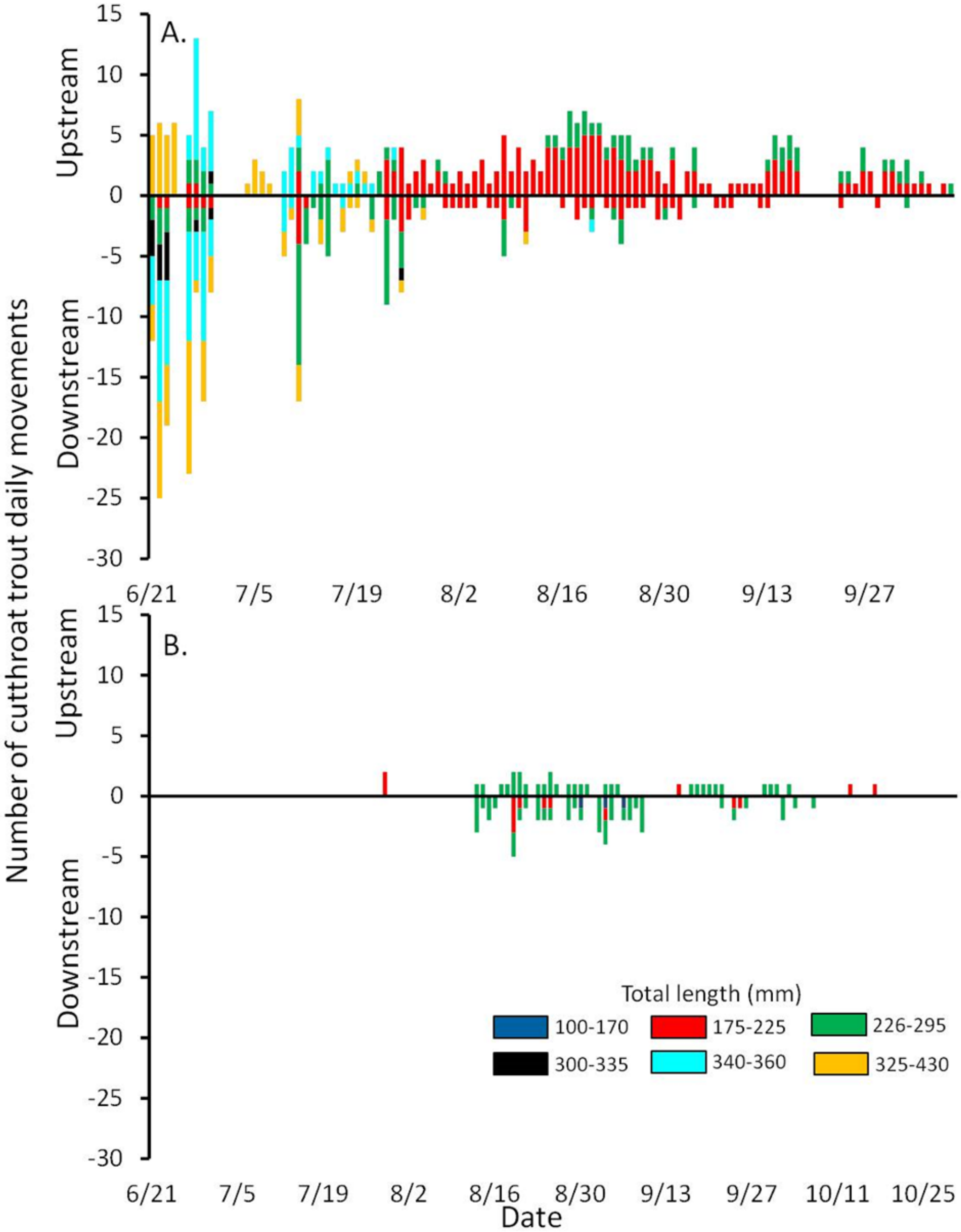

Figure 7. Cutthroat trout movements during 2013 from reservoir to Clinton Creek (A) and Clinton Creek meadow to upper Clinton Creek (B).

thermal habitats throughout the CG basin with colder habitats found in Clinton Creek and the hypolimnion of the reservoir and warmer habitats found in the surface water of the reservoir (Figure 6). Anecdotally, we also observed recently hatched fry in stream eddies and lake margins beginning in early September during both years. This suggests that some fry are

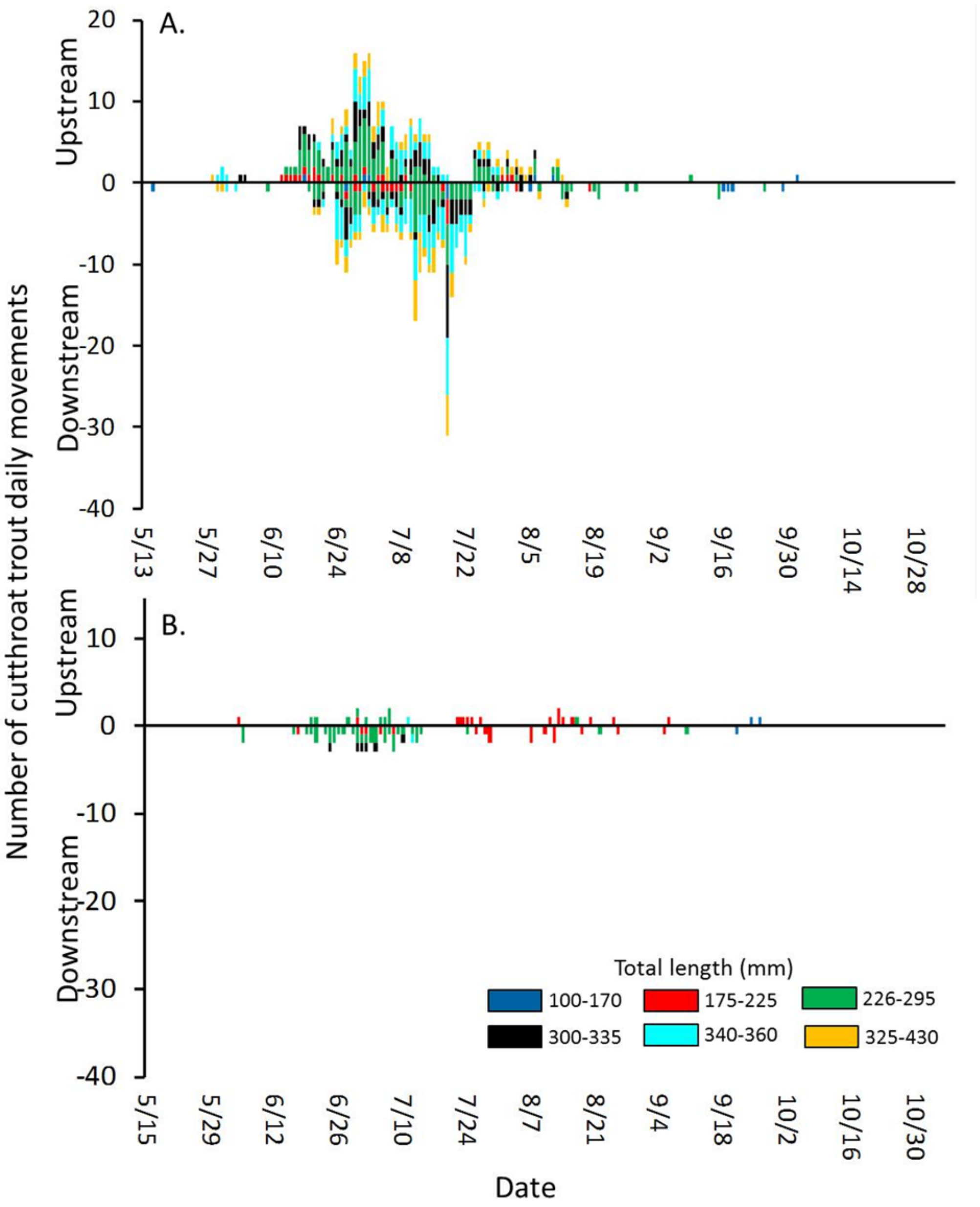

Figure 8. Cutthroat trout movements during 2014 from reservoir to Clinton Creek (A) and Clinton Creek meadow to upper Clinton Creek (B).

exported from lotic (coldest) to lentic (warmer) habitat upon hatching.

The PIT tag antennas recorded data from 6/14 thru 10/8 in 2013 and 5/13 thru 11/5 in 2014. The fish movement results from the PIT antennas show similar movement patterns across both years. A group of larger fish moved in and then out of Clinton Creek from the beginning of sampling (May or June) until mid-July (Figures 7 and 8). These movements are likely related to spawning in the meandering and meadow areas of Clinton Creek, a pattern corroborated by visual observations of redds and spawning fish lasting until late July in both years. In 2014 we were able to record movement prior to spawning behavior and detect the first fish moving into Clinton Creek, which occurred around 6/10/2014 (Figure 8A). These initial movements tended to be larger fish. Once these large spawning fish decreased in frequency within Clinton Creek in mid-July, smaller fish began to move in and out of the Clinton Creek, a pattern which continued until the PIT-tag readers were removed in the fall. This pattern was more evident in 2013 and in 2014 the post-spawning movement appeared less frequently. The upstream reader at CG detected far fewer fish. However, a few medium-sized fish were detected passing this reader into the upstream portions of Clinton Creek from August through October (Figures 7B and 8B). There was annual variation of movement in the upstream portion of Clinton Creek with more fish passing this reader in 2014. The 2014 movement showed post-spawning incidents of smaller fish moving in the upstream areas of Clinton Creek similar to what was observed during late summer/early fall at the downstream reader in 2013.

The PIT reader array deployed at the Fryingpan lakes included two readers in 2013 and three readers in 2014, each with paired antennas. The two readers deployed in both years included one reader just upstream of Lake #3 in the Fryingpan River, but downstream of a beaver meadow complex and a second reader was located downstream of Lake #2 in the

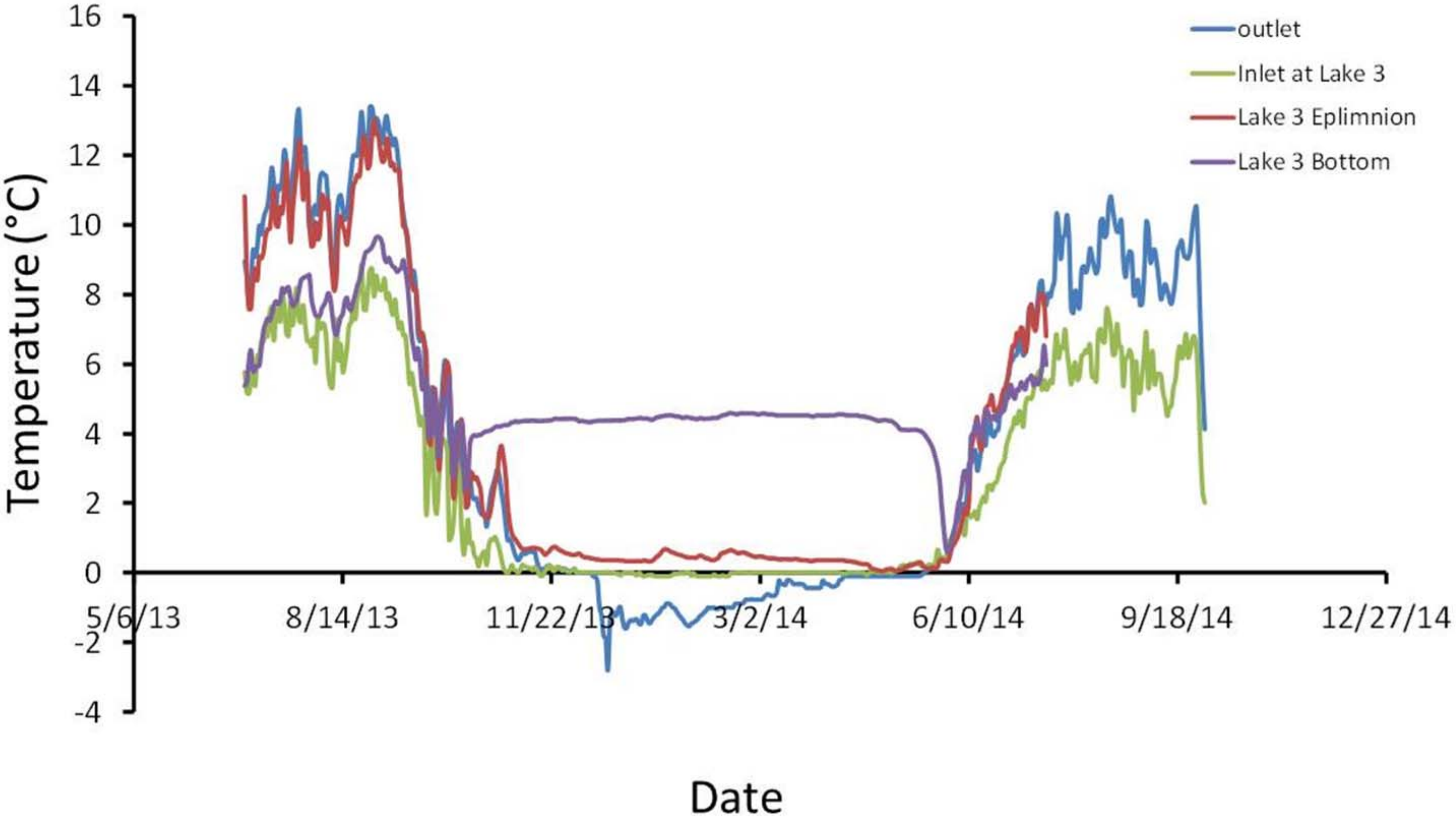

Figure 9. Thermal characteristics for Fryingpan Lakes and Fryingpan River.

Fryingpan River outlet. During 2014 a third reader was placed in the connecting channel between Lake #2 and #3 (Figure 4). In addition to PIT readers we also deployed three temperature loggers and two temperature/pressure loggers. A buoy was placed in Lake #3 at the deepest point (7 m) with a temperature logger every meter of depth and a temperature/dissolved

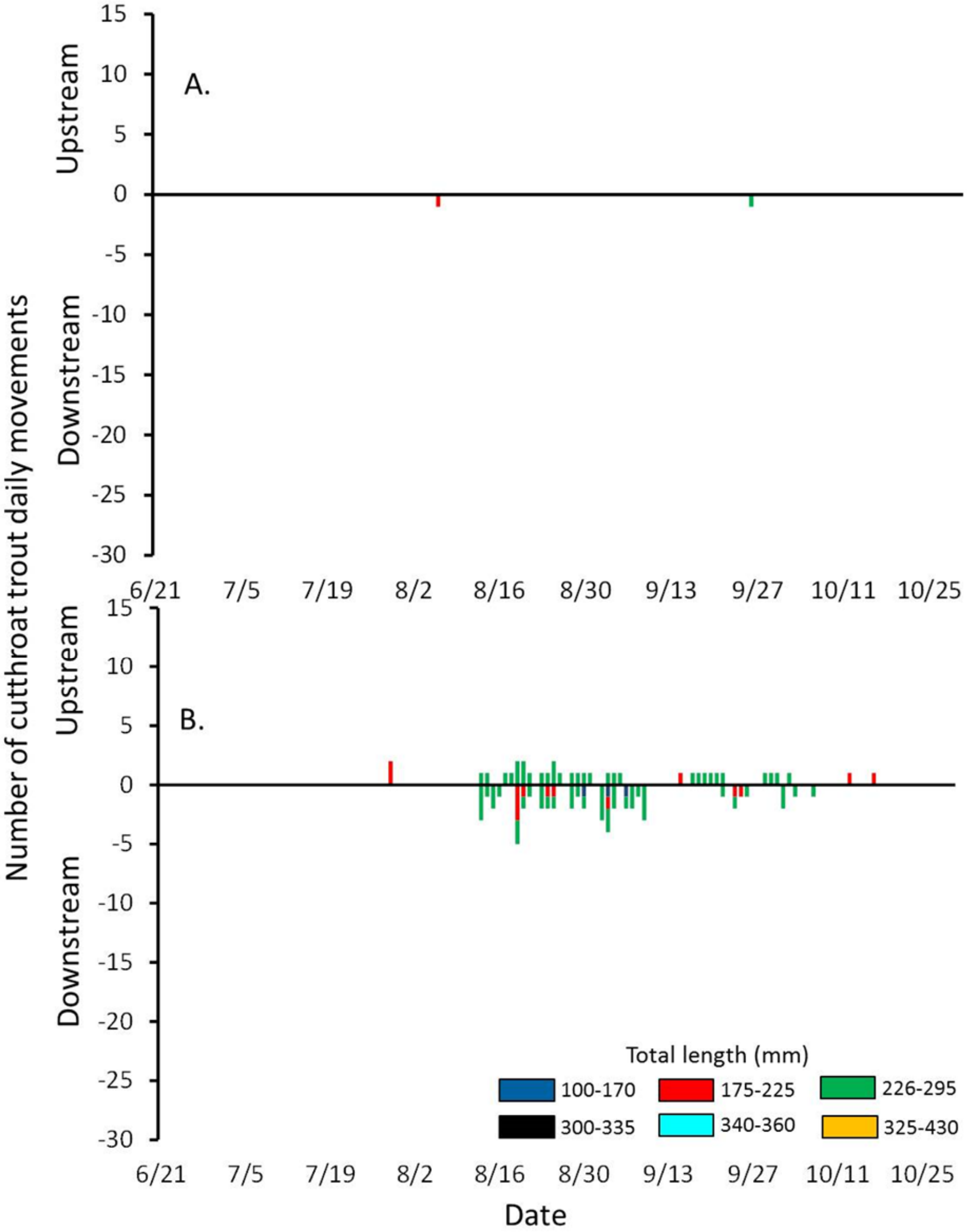

Figure 10. Cutthroat trout movements during 2013 from Fryingpan Lakes2 to outlet (A) and Fryingpan Lake 3 to inlet (B).

oxygen logger 2 m from the bottom. The temperature/pressure loggers were placed at the inlet of Lake #3 and outlet of Lake #2 to measure stream discharge. The other three temperature loggers were placed upstream of the beaver meadow complex, in the channel connecting Lakes #2 and #3, and in littoral habitat of Lake #2 (Figure 4). These thermograph records show that water

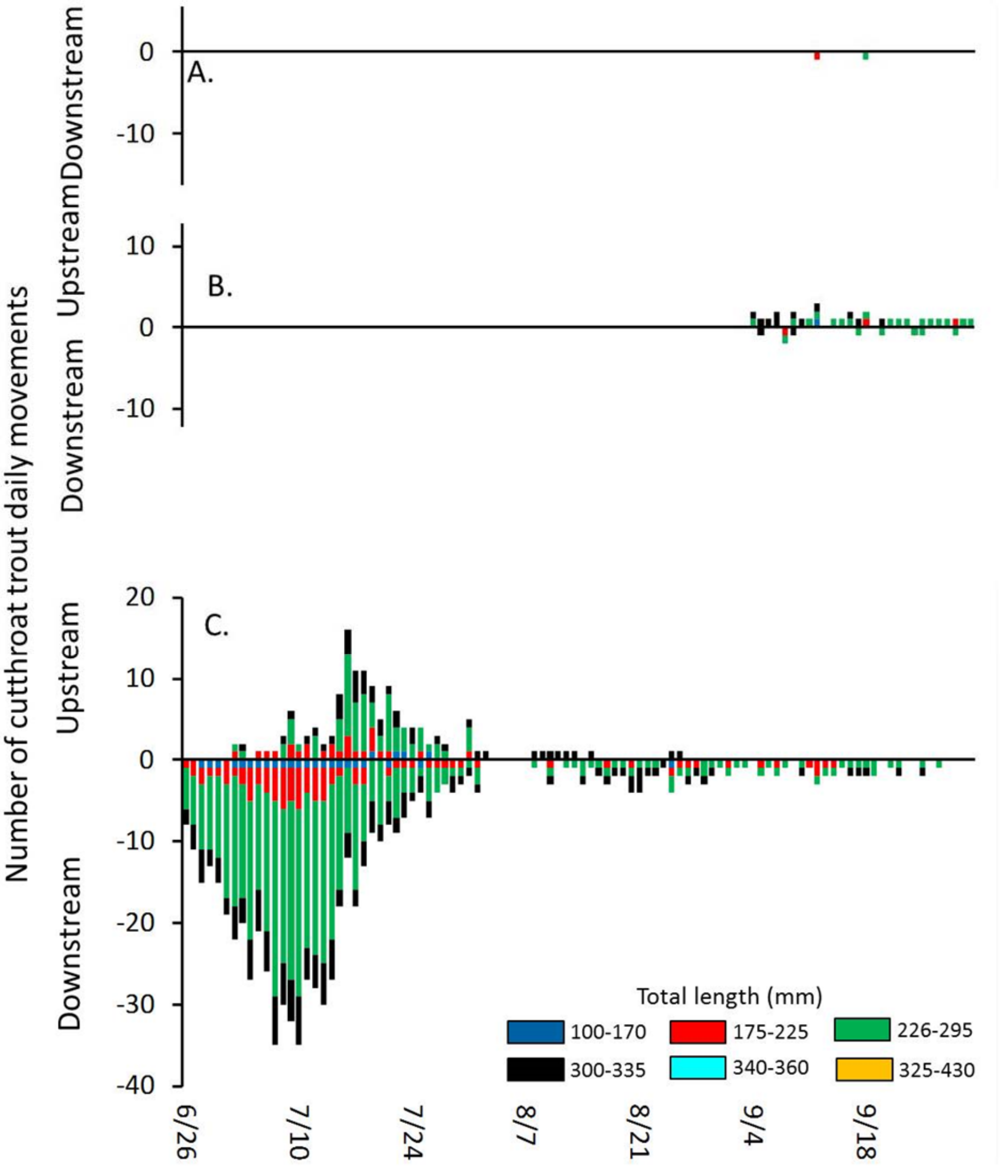

Figure 11. Cutthroat trout movements during 2014 from Fryingpan Lake 2 to outlet (A), from Fryingpan Lake 2 to 3, (B) and Fryingpan Lake 3 to inlet (C).

temperatures in the outlet and surface of Lake #3 were warmer than those in the inlet. However, the bottom waters of Lake #3 remained close to 4°C during the winter while the rest of these thermal habitats where close to 0°C (Figure 9).

The PIT tag antennas were deployed on 7/29/13 and 6/25/14 owing to logistics, so data on fish movements at the Fryingpan Lakes are for periods later in summer than for CG. These logistical constraints include 1) the remote location of Fyringpan Lakes 2 and 3 in the Hunter/Fyringpan Wilderness, a location 5 miles from the nearest trailhead and 2) the short snow –free portion of the year at this site owing to the 11,000 foot elevation. In 2014 the most upstream reader was recording data from 6/25 thru 10/6, but the readers in the inlet and connecting channel were operational only from 9/4 thru 10/6. However, large numbers of spawning fish were observed in the connecting channel, the inlet stream, and outlet stream on 6/27/13 and throughout June and early July 2014. Once our readers were set up and detecting tagged fish, smaller fish were detected moving in and out of the inlet, similar to CG (Figure 10B and 11C). In 2014 the most upstream reader detected large numbers of fish moving in and out of the inlet stream, a pattern that tapered off in early August (Figure 11C). Visual observation of redds and spawning behavior suggest these movements are spawning related. The outlet reader detected only two fish moving downstream in the outlet stream in both years (Figures 10A and 11A). The reader in the connecting channel during 2014 recorded medium to small fish moving between the two lakes at the onset of fall indicating that there is movement between lakes (Figure 11B). These data show that spawning related movements are very common in the inlet stream and that fish disperse throughout both Fryingpan lakes during the summer and fall seasons.

Management Implications

Data and models from these 26 lakes in Northern Colorado indicate than high elevation lakes have been and will continue to warm owing to a changing climate. However, few will become warm enough to be considered unsuitable for cutthroat trout. These lentic systems also provide a vertical thermal gradient (colder deeper waters) that could provide fish refuge from warm surface temperatures. In contrast, this thermal habitat heterogeneity is not found in the adjacent high-elevation streams and rivers. From an ecosystem perspective these thermal changes are likely to have more drastic consequences on the food web structure of high elevation systems rather than directly on cutthroat trout populations. The food web implications of warming thermal conditions in mountain lakes was something we did not study, but might include changes in zooplankton population dynamics and primary production resulting from warming and changes in growing season length (Parker et al. 2008, Gauthier et al. 2014).

We have shown that cutthroat in these mountain lakes use adjacent streams for spawning, and some small and medium-sized fish rear there during the summer. Interestingly it also appears these lakes may provide thermal habitat that is warmer and more suitable than that found in streams and rivers (<8°C which correlates to low growth and recruitment eco-physiological conditions) at these high elevations (~11,000ft). These results indicate that headwater lakes provide a novel habitat for cutthroat trout, one that provides more suitable thermal habitat than streams alone provide, at these elevations. However, connectivity between lakes and streams is essential for the life histories exhibited by cutthroat populations in SRM high elevation lake-stream networks.

Products

Dr. Roberts has given two professional presentations of these data thus far, one in February 2014 (Colorado-Wyoming American Fisheries Society annual meeting, Laramie, WY) and another in May 2014 (Joint Aquatic Sciences Meeting, Portland, OR). An additional presentation on some of these data were also given as a guest lecture for Dr. Fausch's course in Conservation of Fish in Aquatic Ecosystems during fall 2013 and 2014. Dr. Roberts will also present these data as an invited speaker at the national American Fisheries Society meeting in Portland, OR during September 2015. A workshop presentation of these data was also presented by Dr. Roberts (Bozeman, MT) in efforts related to a pending national research project using existing data to investigate potential response of trout demographic processes to changing climatic conditions and non-native species for inland trout across the conterminous United States. Multiple manuscripts are also being prepared and we anticipate two publications from this research in peer review journals.

Presentations:

Roberts, J.J., K.D. Fausch, T.S. Schmidt, D.M. Walters. (2015) Changing thermal conditions and Cutthroat Trout movement in southern Rocky Mountain lake-stream networks. American Fisheries Society Meeting. Portland, OR.

Roberts, J.J., K.D. Fausch, T.S. Schmidt, D.M. Walters. (2014) Ecological consequences of climate change for mountain lake-stream populations of cutthroat trout in the Southern Rocky Mountains. Joint Aquatic Sciences Meeting. Portland, OR.

Roberts, J.J., K.D. Fausch, T.S. Schmidt, D.M. Walters. (2014) Ecological consequences of climate change for mountain lake-stream populations of cutthroat trout in the Southern Rocky Mountains. CO/WY American Fisheries Society Annual Meeting. Laramie, WY.

Roberts, J.J. (2013) Threats of climate change and fragmentation for native trout in the southern Rocky Mountains. Climate change and native salmonids working group meeting. Bozeman, MT.

Roberts, J.J. (2013 and 2014) Climate change and lake DO matter for fish conservation. CSU *(Guest Lecture)*- Conservation of Fish in Aquatic Ecosystems. Fort Collins, CO.

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