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Water Temperature, Dissolved Oxygen, Flow, and Shade Measurements in the Three Stream Sections of the Golden Trout Wilderness

Kathleen R. Matthews[1]

Abstract

To determine the current range of water temperatures in the streams inhabited by California golden trout, *Oncorhynchus mykiss aguabonita,* I deployed and monitored water temperature recording probes from 2008 through 2013 in three meadows in the Golden Trout Wilderness (GTW). Ninety probes were placed in three meadow streams: Mulkey Creek in Mulkey Meadows (elevation 2838 m), South Fork Kern River in Ramshaw Meadows (2640 m), and Golden Trout Creek in Big Whitney Meadow (2963 m). Year-round water temperatures were successfully downloaded from 83 probes along with measurements of dissolved oxygen, flow, and shade. Water temperatures ranged from -0.1 to 26 °C in Mulkey and Ramshaw Meadows, whereas in Big Whitney Meadow, maximum temperatures did not exceed 21 °C. Temperatures were highest in late July through mid-September. Future monitoring can build on the detailed temperature data reported here to further assess climate warming in the streams occupied by this important native trout. Salmonids generally prefer cool water and become stressed when temperatures exceed 22 °C. Thus, these results indicate that current GTW stream temperatures are high and may lack the resiliency to withstand increased water temperatures from climate warming, predicted to increase from 1 to 7 °C within the next 100 years.

Keywords: Water temperature, climate warming, California golden trout.

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Introduction

The California golden trout (*Oncorhynchus mykiss aguabonita*) (fig. 1) is native to the South Fork Kern River and Golden Trout Creek (Behnke 1992), and most of its native range lies within the Golden Trout Wilderness (GTW) (fig. 2) in the Inyo National Forest in California. California golden trout (CGT) stream populations in the GTW are long lived and slow growing, and they exist at high densities because cattle grazing impacts lead to widened streams, resulting in increased spawning habitat (Knapp and Dudley 1990, Knapp and Matthews 1996, Knapp et al. 1998). The CGT has been the subject of management interest because of its status as California's state fish, its limited natural distribution, and several perceived threats to its viability, including introduction of nonnative brown trout (*Salmo trutta*) and rainbow trout (*O. mykiss*), as well as habitat degradation caused by livestock grazing. The CGT was the focus of a major restoration effort in the 1970s and 1980s (Pister 2008) to remove exotic trout throughout its native range. Although exotic trout have effectively been removed from native CGT habitat, several other stressors still imperil CGT populations, including degraded stream habitat. Several studies that described golden trout habitat preferences (Matthews 1996a, 1996b) concluded that adult trout prefer habitats (vegetated and undercut banks) that typically are reduced by cattle grazing (Knapp and Matthews 1996). Because of the concern of habitat degradation from cattle grazing, several allotments in the GTW were rested starting in 2000.

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Figure 1—California golden trout.

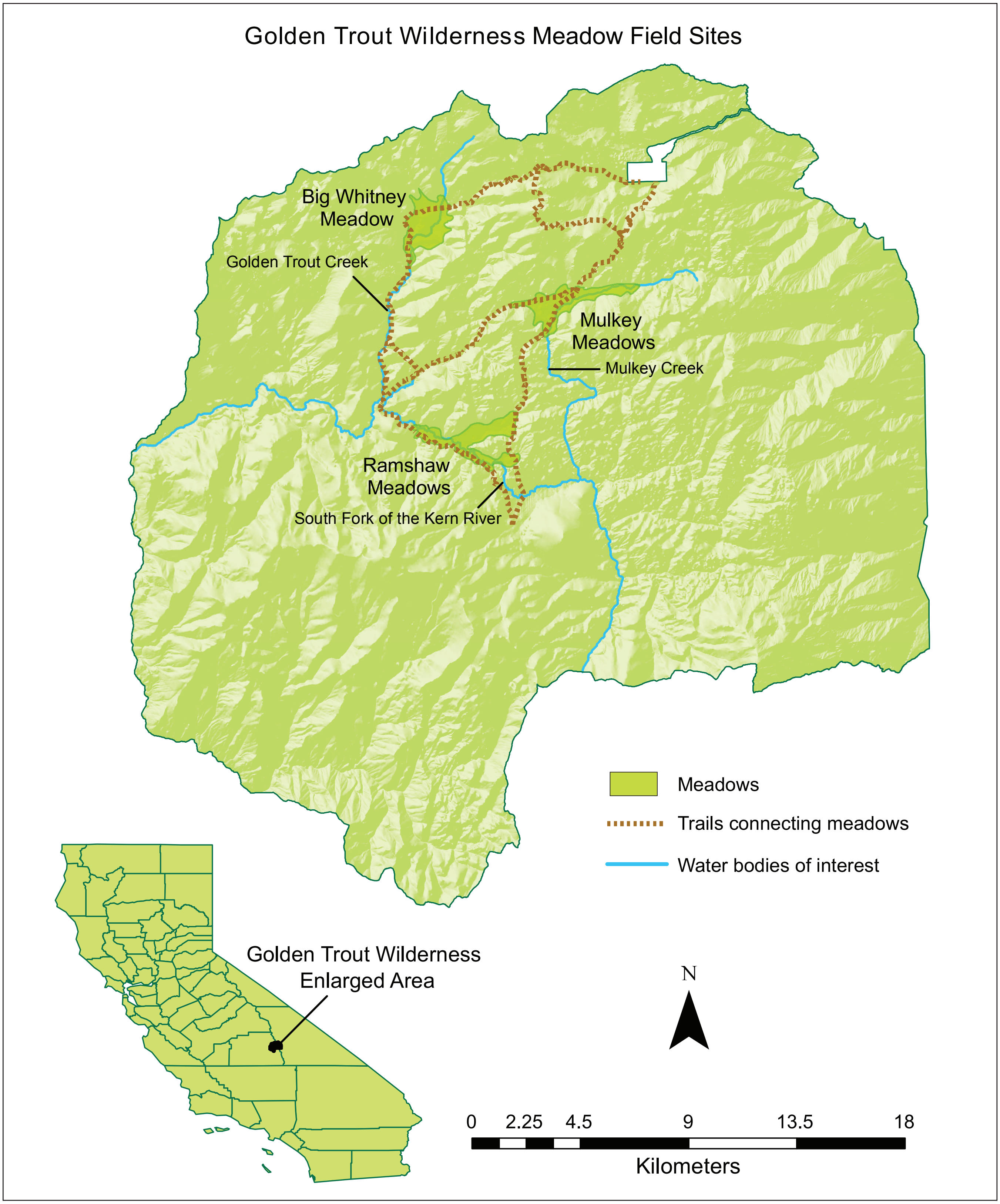


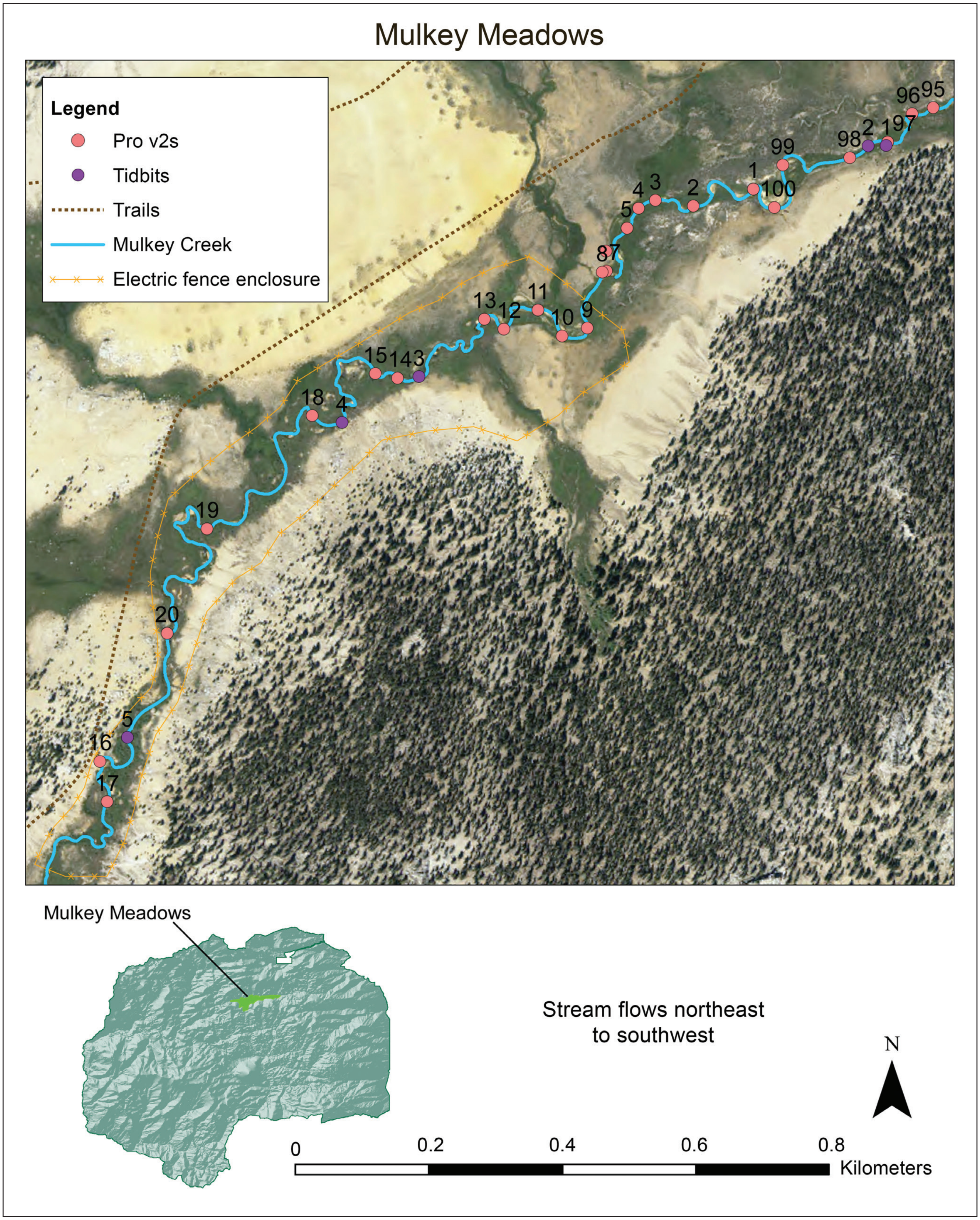
Figure 2—Overview of the Golden Trout Wilderness field sites showing Mulkey Meadows. (Mulkey Creek), Ramshaw Meadows (South fork of the Kern River), and Big Whitney Meadow (Golden Trout Creek).

One additional threat that has not been evaluated is the impact of climate warming, which could further stress CGT stream temperatures already near their maximum limit as CGT habitat. Salmonids are likely to face strong impacts from climate warming (IPCC 2007) because their streams are vulnerable to warming and they have a low tolerance for warm water. A recent report by Trout Unlimited projected that western trout populations could be reduced by more than 60 percent in some areas (Williams et al. 2007) because of climate change. The adverse impacts of livestock grazing to riparian habitat have been well described (Armour et al. 1991, Belsky et al. 1997, Kauffman and Krueger 1984, Platts 1991) and have many similar impacts to climate warming such as increased water temperatures and reduced flow (Beschta et al. 2013). Thus, the combination of cattle grazing and climate warming deserves further attention.

The objectives of this report are to describe specific placement information (global positioning system locations) for all of the temperature probes, to present the year-round water temperatures in three meadow streams of the GTW, and to provide shade, willow counts, dissolved oxygen (DO), and flow data. The information will be used to determine areas vulnerable to stream warming and also provide a baseline for future monitoring. The detailed information on precise probe location, depth, shade, and vegetation will enable future comparative studies of water temperatures. The information will also be referenced in subsequent peer-reviewed publications.

Methods

This study was conducted in three large (5-to 7-km-long) montane meadows of the GTW in the Inyo National Forest of the southern Sierra Nevada, California: Mulkey Meadows (36° 24' 19" N, 118° 11' 42.14" W, 2838 m), Big Whitney Meadow (36° 26' 23" N, 118° 16' 11.66" W, 2963 m) and Ramshaw Meadows (36° 20' 53" N, 118° 14' 52.62" W, 2640 m) (figs. 3 through 5). These meadows are part of the largest meadow complex in the Sierra Nevada and occur in depositional basins along the South Fork Kern River. Only Mulkey Meadows are currently grazed by cattle under regulation by the U.S. Forest Service. The meadows are generally covered with snow from November to May, and the summer growing season typically lasts from late May to August, depending on the timing of snowmelt. The meadows occur in a semiarid region where annual precipitation is 50 to 70 cm and most precipitation is in the form of snow (http://cdec.water.ca.gov). Because these meadow streams are in designated wilderness, travel (4 to 8 hours) by foot or packstock is required (no mechanized equipment is allowed).



Figures 3—Map of Mulkey Meadows showing locations of temperature probes.

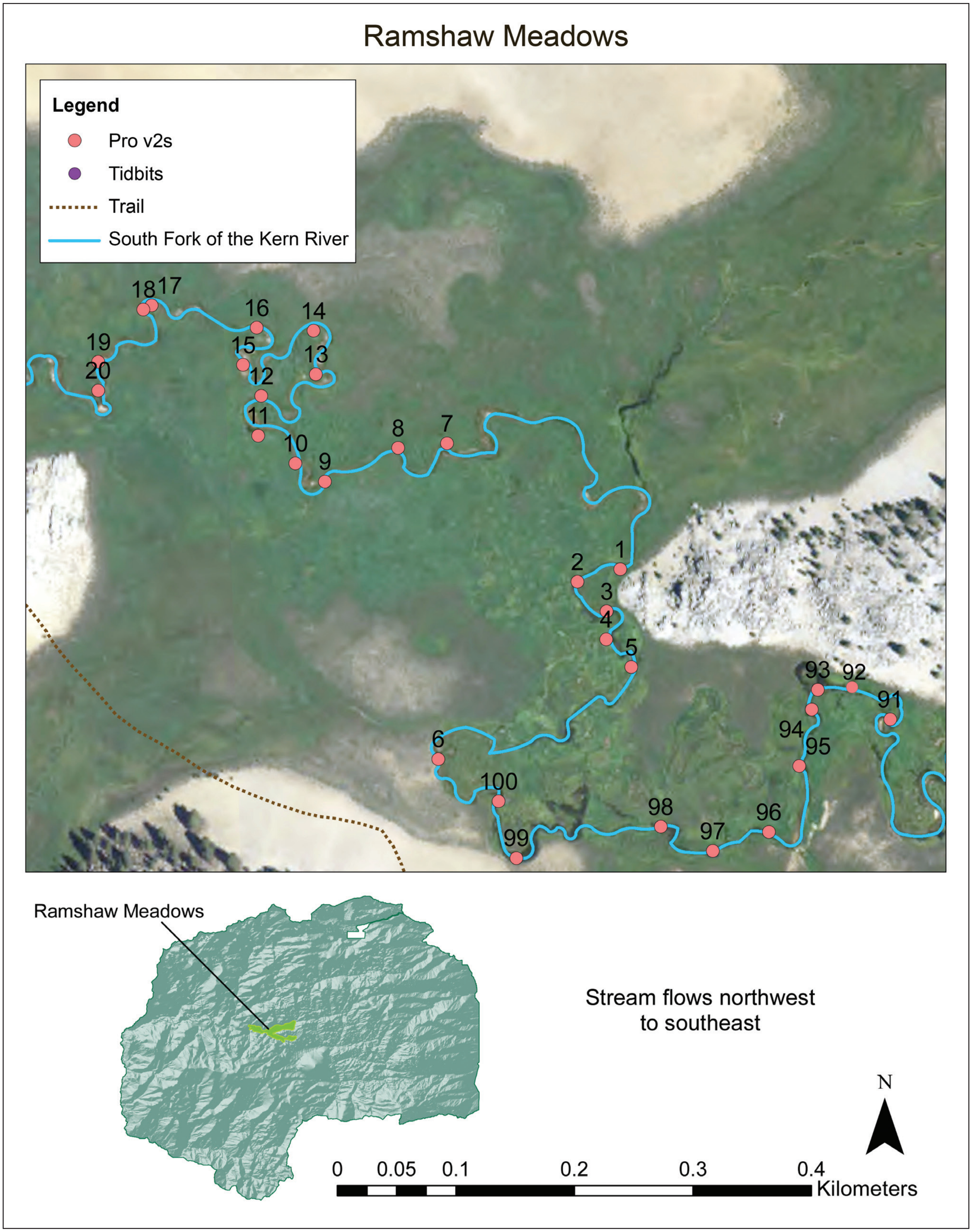


Figure 4—Map of Ramshaw Meadows showing locations of temperature probes.

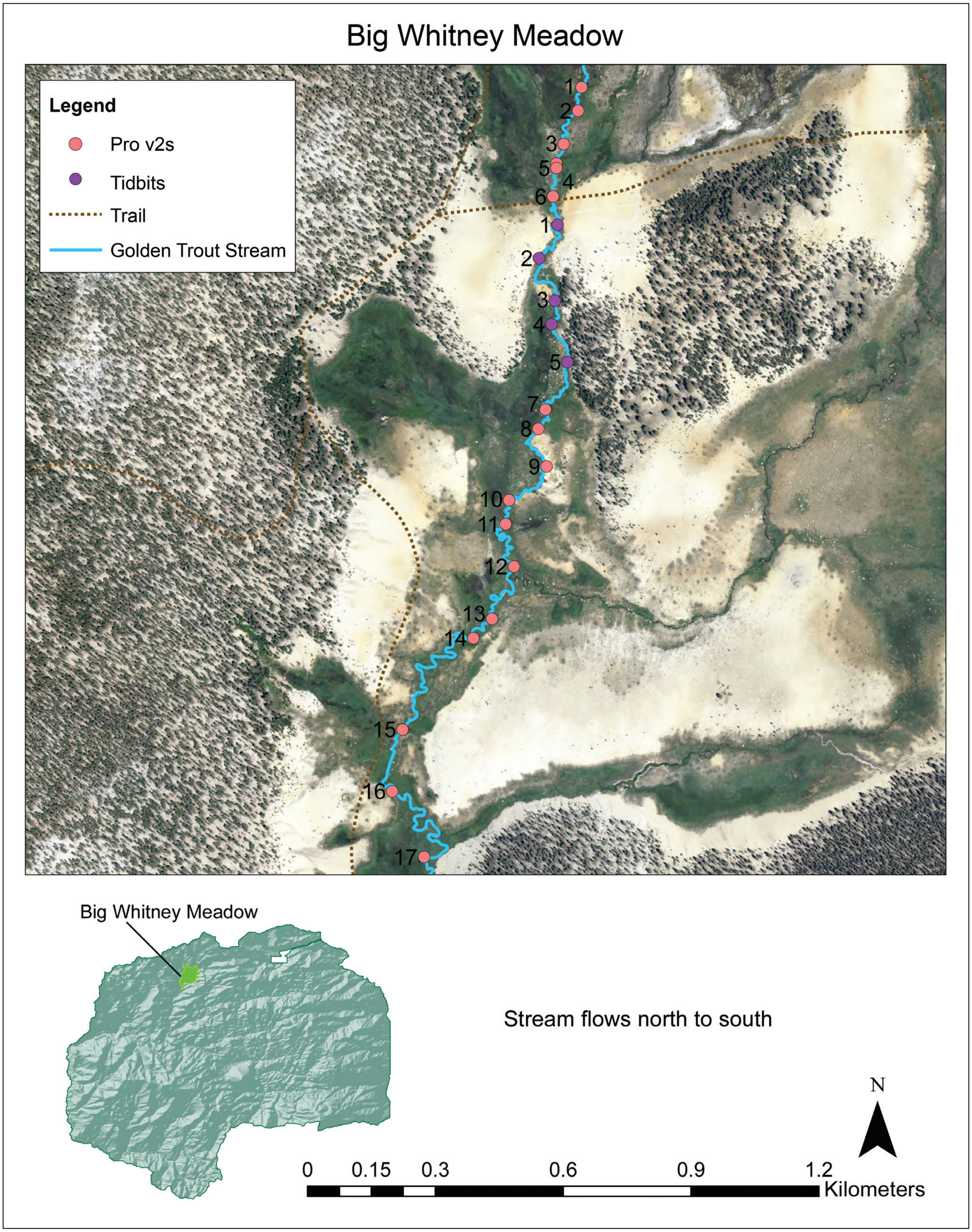


Figure 5—Map of Big Whitney Meadow showing locations of temperature probes.

To determine the water temperatures in CGT streams in the GTW, I deployed temperature probes (Onset[1] HOBO Water Temp Pro v2 ± 0.2 °C and tidbits ± 0.2 °C) throughout the stream to include a typical range of conditions in the stream: areas degraded by cattle grazing (collapsed banks, little vegetation, shallow depth) and those in recovering areas, including exclosures with more vegetation and greater depth. The Pro v2 probes were placed in white thermoplastic elastomer boots to minimize solar radiation absorption and provide cushioning, and were attached with cable ties to 36 cm rebar pieces, then hammered into the stream substrate. Temperature probes were placed during 2008–2011: 32 probes in Mulkey Meadows, 22 in Big Whitney, and 31 in Ramshaw Meadows. Precise GPS coordinates, depth, and habitat characteristics (depth, vegetation, and, in Mulkey Meadows, whether it was inside or outside the cattle exclosure) were recorded (table 1). Most probes were Onset Pro v2; in Mulkey and Big Whitney meadows, tidbit probes were glued directly onto rocks (Isaak et al. 2013) to record temperatures in rocky runs, where it was not possible to place the rebar stakes in the stream bottom. Probes were relocated at least once each summer, and temperature data were downloaded. Because of the heavy sediment load in GTW streams, the probes were often buried under gravel and sand. To relocate the probes, I used GPS, detailed photographs of placement in streams, and sometimes a metal detector to find the attached rebar. Most probes were found under sediment at least once and as a result the maximum temperatures were likely lower when buried.

When each probe was downloaded, DO was measured with a portable YSI 55 DO meter; in other locations, a deployable logger (U26-001) (± 0.2 mg/L up to 8 mg/L) that could be left in the stream for up to 6 months was used. The YSI meter was also used to periodically check accuracy of temperature probes.

Shade was measured using a handheld solar input recording device (Solmetric Suneye 210) that standardizes measurements from a south-facing, level direction and digitally records information. The Suneye 210 measures solar radiation (1-solar radiation = shade) by considering characteristics of solar radiation such as latitude, solar azimuth, time of day, and season while integrating local features including channel aspect, topography, and streamside vegetation. All willows within 2 m of the bank were measured with a measuring rod. The height (centimeters) and the GPS location of each willow were also recorded. Water velocity/streamflow at each probe was measured in meters per second (m/s) at the beginning and at the end of the summer in 2011 using a Swoffer Model 3000 Current Velocity Meter-Flowmeter.

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[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 1—List of all temperature probes locations (latitude, longitude), probe type (Pro v2 or Tidbit) probe number, serial number, vegetation type near probe, habitat type, elevation, inside or outside exclosure (Mulkey Meadows probes only), and depth

Meadow	Probe number	Latitude	Longitude	Probe type	Serial number	Vegetation	Habitat	Elevation	Exclosure	Depth
								Meters		*Centimeters*
BigWhitney	1	36.43975	-118.269906	Pro v2	9778993	Sedge	Riffle	2958	NA	15
BigWhitney	2	36.439344	-118.270019	Pro v2	9778987	None	Run	2958	NA	14
BigWhitney	3	36.438586	-118.270406	Pro v2	9778998	Sedge	Run	2957	NA	14
BigWhitney	4	36.438236	-118.270631	Pro v2	9779003	None	Run	2956	NA	12
BigWhitney	5	36.438103	-118.270569	Pro v2	9778991	Sedge	Undercut	2954	NA	23
BigWhitney	6	36.43745	-118.270706	Pro v2	9887953	Sedge	Pool	2950	NA	48
BigWhitney	7	36.449708	-118.270989	Tidbit	9948090	None	Pool	2950	NA	24
BigWhitney	8	36.449308	-118.271156	Tidbit	9448127	None	Pool	2945	NA	28
BigWhitney	9	36.448478	-118.270978	Tidbit	9948089	None	Pool	2945	NA	40
BigWhitney	10	36.447811	-118.271961	Tidbit	9948108	None	Pool	2943	NA	15
BigWhitney	11	36.447294	-118.272078	Tidbit	9948064	None	Run	2941	NA	30
BigWhitney	12	36.446342	-118.271883	Pro v2	9779000	Sedge	Riffle	2940	NA	18
BigWhitney	13	36.445225	-118.272528	Pro v2	9778988	Sedge	Pool	2940	NA	12
BigWhitney	14	36.444889	-118.272967	Pro v2	9779002	None	Pool	2937	NA	26
BigWhitney	15	36.442978	-118.274922	Pro v2	9778997	None	Riffle	2935	NA	14
BigWhitney	16	36.441628	-118.275158	Pro v2	9984787	Sedge	Undercut	2935	NA	24
BigWhitney	17	36.440256	-118.274369	Pro v2	9778996	Sedge	Run	2933	NA	24
BigWhitney	18	36.436881	-118.270606	Pro v2	9779001	None	Run	2933	NA	32
BigWhitney	19	36.436247	-118.271064	Pro v2	9778995	Willow	Run	2933	NA	38
BigWhitney	20	36.435317	-118.270700	Pro v2	9987856	Sedge	Run	2933	NA	36
BigWhitney	21	36.434817	-118.270775	Pro v2	9778999	Sedge	Riffle	2933	NA	12
BigWhitney	22	36.433997	-118.270442	Pro v2	9778994	Sedge	Pool	2933	NA	44
Ramshaw	1	36.349256	-118.250425	Pro v2	9776542	Willow	Pool	2640	NA	61
Ramshaw	2	36.349164	-118.250836	Pro v2	9793297	Sedge	Run	2639	NA	31
Ramshaw	3	36.348936	-118.250544	Pro v2	9776556	Sedge	Run	2639	NA	31
Ramshaw	4	36.348744	-118.250567	Pro v2	9793301	Sedge	Pool	2637	NA	46
Ramshaw	5	36.348514	-118.250356	Pro v2	9776543	Sedge	Run	2637	NA	31
Ramshaw	6	36.347769	-118.252167	Pro v2	9793307	Sedge	Riffle	2637	NA	15
Ramshaw	7	36.350239	-118.252036	Pro v2	9793312	Sedge	Pool	2637	NA	30

Table 1—List of all temperature probes locations (latitude, longitude), probe type (Pro v2 or Tidbit) probe number, serial number, vegetation type near probe, habitat type, elevation, inside or outside exclosure (Mulkey Meadows probes only), and depth (continued)

Meadow	Probe number	Latitude	Longitude	Probe type	Serial number	Vegetation	Habitat	Elevation	Exclosure	Depth
								Meters		*Centimeters*
Ramshaw	8	36.350210	-118.252496	Pro v2	9793295	Sedge	Pool	2637	NA	91
Ramshaw	9	36.350210	-118.253191	Pro v2	9984808	Sedge	Run	2637	NA	46
Ramshaw	10	36.350109	-118.253191	Pro v2	9984791	Grass	Run	2637	NA	10
Ramshaw	11	36.350350	-118.253811	Pro v2	9984805	Sedge	Pool	2637	NA	25
Ramshaw	12	36.350644	-118.253761	Pro v2	9793313	Sedge	Run	2637	NA	22
Ramshaw	13	36.350817	-118.253311	Pro v2	9987852	Willow	Pool	2637	NA	29
Ramshaw	14	36.351158	-118.253281	Pro v2	9793308	None	Run	2636	NA	30
Ramshaw	15	36.350858	-118.253883	Pro v2	9984793	None	Run	2636	NA	29
Ramshaw	16	36.351150	-118.253828	Pro v2	9793305	Sedge	Run	2636	NA	35
Ramshaw	17	36.351367	-118.254803	Pro v2	9793315	None	Run	2636	NA	51
Ramshaw	18	36.351331	-118.254781	Pro v2	9776550	Sedge	Pool	2636	NA	45
Ramshaw	19	36.351053	-118.255103	Pro v2	2011620	Sedge	Run	2636	NA	88
Ramshaw	20	36.350661	-118.255289	Pro v2	9984802	Willow	Run	2636	NA	22
Ramshaw	21	36.348028	-118.247950	Pro v2	9987855	Willow	Run	2636	NA	45
Ramshaw	22	36.348261	-118.248064	Pro v2	9984789	Sedge	Pool	2636	NA	22
Ramshaw	23	36.348336	-118.248556	Pro v2	9984796	None	Pool	2636	NA	66
Ramshaw	24	36.348156	-118.248644	Pro v2	9793306	Willow	Run	2636	NA	110
Ramshaw	25	36.347731	-118.248772	Pro v2	9793310	Grass	Run	2636	NA	55
Ramshaw	26	36.347242	-118.249072	Pro v2	9776552	Sedge	Run	2636	NA	32
Ramshaw	27	36.347106	-118.249589	Pro v2	9984788	None	Pool	2632	NA	44
Ramshaw	28	36.347297	-118.250090	Pro v2	9776549	Sedge	Run	2632	NA	34
Ramshaw	29	36.347080	-118.251455	Pro v2	9793302	Sedge	Run	2632	NA	48
Ramshaw	30	36.347512	-118.251612	Pro v2	9984795	Willow	Pool	2632	NA	90
Mulkey	1	36.404247	-118.198037	Pro v2	9793298	Sedge	Pool	2839	Out	65
Mulkey	2	36.404033	-118.199046	Pro v2	9984807	Sedge	Pool	2839	Out	32
Mulkey	3	36.404121	-118.199684	Pro v2	9984801	Sedge	Run	2837	Out	34
Mulkey	4	36.403758	-118.200183	Pro v2	2011610	Sedge	Run	2839.7	Out	36
Mulkey	5	36.403753	-118.200165	Pro v2	2011607	Sedge	Pool	2839	Out	31

Table 1—List of all temperature probes locations (latitude, longitude), probe type (Pro v2 or Tidbit) probe number, serial number, vegetation type near probe, habitat type, elevation, inside or outside exclosure (Mulkey Meadows probes only), and depth (continued)

Meadow	Probe number	Latitude	Longitude	Probe type	Serial number	Vegetation	Habitat	Elevation	Exclosure	Depth
								Meters		*Centimeters*
Mulkey	6	36.403446	-118.200525	Pro v2	9984810	Sedge	Pool	2835	Out	30
Mulkey	7	36.403179	-118.200522	Pro v2	2011605	Sedge	Run	2835	Out	10
Mulkey	8	36.403163	-118.200594	Pro v2	2013134	None	Pool	2835	Out	20
Mulkey	9	36.402412	-118.200866	Pro v2	9793296	Sedge	Run	2835	In	45
Mulkey	10	36.402313	-118.201292	Pro v2	9987854	Willow	Pool	2836	In	30
Mulkey	11	36.402667	-118.201682	Pro v2	9984792	Willow	Run	2834	In	22
Mulkey	12	36.402419	-118.202259	Pro v2	9984798	Willow	Pool	2833	In	65
Mulkey	13	36.402559	-118.202582	Pro v2	2011611	Sedge	Pool	2833	In	36
Mulkey	14	36.401785	-118.204059	Pro v2	9984799	Willow	Pool	2833	In	42
Mulkey	15	36.401851	-118.204429	Pro v2	9984790	Sedge	Pool	2833	In	65
Mulkey	16	36.396686	-118.209168	Pro v2	9776540	Willow	Pool	2833	In	20
Mulkey	17	36.396138	-118.20906	Pro v2	9793301	Willow	Pool	2839	In	10
Mulkey	18	36.401331	-118.205531	Pro v2	9984804	Sedge	Run	2839	In	14
Mulkey	19	36.399778	-118.207303	Pro v2	9984809	Willow	Undercut	2838	In	20
Mulkey	20	36.398358	-118.208056	Pro v2	9984806	Willow	Run	2838	In	20
Mulkey	21	36.405269	-118.195039	Pro v2	9987857	Willow	Run	2839	Out	15
Mulkey	22	36.405222	-118.195352	Pro v2	9984797	Sedge	Run	2838	Out	10
Mulkey	23	36.404848	-118.19577	Pro v2	9984800	Sedge	Run	2838	Out	12
Mulkey	24	36.404645	-118.196413	Pro v2	9776547	Grass	Run	2838	Out	25
Mulkey	25	36.404563	-118.197539	Pro v2	9984794	Sedge	Run	2838	Out	20
Mulkey	26	36.403995	-118.19769	Pro v2	9776567	Sedge	Run	2838	Out	10
Mulkey	27	36.404815	-118.195802	Tidbit 1	9948047	Sedge	Pool	2839	Out	12
Mulkey	28	36.404815	-118.196098	Tidbit 2	9991116	Sedge	Pool	2839	Out	24
Mulkey	29	36.401190	-118.20497	Tidbit 3	9991148	Grass	Run	2839	Out	26
Mulkey	30	36.400150	118.20695	Tidbit 4	9948079	Sedge	Run	2839	Out	25
Mulkey	31	36.397012	-118.208698	Tidbit 5	9948147	Willow	Pool	2839	In	18

Results

Temperature probes were successfully downloaded from 83 probes; 31 from Mulkey Meadows, 30 from Ramshaw Meadows, and 22 from Big Whitney Meadow (table 1). I originally deployed 90 probes, but five were never recovered and two were found out of the stream and damaged by animals (likely marmots or coyotes).

Year-round temperatures ranged from -0.1 to 26 °C in Mulkey and Ramshaw Meadows, whereas in Big Whitney Meadow maximum temperature did not exceed 21 °C (fig. 6). Median year-round temperatures were highest in Mulkey and lowest in Big Whitney (fig. 6). Water temperatures were highest during summer weeks 27 through 34 (late June to mid September) (figs. 7 through 9). During the summer diel (24 hr), fluctuations sometimes ranged from ± 16 °C as seen in a Mulkey Meadows probe (fig. 10). Temperatures were influenced by probe location: temperatures were most variable with ±3 °C differences between individual probes in Mulkey Meadows, and ±2.5 °C in Ramshaw Meadow. Temperatures were the least variable in Big Whitney Meadow at ±1 °C (fig. 11).

Graphs of individual probe's monthly maximum, minimum, and mean temperatures demonstrate the variability of temperatures amongst the 83 probes (figs. 12 through 14). Temperatures were highest from May through November and typically hovered near 0 °C during the winter. Big Whitney temperatures did not exceed 21.2 °C; Mulkey and Ramshaw temperatures reached 26 °C. I only retrieved 1 year of data from three probes in Ramshaw Meadows.

Median DO ranged from 5.9 mg/L in Mulkey to 6.2 mg/L in Ramshaw Meadows in 2012 (fig. 15). The diel (24-hour) range of and water temperatures DO from August 2013 demonstrates the lag and decline of DO after the afternoon warmest temperature (fig. 16). In a typical 24-hour period, DO was lowest around midnight (2 mg/L) and highest in the afternoon (8 mg/L). The 24-hour recording DO probe in Mulkey Meadows from 7/12/2013 to 8/15/2013 found that oxygen levels plummeted to 0 mg/l during a week-long series of thunderstorms (fig. 17). Flow measurements were low in all meadows (fig. 18). Median flow (m/s) was below 0.4 m/s in all three meadows during the summer. Flow was highest in Big Whitney Meadow (median 0.38 m/s) and lowest in Mulkey Meadows (median 0.07 m/s).

Solar radiation estimates were high (>90 percent) and shade estimates (opposite of solar radiation) were low (<10 percent) in all three meadows (fig. 19). Counts and measurements of willows inside and outside the exclosures found 13 times more willows (980 willow trees, for a river length of 1200 m) inside the exclosures compared to the area where cattle were present (75 willow trees, for a river length of 900 m). Willows in the exclosure were on average twice as high (0.92 ± 0.56 m) compared to the willow outside of the exclosure (0.43 ± 0.29 m) (Welsch two-sample t-test: $t122.6 = 12.7$, $p < 0.001$) (fig. 20).

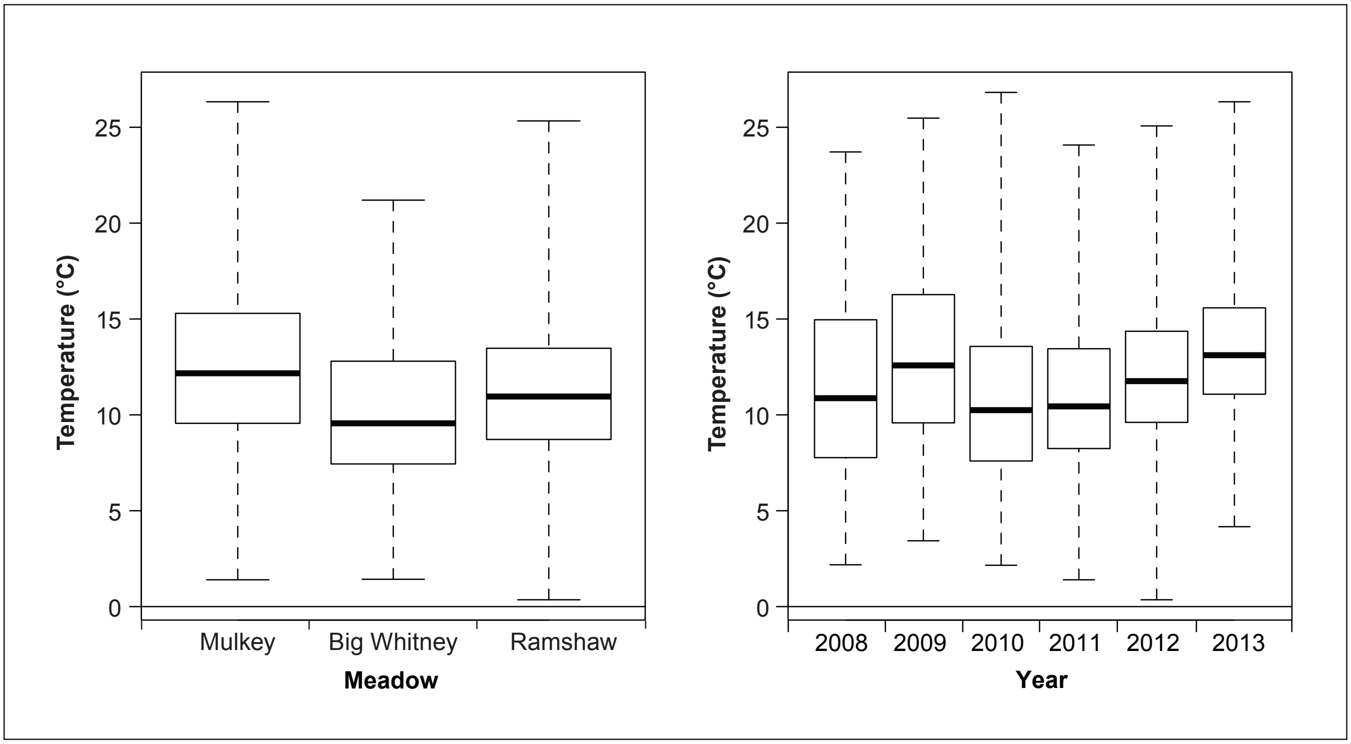


Figure 6—(A) Overall median water temperatures (°C) for Mulkey, Big Whitney, and Ramshaw Meadows; (B) annual median water temperatures for all meadows from 2008 to 2013.

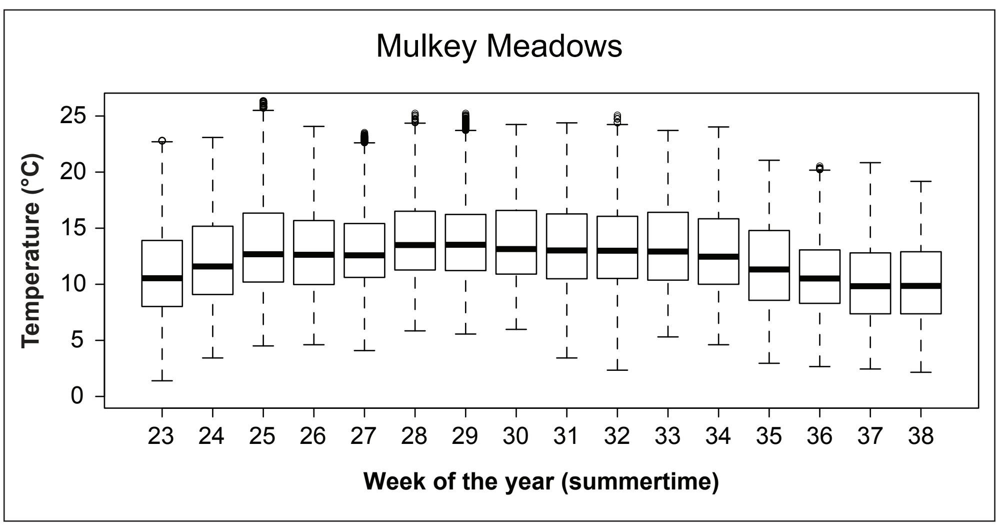


Figure 7—Summer (weeks 23 through 38) median water temperatures (°C) for Mulkey Meadows.

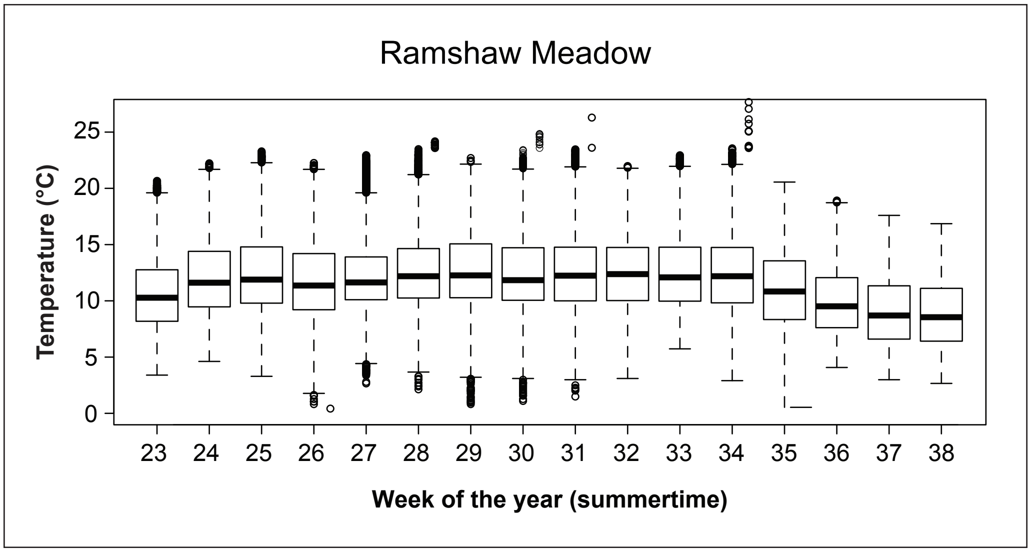


Figure 8—Summer (weeks 23 through 38) median water temperatures (degrees Celsius) for Ramshaw Meadows.

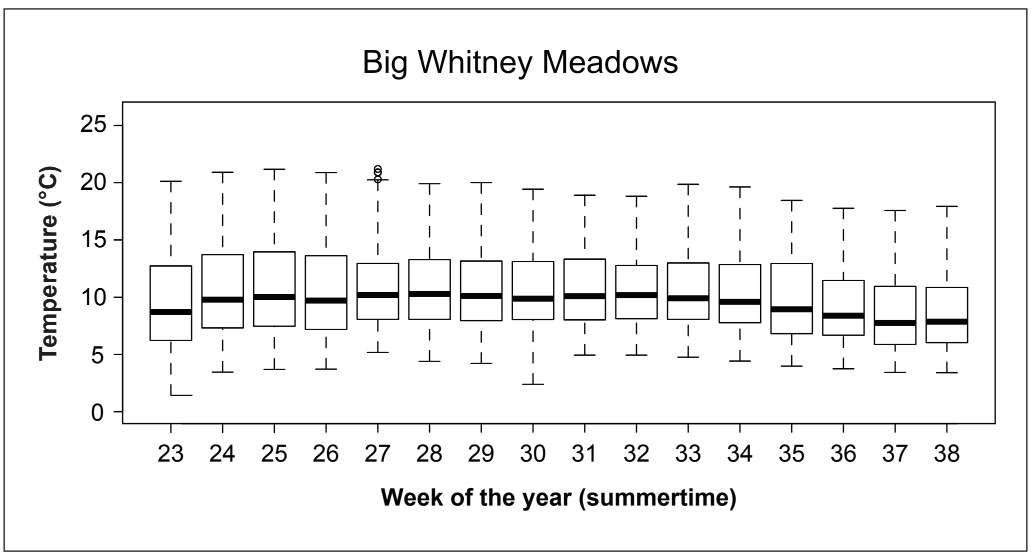


Figure 9—Summer (weeks 23 through 38) median water temperatures (degrees Celsius) for Big Whitney Meadow.

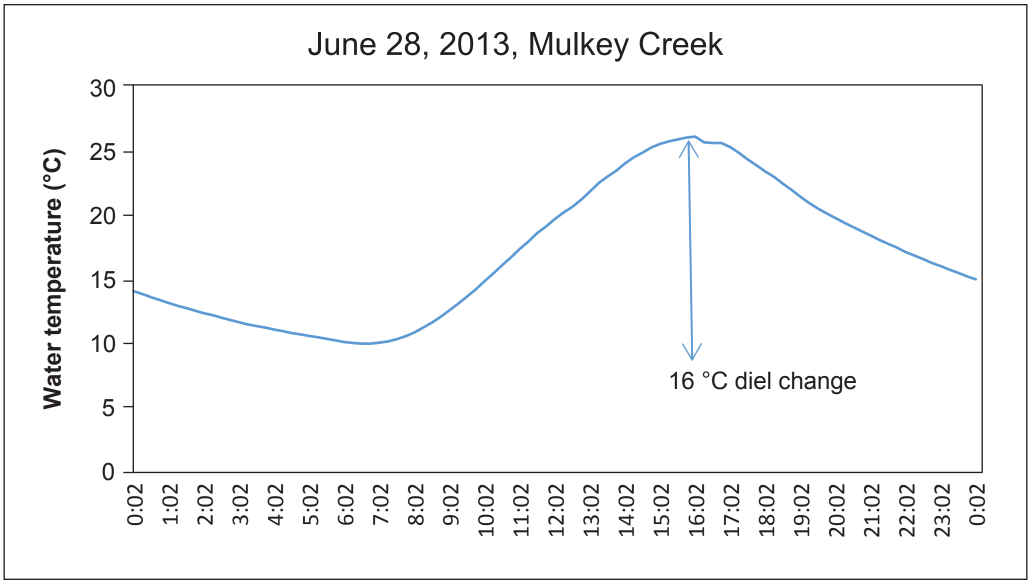


Figure 10—Diel water temperature change in Mulkey Creek on June 28, 2013.

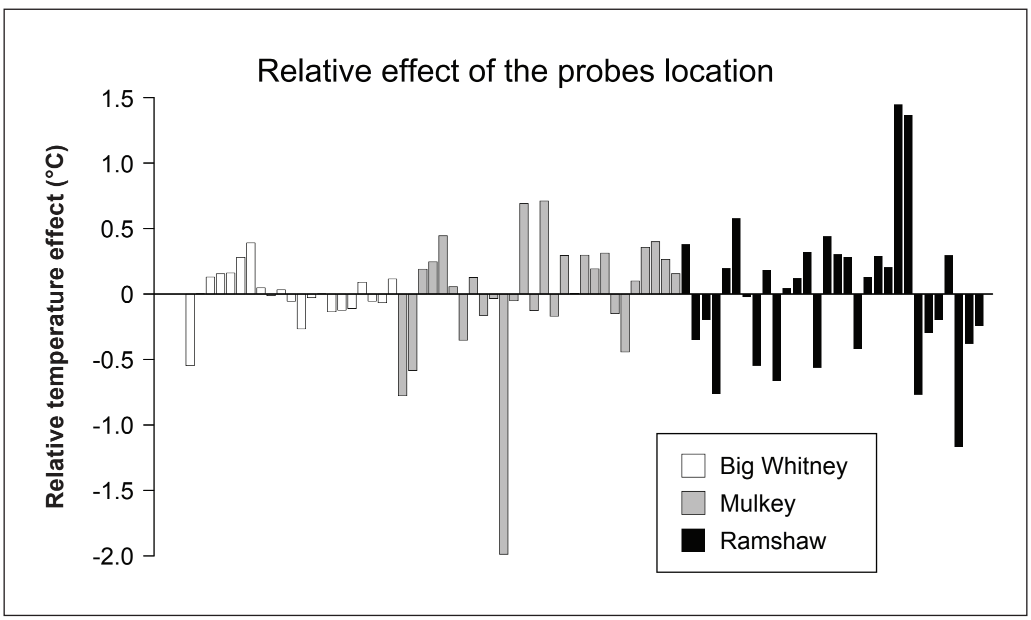


Figure 11—Relative water temperature differences between individual probes in the three streams.

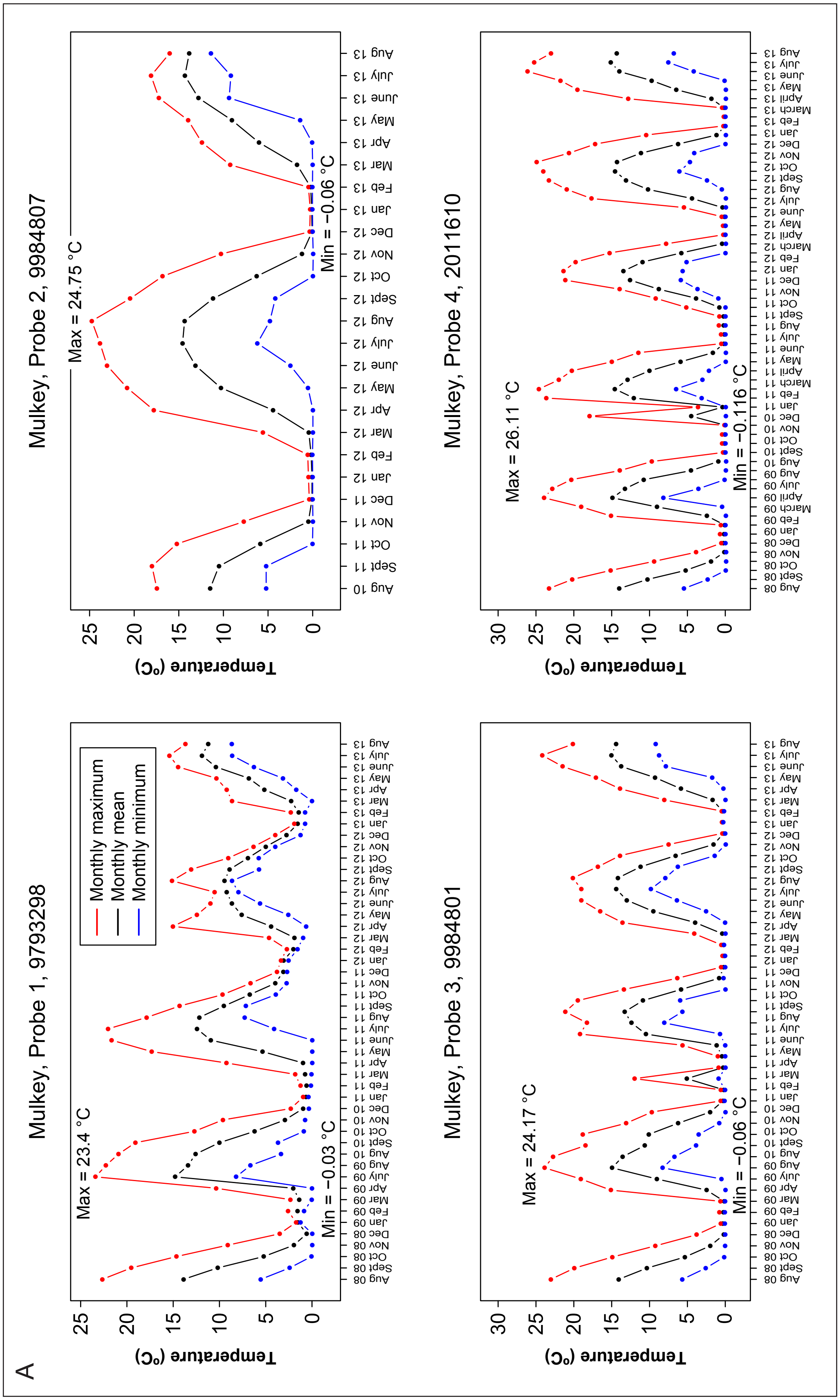


Figure 12—All individual water temperature graphs for Mulkey Meadows (a through h).

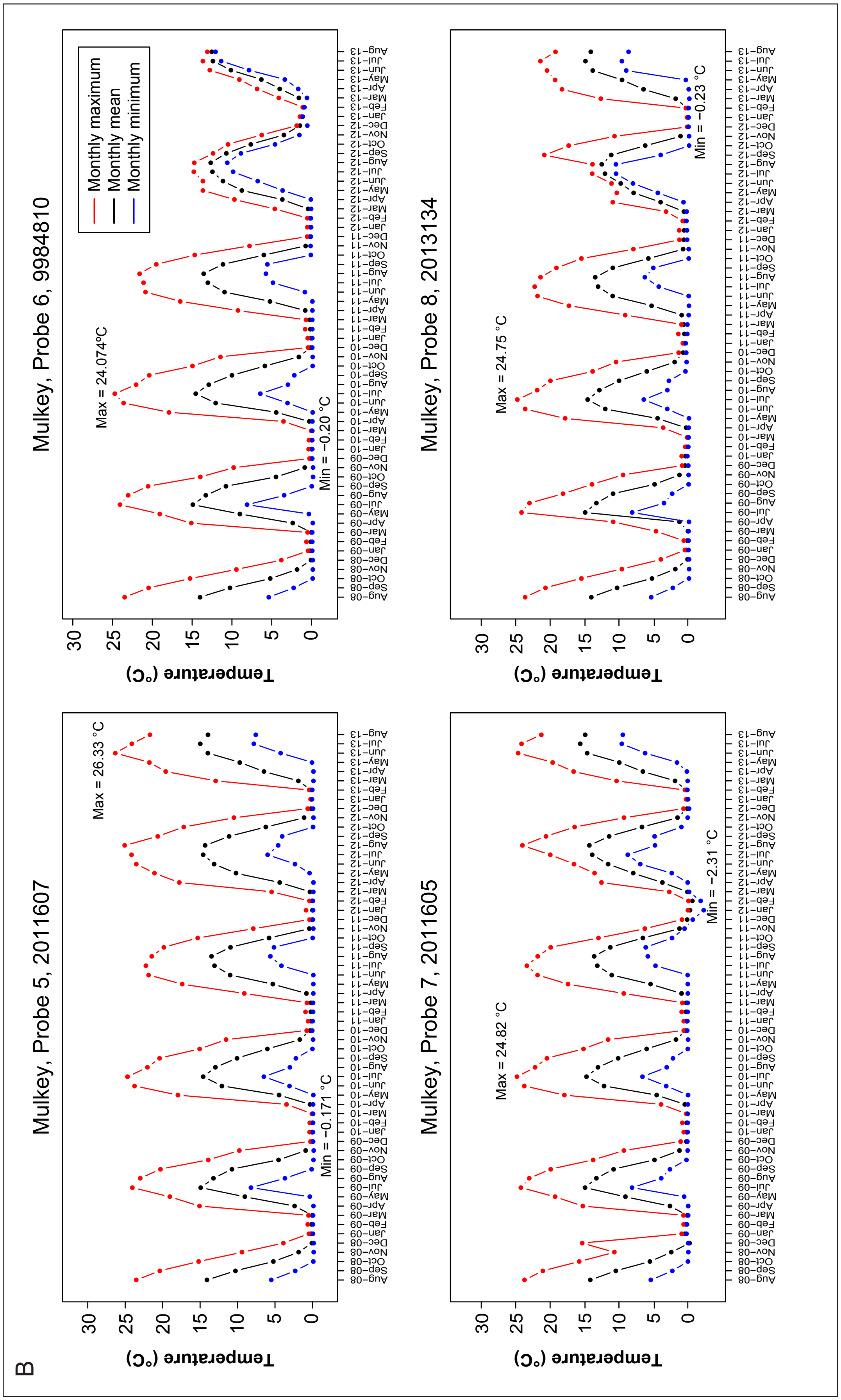


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

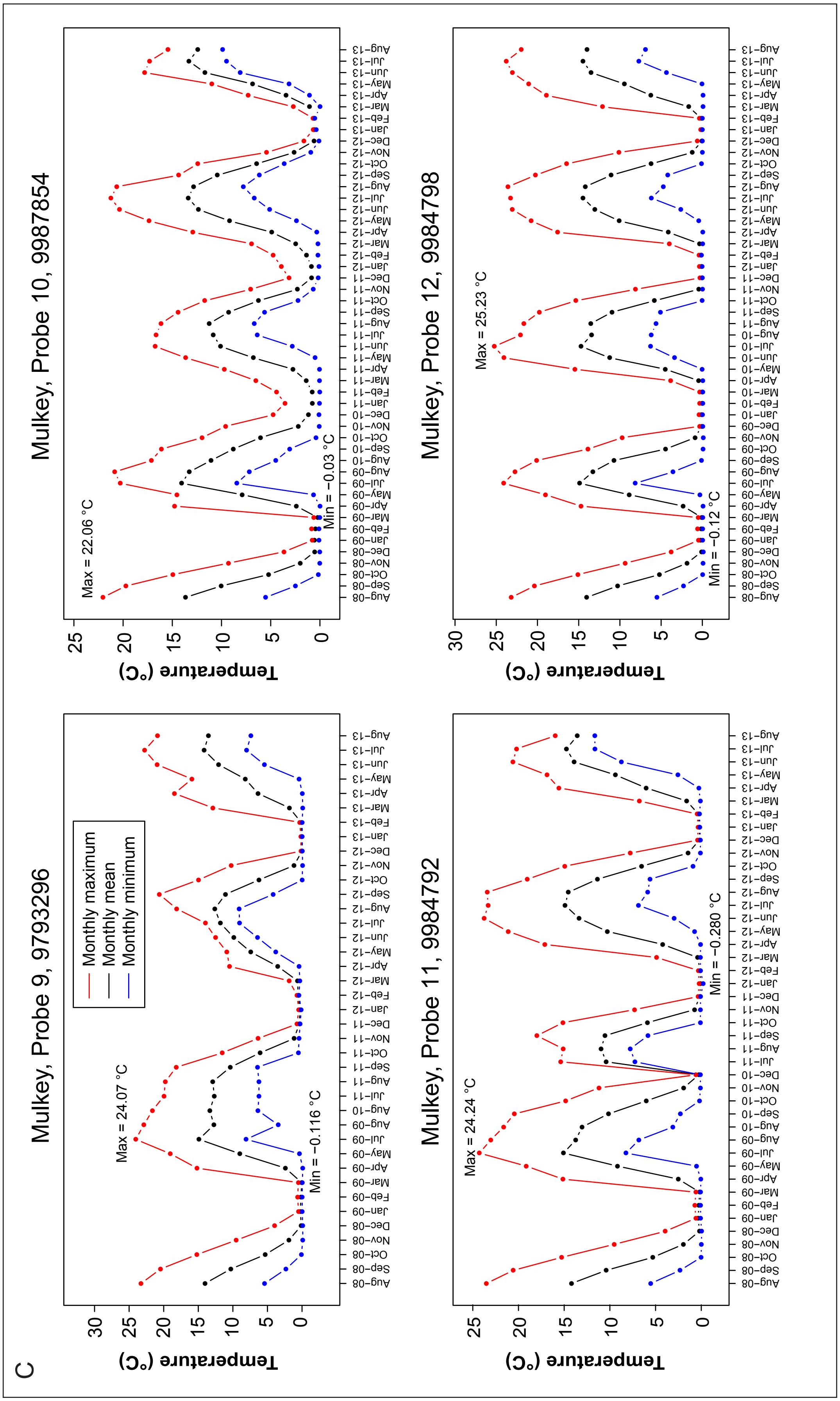


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

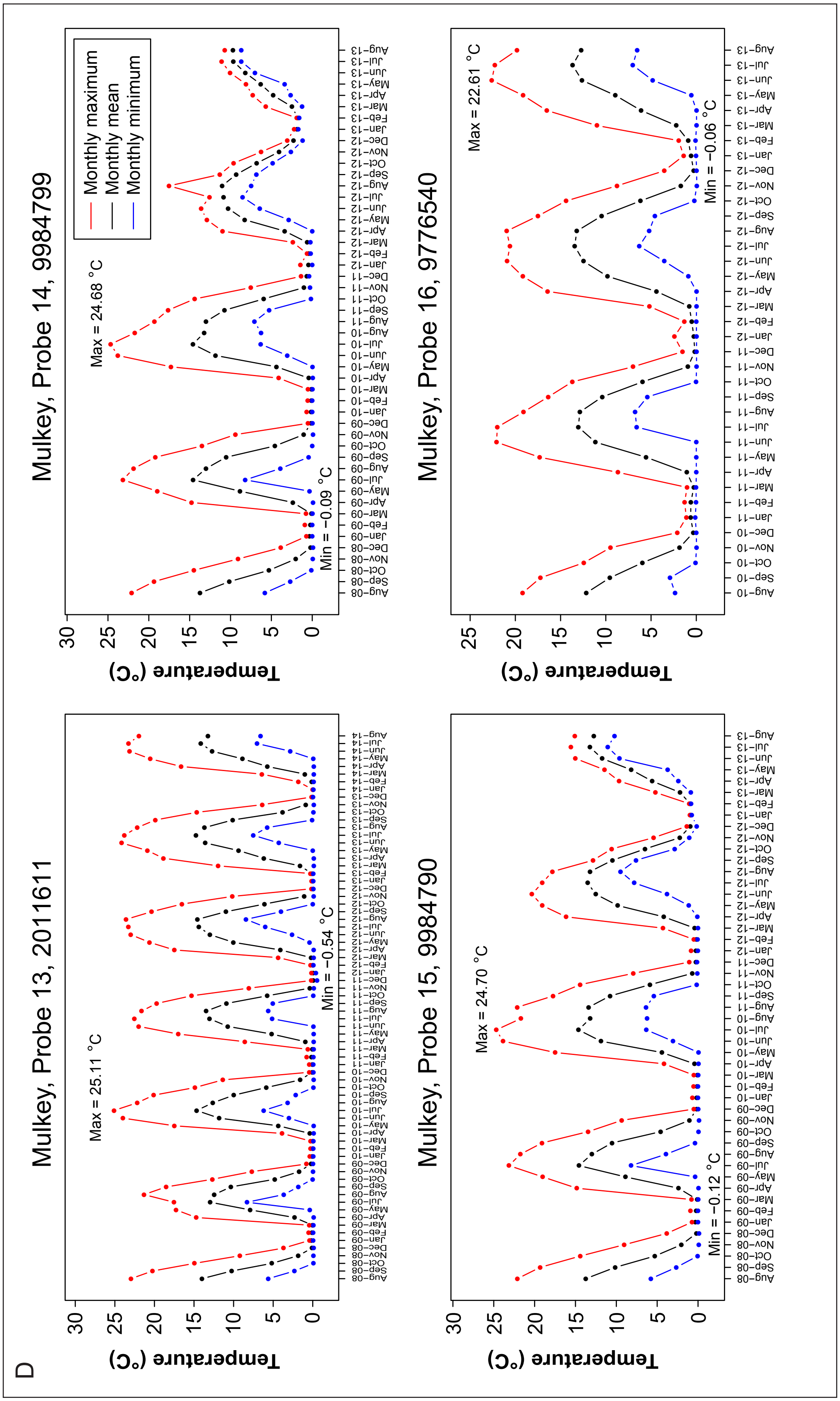


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

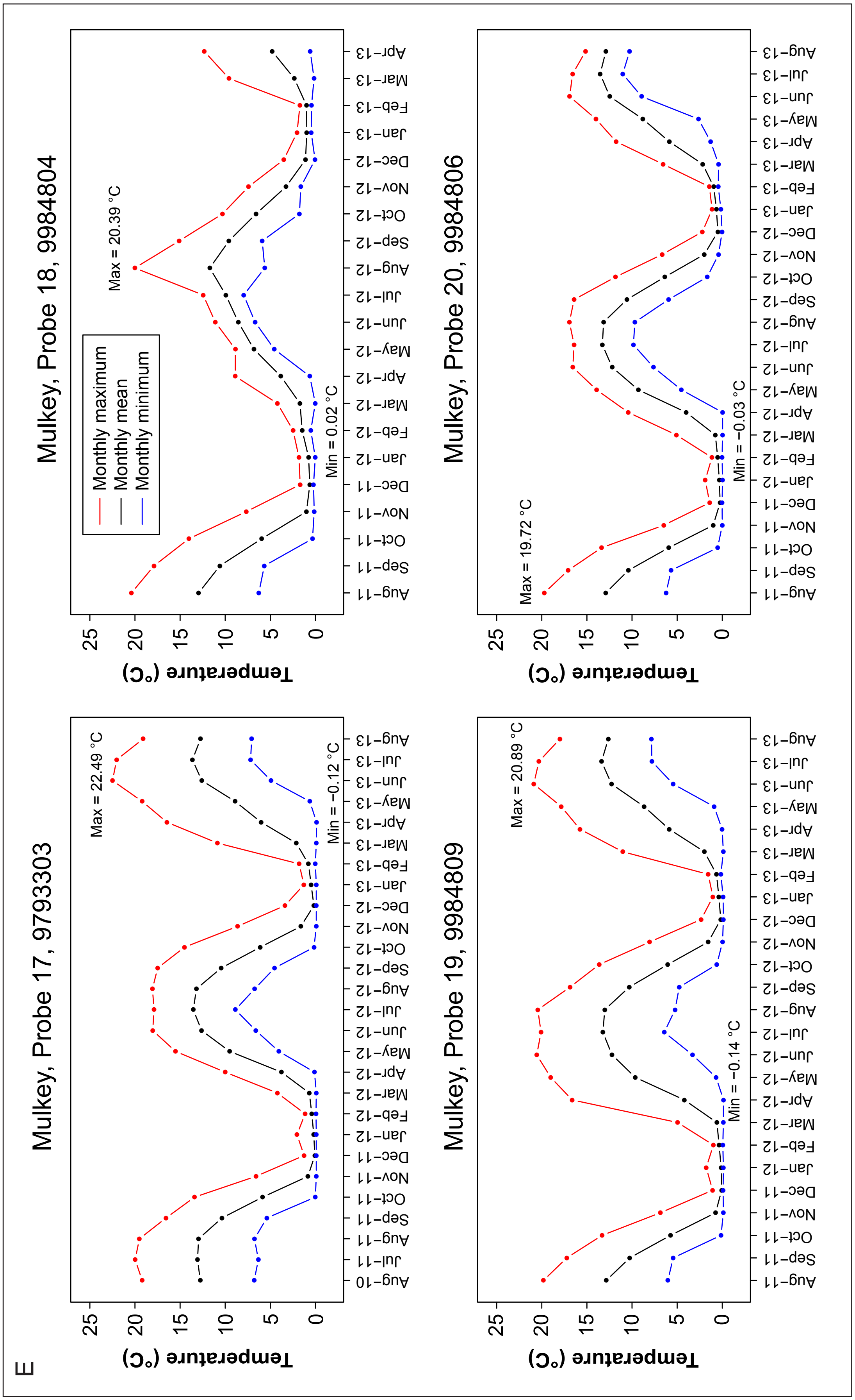


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

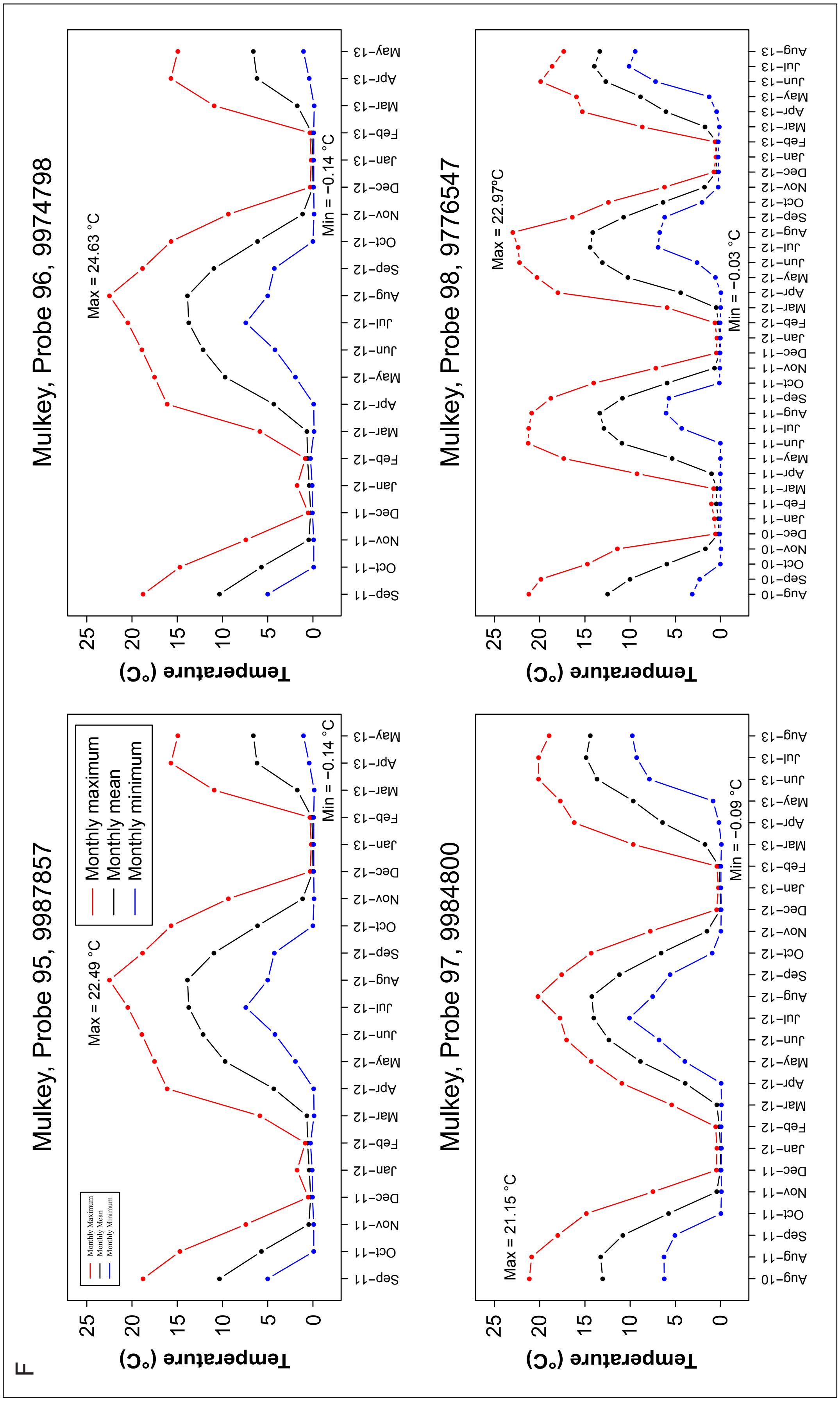


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

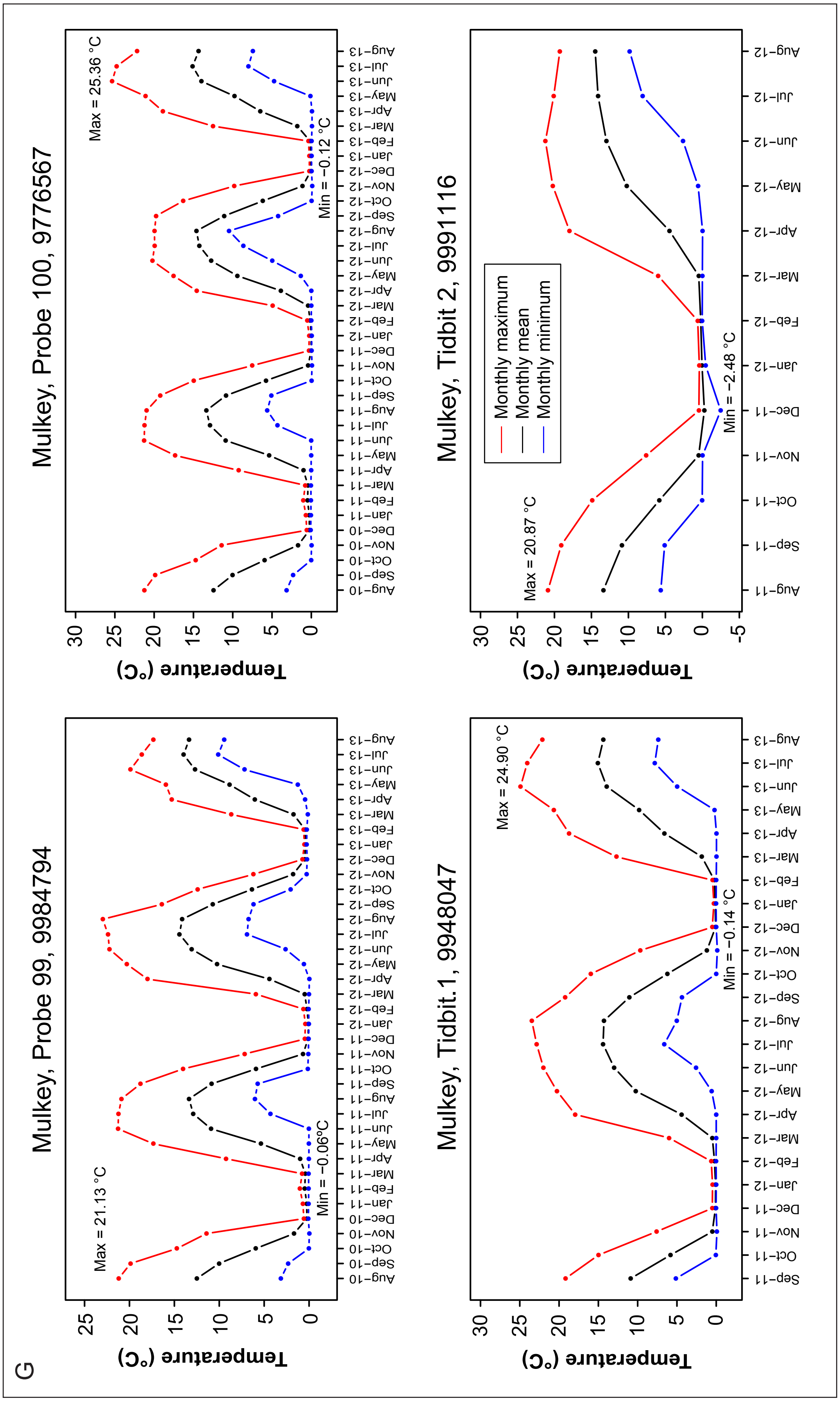


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

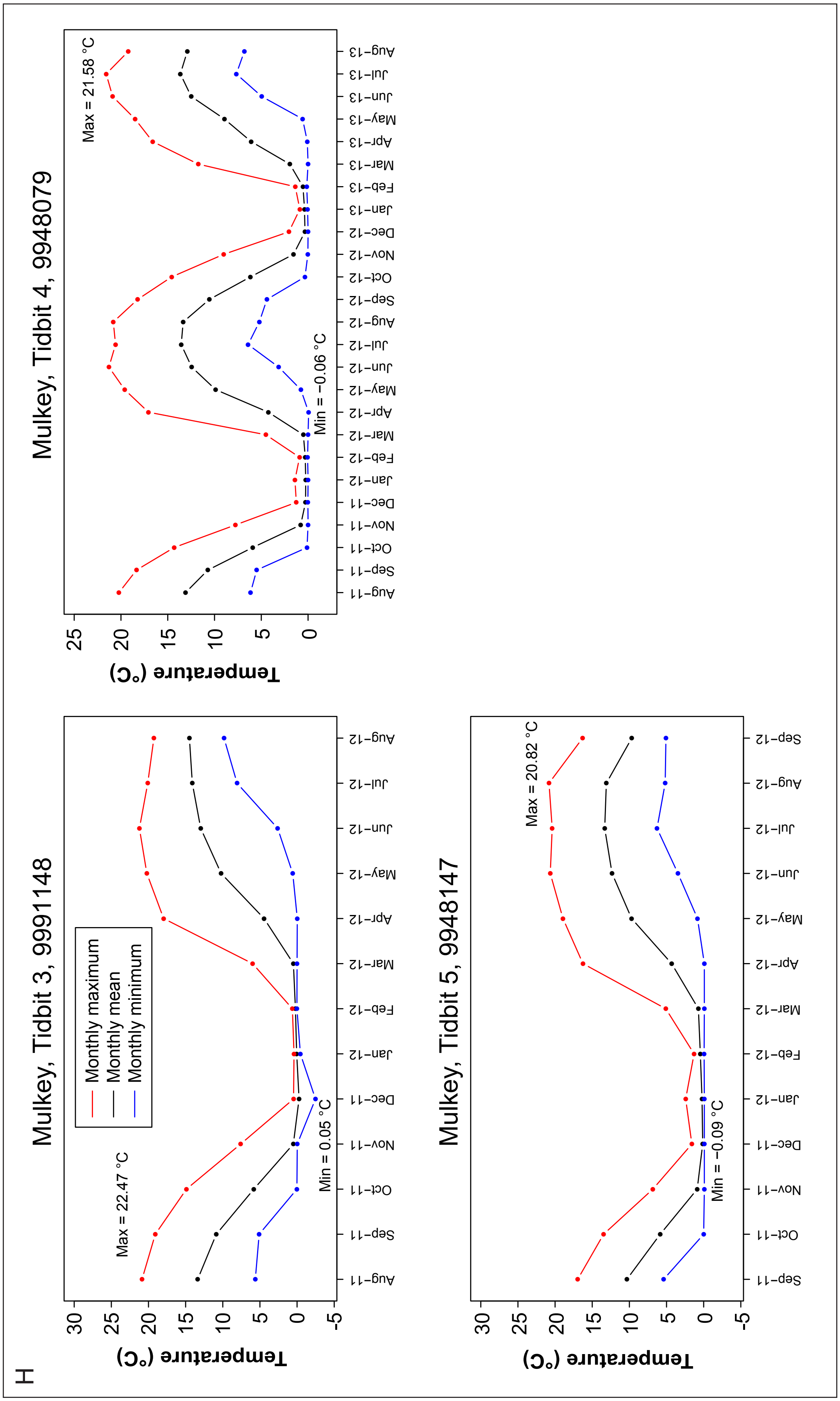


Figure 12 continued—All individual water temperature graphs for Mulkey Meadows (a through h).

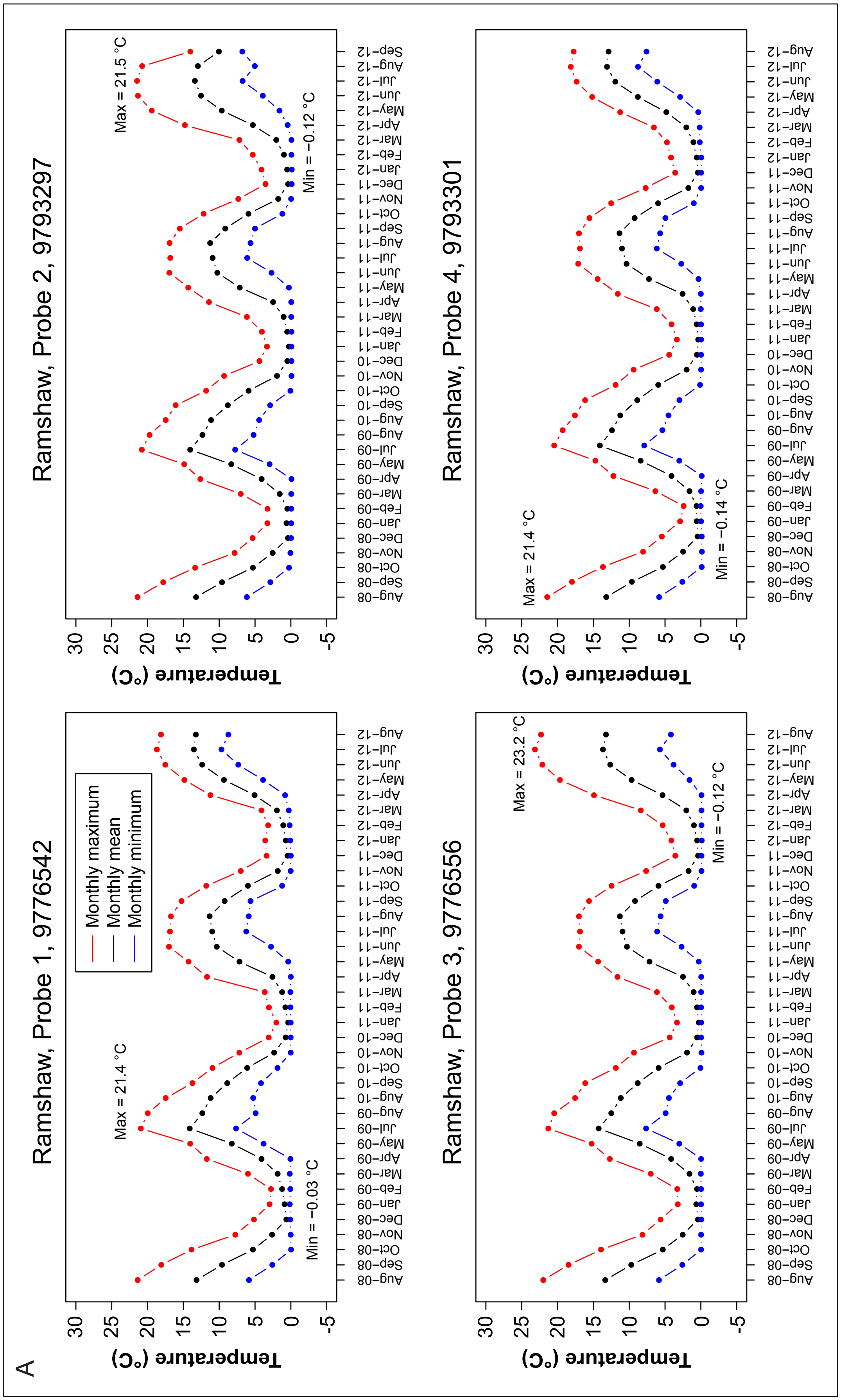
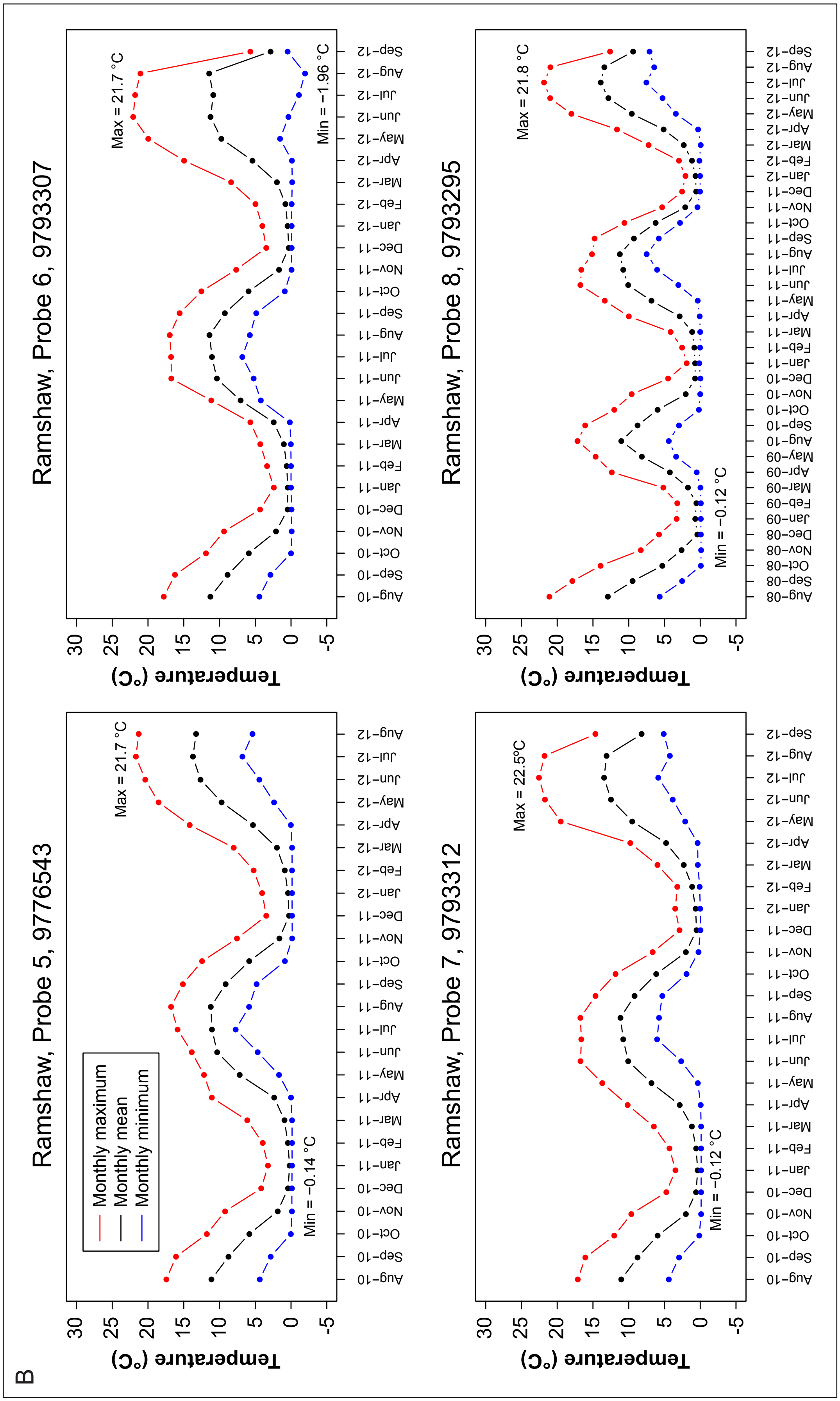


Figure 13—All individual water temperature graphs for Ramshaw Meadows (a through h).



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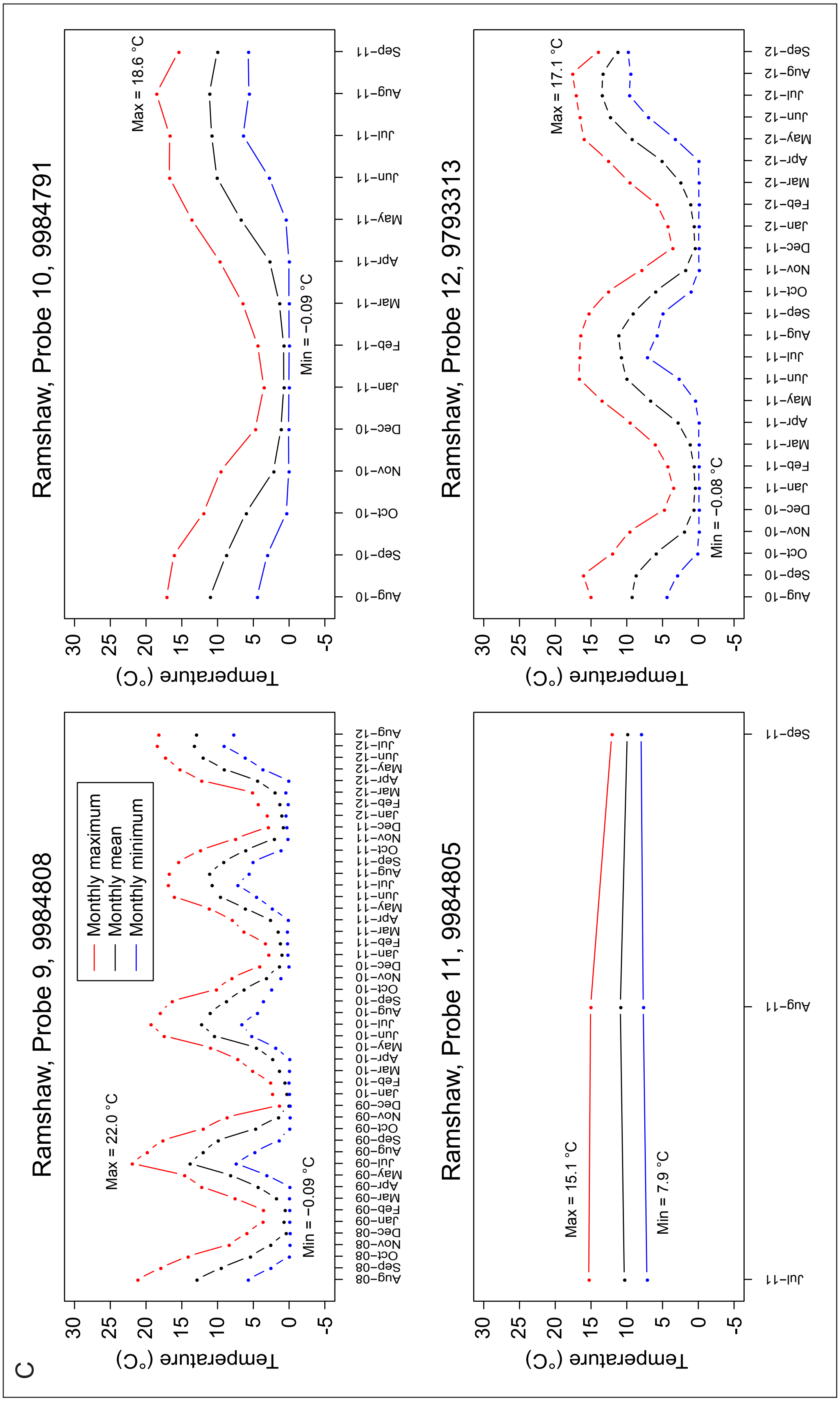

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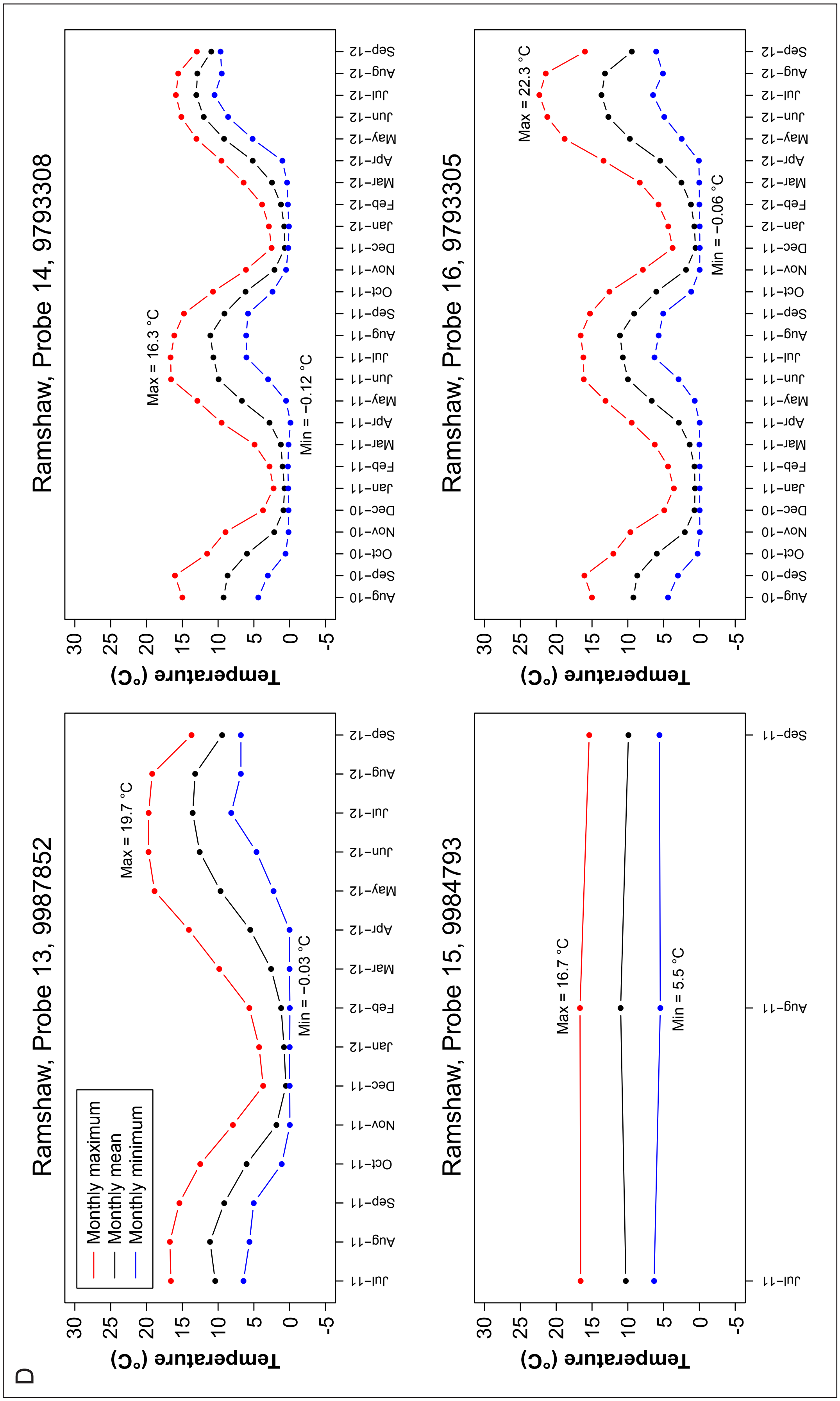

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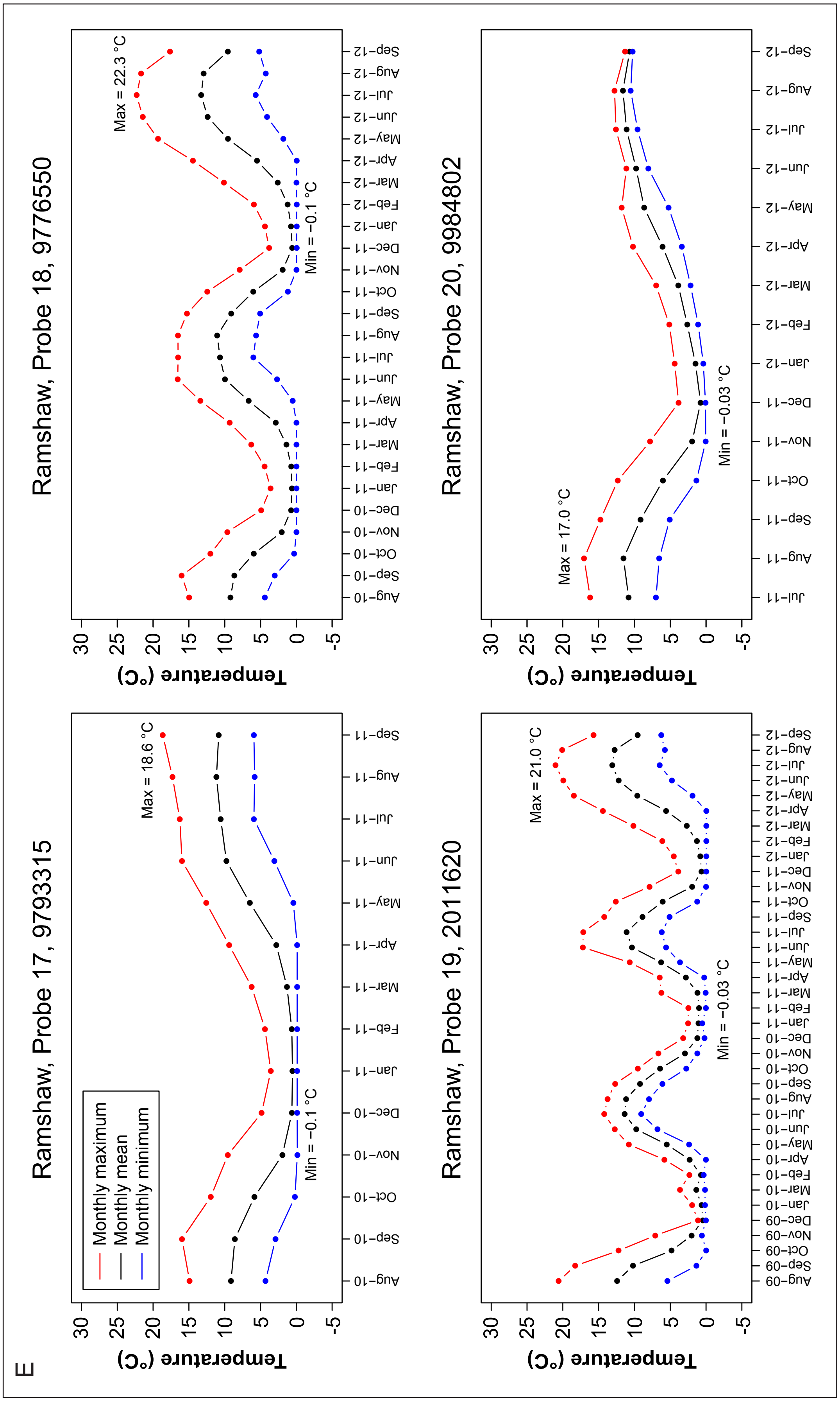

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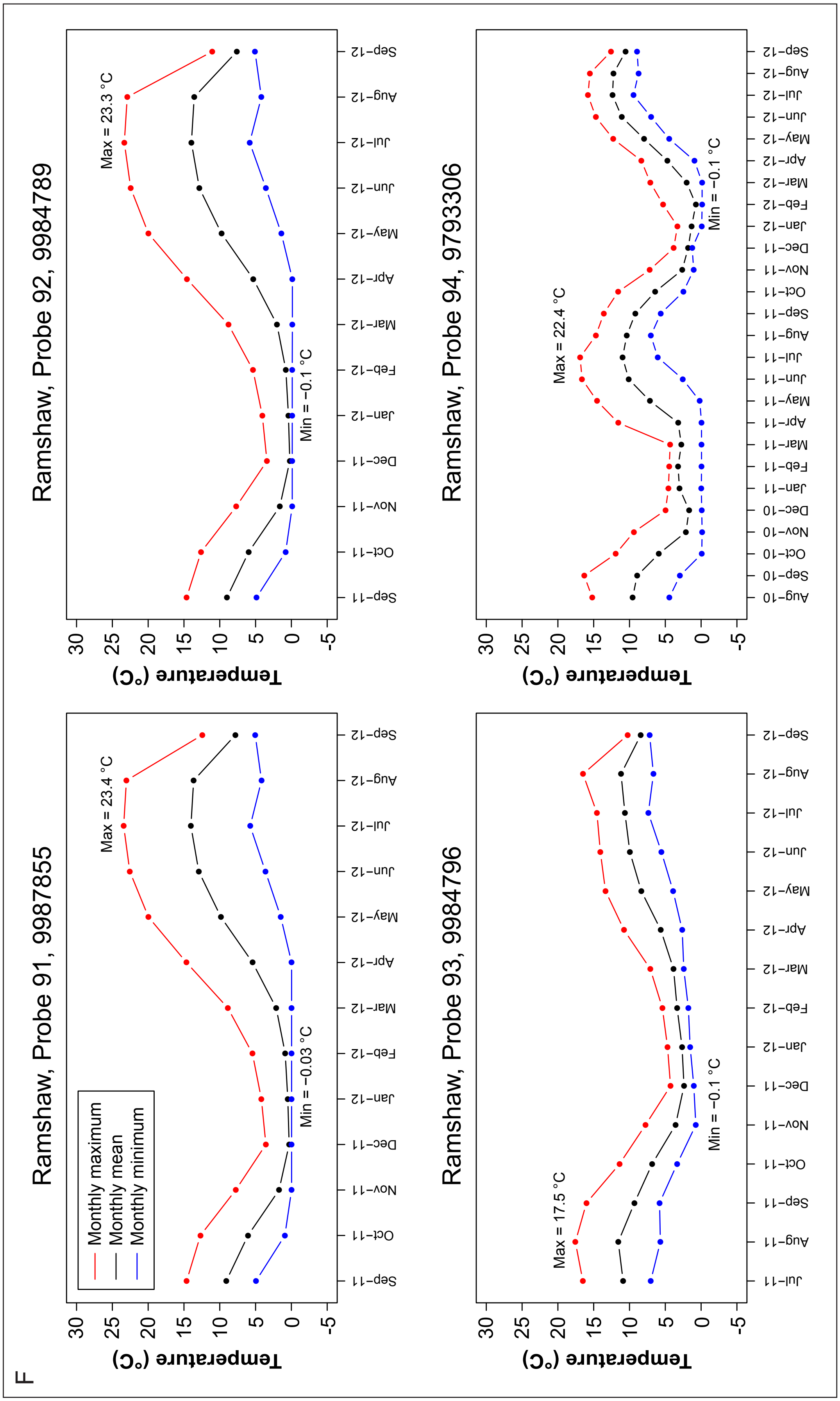

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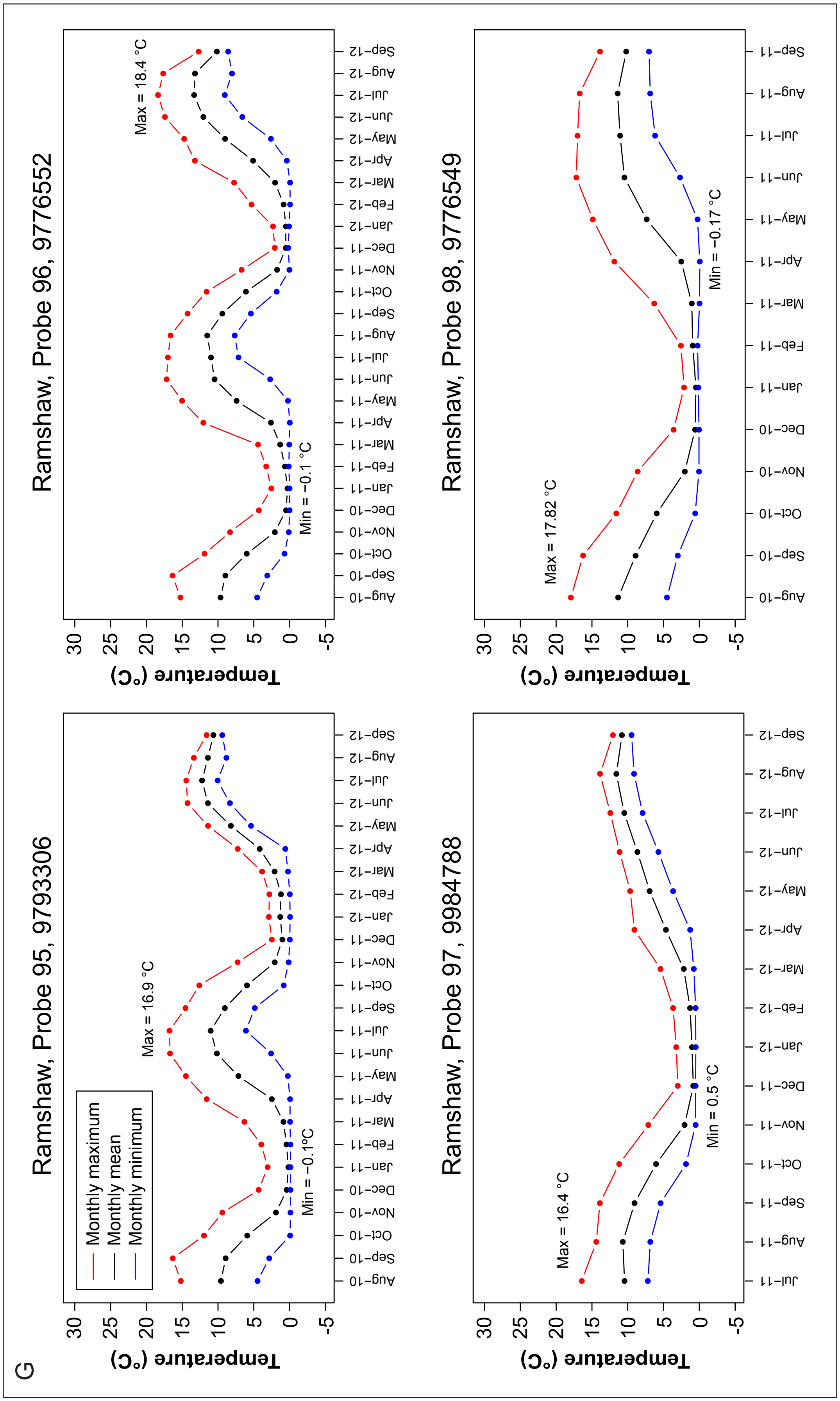

Figure 13 continued—All individual water temperature graphs for Ramshaw Meadows (a through h).

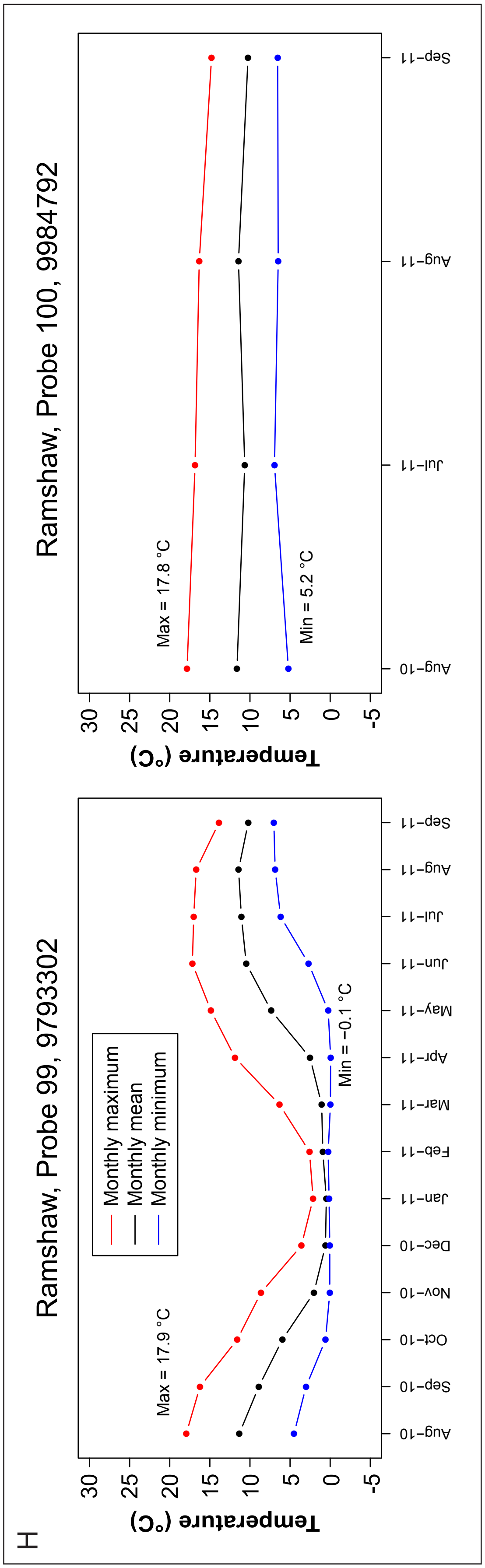

Figure 13 continued—All individual water temperature graphs for Ramshaw Meadows (a through h).

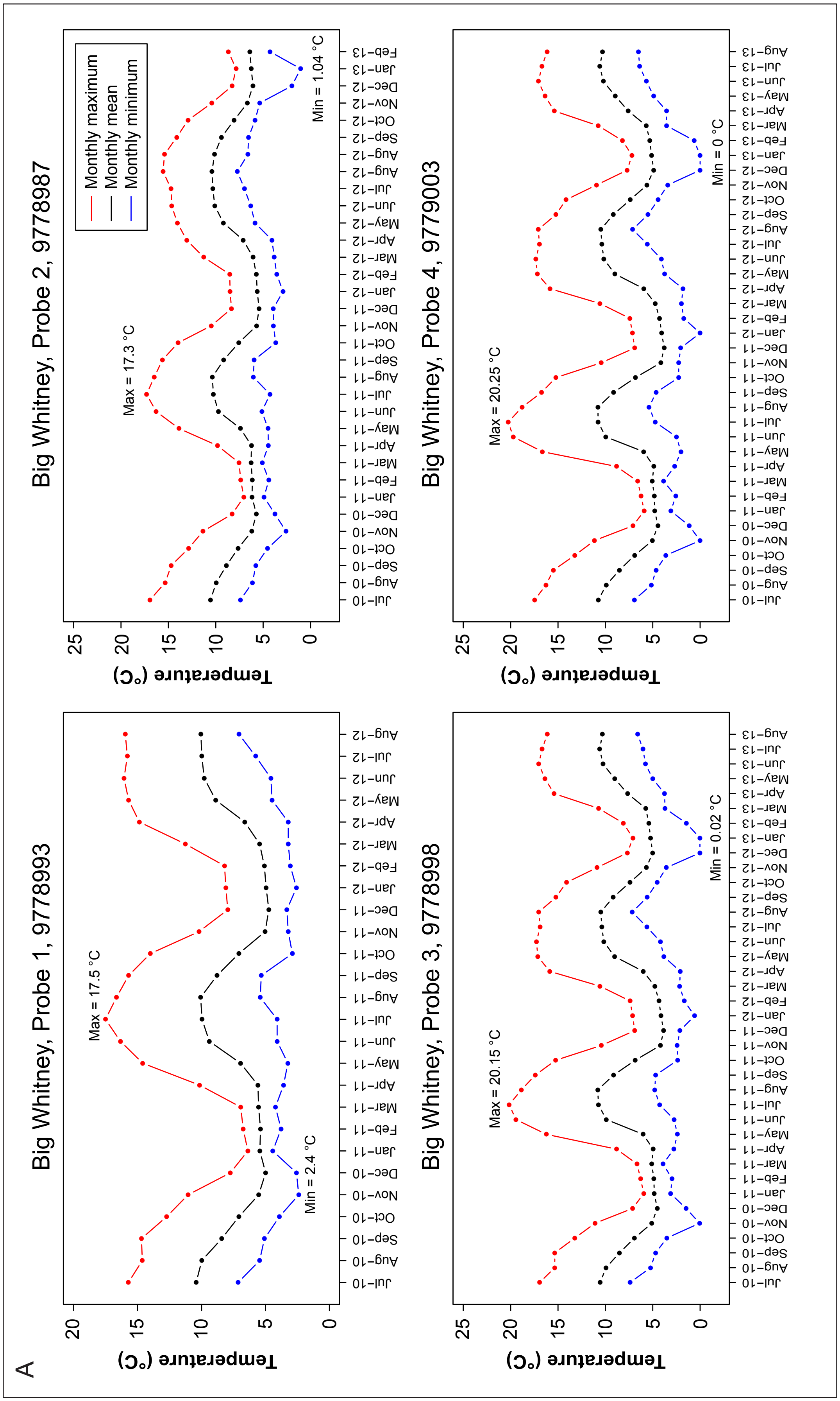

Figure 14—All individual water temperature graphs for Big Whitney Meadow (a through f).

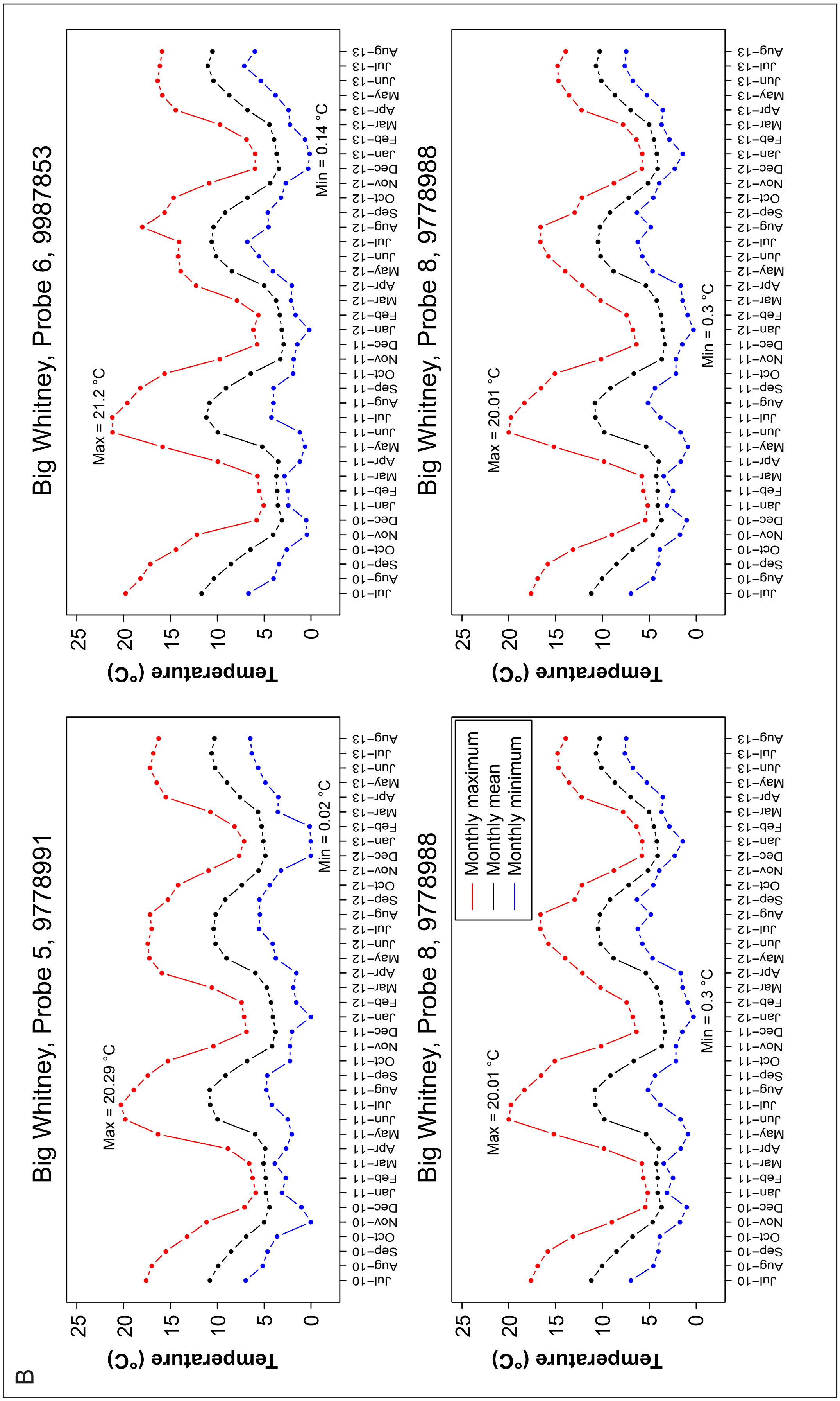

Figure 14 continued—All individual water temperature graphs for Big Whitney Meadow (a through f).

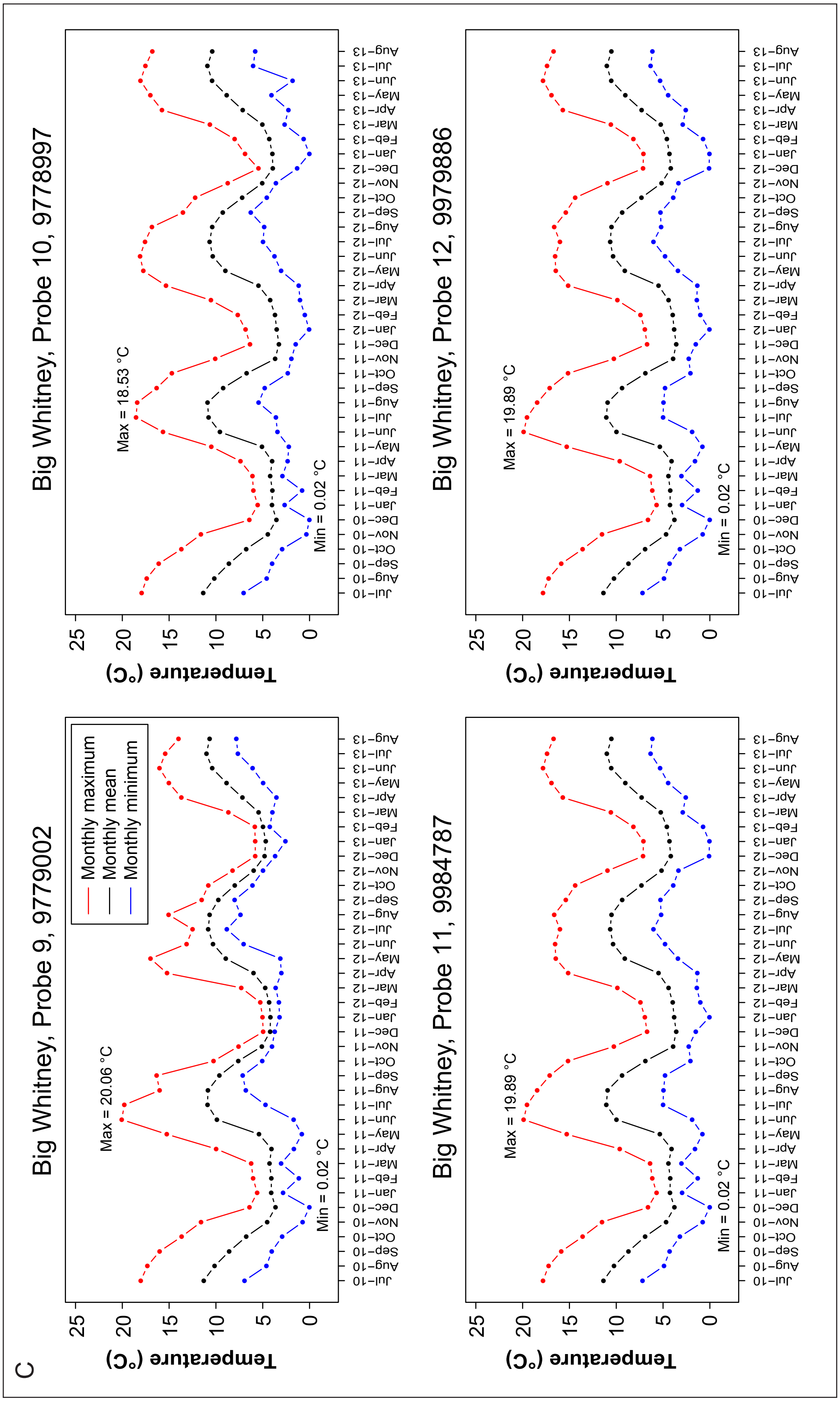

Figure 14 continued—All individual water temperature graphs for Big Whitney Meadow (a through f).

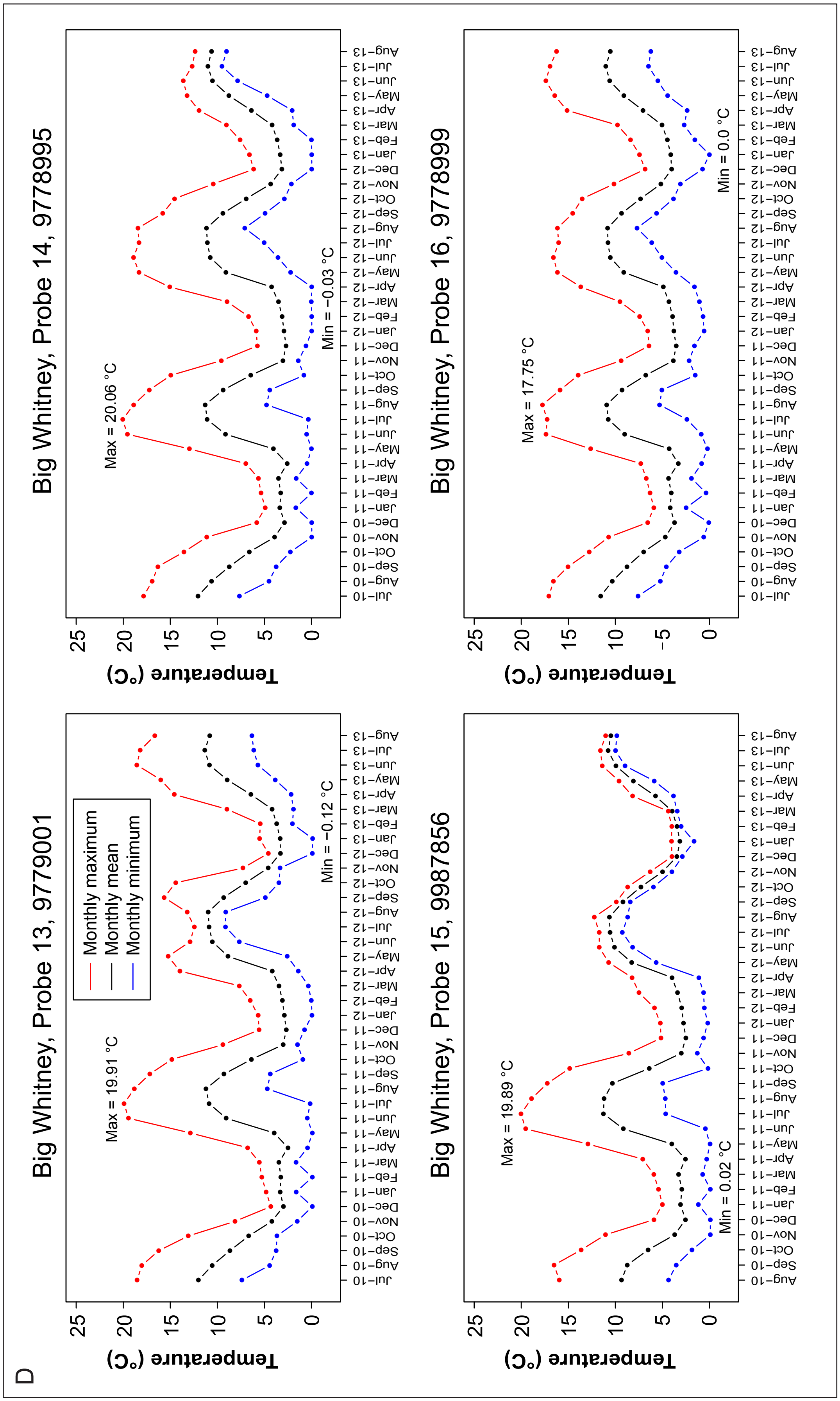

Figure 14 continued—All individual water temperature graphs for Big Whitney Meadow (a through f).

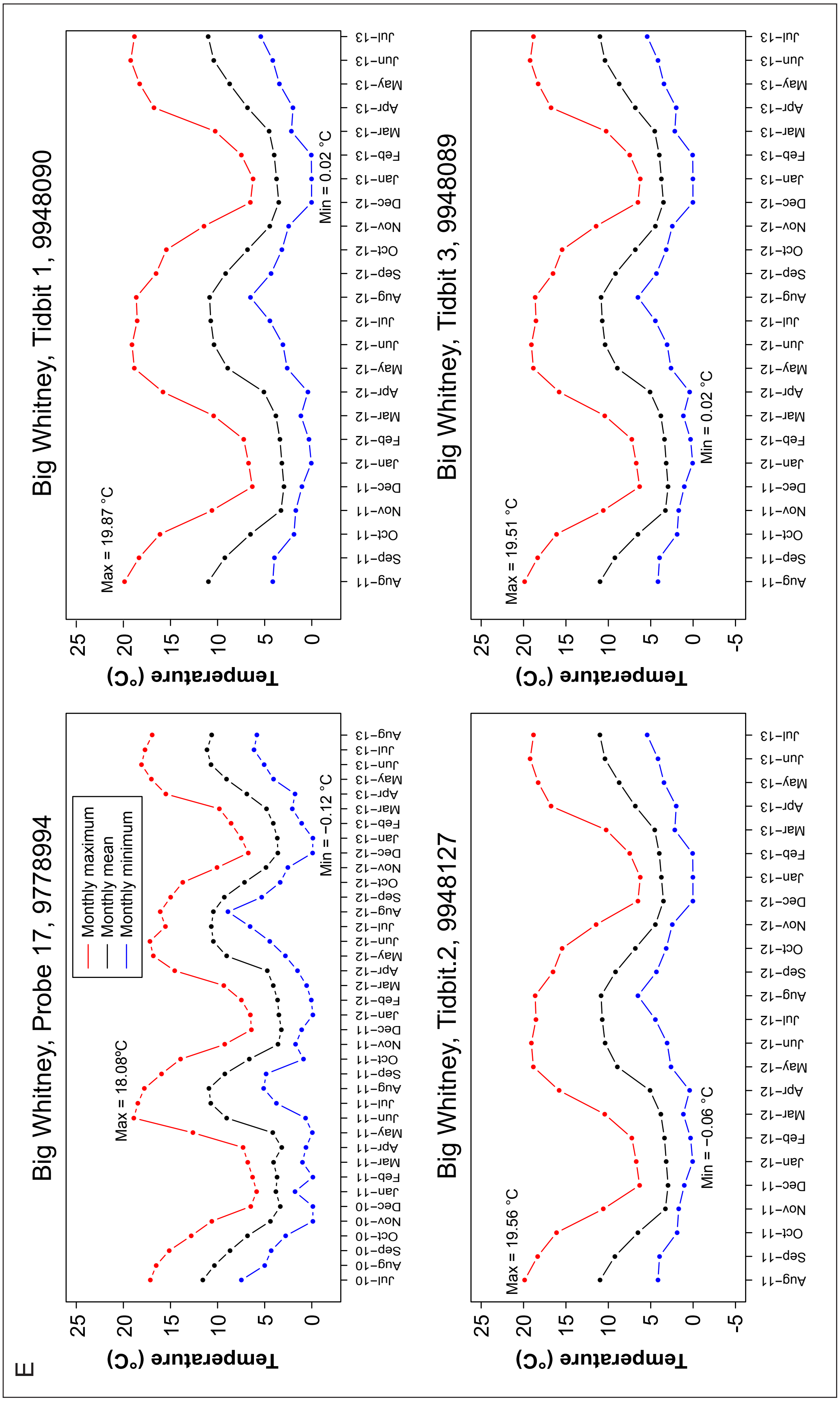

Figure 14 continued—All individual water temperature graphs for Big Whitney Meadow (a through f).

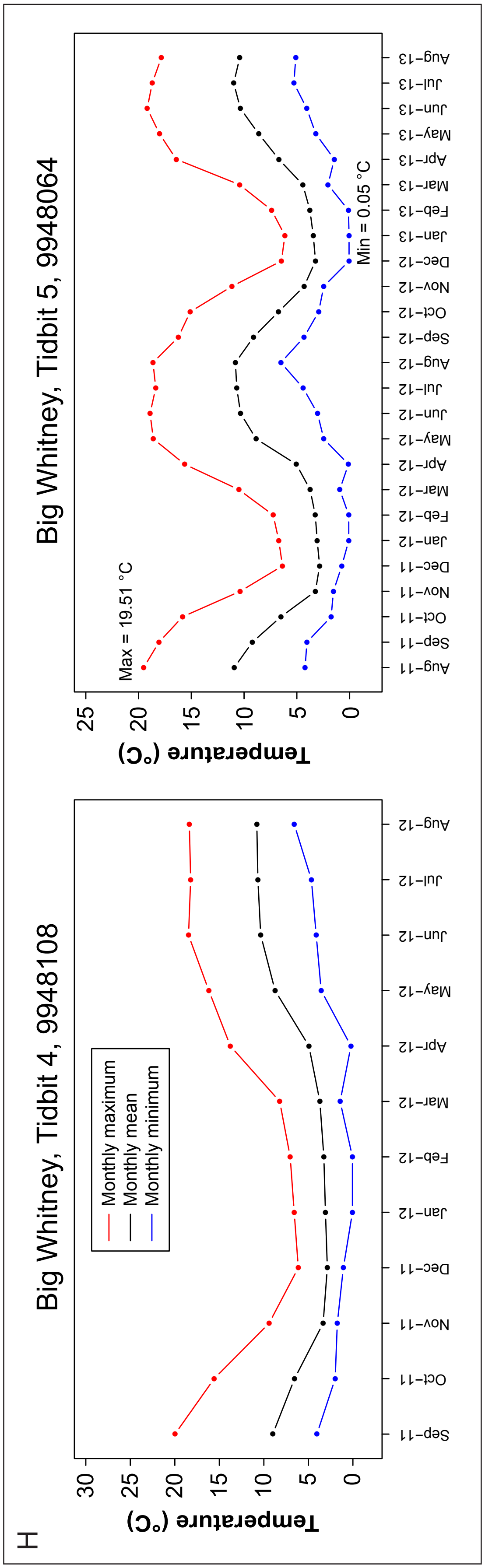

Figure 14 continued—All individual water temperature graphs for Big Whitney Meadow (a through f).

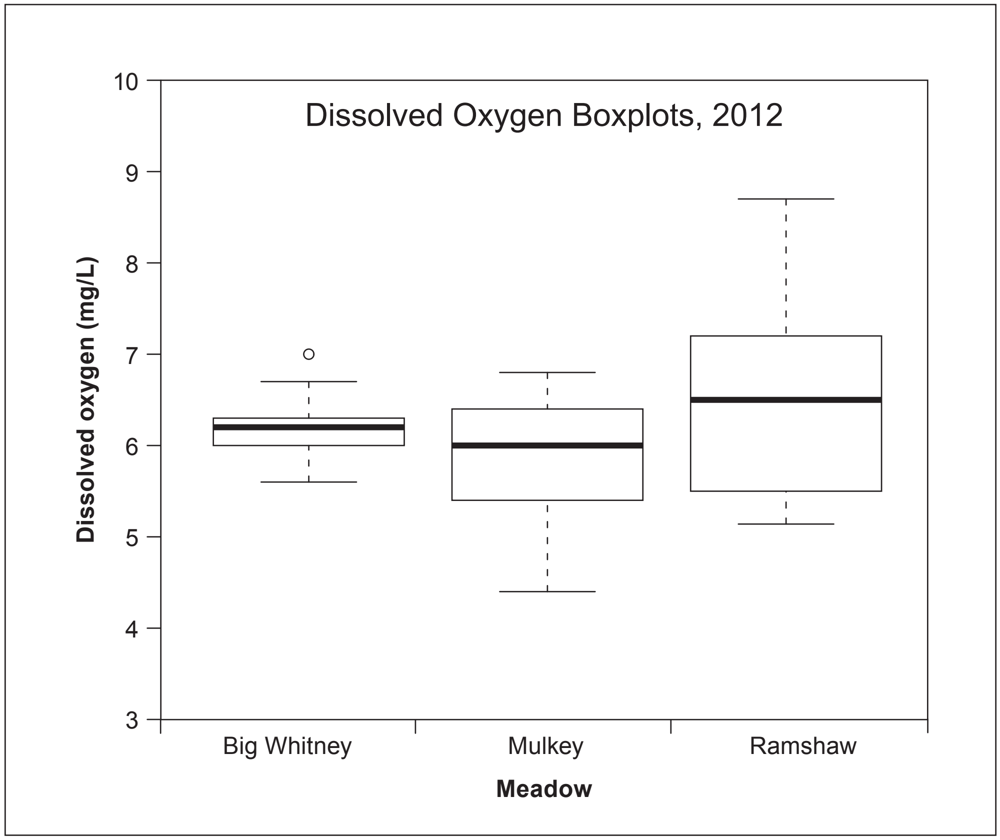

Figure 15—Dissolved oxygen (mg/L) measurements in 2012 in all three meadows.

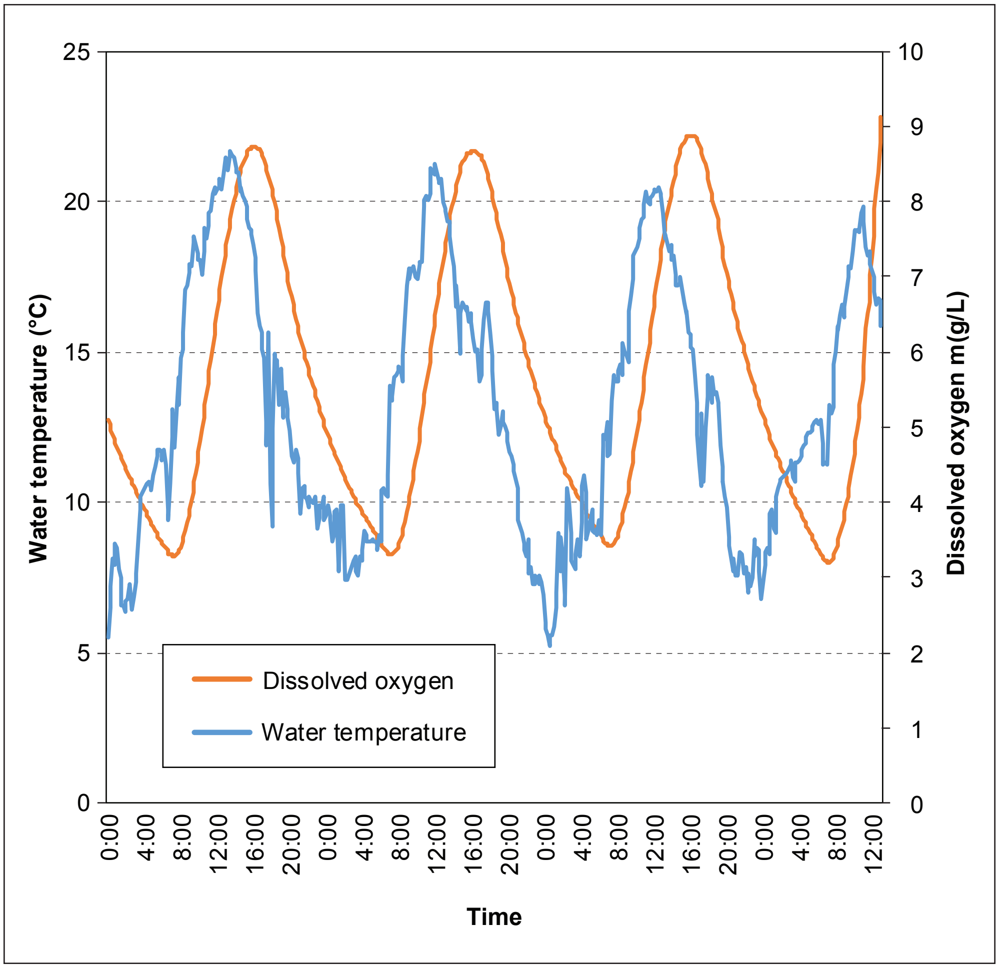

Figure 16—Diel measurements of dissolved oxygen and water temperature in Mulkey Meadows.

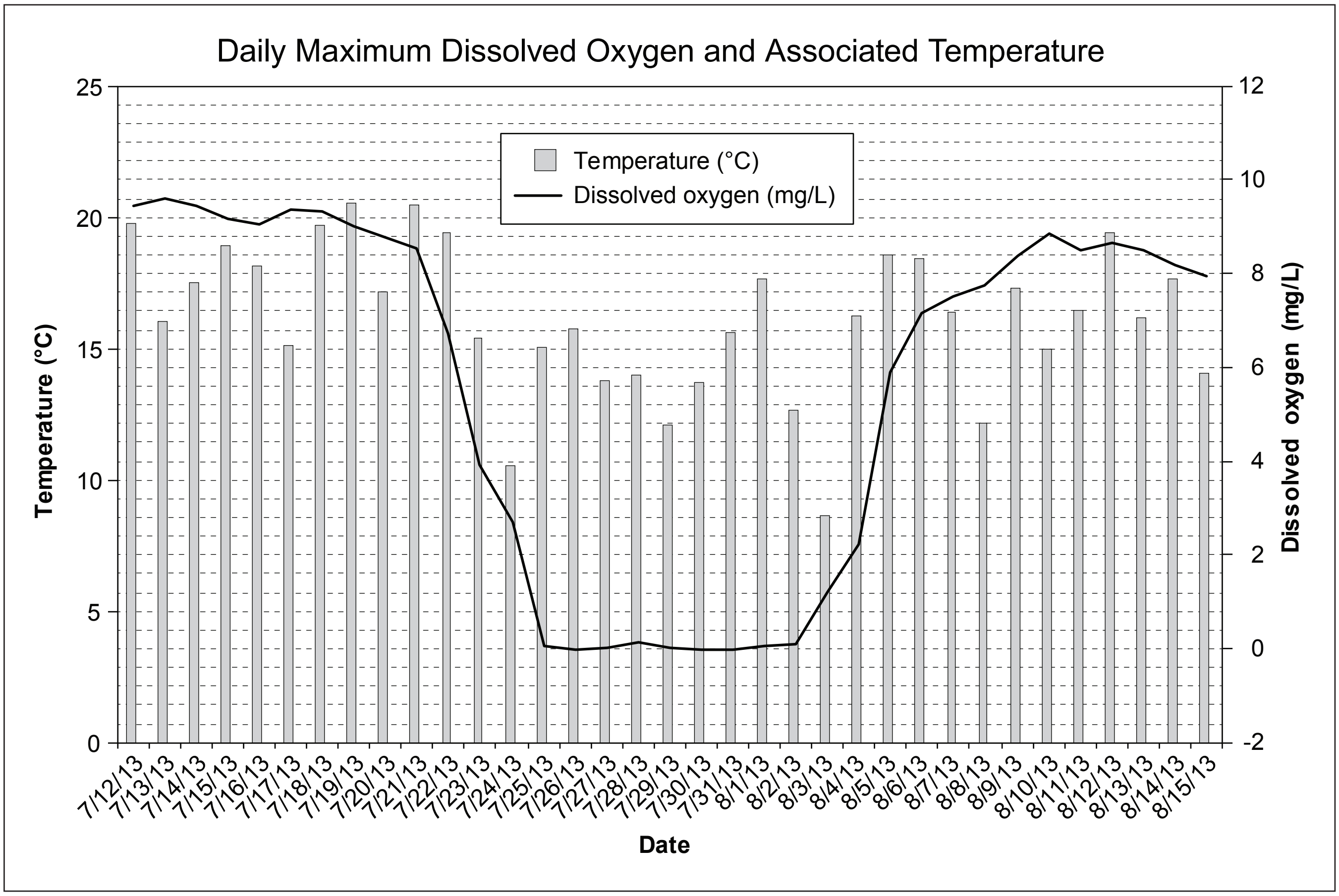

Figure 17—2013 32-day dissolved oxygen levels and temperatures in Mulkey Creek.

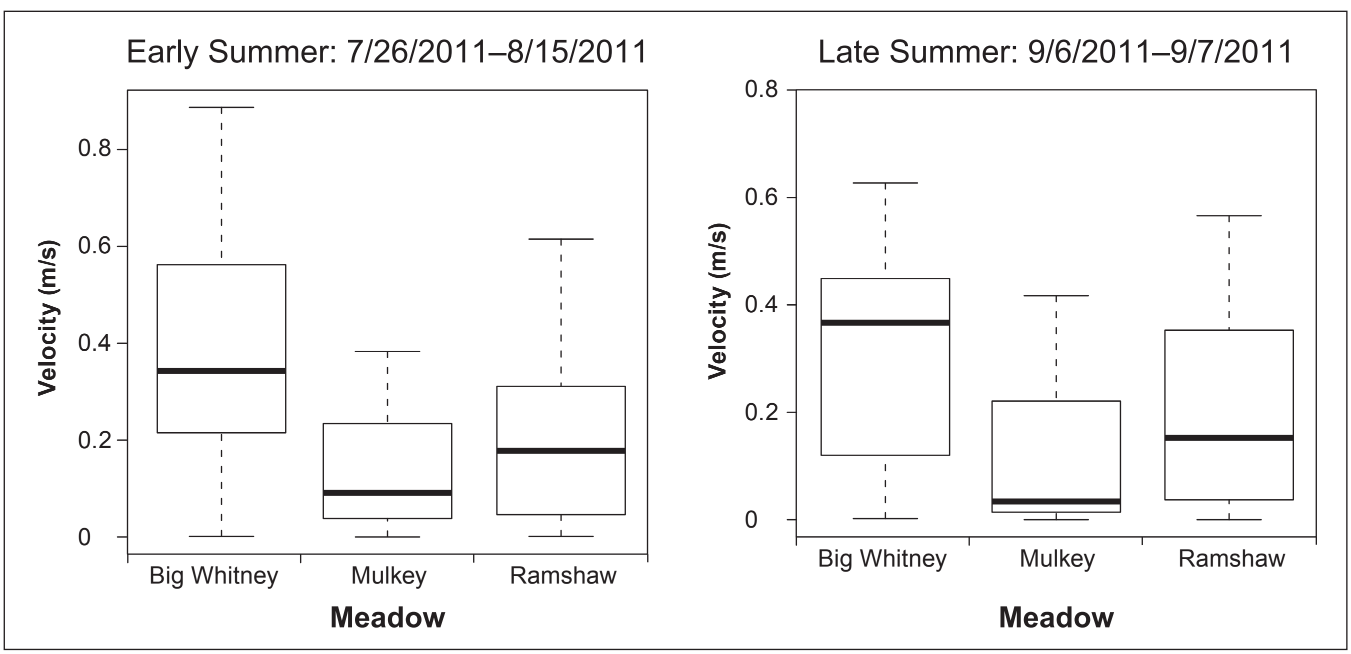

Figure 18—Flow measurements (meters per second (m/s)) in Big Whitney, Mulkey, and Ramshaw Meadows in 2011.

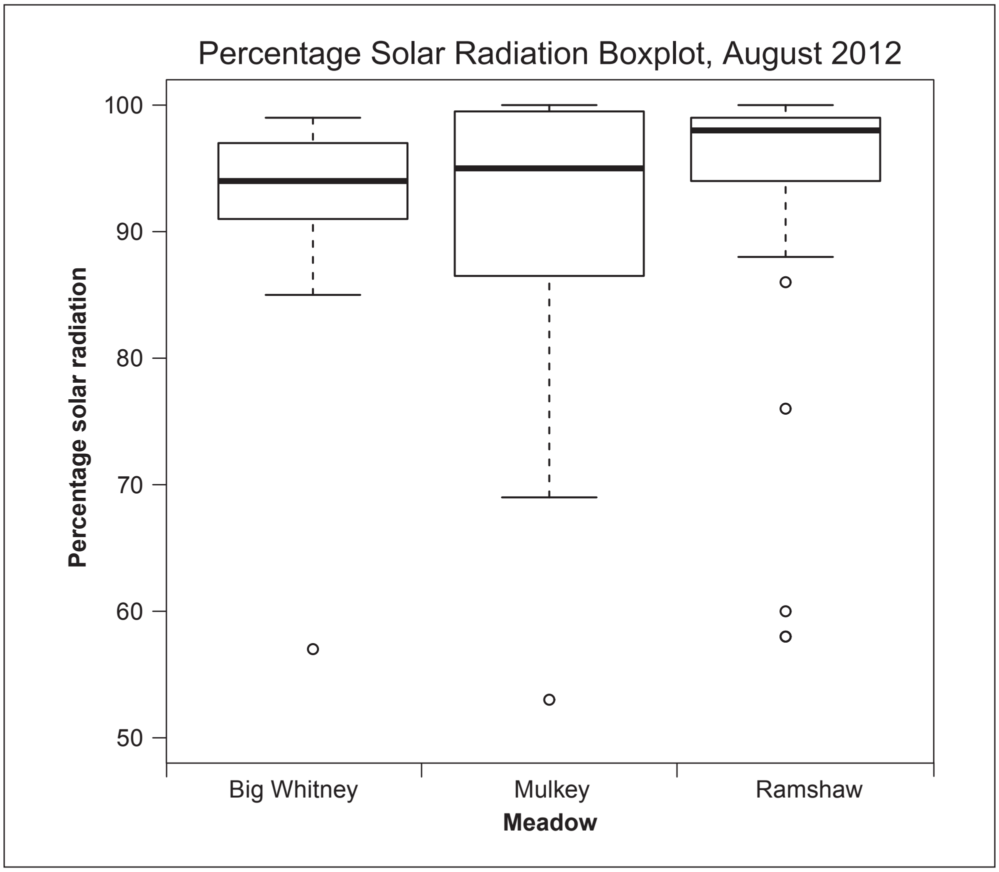

Figure 19—Shade/solar input measurements (percentage solar radiation) in 2012 in the three meadows.

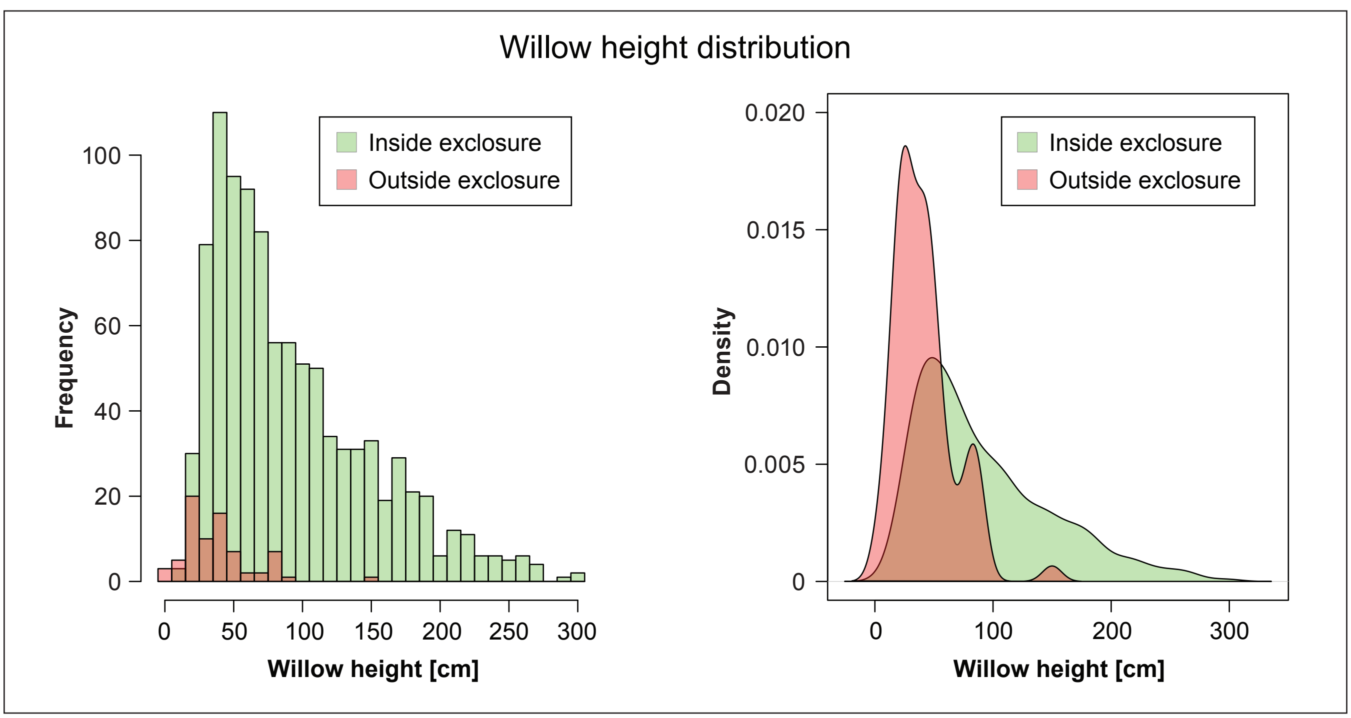

Figure 20—(A) Willows height (centimeters) distribution inside and outside the exclosure in Mulkey Meadows and (B) willow height density inside and outside the exclosure.

Discussion

This is the first documentation of year-round water temperatures in GTW streams. Water temperatures from 2008 through 2013 indicate several vulnerabilities: water temperatures in some areas of the GTW are already at stressful levels (>26 °C) (Bjornn and Reiser 1991), and these areas will not be resilient to future increased warming. The natural conditions of Kern Plateau with wide open meadows combined with reduced streamside vegetation have reduced the capacity of these streams to remain cool, and future warming could result in lethal water temperatures. The higher abundance and height of willows inside the areas excluded to cattle should be explored as a possible way to restore and keep streams cooler.

California golden trout inhabit streams with temperatures at critical levels. Past research found rainbow trout in southern California streams at temperatures up to 28 °C, but trout sought out cool water seeps and did not use the warmer areas (Matthews and Berg 1997). In the GTW, CGT are extremely abundant throughout the stream (Knapp and Matthews 1996) and inhabit all parts (runs, pools, etc.) of the stream (Matthews 1996a, 1996b). Redband trout, *Oncorhynchus mykiss gairdneri,* inhabit desert basin streams at mid-elevations (1600 to 1700 m) and may be found in water with temperatures as high as 29 °C (Rodnick et al. 2004, Zoellick 1999). Redband trout are considered the most temperature-tolerant of the salmonids. However, Meyer et al. (2010) reported that redband trout were more abundant in areas of increased shade and temperatures between 10 to 16 °C and that they steadily declined as mean summer temperature exceeded 16 °C; higher temperatures may affect the condition and performance of the trout (Rodnick et al. 2004). Perhaps CGT are heat tolerant but little is known about their thermal preference. In the absence of this information, it would be prudent to promote activities that cool the streams.

Climate models predict that water temperature will increase from 1 to 7 °C in the Sierra Nevada (Dettinger 2012, Null et al. 2013) and none of the streams currently has the resiliency to withstand these increased temperatures. Although temperatures in Golden Trout Creek (Big Whitney Meadow) were lower than those in Mulkey Creek and South Fork Kern (Ramshaw Meadows), Golden Trout Creek temperatures could reach stressful levels (>25 °C) when temperatures rise. Beschta et al. (2013) reported that climate warming has many impacts similar to those of overgrazing. They recommended that grazing on public lands, especially in wilderness areas, be eliminated to help meadow streams recover and become more resilient to climate-warming impacts. Because future climate warming could increase water temperatures to lethal levels, the current results emphasize the importance of continued monitoring and restoration activities that promote stream cooling.

Acknowledgments

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References

Armour, C.L.; Duff, D.A.; Elmore, W. 1991. The effects of livestock grazing on riparian and stream ecosystems. Fisheries. 16: 7–11.

Behnke, R.J. 1992. Native trout of western North America. Monograph 6. Bethesda, MD: American Fisheries Society. 275 p.

Belsky, A.J.; Matzke, A.; Uselman, S. 1997. Survey of livestock influences on stream and riparian ecosystems in the western United States. Journal of Soil and Water Conservation. 54: 416–531.

Beschta, R.L.; Donahue, D.L.; DellaSala, D.A.; Rhodes, J.J.; Karr, J.R.; O'Brien, M.H.; Fleischner, T.L.; Williams, C.D. 2013. Adapting to climate change on western public lands: addressing the ecological effects of domestic, wild, and feral ungulates. Environmental Management. 51: 474–491.

Bjornn, T.C.; Reiser, D.W. 1991. Habitat requirements of salmonids in streams. In: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats. Special Publication 19. Bethesda, MD: American Fisheries Society: 83–138.

Dettinger, M.D. 2013. Projections and downscaling of 21st century temperatures, precipitation, radiative fluxes and winds over the southwestern US, with a focus on Lake Tahoe. Climatic Change. 116: 17–33.

Isaak, D.J.; Horan, D.L.; Wollrab, S.P. 2013. A simple protocol using underwater epoxy to install annual temperature monitoring sites in rivers and streams. Gen. Tech. Rep. RMRS-GTR-314. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 21 p.

Kauffman, J.B.; Krueger, W.C. 1984. Livestock impacts on riparian ecosystems and streamside management implications: a review. Journal of Range Management. 37: 430–437.

Knapp, R.A.; Dudley, T.L. 1990. Growth and longevity of golden trout, *Oncorhynchus aguabonita*, in their native streams. California Fish and Game. 76: 161–173.

Knapp, R.A.; Vredenburg, V.T.; Matthews, K.R. 1998. Effects of stream channel morphology on golden trout spawning habitat and population structure. Ecological Applications. 8: 1104–1117.

Knapp, R.A.; Matthews, K.R. 1996. Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: impacts and management implications. North American Journal of Fisheries Management. 16: 805–820.

Matthews, K.R. 1996a. Golden trout habitat selection and movement patterns in degraded and recovering sites within the Golden Trout Wilderness, California. North American Journal of Fisheries Management. 16: 578–590.

Matthews, K.R. 1996b. Diel movement and habitat use of the golden trout *Oncorhynchus mykiss aguabonita* in their native habitat on the Golden Trout Wilderness, California. Transactions of the American Fisheries Society. 125: 78–86.

Matthews, K.R.; Berg, N.H. 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. Journal of Fish Biology. 49: 1–18.

Null, S.E.; Viers, J.H.; Deas, M.L.; Tanaka, S.K.; Mount, J.F. 2013. Stream temperature sensitivity to climate warming in California's Sierra Nevada: impacts to coldwater habitat. Climatic Change. 116: 149–170.

Pister, E.P. 2008. Restoration of the California golden trout in the South Fork Kern River, Kern plateau, Tulare County, California, 1966–2004, with reference to golden trout creek. Administrative Report No. 2008-1. Sacramento, CA: California Department of Fish and Game. 122 p.

Platts, W.S. 1991. Livestock grazing. In: Meehan, W.R., ed. Influences of forest and rangeland management on salmonid fishes and their habitats. Special Publication 19. Bethesda, MD: American Fisheries Society: 389–423.

Rodnick, K.J.; Gamperl, A.K.; Lizars, K.R.; Bennett, M.T.; Rausch, R.N.; Keeley, E.R. 2004. Thermal tolerance and metabolic physiology among redband trout populations in south-eastern Oregon. Journal of Fish Biology. 64: 310–335.

Williams, J.E.; Haak, A.L.; Neville, H.M.; Colyer W.T.; Gillespie, N.G. 2007. Climate change and western trout: strategies for restoring resistance and resilience in native populations. In: Carline, R.F.; LoSapio, C., eds. Sustaining wild trout in a changing world; proceedings of Wild Trout IX symposium: 236–246.

Zoellick, B.W. 1999. Stream temperatures and the elevational distribution of redband trout in southwestern Idaho. Great Basin Naturalist. 59: 136–143.