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Klamath Basin Water Temperature Summary, Water Year 2019

Taylor T. Daley, Nicholas R. Glaser, Samantha A. Adams, and Nicholas A. Som

U.S. Fish and Wildlife Service
Arcata Fish and Wildlife Office
1655 Heindon Road
Arcata, CA 95521
(707) 822-7201

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Taylor T. Daley*, Nicholas R. Glaser, Samantha A. Adams, and Nicholas A. Som

U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office
1655 Heindon Road; Arcata, California

**Corresponding author*
Taylor_Daley@fws.gov

Abstract.— The U.S. Fish and Wildlife Service began extensively monitoring water temperature in the Klamath basin in 2001 due to growing interest and concern over the effects of elevated water temperatures, particularly in relationship to Pacific salmonids. This report summarizes the results of 2019 water temperature monitoring for a set of locations within the Klamath River watershed that are accessible to anadromous fish. Temperature criteria for the Trinity River have been adopted by the Trinity River Restoration Program and are based upon the Trinity River Flow Evaluation Study and the Trinity River Mainstem Fishery Restoration: Final Environmental Impact Statement/Environmental Impact Report. We compared water temperatures on the Klamath River to the U.S. Environmental Protection Agency's Pacific Northwest salmonid life history stage temperature criteria. The 2019 water year was designated as 'Wet'. All criteria for all focal sites evaluated were exceeded on the Trinity and Klamath rivers. All five focal sites on the Klamath River experienced a new record by surpassing the historical seven-day average daily maximum temperature (range 8 to 15 days exceeded). On the Trinity River, the daily average water temperatures surpassed the maximum historical daily average water temperatures at three of the four focal sites (range 7 to 12 days exceeded). Although supplemental flow criteria of $\geq$23 °C for migrating adult salmon was exceeded, no emergency flows were released from either Iron Gate Dam or Lewiston Dam in 2019.

Introduction

The Klamath River basin historically supported large runs of Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *O. kisutch*, and steelhead *O. mykiss* that contributed to economically and culturally important subsistence, sport, and commercial fisheries (Leidy and Leidy 1984; KRBFTF 1991; NAS 2004; USDOI et al. 2013). Dramatic declines in native fish populations over the past century have been attributed to various anthropogenic-linked factors, including construction and operation of a series of hydropower dams on the mainstem Klamath and Trinity rivers (Poole and Berman 2001; Caissie 2006; Moyle et al. 2008, 2011; Hester and Doyle 2011). Some of these anthropogenic influences have exacerbated naturally warm water temperatures in parts of the basin, resulting in negative impacts to salmonid populations (KRBFTF 1991; McCullough 1999; NAS 2004; Bartholow 2005; NCRWQCB 2010).

The thermal regime of a river characterizes the central tendency and variability in temperature seasonally and over time, and has numerous cascading influences on the physiological, ecological, and life-history traits of salmonids and other aquatic organisms (Olden and Naiman 2010; Hallock et al. 1970; McCullough 1999; Harmon et al. 2001; USEPA 2003; Carter 2006). Water temperature influences the population performance of fishes, the impact of which is particularly well studied on the spawning and early life stages of salmonids (Brett 1971; Bjornn and Reiser 1991; Baker et al. 1995; Marine and Cech 2004; Richter and Kolmes 2005). As poikilotherms, salmonid metabolic rates are directly impacted by the temperature of their environment. These metabolic changes have been linked to behavioral shifts such as a reduction in feeding (Brett 1971) and seeking thermal refugia (Sullivan et al. 2000; Goniea et al. 2006). Salmonid embryos and larvae are particularly susceptible to elevated temperatures, which can impact their ability to initiate exogenous feeding (Heming 1981). Temperature can also influence diseases prevalent in salmonid populations, inhibit individual survivability, and amplify group transmission (Harmon et al. 2001; Guillen 2003; Turek at al. 2004; Ray et al. 2014). While there is often a focus on maintaining cooler water temperatures, warm water also plays an important role in fish life history (Armstrong et al. 2021).

The Klamath River’s largest tributary, the Trinity River, is the focus of a large-scale habitat restoration and salmon recovery effort coordinated by the Trinity River Restoration Program (TRRP). The goal of this effort is to restore and maintain the anadromous fishery resources of the Trinity River (USFWS and HVT 1999; USDOI 2000; USFWS et al. 2000). One component of the restoration effort is the management of flows out of Trinity and Lewiston dams to improve thermal regimes for all life stages of anadromous salmon that use the mainstem Trinity River. Temperature criteria were developed for holding and spawning adult salmon and for outmigrating juvenile salmon in the Trinity River Flow Evaluation Study (TRFES; USFWS and HVT 1999) and were adopted by the Trinity River Mainstem Fishery Restoration: Final Environmental Impact Statement/Environmental Impact Report, Record of Decision (USDOI 2000; USFWS et al. 2000). The annual flow release schedule for the Trinity River is based on the recommendations of the December 2000 Trinity River Mainstem Fishery Restoration Record of Decision (ROD) and incorporates the water year (WY) type and restoration needs (USDOI 2000).

A set of numeric water temperature criteria comparable to the Trinity River’s do not exist for the Klamath River. Instead, the Environmental Protection Agency’s (EPA) criteria for

Pacific Northwest water temperatures were adopted (USEPA 2003; Carter 2006). The EPA prepared these criteria as a set of guidelines for the development of water quality standards by Pacific Northwest states and Native American tribes. Using these criteria is not an assertion of any regulatory compliance, or lack thereof, but represent science-based, peer-reviewed criteria as a measure of the magnituge to which water temperatures may be impairing Pacific salmon populations in the Klamath River.

Supplemental flows have been used in previous years as a water management tool to reduce the risk of disease in August and September. The temperature objective (Lagomarsino and Hetrick 2013) of the supplemental flows is to reduce the daily mean temperature below 23 ℃, the migration threshold for adult Chinook Salmon in the lower Klamath River (Strange 2010). These criteria were developed in response to the 2002 fish die-off in the lower Klamath River, where an estimated minimum of 34,000 adult salmonids died prior to spawning. This die-off was attributed to the increased spread of disease outbreaks of *Ichthyophthirius multifiliis* and *Flavobacterium columnare* in adult salmon returning to spawn. This was likely due to low river discharge, high water temperatures, and a large run size (Guillen 2003; Belchik et al. 2004; Turek et al. 2004). Efforts to abate the fish die-off in 2002, occurred too late for the water release to mitigate the effects of high-water temperatures and disease. Emergency flow releases are now used as preventative measures to minimize the risk of infection during adult migration in August and September.

The Arcata office of the U.S. Fish and Wildlife Service (USFWS) began monitoring water temperatures in the lower Klamath basin in 2001 due to the significant effects of water temperatures on anadromous salmonids and concern that elevated water temperatures in the Klamath basin could be impacting salmonid populations. The primary intent of this report is to summarize the monitored thermal regime from 2019 and compare with established criteria to inform water management decisions in the Klamath basin. Further details of these criteria and the management responses can be found in reports written by the Trinity River Restoration Program (TRRP; TRRP 2012; Lagomarsino and Hetrick 2013; Hetrick and Polos 2015). The secondary objectives are to increase understanding of the areas of concern within the basin, and the consequences of water temperatures outside the optimal range for salmonid life history requirements. Water temperature data included in this report are also used in the development, validation, and refinements of a predictive water temperature model for the basin, (Perry et al. 2011; Jones et al. 2016), which is also a foundational driver in the Stream Salmonid Simulator (S3) salmon production model (Perry et al. 2018), which is relied upon to inform resource management decision making in the Klamath Basin (e.g., Polos 2016; Som and Hetrick 2017).

Methods

Study Area

This report focuses on access points for anadromous fish in the lower Klamath Basin, namely the Trinity and Klamath rivers and their tributaries. Monitoring locations on the Trinity River extend from below Lewiston Dam (TRBL) to the confluence with the Klamath River (TRWE). In 2019, two non-focal sites were added on the Trinity River above Lewiston on the East Fork near the mouth (EFTL) and above Trinity Lake (TRTL). Klamath River monitoring locations extend from Iron Gate Dam (KRIG) to near the mouth (KRTG; Figure 1; Table 1).

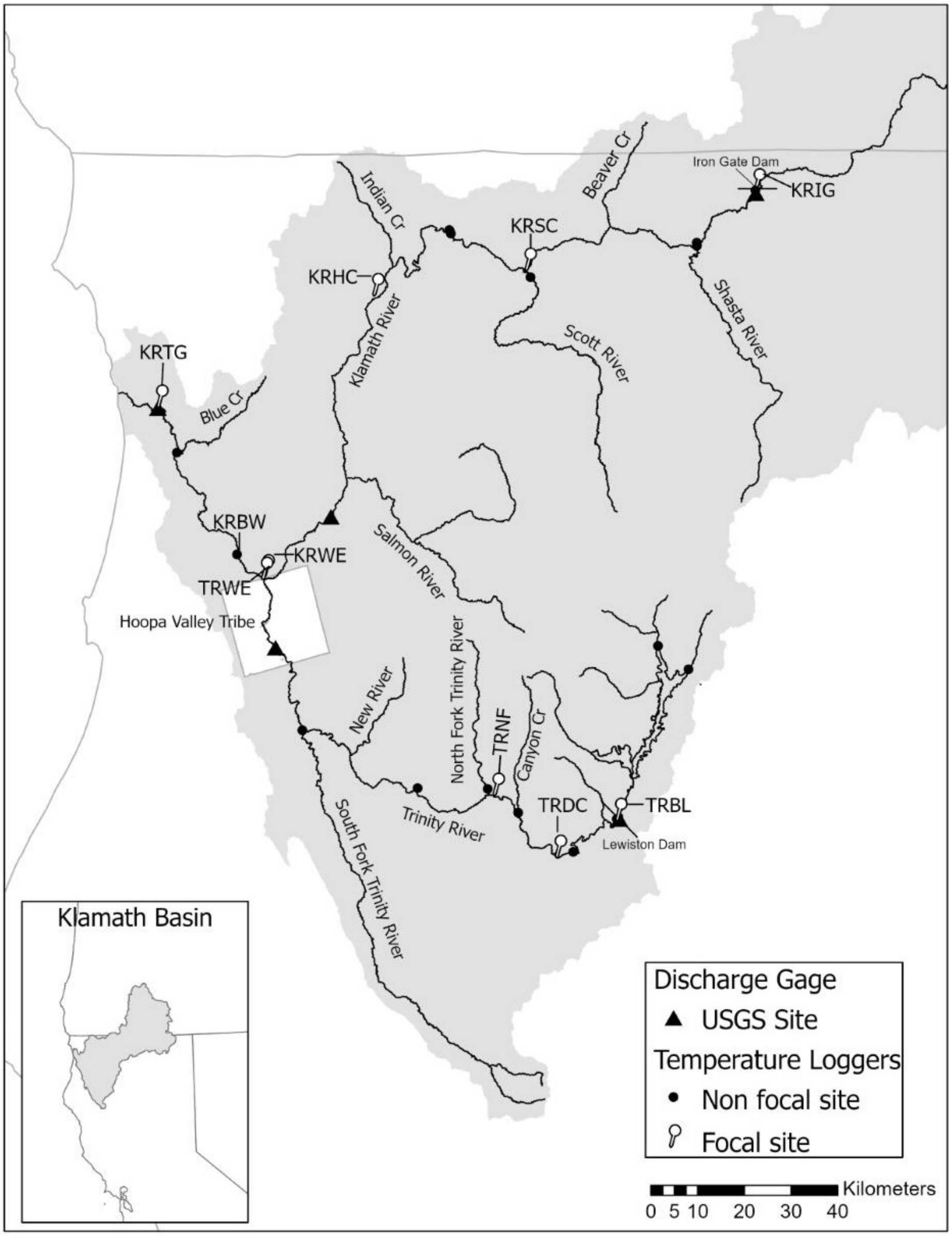

Figure 1. Locations in the lower Klamath basin where flows were recorded at U.S. Geological Survey (USGS) gaging sites and water temperatures were recorded at U.S. Fish and Wildlife Service monitoring sites in 2019. Anadromy is limited to below Iron Gate Dam on the Klamath River and below Lewiston Dam on the Trinity River. *Note*: due to their close proximity, the non-focal monitoring sites on the South Fork and Trinity River above the South Fork overlap on the map and appear to be one site, which is also the case on the Shasta River and Klamath River above the Shasta River.

Table 1. Temperature monitoring locations in the Klamath basin operated by the U.S. Fish and Wildlife Service in 2019. Locations are ordered from upstream to downstream by river kilometer (Rkm) along the Klamath and Trinity rivers, with tributaries arranged by their entrance to the respective river. Focal monitoring sites are highlighted in gray and *. Years operated before 2019 do not include infilled data.

River/Creek	Location	Location Code	Rkm	Latitude	Longitude	Years Operated
Klamath River	Below Iron Gate Dam*	KRIG	309.7	41.931049	-122.4414	2001-2019
Klamath River	Above Shasta River	KRSH	288.5	41.83124	-122.59338	2002-2019
Shasta River	Near mouth	SHKR	0.8	41.824759	-122.59392	2001-2003, 2005-2018
Klamath River	Above Scott River*	KRSC	233.2	41.779236	-123.03325	2002-2018
Scott River	Johnson Bar	SCKR	2.5	41.765479	-123.02266	2004, 2006-2018
Klamath River	Seiad Valley	KRSV	209.3	41.854087	-123.23147	2001-2018
Klamath River	Below Happy Camp*	KRHC	164.2	41.729647	-123.42558	2002-2018
Klamath River	Weitchpec*	KRWE	70.2	41.185991	-123.70228	2002-2019
Klamath River	Below Weitchpec	KRBW	61.7	41.227666	-123.77259	2004, 2007-2019
Klamath River	Above Blue Creek	KRBC	26.2	41.423077	-123.92933	2003-2019
Klamath River	Blakes Riffle*	KRTG	12.7	41.511184	-123.97844	2004-2019
E.F. Trinity River	Near mouth	EFTL	4.1	41.008173	-122.62036	2019
Trinity River	Above Trinity Lake	TRTL	226.6	41.053538	-122.69754	2019
Trinity River	Below Lewiston Dam*	TRBL[b]	180.6	40.717945	-122.80313	2017-2019
Trinity River	Below Lewiston Dam*	TRRC	173	40.720869	-122.82912	2002-2003, 2005-2017
Indian Creek	Near mouth	ICTR	0.2	40.656452	-122.91388	2002-2019
Trinity River	Douglas City*	TRDC	151.3	40.646797	-122.9562	2019
Trinity River	Douglas City*	DGC[a]	148.5	40.645278	-122.95667	2002-2018
Canyon Creek	Near mouth	CNTR	0.3	40.731906	-123.05382	2001-2019
Trinity River	Above North Fork*	TRNF	1.2	40.777677	-123.13138	2019
	Above North Fork*	NFH[a]	119.7	40.766532	-123.11448	2005-2018
N.F. Trinity River	Near mouth	NFTR	0.1	40.770324	-123.12748	2001-2019
Trinity River	Above Big French Creek	TRBF	96.8	40.779208	-123.3085	2001-2019
Trinity River	Above South Fork	TRSF	50.8	40.88981	-123.60204	2001-2003, 2005-2019
S.F. Trinity River	Near mouth	SFTR	0.1	40.889434	-123.60221	2001-2019
Trinity River	Above Klamath*	TRWE	0.8	41.181077	-123.70581	2002-2019

[a] The locations at Douglas City and above the North Fork on the Trinity River are monitored by the Bureau of Reclamation prior to 2019. These data were obtained from the California Data Exchange Center website (https://cdec.water.ca.gov/index.html).

[b] The site 'Below Lewiston Dam' was relocated upstream in 2017 and the coordinates for TRBL have replaced TRRC as the location for this site.

Data Sources and Protocols

The USFWS monitored water temperatures at 23 sites in the Klamath basin in 2019 (Figure 1; Table 1). As of 2019, water temperature data previously reported by USGS at the Douglas City site (DGC) and the above North Fork site (NFH) are now collected at the USFWS sites TRDC and NFTR, respectively. Of the 23 locations, 12 were on the Trinity River and its tributaries and 11 were on the Klamath River and its tributaries. These locations were selected to be representative of different reaches in their respective rivers and were not determined to be inadvertently influenced by local conditions such as by springs, tributaries, or other thermal anomalies.

All USFWS monitoring locations were fitted with digital data loggers (HOBO Water Temp Pro v2, Onset Computer Corporation) and used standardized protocols (Dunham et al. 2005) to monitor water temperatures. Loggers were set to record at 30-minute intervals and were swapped out twice per year, once in late spring or early summer and once in late fall or early winter. Prior to and after deployment, each logger was tested to verify operation within the manufacturer's accuracy specification of ± 0.2℃. Data from USFWS monitoring locations are stored in a Water Information Systems by Kisters (WISKI) relational database and are available upon request.

Focal Sites

Focal site selection was based on points representing the longitudinal thermal gradients of the mainstem Klamath or Trinity rivers. These points usually correspond to a landmark (e.g., a dam or large tributary) or are associated with temperature criteria requirements. Four focal sites on the Trinity River and five focal sites on the Klamath River were selected for this analysis.

On the Trinity River, the most upstream focal site is just below Lewiston Dam (TRBL), the upper limit to anadromy. The remaining focal sites are located at Douglas City (TRDC), above the North Fork Trinity River (NFTR), and above the Klamath River (TRWE) and were chosen based on downstream extents of water temperature criteria set by the TRRP.

On the Klamath River the most upstream focal site is below Iron Gate Dam (KRIG), which marks the current upper limit to anadromy. The other four focal sites are above the Scott River (KRSC), below Happy Camp (KRHC), at Weitchepec Trinity River (KRWE), and above the mouth of the Klamath River (KRTG). The KRSC site was chosen because it encompasses the first tributary that can substantially influence water temperatures in the Klamath River downstream of Iron Gate Dam. The KRHC site was selected because previous monitoring identified this reach as the location where peak summer water temperatures occur in the mainstem Klamath River downstream of Iron Gate Dam (Magneson 2015). KRWE was chosen because it is upstream of the confluence with the Trinity River. Finally, KRTG was chosen as it is the terminus of the river.

Infilling Data Gaps

Water temperature time series at some focal sites contained gaps due to the loss of loggers by high flow events or theft, exposure of loggers to air temperatures during low-flow periods, or corruption of logger data after it was collected. When available, data from other loggers at the same or nearby locations were used to infill time series gaps. Sources of supplemental data include additional USFWS monitoring locations and data collected by the Karuk Tribe Department of Natural Resources, U.S. Forest Service (USFS), USGS, and the Yurok Tribe Environmental Program (YTEP). If directly comparable data were not available to infill missing data, but data were available from a relatively nearby monitoring location (maximum distance between locations = 69 rkm), a regression relationship within a season was developed between water temperatures at the two locations to estimate water temperatures on missing days at the focal location. Generalized least squares (GLS) regression with a first-order autoregressive correlation structure was used to account for the temporal error structure due to the strong thermal inertia of water. The GLS regressions were implemented using the *nlme* R package (Pinheiro et al. 2017). Historical data prior to 2019 was not infilled. A summary of data gaps is shown in Appendix F using secci plots.

Historical Data Gaps

It should be noted that upon review of the temperature criteria in the original literature, it was discovered that the criteria were applied incorrectly in previous water temperature reports. Missing historical data were not infilled, but the methods were corrected and all figures and calculations using historical data were redone and presented in this report. As a result, some of this report’s figures and calculations may be different from prior reports purported to be presenting the same information. Please contact the lead author if further clarification is required.

Trinity River Evaluation Criteria

A WY is defined as the 12-month period between October 1 and September 30 of the next calendar year (Paulson et al. 1985). Trinity River WY is further described by type: ‘Normal’, ‘Wet’, ‘Extremely Wet’, ‘Dry’, and ‘Critically Dry’ (USDOI 2000). During ‘Normal’, ‘Wet’, and ‘Extremely Wet’ WYs, flows out of Trinity and Lewiston dams are managed to provide optimal thermal conditions throughout the primary juvenile salmon outmigration period. During ‘Dry’ or ‘Critically Dry’ WYs, flows out of Trinity and Lewiston dams are managed to facilitate outmigration and provide thermal conditions conducive to juvenile survival.

Adult salmonid temperature criteria are the same regardless of WY and are applied from July to December (Table 2). Juvenile salmonid outmigration temperature criteria differ depending on the WY type for the Trinity River and begin in early April and end July 9. In this report, April 1 was used as the beginning of the juvenile salmonid temperature objectives (USFWS and HVT 1999; USFWS et al. 2000). This date also coincides with the WY type determination on April 1st.

Table 2. Numeric water temperature criteria for the Trinity River as defined by the Trinity River Flow Evaluation Study and the Trinity River Mainstem Fishery Restoration: Final Environmental Impact Statement/Environmental Impact Report (USFWS and HVT 1999; USFWS et al. 2000).

WY Type	Locations	Time Period	Days criteria is in effect	Temperature criteria (daily mean °C)	Life stage applicable to criteria
All types	Douglas City	July 1 - Sept. 14	77	< 15.6	Adult salmonid holding and spawning
All types	Douglas City	Sept. 15 - Sept. 30	16	< 13.3	Adult salmonid holding and spawning
All types	North Fork	Oct. 1 - Dec. 31	92	< 13.3	Adult salmonid holding and spawning
Normal, Wet, and Extremely Wet	Weitchpec (above KR)	April 1 - May 22	52	< 13.0	Outmigrant salmonid
Normal, Wet, and Extremely Wet	Weitchpec (above KR)	May 23 - June 4	13	< 15.0	Outmigrant salmonid
Normal, Wet, and Extremely Wet	Weitchpec (above KR)	June 5 - July 9	35	< 17.0	Outmigrant salmonid
Dry and Critically Dry	Weitchpec (above KR)	April 1 - May 22	52	< 15.0	Outmigrant salmonid
Dry and Critically Dry	Weitchpec (above KR)	May 23 - June 4	16	< 17.0	Outmigrant salmonid
Dry and Critically Dry	Weitchpec (above KR)	June 5 - July 9	35	< 20.0	Outmigrant salmonid

Klamath River Evaluation Criteria

The primary metric recommended by the EPA for evaluating water temperatures is the seven-day average daily maximum temperature (7DADM), calculated as the average of daily maximum temperatures across a seven-day period, beginning three days before and ending three days after any given date. The EPA guidelines also recommend different criteria for each of the life history stages of Pacific salmonids (Table 3; USEPA 2003; Carter 2006). Spawning, egg incubation, and emergence criteria (13°C 7DADM) were applied to the period of October 1 through April 30, the time frame when most reproductive activities occur in the Klamath basin (Leidy and Leidy 1984; Shaw et al. 1997). Criteria were applied to the Klamath River for juvenile rearing and redistribution (16°C 7DADM) starting April 1, and June 1 for adult migration (20°C 7DADM) criteria (Table 3). The period for both criteria extend through September 30, due to overlapping run timing and life history strategies (Leidy and Leidy 1984; Shaw et al. 1997).

Table 3. Environmental Protection Agency criteria for Pacific Northwest water temperatures to protect Pacific salmonids (USEPA 2003). These criteria were interpreted using the EPA recommended metric of seven-day average daily maximum temperatures and were used in the evaluation of Klamath River during periods of water temperature concern.

Temp. criteria (°C)	Time Period	Days	Life history focus
< 13.0	Oct. 1 - April 30	212	Spawning, egg incubation, and emergence
< 16.0	April 1 - Sept. 30	183	Rearing and redistribution juvenile salmonids
< 20.0	June 1 - Sept. 30	122	Migrating adult salmonids

Supplemental Flow Evaluation Criteria

To evaluate supplemental flow criteria, daily mean water temperatures were compared from five focal sites (TRBL; TRWE; KRIG; KRWE; KRTG), which are located just downstream of USGS streamflow gaging stations recording discharge. Daily mean water temperatures from an additional non-focal site located on the Klamath River below the confluence with the Trinity River (KRBW) were also evaluated using the supplemental flow evaluation criteria. Temperature below the Trinity River confluence (KRBW) represents the most upstream site on the Klamath River after the confluence of the Trinity and Klamath rivers, while temperature near the mouth of the Klamath River (KRTG) represents the most downstream site. TRBL is located just below Lewiston Dam and KRIG just Below Iron Gate Dam. TRWE and KRWE are located upstream of the confluence on the Trinity and Klamath rivers. Daily mean discharge values were gathered from five USGS gaging stations to assess supplemental flow criteria exceedances on the lower Klamath River. USGS stations were located on the Klamath River at Iron Gate Dam (gage 11516530), Orleans (gage 11523000), and the town of Klamath (gage 11530500). On the Trinity River discharge data was used from stations at Lewiston Dam (gage 11525500) and Hoopa (gage 11530000).

Due to the variation in timing of supplemental flow releases from Lewiston Dam, the period of evaluation shifts between years. Generally, the evaluation period runs August 1 through September 30, but changes are based upon the supplemental flow release timing.

Analysis

Data for February 29 was removed for all leap years to make the number of days criteria consistent among years. For each day of the year at each focal site, the historical average, minimum, and maximum of daily mean water temperatures on the Trinity River and 7DADM on the Klamath River were calculated across all years of available data (historical data was not infilled). These values provided the context (mean and range of observed values) for which to compare 2019 water temperatures. The number of days that exceeded the associated water temperature criteria were calculated for each focal monitoring location in each year. The highest and lowest of these annual values for each site are referred to as the historical range of criteria exceedance. If data were not complete during the period over which the criteria was applied, the calculations were done and reported, but not included in the historical ranges. Finally, for each focal location’s criteria, the historical average, minimum, and maximum number of days exceeding the associated water temperature criteria across all years were calculated. All analyses were performed using R software for statistical computing (R Core Team 2021).

Results

Trinity River

Water year 2019 was designated as a 'Wet' WY on the Trinity River. Daily average water temperatures surpassed the maximum of historic daily averages for 0 days at TRBL, 7 days at TRDC, 12 days at TRNF, and 11 days at TRWE (Table 4; Figure 2). During this period there were temperature criteria exceedances at all focal sites with established criteria. Daily criteria were exceeded for 4 days at TRDC, 5 days at NFTR, and 42 days at TRWE (Table 4; Figure 2). The number of days criteria were exceeded in 2019 was more than the historical mean number of days exceeded at TRDC for the 13.3 ℃ criteria (1.3 days, Appendix A), but not the 15 ℃ criteria. The historical average was also exceeded at TRWE for all three temperature criteria periods (7.9 days, 5.2 days, 17.3 days, Appendix A) and NFTR (4.7 days, Appendix A). The upper historical range of criteria exceedance was not surpassed by any sites in 2019.

Table 4. The number of days exceeded temperature management targets in water year (WY) 2019 at focal sites on the Trinity River, 'Wet' WY criteria. TRBL = Trinity River below Lewiston Dam; TRDC = Trinity River at Douglas City; NFTR = Trinity River below North Fork Trinity; TRWE = Trinity River above confluence of Klamath River. Rows that do not have a value occurred during time period where no management criteria were identified for the site.

Site Name	Location Code	4/1-5/22 13℃	5/23-6/4 15℃	6/5-7/9 17℃	10/1-12/31 13.3℃	7/1-9/14 15.6℃	9/15-9/30 13.3℃
Below Lewiston Dam	TRBL [a]	-	-	-	-	-	-
Douglas City	TRDC [b]	-	-	-	-	2	2
Above North Fork	NFTR [c]	-	-	-	5	-	-
Above Klamath	TRWE [c, b]	16	6	20	-	-	-

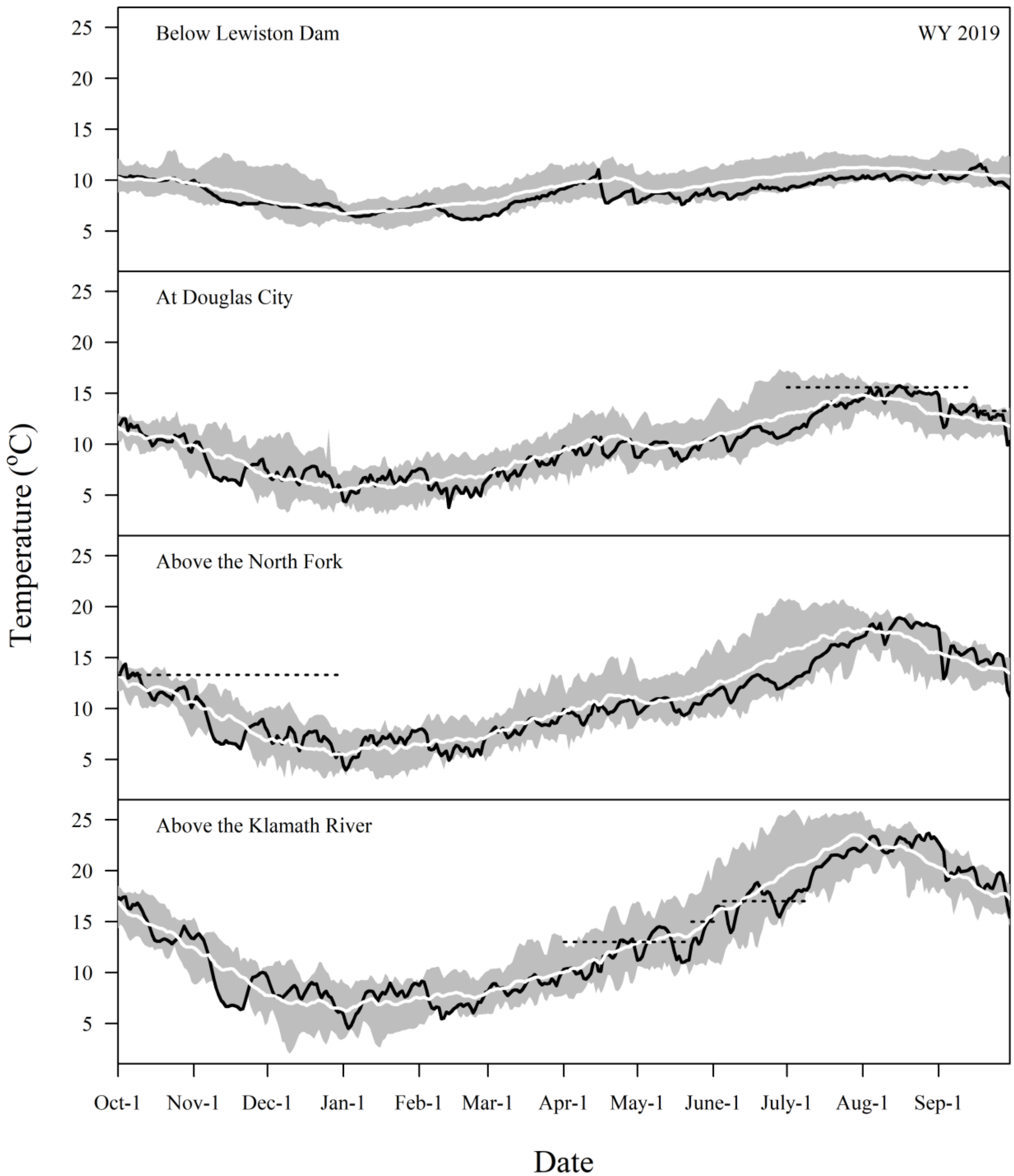

Figure 2. Daily mean water temperatures at focal Trinity River monitoring locations in water year (WY) 2019 (i.e., October 1, 2018 – September 30, 2019), with historical summaries from WYs 2002 to 2018. Black line = daily mean water temperatures in 2019; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature criteria.

Outmigrant criteria, evaluated April 1 through July 9, was exceeded in all three periods at TRWE (Table 4). Temperatures exceeded 13 ℃ for 16 of 52 days, 15 ℃ for 6 of 13 days, and 17 ℃ for 20 of 35 days (Table 4). The adult holding and spawning criterion was exceeded for both periods at TRDC (Table 4). Temperature exceeded the 15.6 ℃ criteria during the period July 1 through September 14 for 2 of 77 days, and 13.3 ℃ for 2 of 16 days from September 15 through September 30. The 13.3 ℃ criteria period, October 1, 2018 through December 31, 2018 was exceeded for 5 of 92 days at NFTR (Table 4).

Water year 2019 was both forecasted and observed to be a “Wet” WY on the Trinity River. Despite several occasions where the 23 ℃ criteria was exceeded, an emergency release of supplemental flows was not triggered from Lewiston Dam. The criteria were not exceeded at TRBL, located just below Lewiston Dam. On the Trinity River, TRWE was the only site evaluated where the 23 ℃ criteria were exceeded. Exceedances occurred for 15 days in August (Figure 4).

Except for flows released for the culturally significant Boat Dance of the Hoopa Valley Tribe, all other discharges were based on the standard TRRP hydrograph planning process. The resulting hydrograph contained three peak releases scheduled for habitat restoration in the spring of 2019 (TRRP 2019). Daily mean discharges from the USGS gage 11525500 showed recorded flows (1) above 7,000 cfs for two days on April 17 and 18, (2) above 8,000 cfs April 29 and 30, and (3) 7,920 cfs on May 19. The highest instantaneous discharge was reported on April 29 with a peak discharge of 10,800 cfs.

The planned hydrograph also included pulse flows in the month of June to aid in the dispersion of juvenile Chinook Salmon from Trinity Hatchery (TRRP 2019). Flows released from Lewiston Dam steadily declined the entire month of July from 2,100 cfs to the base flow of 450 cfs by August. Water released below Lewiston Dam to accommodate the culturally significant Boat Dance of the Hoopa Valley Tribe reached a peak flow of 2,700 cfs on September 2, 2019 (TRRP 2019).

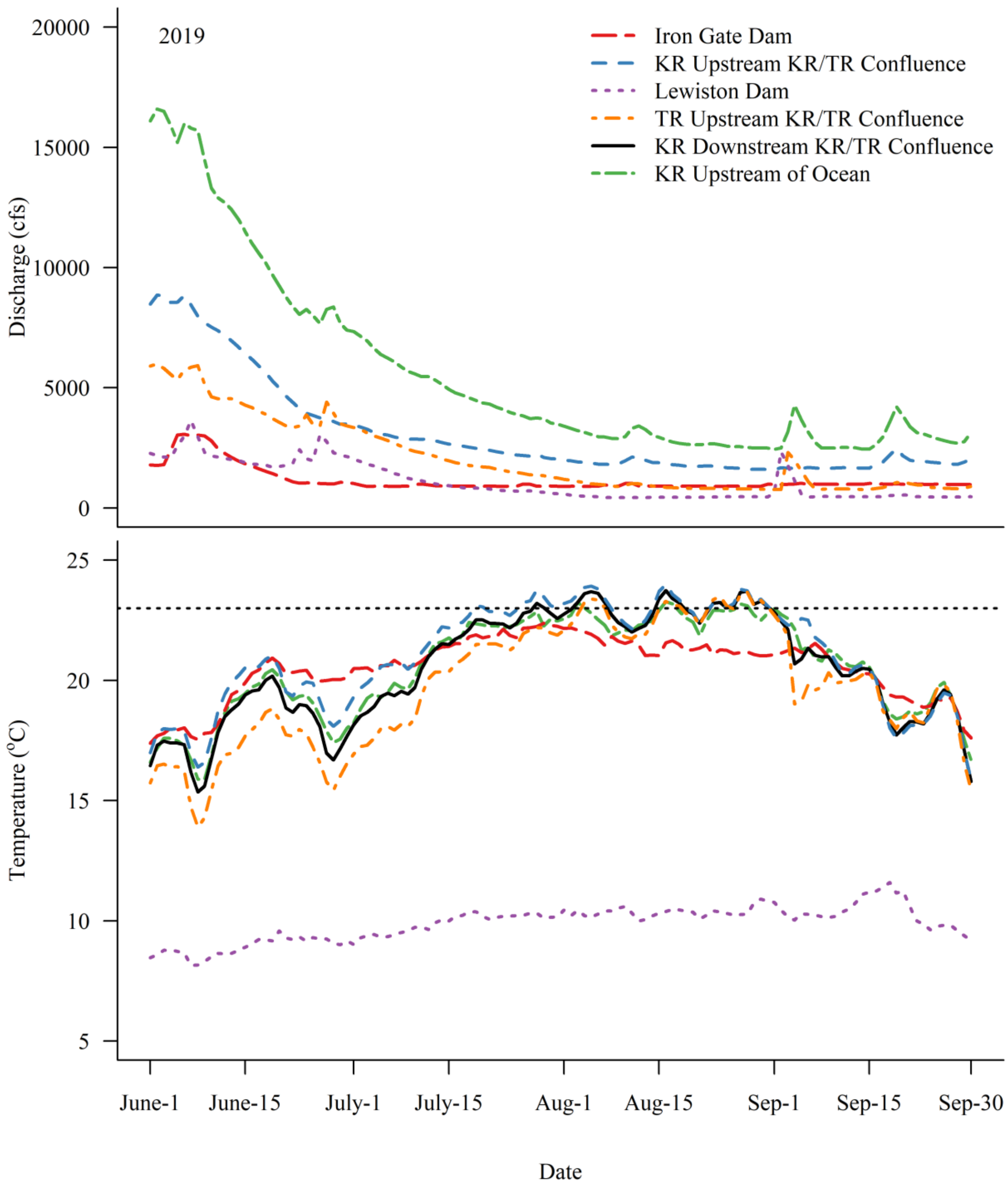

Figure 3. River discharge (cfs) at five locations and daily mean water temperature (°C) at six locations in the Klamath River (KR) and Trinity River (TR) before, during, and after supplemental releases from Trinity Reservoir and Iron Gate Dam, June 1 – September 30, 2019. Horizontal dotted black line on the bottom graph represents 23℃ criteria. U.S. Fish and Wildlife Service water temperature monitoring sites are just downstream of U.S. Geological Survey gages recoding flows.

Klamath River

On the Klamath River, temperature data were infilled for 21 days (10/1/2018-10/5/2018; 5/28/2019-6/12/2019) at the Klamath River site near the mouth of the Klamath River (KRTG). Data from USGS gage 11530500 were used to model and infill KRTG, which was at approximately the same location. Plots of the regression model used, and root mean square error values are available in Appendix E.

The number of days exceeding the spawning, incubation, and emergence EPA 13.0 ℃ 7DADM criteria at focal Klamath River monitoring sites ranged from 20 days at KRHC, to 37 days at KRIG (Table 5; Figure 3; Appendix C). The number of days exceeding the juvenile rearing EPA 16.0 ℃ 7DADM criteria ranged from 123 days at KRWE and KRTG, to 136 days at KRIG (Table 5; Figure 3; Appendix C). The number of days exceeding the adult migration EPA 20.0 ℃ 7DADM criteria ranged from 69 days at KRTG, to 92 days at KRIG (Figure 3; Table 5; Appendix C).

The historical range of criteria exceedance was not exceeded at any site for any of the criteria (Appendix C). The number of days exceeding 13.0 ℃ 7DADM criterion were above their respective historical averages at all sites except KRHC (Table 5). For the 16.0 ℃ 7DADM criteria, the number of days exceeded were above their respective historical averages at all sites (Appendix C). The number of days exceeding the 20.0 ℃ 7DADM criterion were above their respective historical averages at all sites except KRTG (Appendix C). 7DADM water temperatures surpassed the maximum of historic 7DADM for 5 days at KRIG, 12 days at KRSC, 8 days at KRHC, 15 days at KRWE, and 11 days at KRTG (Figure 3).

On the Klamath River, the mean temperature was never ≥ 23 ℃ criteria at KRIG below Iron Gate Dam. This criterion were exceeded for 29 days immediately upstream of the Trinity River confluence with the Klamath at KRWE, 20 days just below the confluence of the Klamath and Trinity rivers at KRBW, and 6 days at KRTG (Figure 4). Exceedances began in late July and continued through late August.

Table 5. The number of days exceeding the Environmental Protection Agency’s seven-day average daily maximum temperature (7DADM) criteria for Pacific Northwest water temperatures to protect Pacific salmonids at Klamath River focal monitoring sites in 2019. Values were not included in the summaries of historical data if the full range of the period the criteria were applied to was not available.

Site	Location code	13.0°C 7DADM	16.0°C 7DADM	20.0°C 7DADM
Below Iron Gate	KRIG	37	136	92
Above Scott	KRSC	34	131	87
Below Happy Camp	KRHC	20	124	83
At Weitchpec	KRWE	33	123	80
Blakes Riffle	KRTG	36	123	69

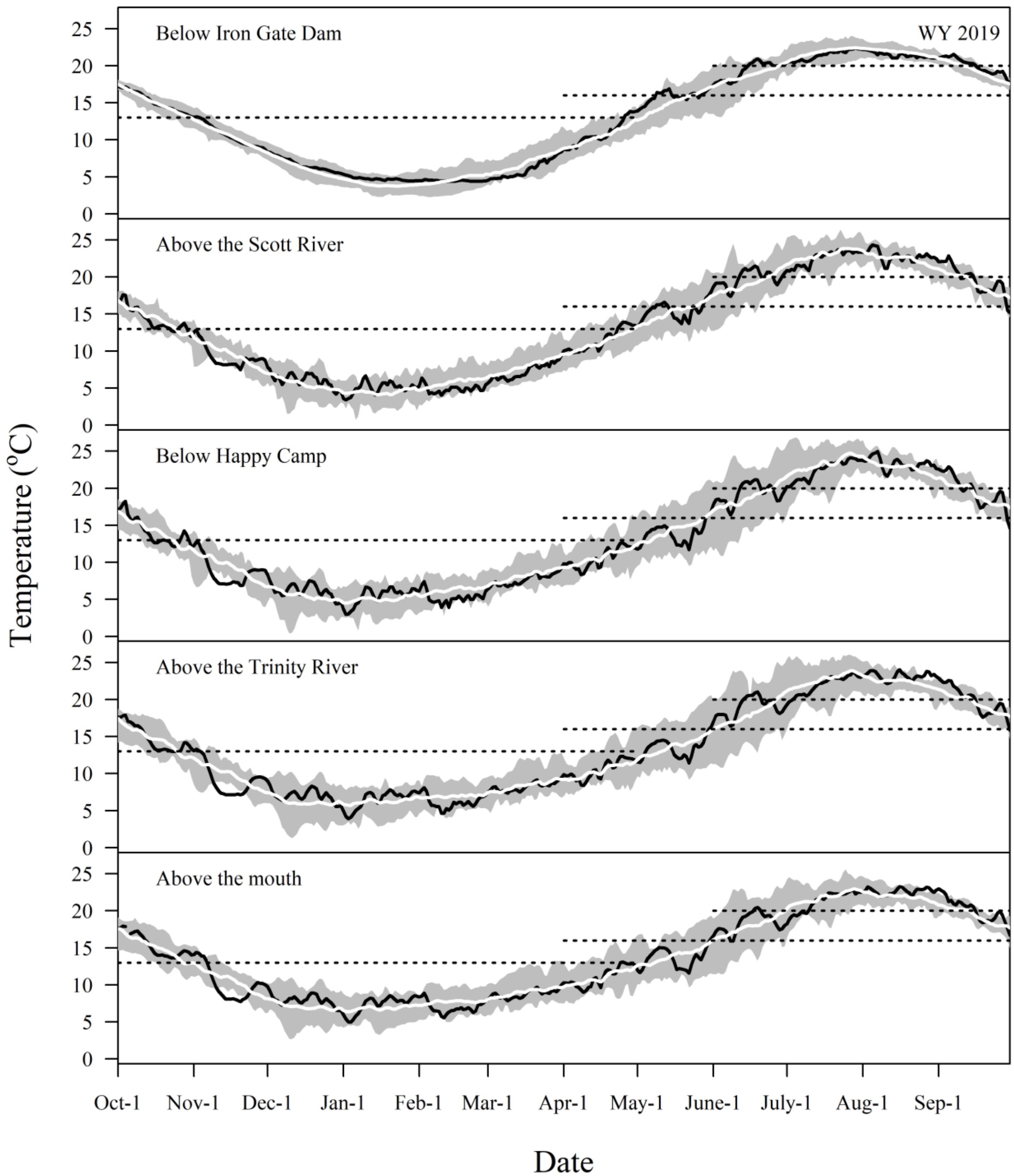

Figure 4. Seven-day average daily maximum temperature (7DADM) at focal Klamath River monitoring sites during water year (WY) 2019 (i.e., October 1, 2018 – September 30, 2019), with historical summaries from WYs 2001 to 2018. Black line = 7DADM water temperatures in 2019; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM for each day of the year; black dotted line = EPA Pacific Northwest water temperature criteria.

Daily mean discharge observed at USGS gage 11516530, directly below Iron Gate Dam, varied between 1,550 cfs to 2,430 cfs from March 1 to March 30. To align a flushing flow with a naturally occurring hydrologic event in the Upper Klamath Basin, BOR implemented a management-prescribed, sediment flushing flow release from Iron Gate Dam between April 9 and April 13 to align with a naturally occurring hydrologic event in the upper Klamath Basin. The peak release from this event occurred on April 10 at 9,880 cfs. Following the surface flushing flow event, average daily flows from Iron Gate Dam steadily declined to 2,350 cfs through the end of May.

In early June, flows below Iron Gate Dam were increased to encourage the out-migration of hatchery-reared juvenile Chinook Salmon in the Lower Klamath River. Increased flow began on June 4 and continued through June 10. During this period, the peak release of 3,100 cfs occurred on June 6. Following the flow event, discharge below Iron Gate Dam steadily decreased to NOAA’s Biological Opinion minimum flows (NMFS 2019).

Discussion

The TRRP and Trinity Management Council (TMC) based their annual water release schedule on California Department of Water Resources’ forecasted WY type as “Wet” in 2019 (TRRP 2019). The monthly volume of flows out of Lewiston Dam was two to four times higher in April through June in 2019 relative to 2018. In August, flows decreased and were approximately half of what was released in 2018 (CDEC 2022a). Water temperature criteria for the Trinity River (Table 2) were exceeded more days in 2019 than 2018 for one of the two periods at TRDC, one of three periods at TRWE, and for the single period evaluated at NFTR. The 2018 WY was designated as “Critically Dry” resulting in less strict water temperature criteria being applied at TRWE. However, criteria at NFTR were exceeded more times in 2019 despite those criteria remaining the same regardless of WY. The total number of days criteria were exceeded at TRDC (4 days) in 2019 was less than the total number of days in 2018 (23 days). The number of exceedances at NFTR and TRWE in WY 2019 was similar to WY 2017 which was designated as an “Extremely Wet” year (Appendix A).

In 2019, the monthly volume of flow out of Iron Gate Dam (108,081 acre-feet (AF)) was higher in June then for that same month in any year since 2010 (145,587 AF; CDEC 2022b). This was much higher than the previous year (2018) when the monthly volume of flows out of Iron Gate was 68,980 AF. Flows over the next several months were comparable to previous years on the Klamath River. This is likely the cause for the 13 ℃ temperature criteria being exceeded for a greater number of days at all sites in 2019 relative to 2018. However, the number of days for the 16 ℃ criteria and the 20 ℃ criteria was only greater at KRTG and at KRIG, respectively, which are used to evaluate temperatures later in spring and summer.

Water temperatures fluctuated around the criteria and historical averages in May on the Trinity River. Pulse flows out of Lewiston Dam helped keep water temperatures cool on the Trinity and lower Klamath rivers during juvenile outmigration in June. On the Klamath River water temperatures climbed steadily throughout the spring until June when pulse flows out of Iron Gate Dam added variation to the 7DADM water temperature and prevented temperature from increasing at a higher rate.

Although the 23 ℃ supplemental flow criterion were exceeded at multiple sites in the Klamath Basin there were no emergency releases from Iron Gate or Lewison Dam. All major flow events taking place during adult migration were for the boat dance or a natural event. The 23 ℃ criteria was exceeded mid-July through the end of August on both the Trinity and Klamath rivers. There was little precipitation during that time, however several small rain events near Weitchpec caused a slight increase in flows and brought water temperatures down to below the 23 ℃ threshold on several occasions (Figure 4). Between August 10 and 11, 0.44 inches of rain fell at Weitchpec (PRISM 2022). Notably, this caused an increase in flow at TRWE and KRWE sites upstream of the confluence on both the Trinity and Klamath rivers, as well as the lower Klamath River at KRTG. Before the resulting dip in temperature, the 23 ℃ criteria were exceeded at TRWE, KRWE, KRTG, and KRBW (Figure 4). A dip in water temperature could be seen at all sites and the criteria were not exceeded for a brief period thereafter (Figure 4).

Water released from Lewiston Dam, for the boat dance on September 2, 2019, caused a sharp, but brief decrease in water temperature at TRDC, TRNF, and TRWE, while water temperatures below Lewiston Dam at TRBL were already relatively cool (Figure 2). Water temperatures also decreased on the lower Klamath at KRTG and KRBW, which are below the confluence of the Klamath and Trinity rivers and are affected by water releases from Lewiston Dam (Figure 4). After water was released from Lewiston Dam, average daily water temperatures briefly fell below the historical daily averages at all sites on the Trinity River (Figure 2). Prior to the boat dance, water temperatures had been exceeding historical averages for extended periods of time in August (Figure 2). A second peak in flow occurred in late September on the Trinity River upstream of the confluence and on the lower Klamath River (Figure 4), which was a result of a precipitation event. Between September 16 and 19 there was a cumulative rainfall of 2.55 inches near Weitchpec (PRISM 2022). The second peak in flow was due in part to a precipitation event that resulted in continued decreases in water temperature (Figure 4) but could also be associated with other weather events (e.g., changes in cloud cover and air temperature).

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Literature Cited

Armstrong, J.B., A.H. Fullerton, C.E. Jordan, J.L. Ebersole, J.R. Bellmore, I. Arismendi, B.E. Penaluna, and G.H. Reeves. 2021.The importance of warm habitat to the growth regime of cold-water fishes. Nature Climate Change 11:354–361.

Baker, P.F., T.P. Speed, and F.K. Ligon. 1995. Estimating the influence of temperature on the survival of Chinook Salmon smolts (*Oncorhynchus tshwaytscha*) migrating through the Sacramento – San Joaquin River Delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52:855–863.

Bartholow, J.M. 2005. Recent water temperature trends in the lower Klamath River, California. North American Journal of Fisheries Management 25:152–162.

Belchik, M., D. Hillemeir, and R.M. Pierce. 2004. The Klamath River fish kill of 2002; analysis of contributing factors. Final Report, Yurok Tribal Fisheries Program.

Bjornn, T.C., and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams. Pages 83-138 in Meehan, editor. Influence of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Publication.

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (*Oncorhynchus nerka*). American Zoologist 11:99–113.

Caissie, D. 2006. The thermal regime of rivers: A review. Freshwater Biology 51:1389–1406.

Carter, K. 2006. The effects of temperature on steelhead trout, Coho Salmon, and Chinook Salmon biology and function by life stage: Implications for Klamath basin TMDLs. California Regional Water Quality Control Board, North Coast Region.

[CDEC] California Department of Water Resources. 2022a. Accessed April 5, 2022. https://cdec.water.ca.gov/dynamicapp/QueryWY?Stations=TNL&SensorNums=66&End=2022-05-04&span=20+years

[CDEC] California Department of Water Resources. 2022b. Accessed April 5, 2022. https://cdec.water.ca.gov/dynamicapp/QueryWY?Stations=KLI&SensorNums=66&End=2022-05-04&span=20+years

Dunham, J., G. Chandler, B. Rieman, and D. Martin. 2005. Measuring stream temperature with digital data loggers: A user's guide. U.S.D.A. Forest Service, Rocky Mountain Research Station. General Technical Report RMRS-GTR-150WWW.

Goniea, T.M., M.L. Keefer, T.C. Bjornn, C.A. Perry, D.H. Bennett, L.C. Stuehrenberg. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook Salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society 135:408–419.

Guillen, G. 2003. Klamath River fish die-off, September 2002: causative factors of mortality. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Report Number AFWO-F-02-03.

Hallock, R.J., R.F. Elwell, D.H. Fry Jr. 1970. Migrations of adult King Salmon *Oncorhynchus tshawytscha* in the San Joaquin Delta as demonstrated by the use of sonic tags. State of California Department of Fish and Game. Fish Bulletin, 151.

Harmon, R., J.S. Foott, K. Nichols, J. Faukner, and B. McCasland. 2001. Physiological responses of juvenile Chinook Salmon held in the lower Klamath River and thermal refugia (June-August 2000). U.S. Fish and Wildlife Service, California-Nevada Fish Health Center.

Heming, T.A. 1981. Effects of temperature on utilization of yolk by Chinook Salmon (*Oncorhynchus tshawytscha*) eggs and alevins. Canadian Journal of Fisheries and Aquatic Science. 39:184–190.

Hester, E.T., and M.W. Doyle. 2011. Human impacts to river temperature and their effects on biological processes: a quantitative synthesis. Journal of the American Water Resources Association. 47(3):571–587.

Hetrick, N., and J. Polos. 2015. Response to request for technical assistance regarding 2015 fall flow release. USFWS Memorandum to Federico Barajas, U.S. Bureau of Reclamation Northern California Area Manager.

Jones, E.C., R.W. Perry, J.C. Risley, N.A. Som, and N.J. Hetrick. 2016. Construction, calibration, and validation of the RBM10 water temperature model for the Trinity River, northern California. U.S. Geological Survey Open-File Report 2016-1056.

[KRBFTF] Klamath River basin Fisheries Task Force. 1991. Long range plan for the Klamath River basin conservation area fishery restoration program.

Lagomarsino, I., and N. J. Hetrick. 2013. 2013 fall flow release recommendation. Joint USFWS/NOAA Memorandum to Brian Person, U.S. Bureau of Reclamation Northern California Area Manager.

Leidy, R.A., and G.R. Leidy. 1984. Life stage periodicities of anadromous salmonids in the Klamath River basin, Northwestern California. U.S. Fish and Wildlife Service, Department of Ecological Services, Sacramento, California.

Magneson, M.D. 2015. Klamath River flow and water temperature, water year 2012. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS 2015-42, Arcata, California.

Marine, K.R., and J.J. Cech Jr. 2004. Effects of high water temperature on growth, smoltification, and predator avoidance in juvenile Sacramento River Chinook Salmon. North American Journal of Fisheries Management. 24:198–210.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon. Prepared for the U.S. Environmental Protection Agency Region 10, Seattle, Washington. EPA 910-R-99-010.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of emblematic fauna. UC Davis Center for Watershed Sciences.

Moyle, P.B., J.V.E. Katz, and R.M. Quiñones. 2011. Rapid decline of California's native inland fishes: a status assessment. Biological Conservation 144:2414–2423.

[NMFS] National Marine Fisheries Service. 2019. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion, and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Response, Klamath Project Operations from April 1, 2019 through March 31, 2024. NMFS Consultation Number: WCR-2019-11512, WCRO-2019-00113. [NAS] National Academy of Sciences. 2004. Endangered and threatened fishes in the Klamath River basin: Causes of decline and strategies for recovery. Committee on Endangered and Threatened Fishes in the Klamath River basin. National Academy Press.

[NCRWQCB] North Coast Regional Water Quality Control Board. 2010. Final staff report for the Klamath River total maximum daily loads (TMDLs) addressing temperature, dissolved oxygen, nutrient, and microcystin impairments in California. Santa Rosa, California.

Olden, J.D. and R.J. Naiman. 2010. Incorporating thermal regimes into environmental flows assessments: modifying dam operations to restore freshwater ecosystem integrity. Freshwater Biology 55:86–107.

Paulson, R.W., E.B. Chase, J.S. Williams, and D.W. Moody, compilers. 1985. National Water Summary 1990-91: Hydrologic events and stream water quality. U.S. Geological Survey Water – Supply Paper 2400:578–585.

Perry, R.W., J.M. Plumb, E.C. Jones, N.A. Som, N.J. Hetrick, and T.B. Hardy. 2018. Model Structure of the Stream Salmonid Simulator (S3)— A Dynamic Model for Simulating Growth, Movement, and Survival of Juvenile Salmonids. U.S. Geological Survey Open-File Report 2018-1056.

Perry, R.W., J.C. Risley, S.J. Brewer, E.C. Jones, and D.W. Rondorf. 2011. Simulating daily water temperatures of the Klamath River under dam removal and climate change scenarios. U.S. Geological Survey Open-File Report 2011-1243.

Pinheiro J., D. Bates, S. DebRoy, D. Sarka, and R Core Team. 2017. nlme: Linear and nonlinear mixed effects models. R package version 3.1-131.

Polos, J. 2016. Adult salmon water temperature targets. Trinity River Restoration Program Performance Measure. Trinity River Restoration Program.

Poole, G.C., and C.H. Berman. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. Environmental Management 27:787–802.

PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu/explorer/, data created 4 Feb 2014, accessed 5 April 2022.

R Core Team. 2021 RStudio: Integrated Development Environment for R. RStudio, PBC, Boston, MA.

Ray, R.A., R.W. Perry, N.A. Som, and J.L. Bartholomew. 2014. Using cure models for analyzing the influence of pathogens on salmon survival. Transactions of the American Fisheries Society 143:387–398.

Richter, A., and S.A. Kolmes. 2005. Maximum temperature limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. Reviews in Fisheries Science 13:23–49.

Shaw, T.A., C. Jackson, D. Nehler, and M. Marshall. 1997. Klamath River (Iron Gate Dam to Seiad Creek) life stage periodicities for Chinook, Coho, and steelhead. U.S. Fish and Wildlife Service, Costal California Fish and Wildlife Office, Arcata, California.

Som, N.A., and N.J. Hetrick. 2017. Response to request for technical assistance – Predictive model for estimating 80% outmigration threshold of natural juvenile Chinook Salmon past the Kinsman trap site, Klamath River. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Technical Memorandum.

Strange, J.S. 2010. Upper Thermal Limits to Migration in Adult Chinook Salmon: Evidence from the Klamath River Basin, Transactions of the American Fisheries Society, 139:4, 1091–1108, DOI: 10.1577/T09-171.1

Sullivan, K., D.J. Martin, R.D. Cardwell, J.E. Toll, and S. Duke. 2000. An analysis of effects of temperature on salmonids of the Pacific Northwest with implications for selecting temperature criteria. Sustainable Ecosystems Institute, Portland Oregon.

[TRRP] Trinity River Restoration Program. 2012. 2012 fall flow release recommendation. Memorandum to Brian Person, U.S. Bureau of Reclamation Northern California Area Manager.

[TRRP] Trinity River Restoration Program. 2019. Trinity River Restoration Program Annual Report. Trinity River Restoration Program, Weaverville, California.

Turek, S., M. Rode, B. Cox, G. Heise, W. Sinnen, C. Reese, S. Borok, M. Hampton, and C. Chun. 2004. September 2002 Klamath River fish-kill: Final analysis of contributing factors and impacts. California Department of Fish and Game.

[USDOI] U.S. Department of the Interior. 2000. Record of decision Trinity River mainstem fishery restoration, final environmental impact statement/environmental impact report.

[USDOI et al.] U.S. Department of the Interior, U.S. Department of Commerce, and National Marine Fisheries Service. 2013. Klamath Dam Removal Overview Report for the Secretary of the Interior an Assessment of Science and Technical Information, Version 1.1, March 2013.

[USEPA] U.S. Environmental Protection Agency. 2003. EPA Region 10 guidance for Pacific Northwest state and tribal temperature water quality standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, Washington.

[USFWS and HVT] U.S. Fish and Wildlife Service and Hoopa Valley Tribe. 1999. Trinity River flow evaluation, final report.

[USFWS et al.] U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Hoopa Valley Tribe, and Trinity County. 2000. Trinity River mainstem fishery restoration, final environmental impact statement/report.

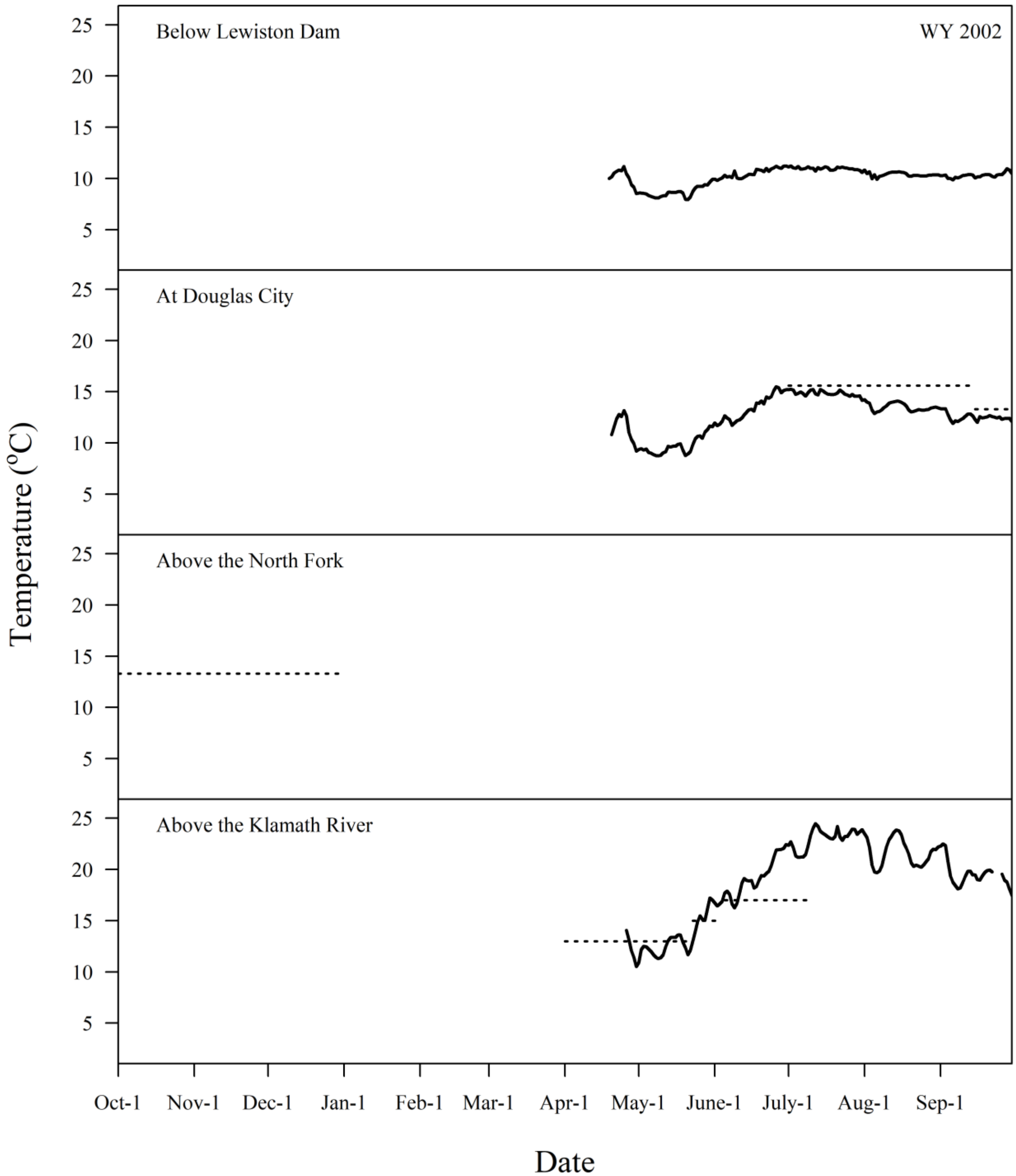
Appendices

Appendix A. Number of days exceeding numeric water temperature criteria for the four focal locations and their criteria on the Trinity River, 2002-2019. The historical range of criteria exceedance is indicated with the upper end of the range highlighted in bold. The highest recorded number of days water temperature criteria were exceeded that year, is highlighted in bold, for each of the criteria. The historic minimum number of days water temperature criteria were exceeded is not highlighted, since it frequently occurred as zero at all sites. TRRC = Trinity River Below Lewiston Dam; TRDC = Trinity River at Douglas City; NFTR = Trinity River above the North Fork Trinity; TRWE = Trinity River above the Klamath River and historic average number of days criteria were exceeded 2002-2018.

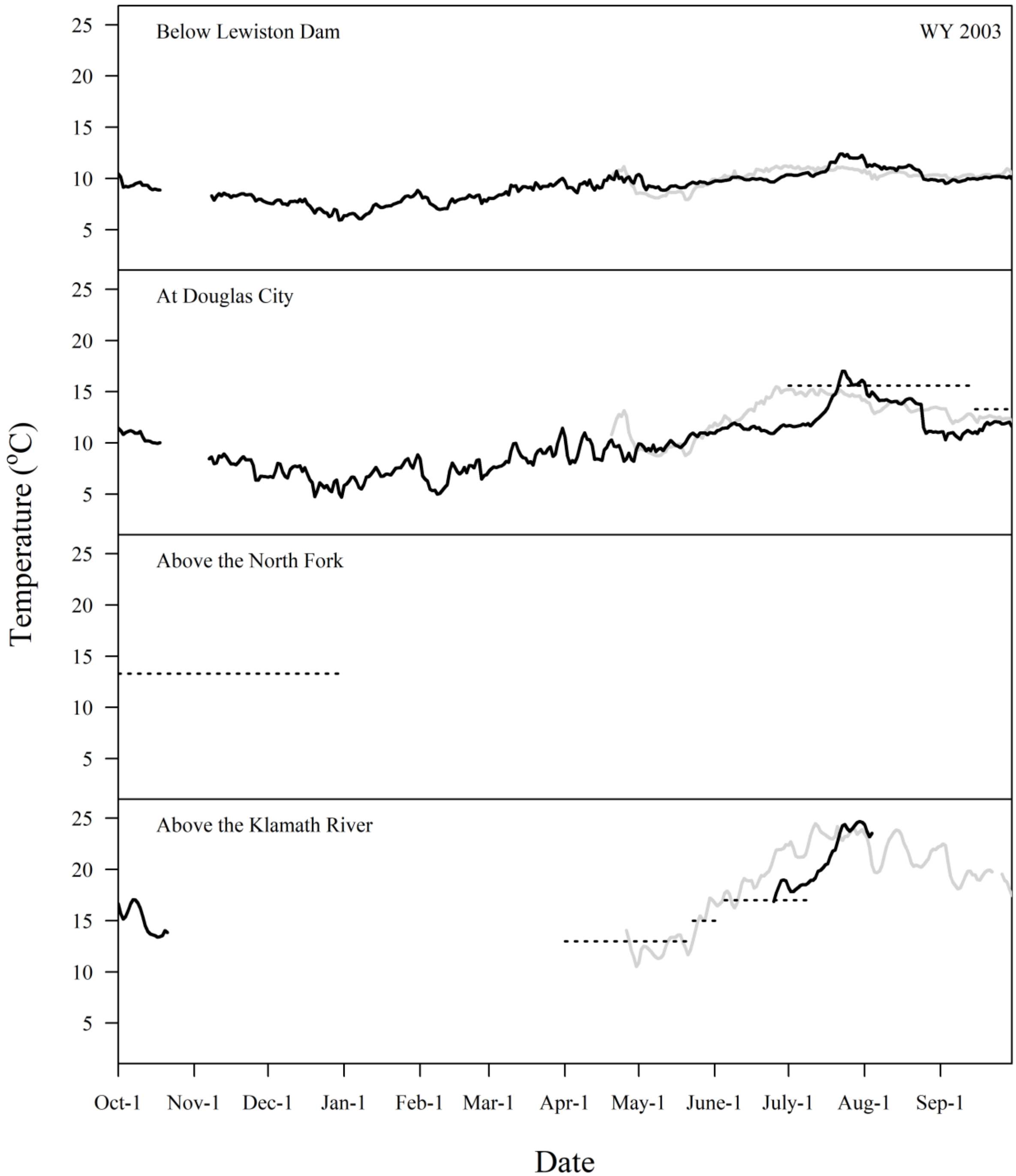
WY	TRDC 15.6 °C	TRDC 13.3 °C	NFTR 13.3 °C	TRWE 13/15 °C	TRWE 15/17 °C	TRWE 17/20 °C	WY Type
2002	0	0	--	8[a]	10	32	Normal
2003	11	0	--	0[a]	0[a]	14[a]	Wet
2004	0	0	--	18[a]	1	24	Wet
2005	1[a]	0	--	0[a]	0[a]	13	Wet
2006	7	0	1	3	0	4	Ex. Wet
2007	4	0	0	0	6	13	Dry
2008	0	0	0	0	0	0	Dry
2009	**26**	**7**	5	0[a]	0[a]	15	Dry
2010	5	1	1[a]	0	0	10	Wet
2011	0	0	7	0	0	7	Wet
2012	0	0	1	8	3	14	Normal
2013	0	0	2	5	3	18	Dry
2014	10	**7**	0[a]	14	11	27	Crit. Dry
2015	15[a]	**7**	15	20	11	**34**	Dry
2016	14	0	**18**	**24**	6	22	Wet
2017	0	0	3	6	**15**	21	Ex. Wet
2018	23	0	0	15	7	22	Crit. Dry
Average	6.7	1.3	4.7	7.9	5.2	17.3	--
2019	2	2	5	16	6	20	Wet

[a] Incomplete data set for period of criteria.

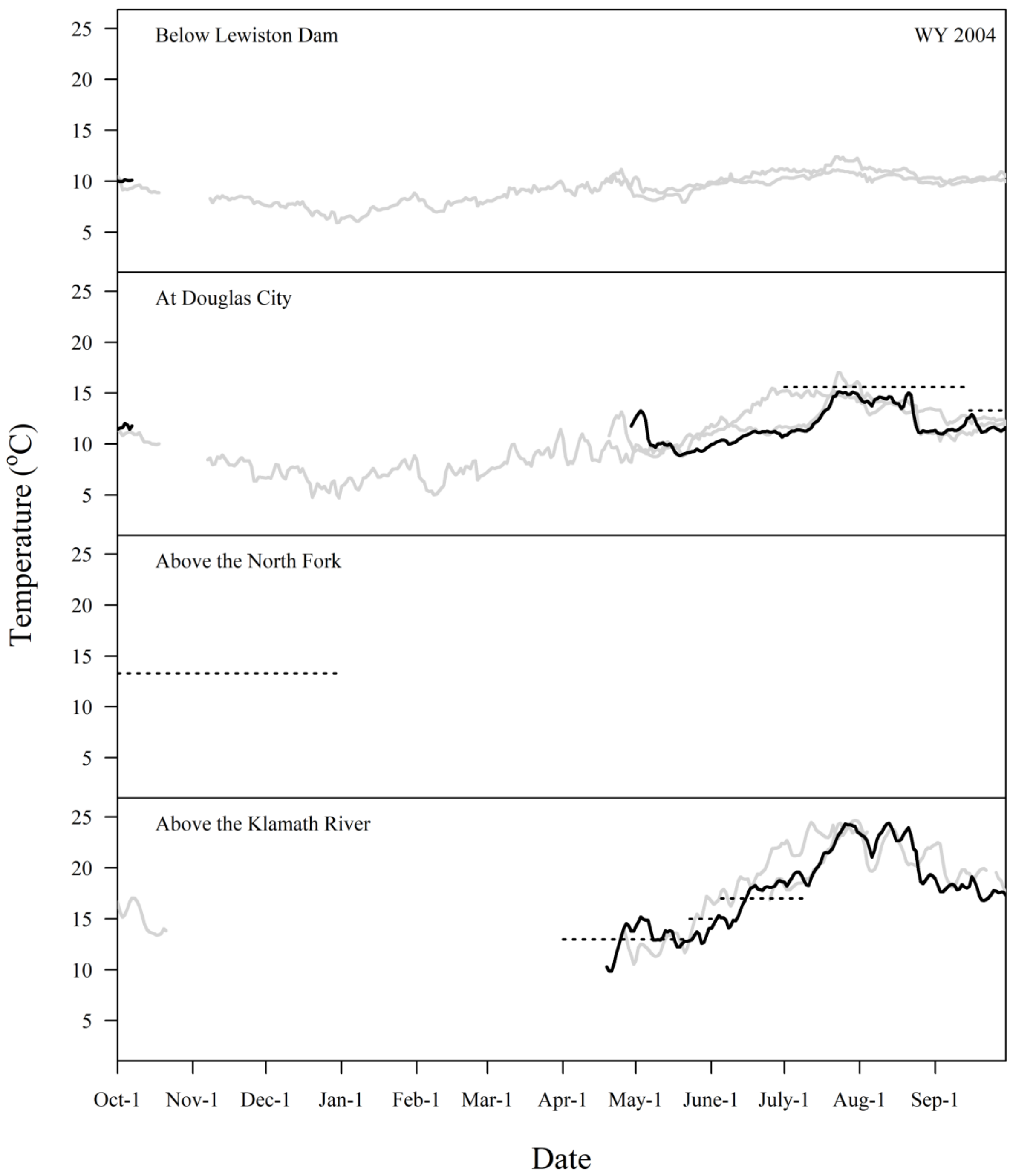
Appendix B. Daily mean water temperatures at focal Trinity River monitoring locations during water years 2002-2018, with historical conditions. Includes only observed water temperatures.



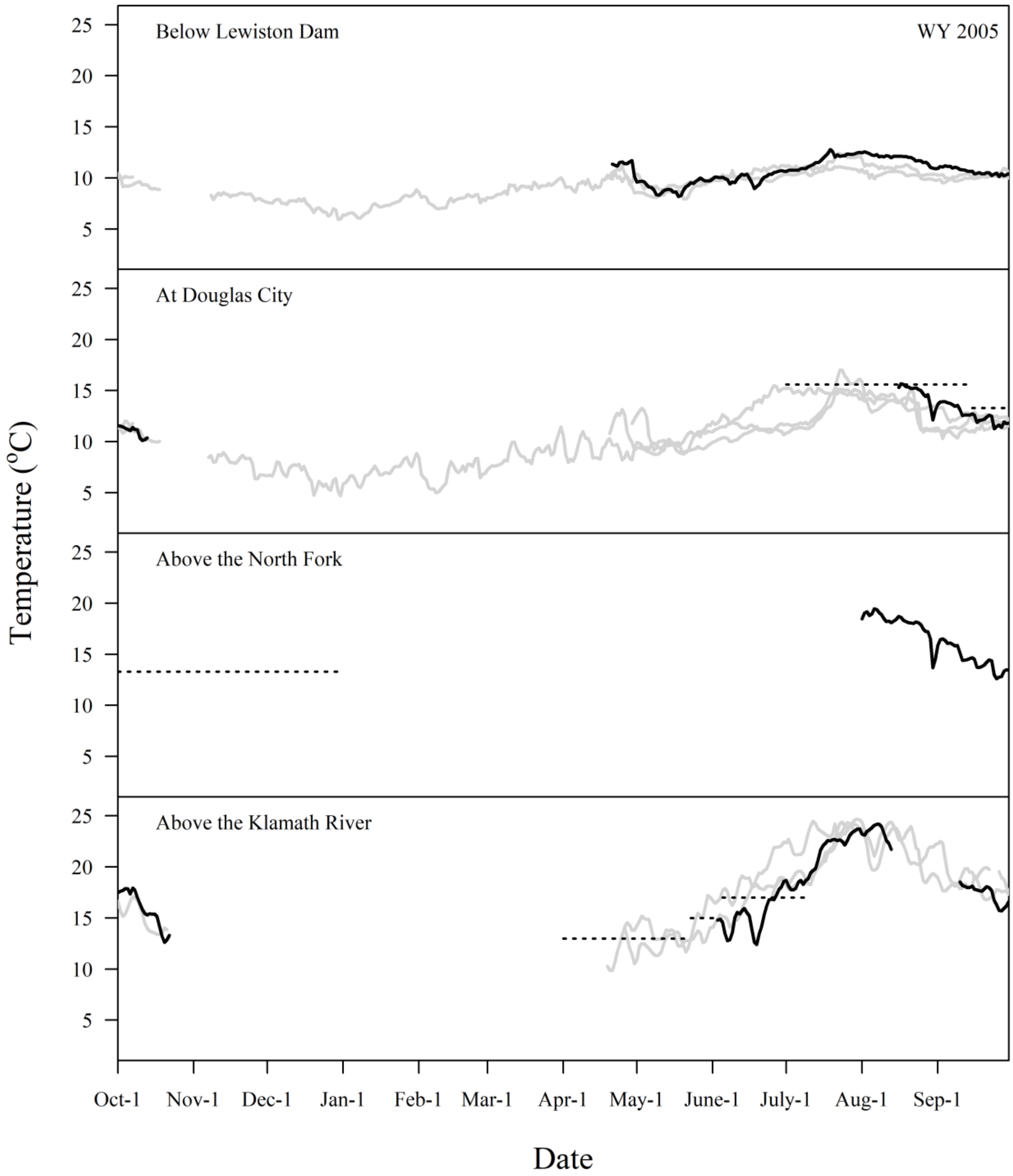
Appendix B1. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2001–September 30, 2002. Black line = daily mean water temperatures in water year (WY) 2002; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives. Sections that are blank indicates no data exists at that site for the period.



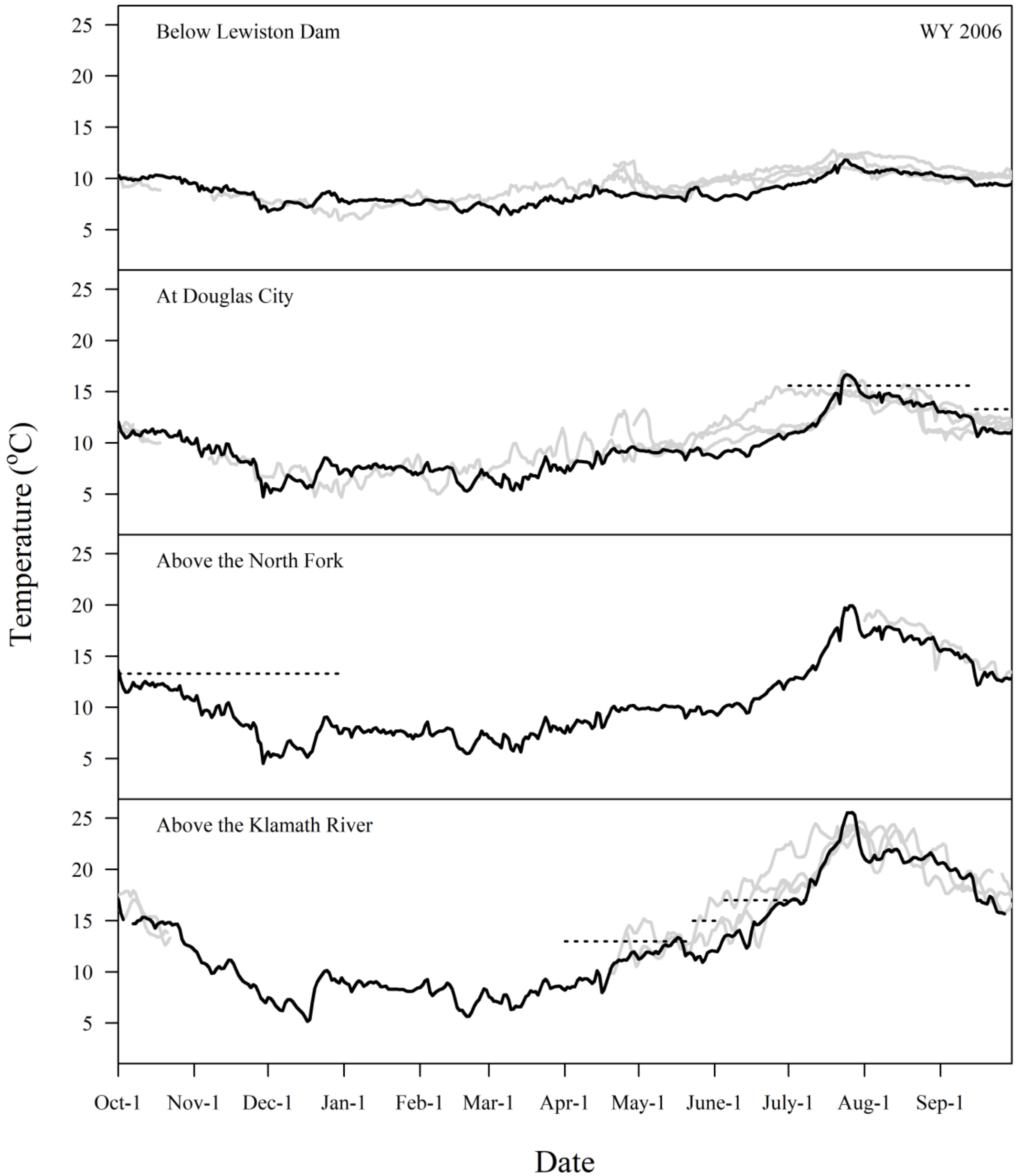
Appendix B2. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2002 – September 30, 2003, with historical summaries from water years (WYs) 2002. Black line = daily mean water temperatures in WY 2003; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives. Sections that are blank indicates no data exists at that site for the period.



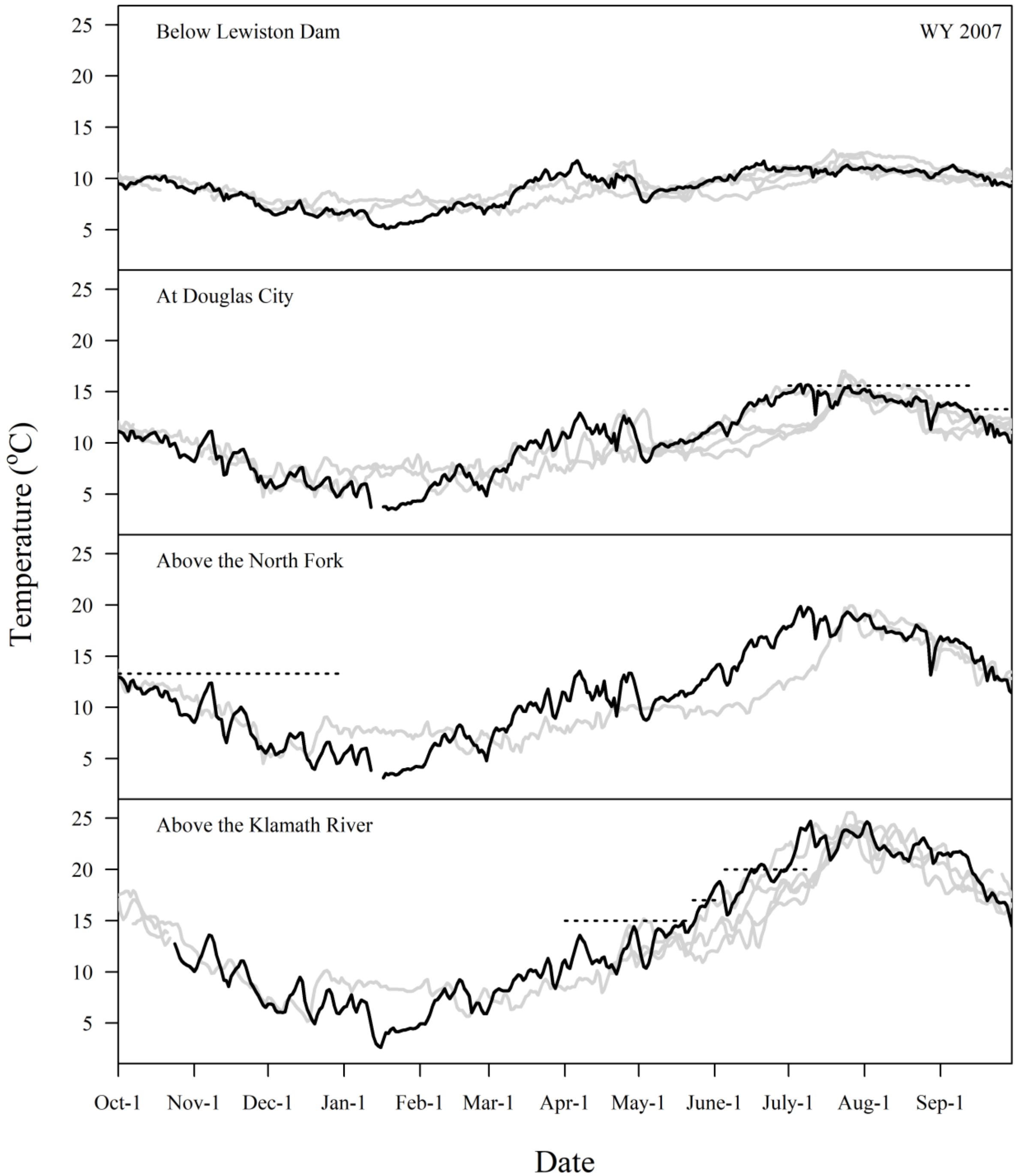
Appendix B3. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2003 – September 30, 2004, with historical summaries from water years (WYs) 2002 to 2003. Black line = daily mean water temperatures in WY 2004; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives. Sections that are blank indicates no data exists at that site for the period.



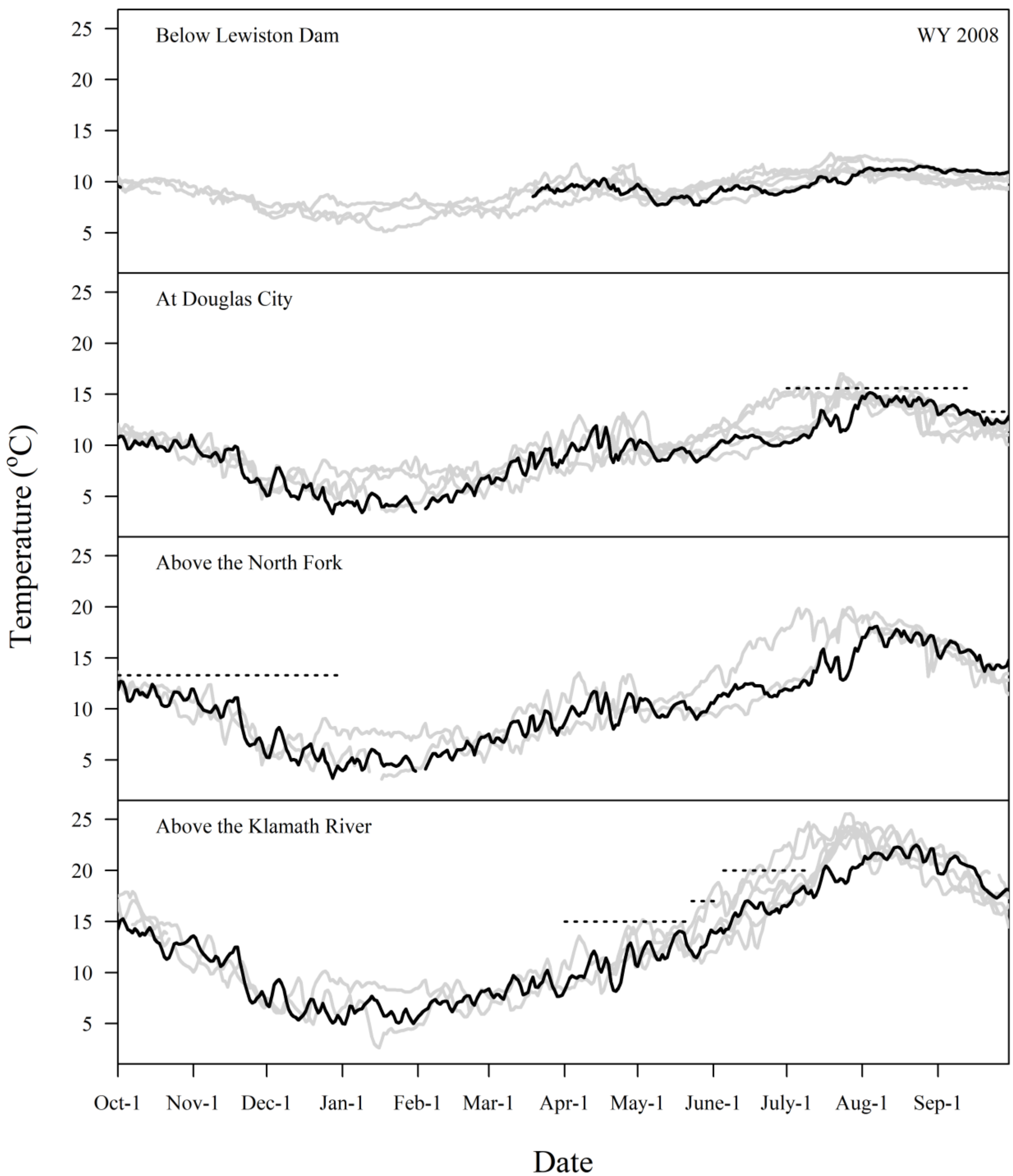
Appendix B4. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2004 – September 30, 2005, with historical summaries from water years (WYs) 2002 to 2004. Black line = daily mean water temperatures in WY 2005; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives. Sections that are blank indicates no data exists at that site for the period.



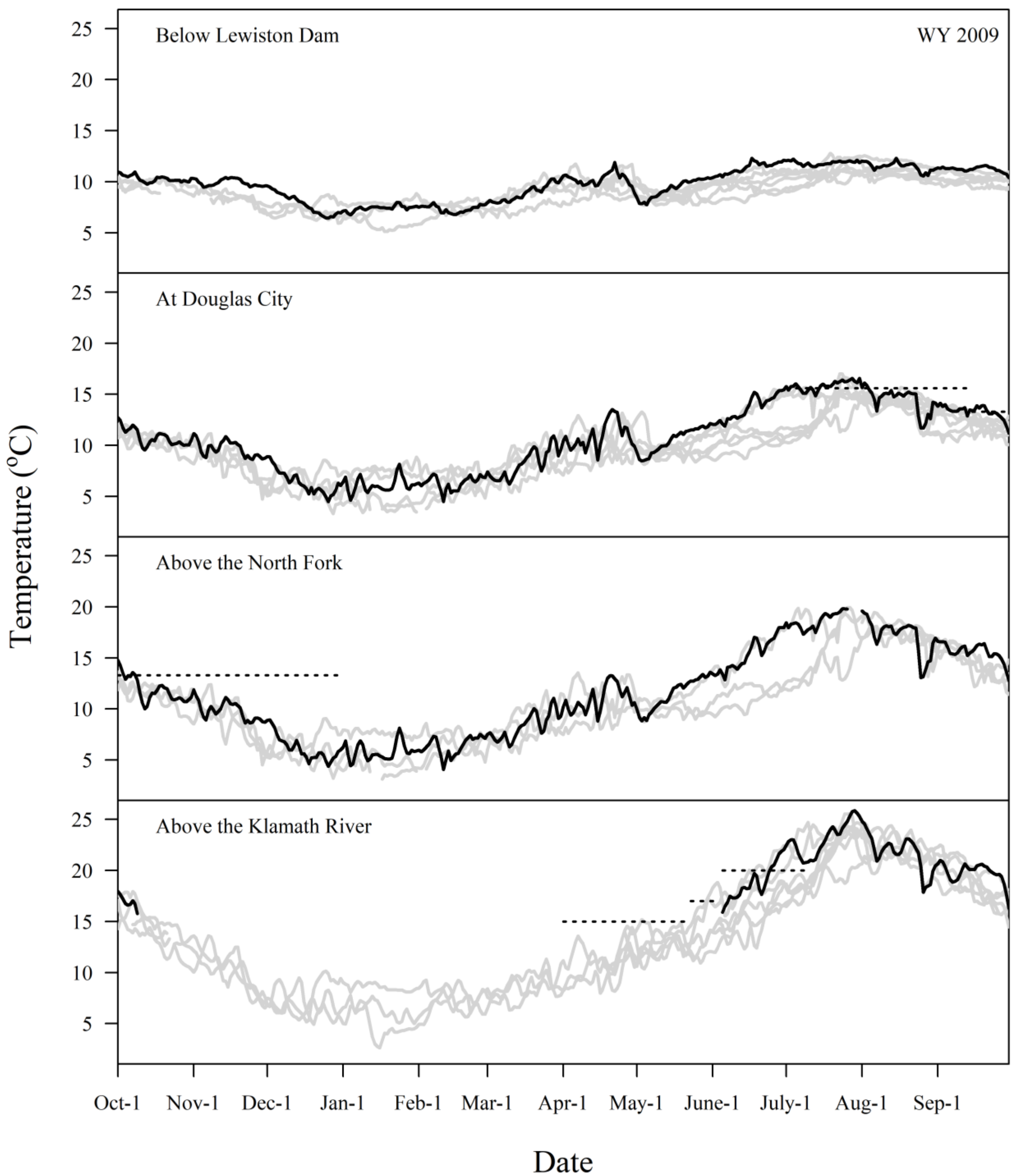
Appendix B5. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2005 – September 30, 2006, with historical summaries from water years (WYs) 2002 to 2005. Black line = daily mean water temperatures in WY 2006; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives. Sections that are blank indicates no data exists at that site for the period.



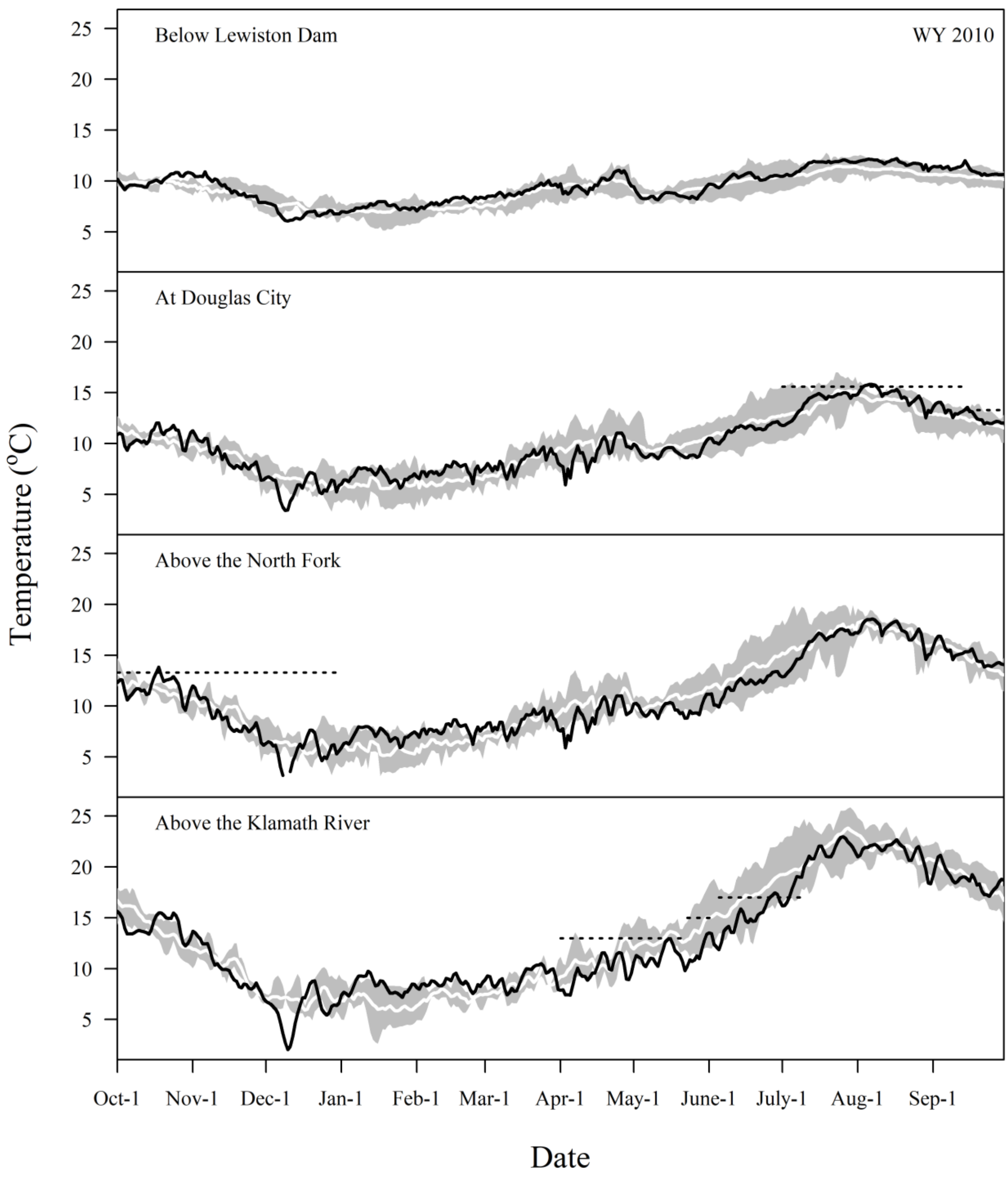
Appendix B6. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2006 – September 30, 2007, with historical summaries from water years (WYs) 2002 to 2006. Black line = daily mean water temperatures in WY 2007; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives.



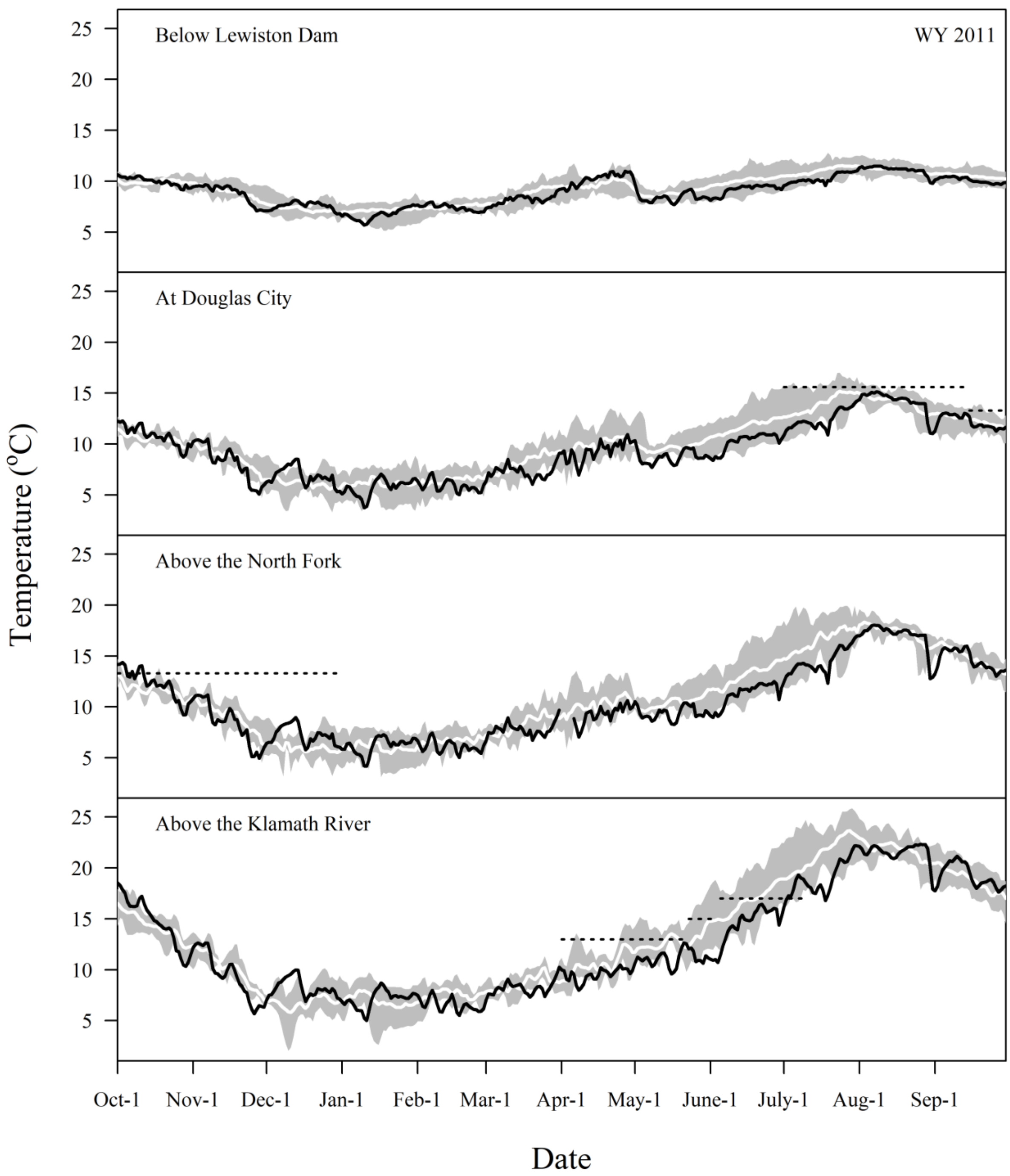
Appendix B7. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2007 – September 30, 2008, with historical summaries from water years (WYs) 2002 to 2007. Black line = daily mean water temperatures in WY 2008; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives.



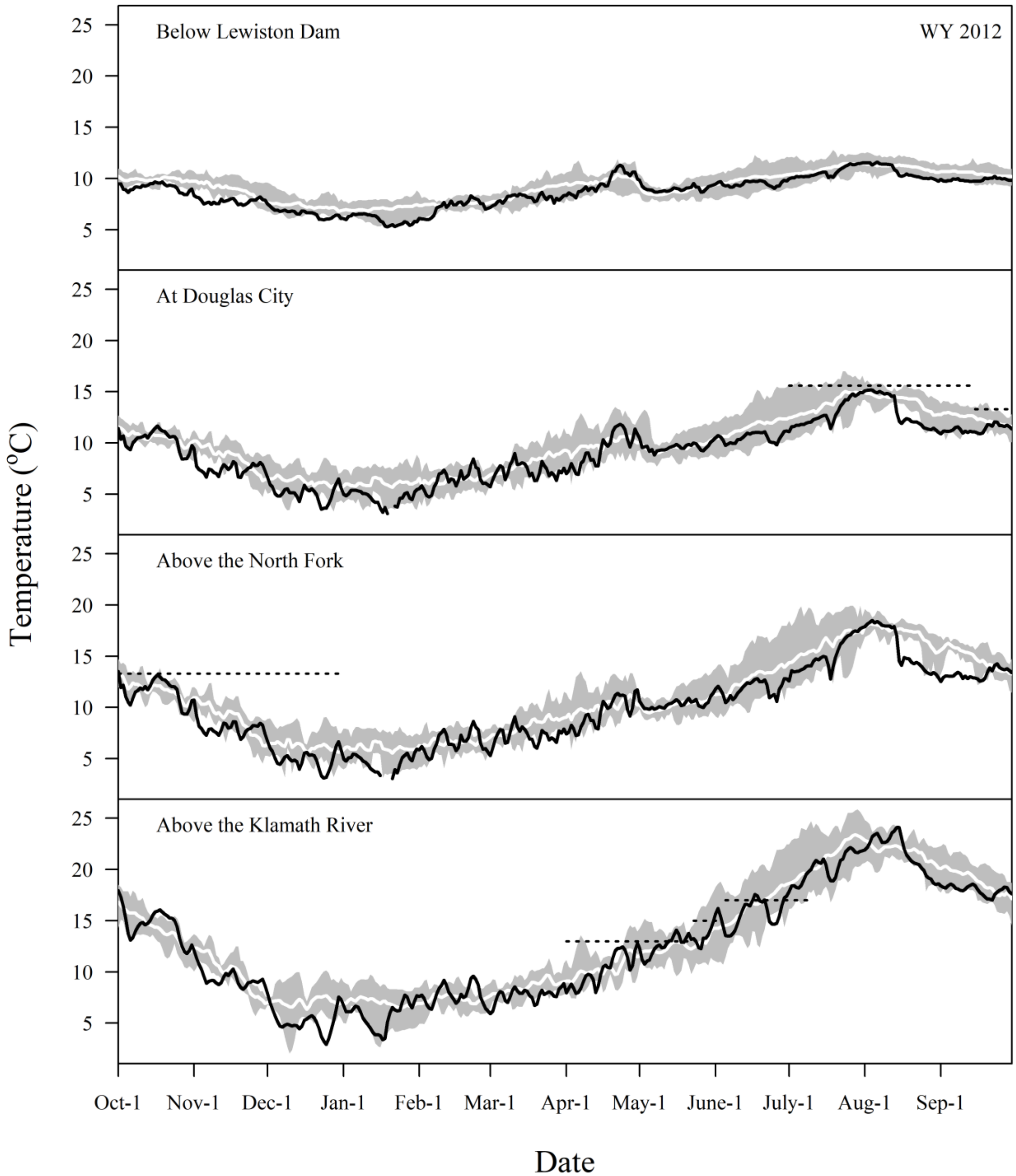
Appendix B8. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2008 – September 30, 2009, with historical summaries from water years (WYs) 2002 to 2008. Black line = daily mean water temperatures in WY 2009; gray line = historical daily mean water temperatures; black dotted line = water temperature objectives.



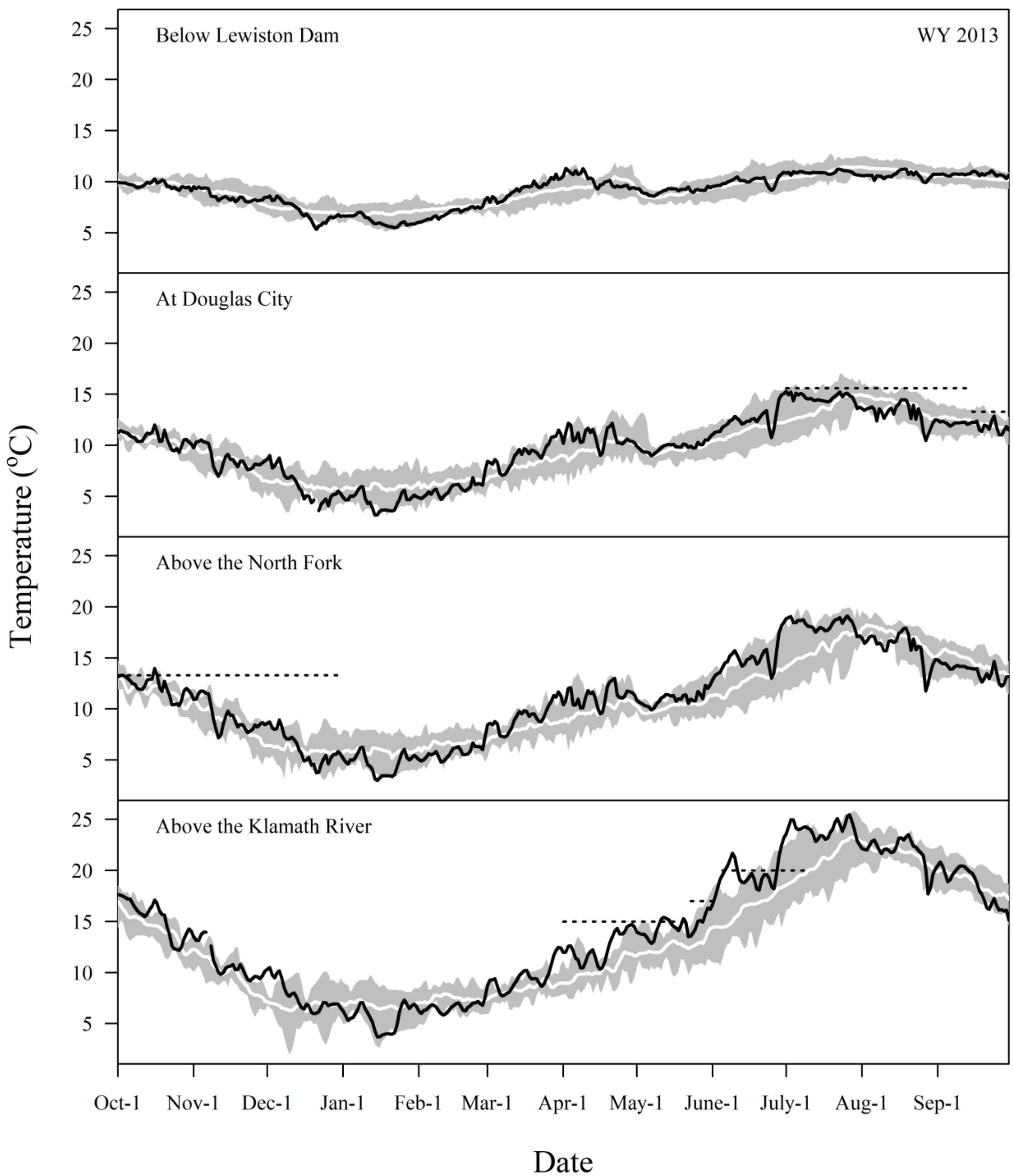
Appendix B9. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2009 – September 30, 2010, with historical summaries from water years (WYs) 2002 to 2009. Black line = daily mean water temperatures in WY 2010; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



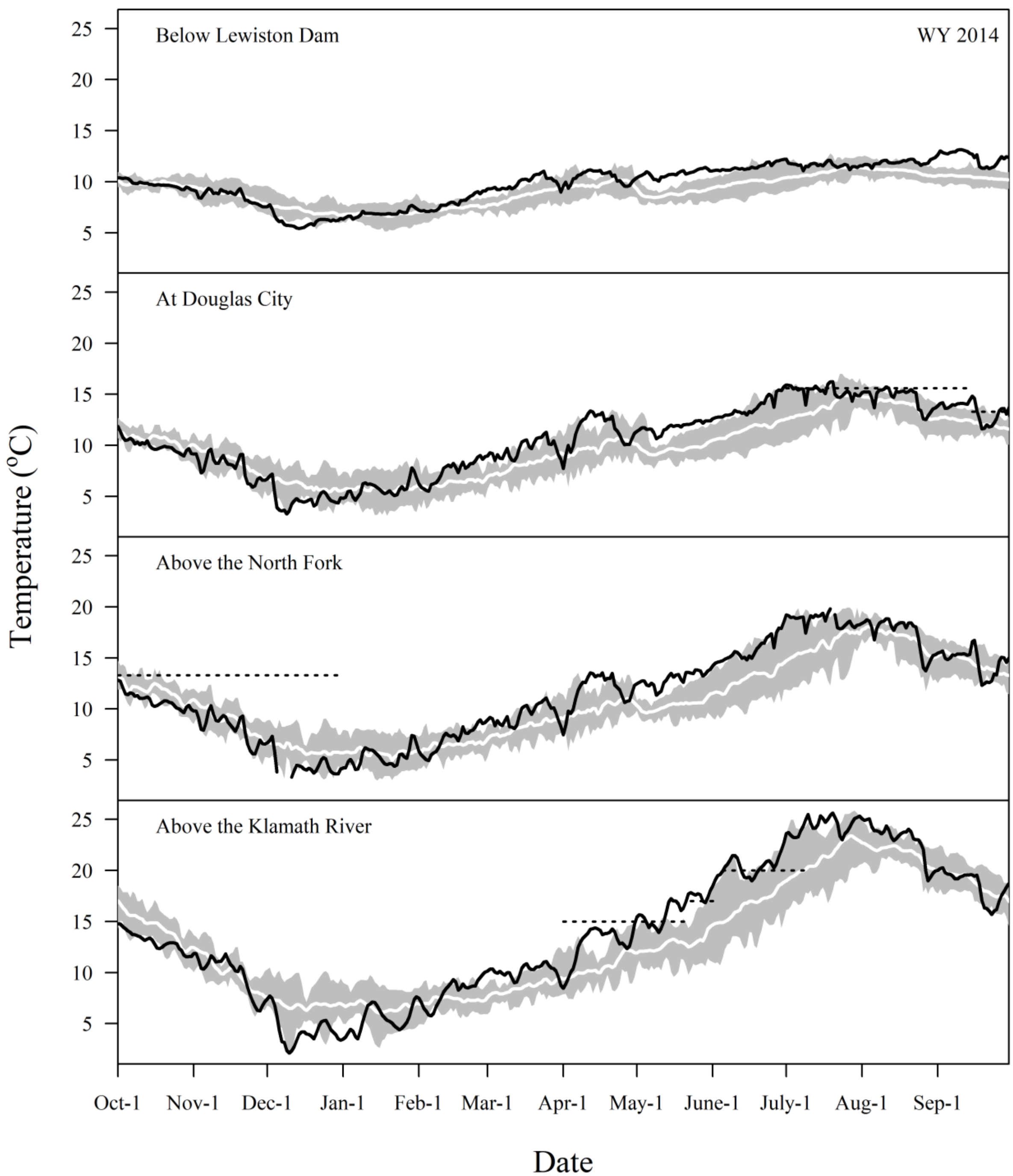
Appendix B10. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2010 – September 30, 2011, with historical summaries from water years (WYs) 2002 to 2010. Black line = daily mean water temperatures in WY 2011; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



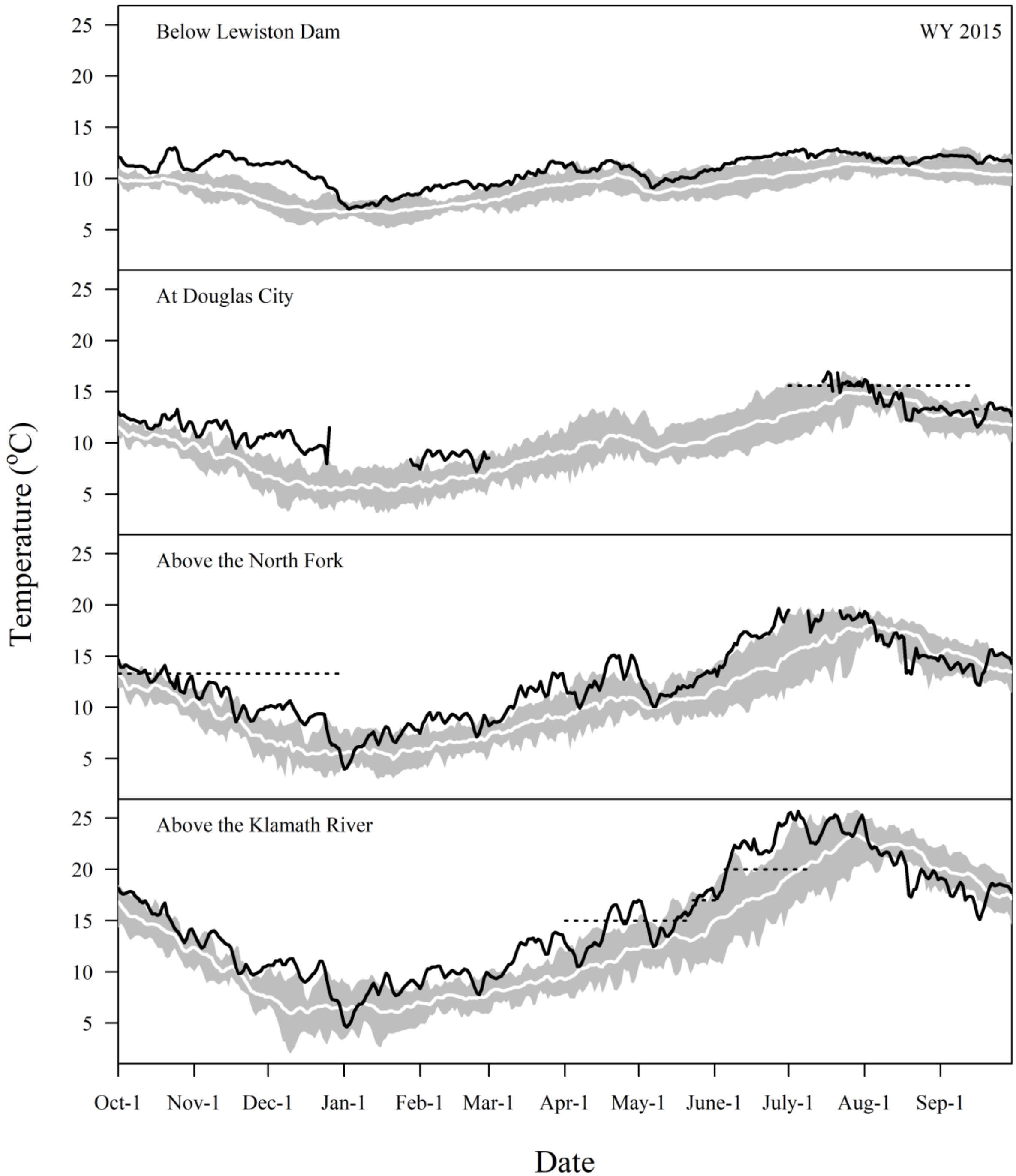
Appendix B11. Daily mean water temperatures at focal Trinity River monitoring locations, October 11, 2011 – September 30, 2012, with historical summaries from water years (WYs) 2002 to 2011. Black line = daily mean water temperatures in WY 2012; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



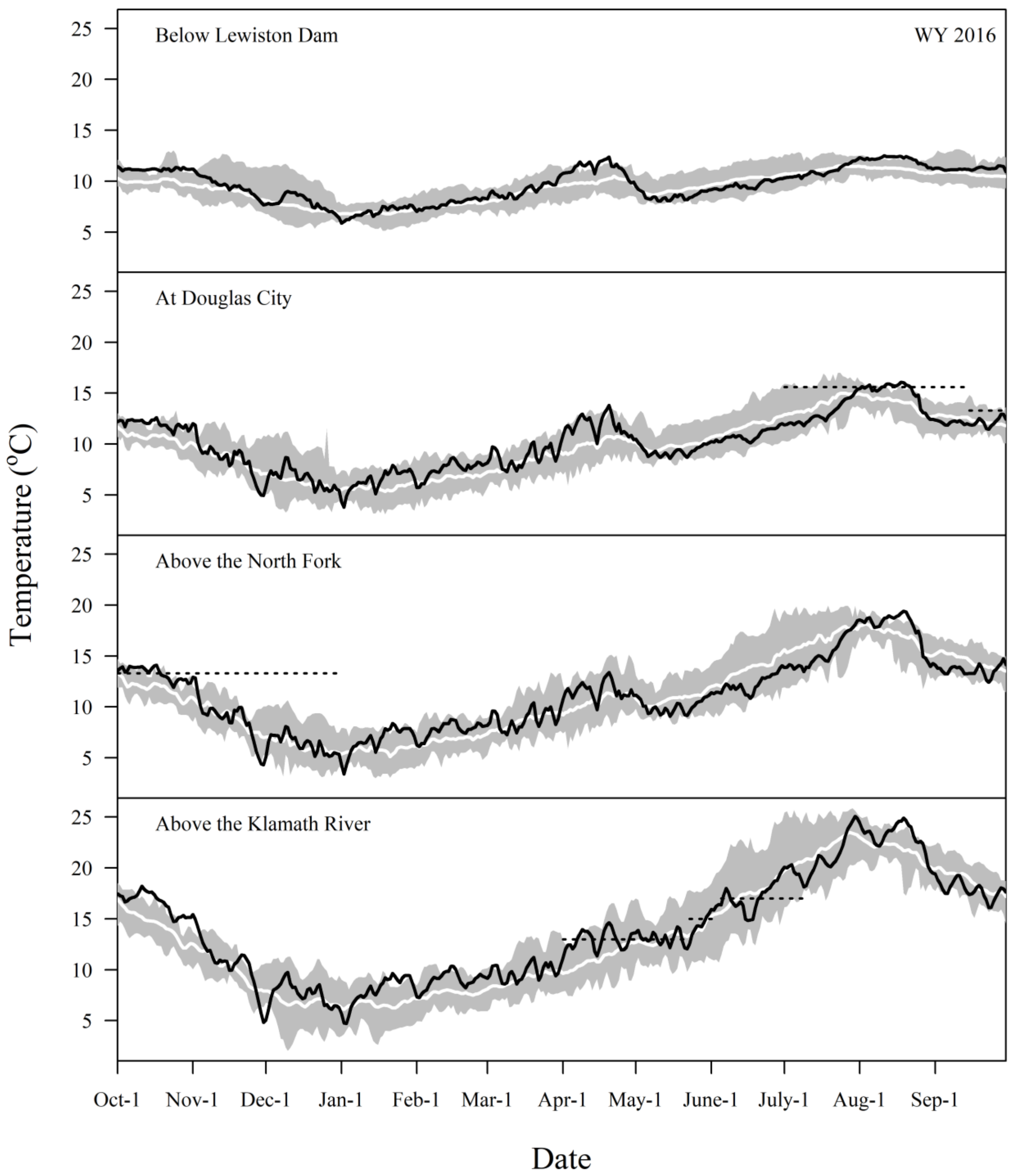
Appendix B12. daily mean water temperatures at focal Trinity River monitoring locations, October 12, 2012 – September 30, 2013, with historical summaries from water years (WYs) 2002 to 2012. Black line = daily mean water temperatures in WY 2013; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



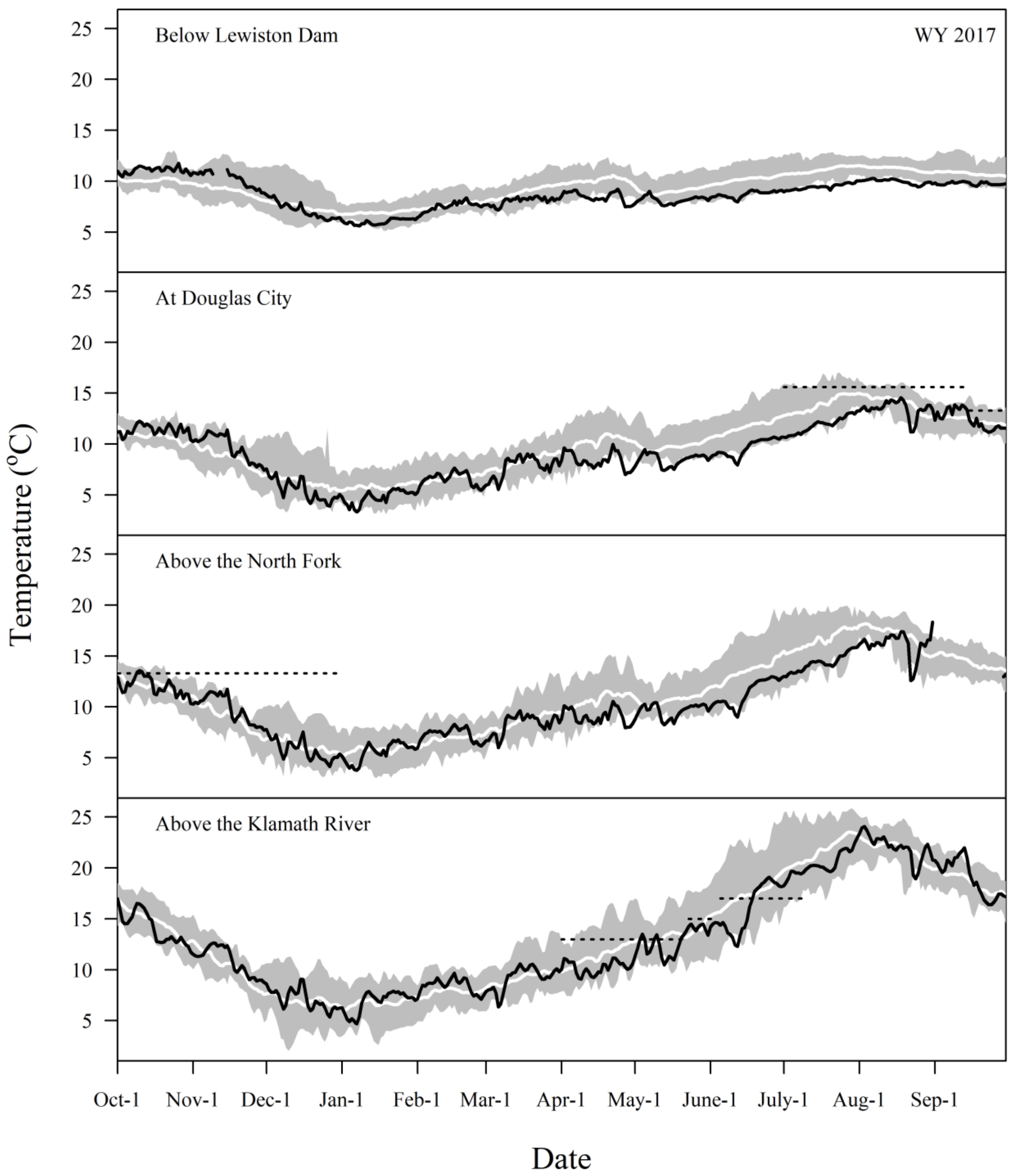
Appendix B13. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2013 – September 30, 2014, with historical summaries from water years (WYs) 2002 to 2013. Black line = daily mean water temperatures in WY 2014; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



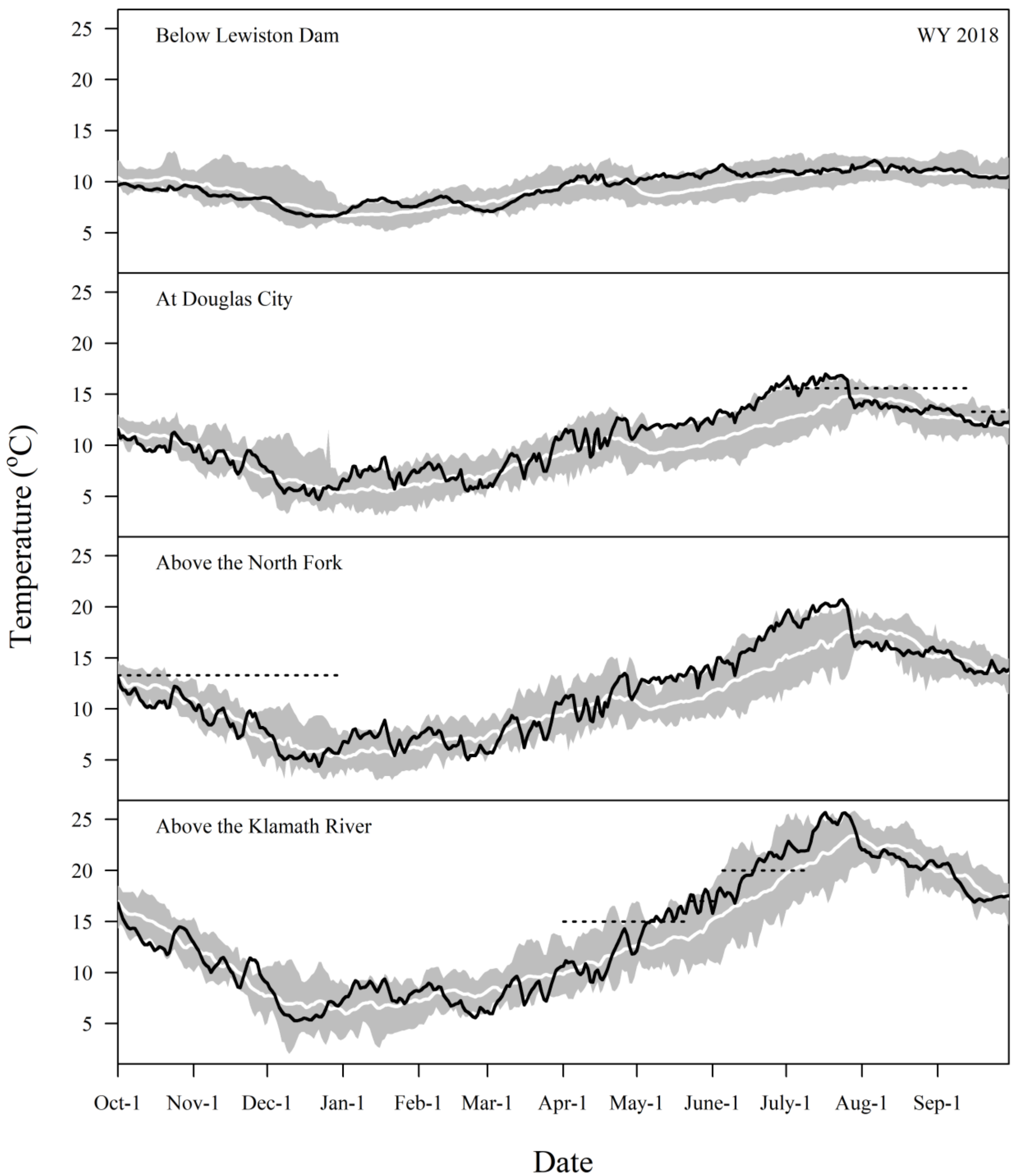
Appendix B14. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2014 – September 30, 2015, with historical summaries from water years (WYs) 2002 to 2014. Black line = daily mean water temperatures in WY 2015; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



Appendix B15. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2015 – September 30, 2016, with historical summaries from water years (WYs) 2002 to 2015. Black line = daily mean water temperatures in WY 2016; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



Appendix B16. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2016 – September 30, 2017, with historical summaries from water years (WYs) 2002 to 2016. Black line = daily mean water temperatures in WY 2017; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.



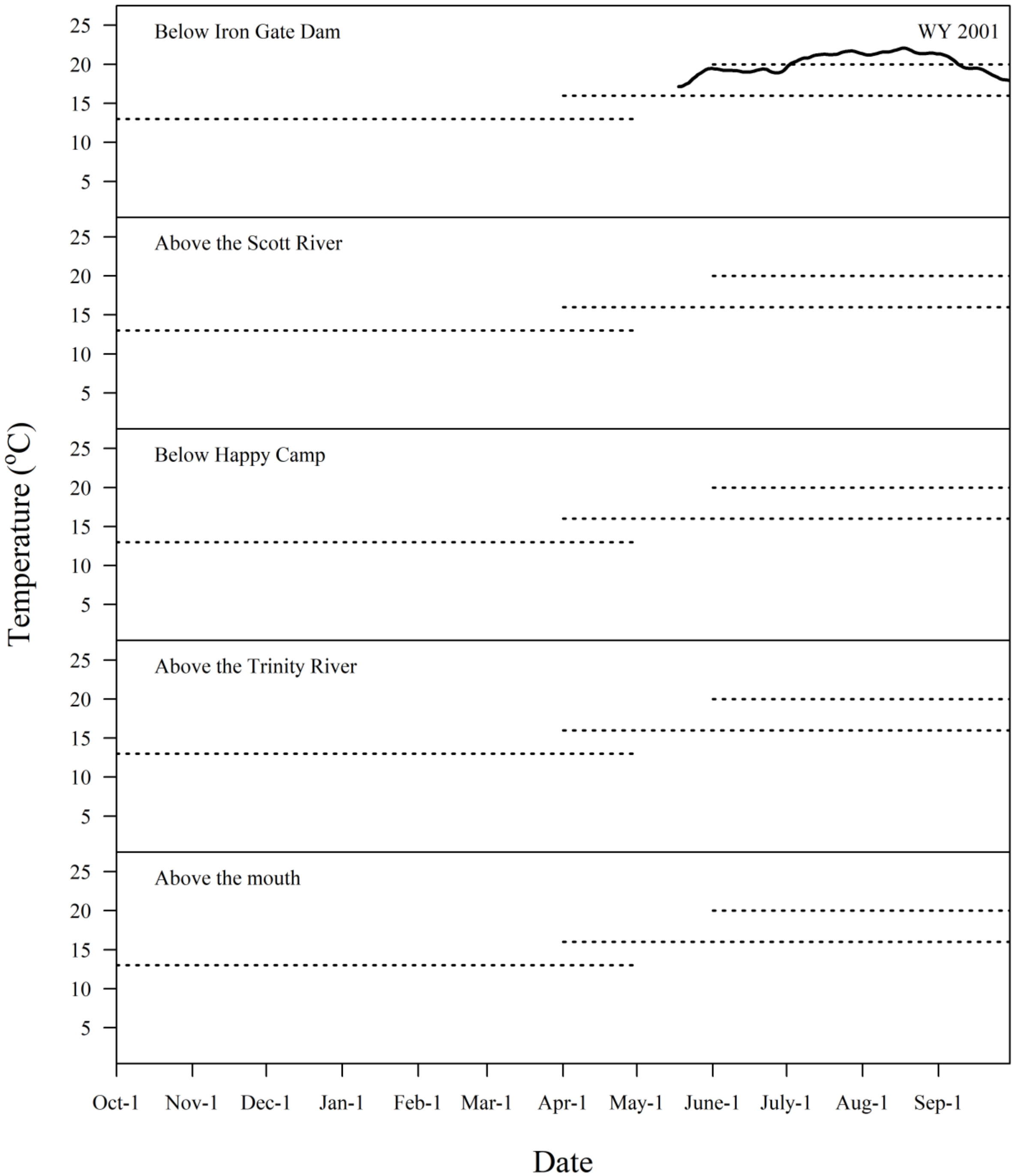
Appendix B17. Daily mean water temperatures at focal Trinity River monitoring locations, October 1, 2017 – September 30, 2018, with historical summaries from water years (WYs) 2002 to 2017. Black line = daily mean water temperatures in WY 2018; white line = average historical daily mean for each day of the year; gray polygon = range of historical daily mean water temperatures for each day of the year; black dotted line = water temperature objectives.

Appendix C. The number of days exceeding seven-day average daily maximum (7DADM) EPA criteria for Pacific Northwest water temperatures to protect Pacific salmon at five Klamath River focal locations, 2001-2019. The historic range of days criteria exceedance is indicated with the minimum and maximum number of days exceeding numeric water temperature criteria highlighted in bold. KRIG = Klamath below Iron Gate Dam; KRSC = Klamath above the Scott River; KRHC = Klamath below Happy Camp; KRWE = Klamath above the Trinity River; KRTG = Klamath above the mouth.

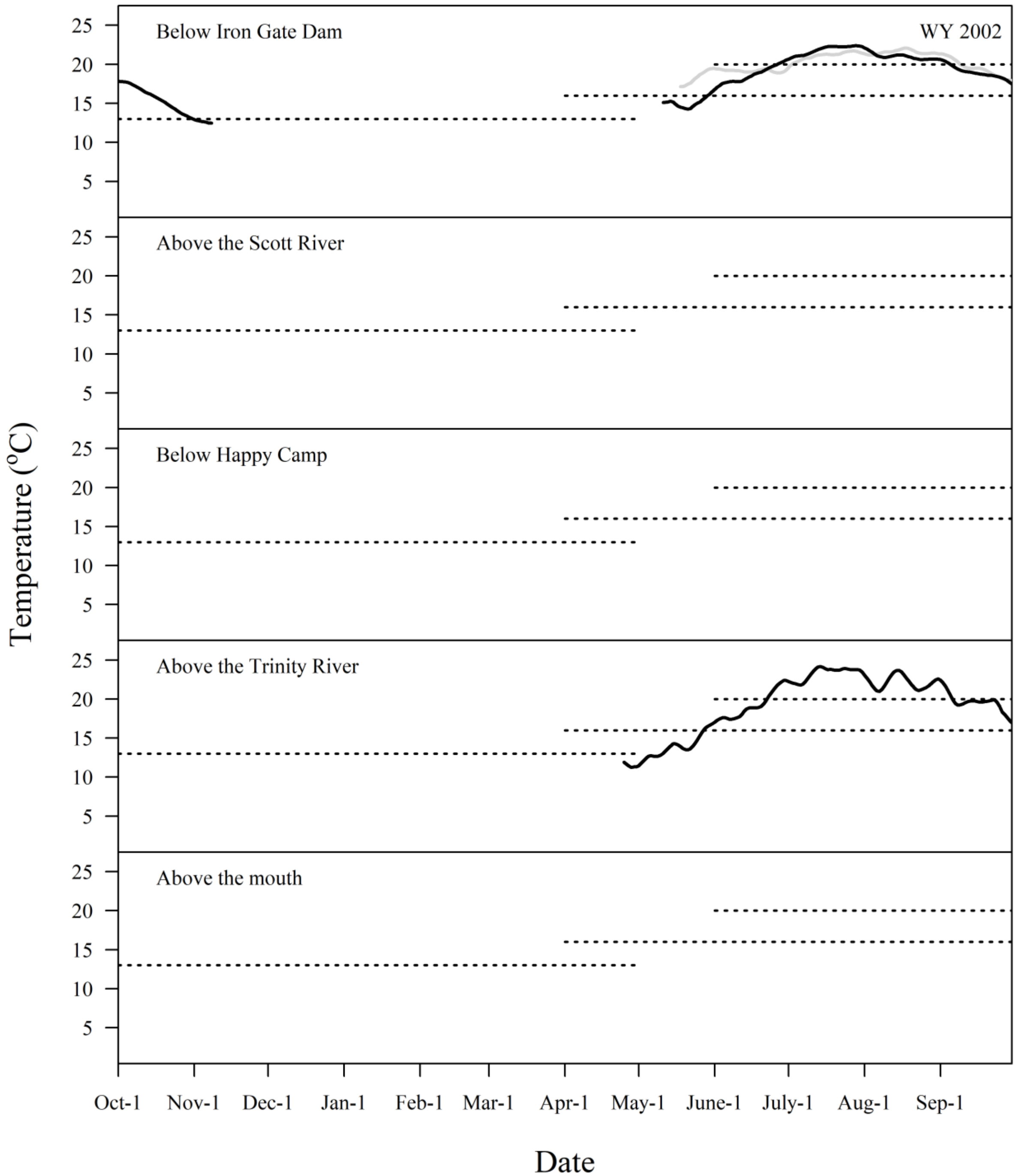
	20°C 7DADM criterion					*16°C 7DADM criterion*					*13°C 7DADM criterion*				
WY	**KRIG**	**KRSC**	**KRHC**	**KRWE**	**KRTG**	**KRIG**	**KRSC**	**KRHC**	**KRWE**	**KRTG**	**KRIG**	**KRSC**	**KRHC**	**KRWE**	**KRTG**
2001	68	-	-	-	-	136[a]	-	-	-	-	-	-	-	-	-
2002	70	-	-	75	-	124[a]	-	-	126[a]	-	31[a]	-	-	0[a]	-
2003	**98**	82	70[a]	**46**	-	126	128	116[a]	**93**	-	25[a]	0[a]	0[a]	24[a]	-
2004	79	86	67[a]	86	-	132[a]	131[a]	103	121	-	15[a]	16[a]	13[a]	9[a]	-
2005	69	74	74[a]	69	62	125[a]	**82**	129[a]	104[a]	104	28[a]	26[a]	21[a]	25[a]	24
2006	81	82	66[a]	83	74	140	130	84[a]	117	107[a]	32	29	-	28	30
2007	85	92	**96**	-	81	138	138	131	-	129[a]	28	27	26	22[a]	27
2008	73	78	15[a]	78	63	120	113	30[a]	111	112	**20**	**17**	17	0[a]	18
2009	72	81	92	85	71[a]	133	137	135	131	103[a]	26	26	9[a]	22	32
2010	**60**	**65**	61	55	56	112	110	101	99	100	25	24	25	27	18[a]
2011	78	70	**57**	55	**54**	**109**	110	**99**	**93**	100	32	23	22	22	24[a]
2012	0[a]	72	75	72	55	0[a]	128	119	114	111	35	24	24	25	28
2013	79	90	94	93	89	140	138	132	130	126	19[a]	39	28	28	44
2014	73	90	92	103	81	**141**	142	141	139	**139**	28	26[a]	27	18	41
2015	85	**92**	78[a]	**104**	**90**	131	146	130[a]	**150**	138	**43**	**44**	**42**	**45**	**57**
2016	65[a]	77	78	3[a]	70	103[a]	133	128	27[a]	126	39[a]	**44**	34	35[a]	42
2017	87	87	85	82	78[a]	129	128	108	107	**99**	28	21	15	**16**	**17**
2018	79	90	88	84	77[a]	**141**	**148**	**142**	138	110	24	21	**14**	18	29
Average	77.3	81.8	81.8	78.0	70.5	130.0	127.4	121.7	118.7	115.0	29.2	28.3	24.9	24.9	32.4
2019	92	87	83	80	69	136	131	124	123	123	37	34	20	33	36

[a] Partial data is missing during the period of the criteria.

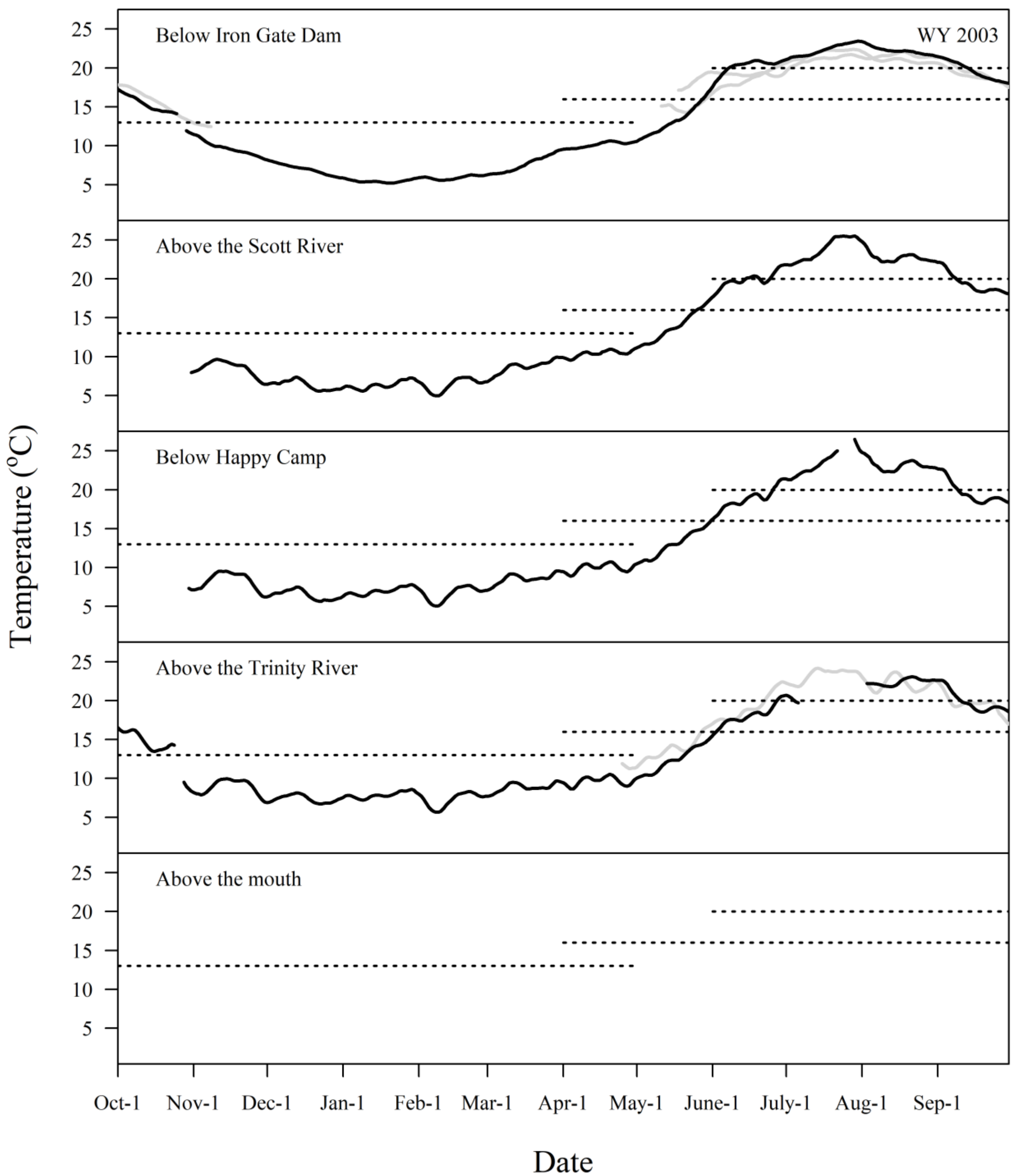
Appendix D. Seven-day average daily maximum water temperatures at focal Klamath River monitoring locations, 2001-2018 water years, with historical conditions. Includes only observed water temperatures.



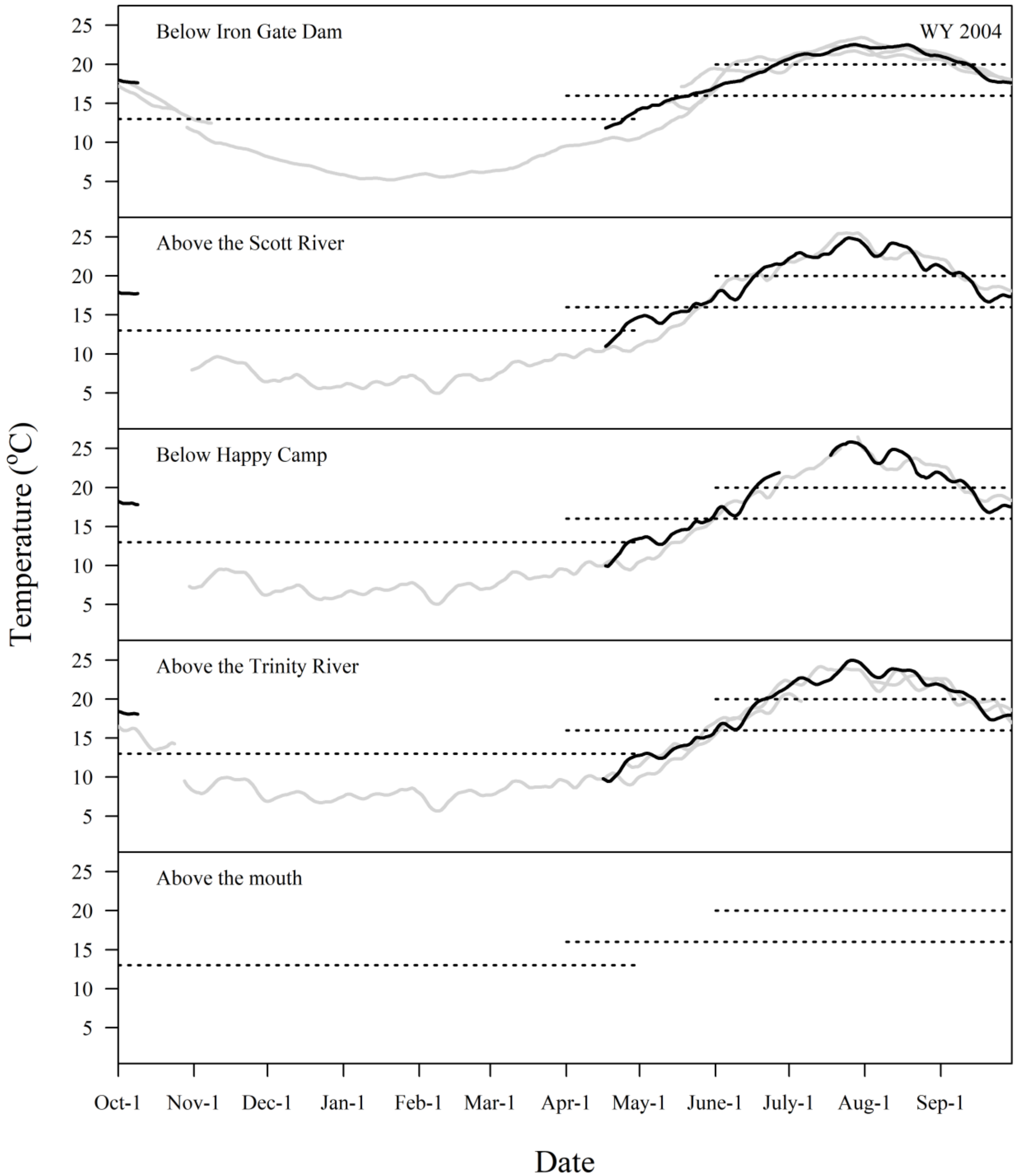
Appendix D1. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2000 – September 30, 2001. Black line = 7DADM water temperatures in water year (WY) 2001; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



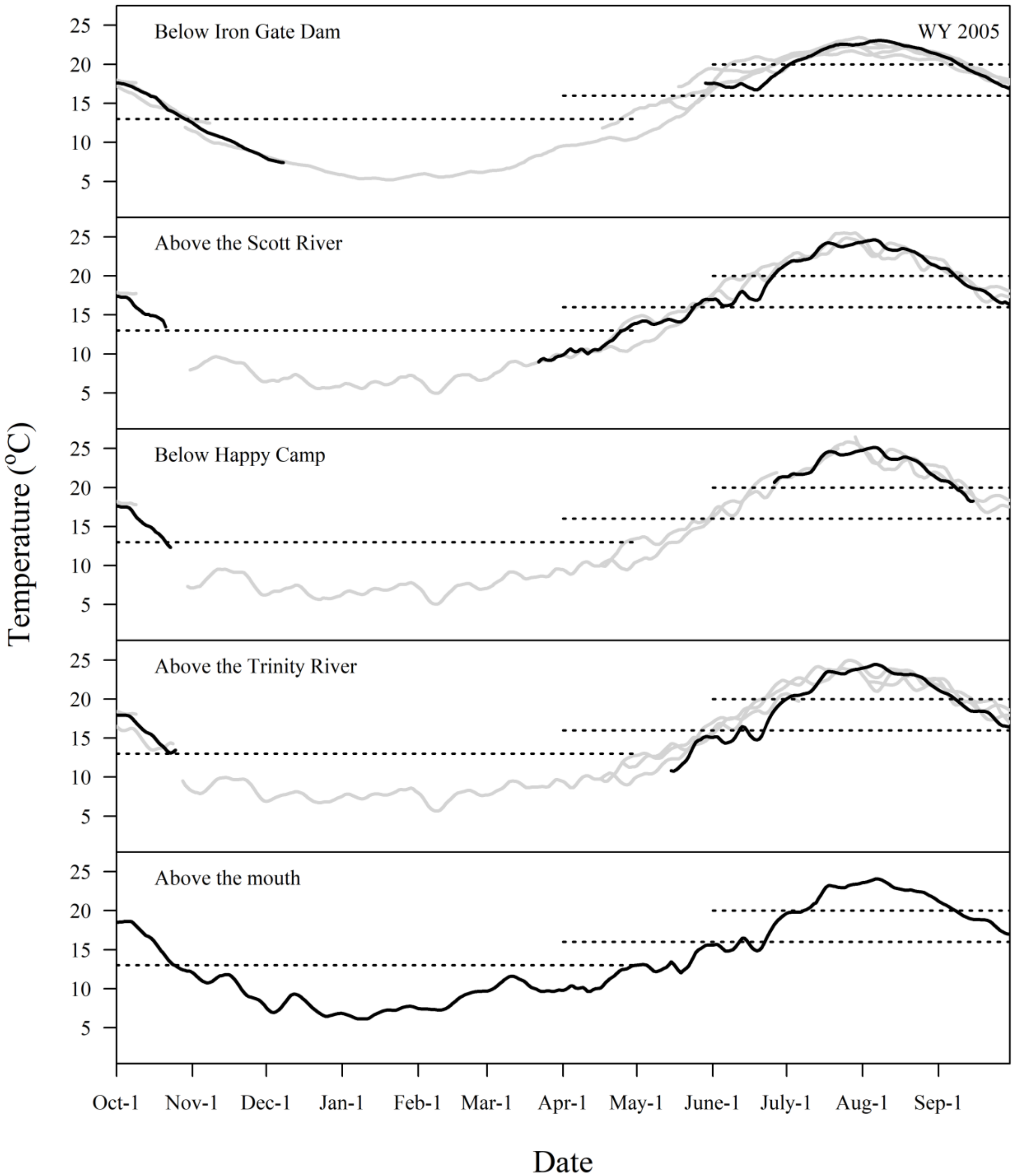
Appendix D2. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2001 – September 30, 2002, with historical summaries from water year (WY) 2001. Black line = 7DADM water temperatures in WY 2002; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



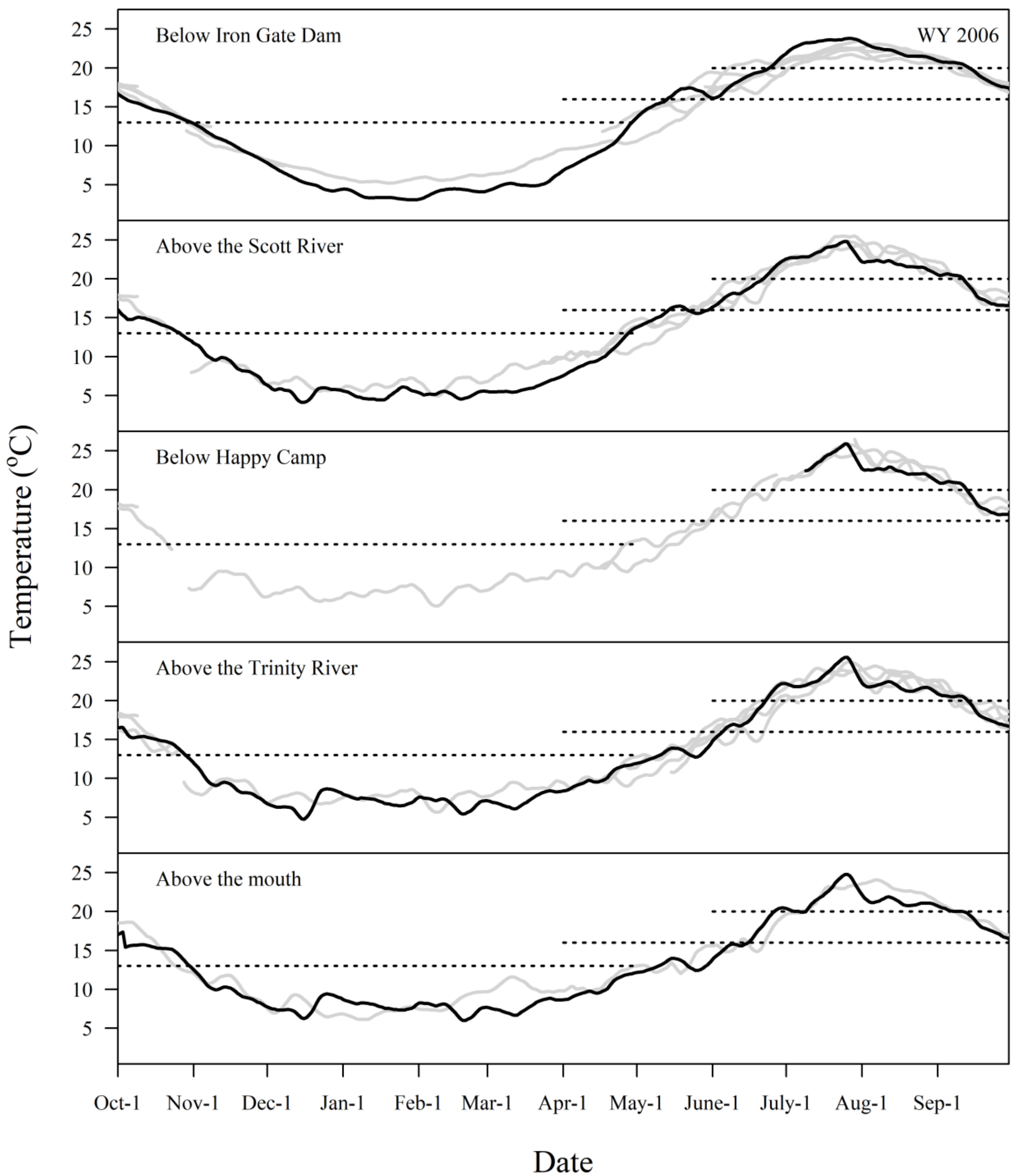
Appendix D3. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2002 – September 30, 2003, with historical summaries from water years (WYs) 2001 to 2002. Black line = 7DADM water temperatures in WY 2003; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



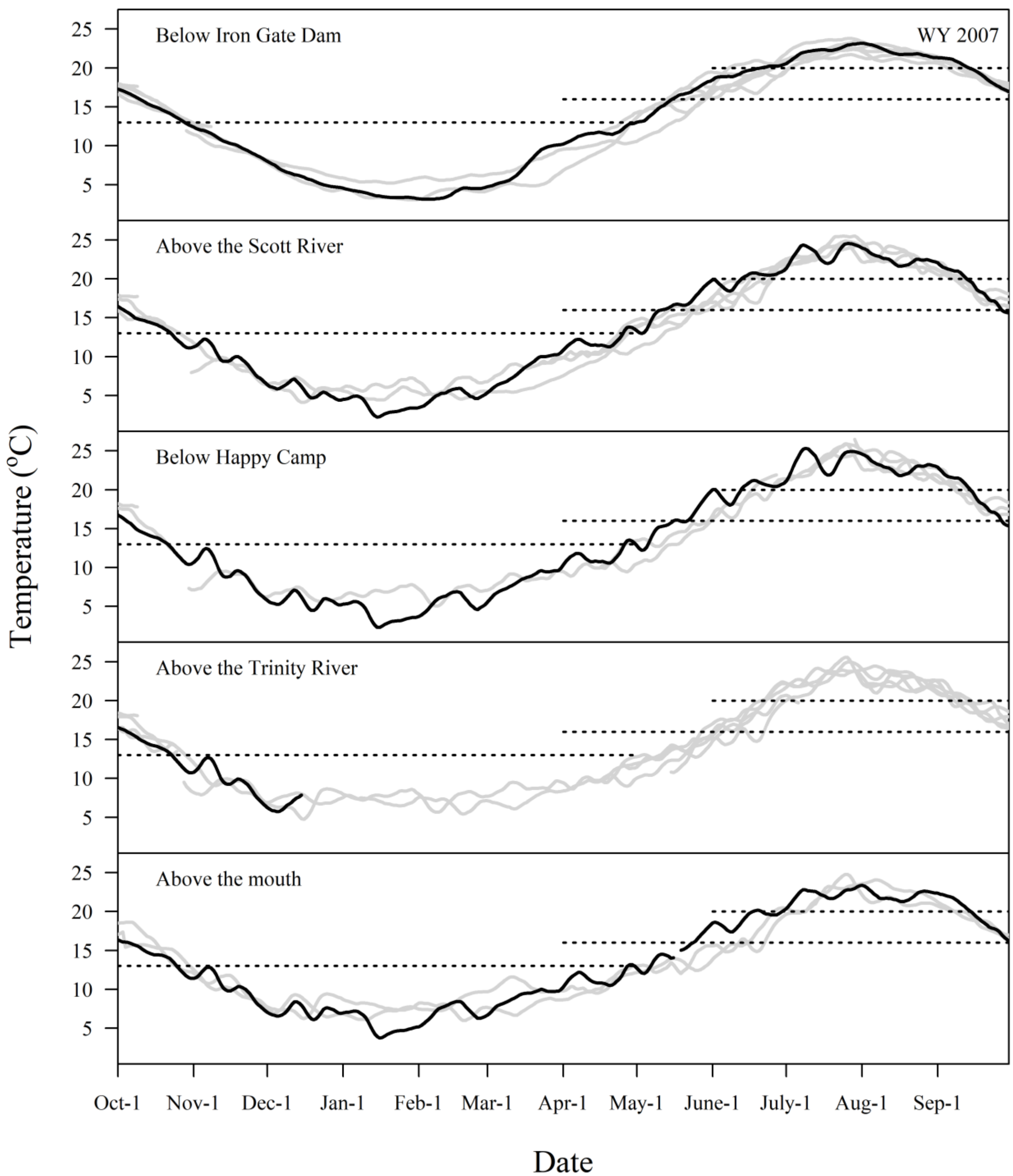
Appendix D4. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2003 – September 30, 2004, with historical with historical summaries from water years (WYs) 2001 to 2003. Black line = 7DADM water temperatures in WY 2004; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



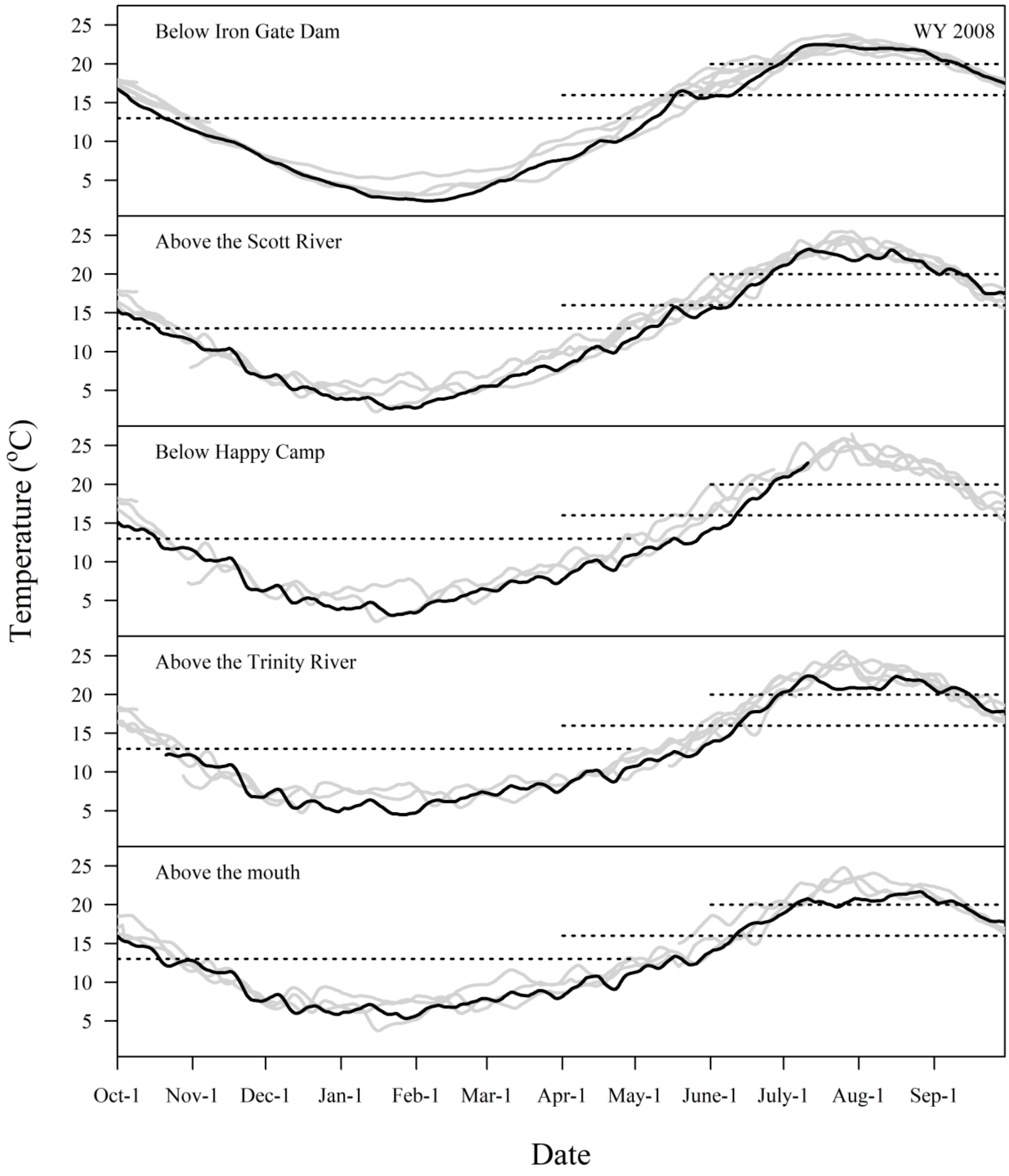
Appendix D5. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2004 – September 30, 2005, with historical summaries from water years (WYs) 2001 to 2004. Black line = 7DADM water temperatures in WY 2005; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



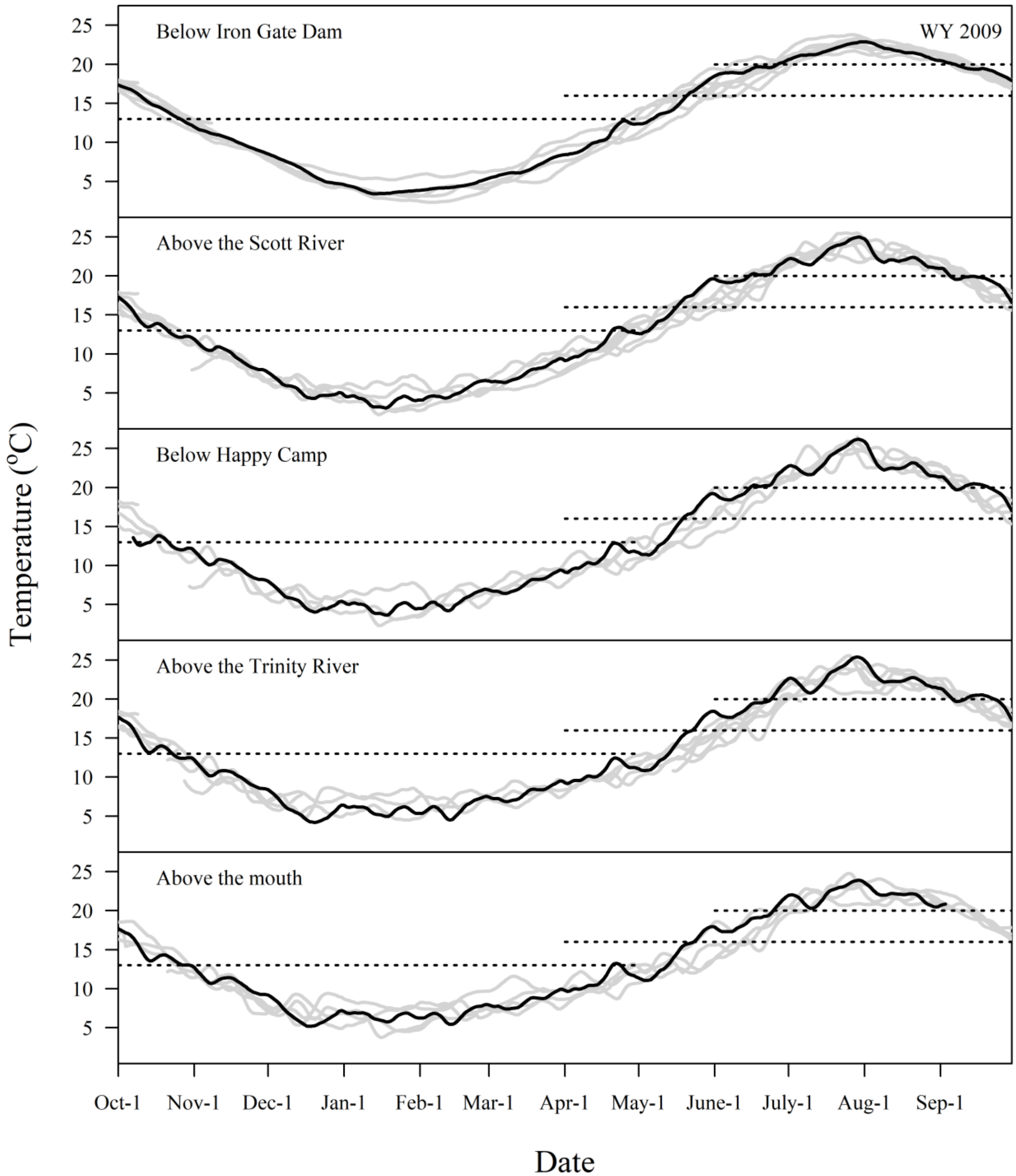
Appendix D6. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2005 – September 30, 2006, with historical summaries from water years (WYs) 2001 to 2005. Black line = 7DADM water temperatures in WY 2006; gray line = historical 7DADM water temperatures; dotted black line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



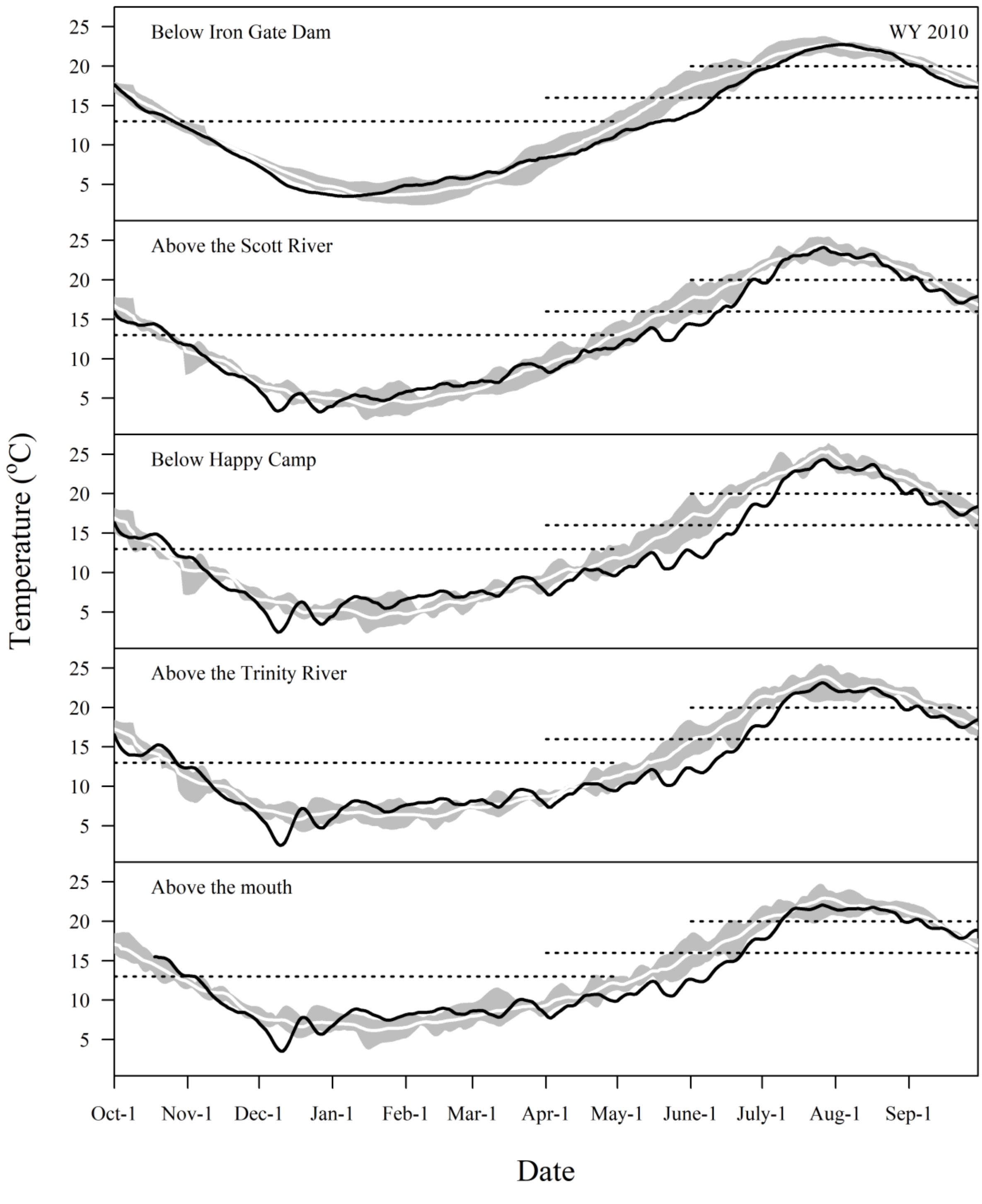
Appendix D7. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2006 – September 30, 2007, with historical summaries from water years (WYs) 2001 to 2006. Black line = 7DADM water temperatures in WY 2007 gray lines= historical 7DADM water temperatures; dotted lines = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



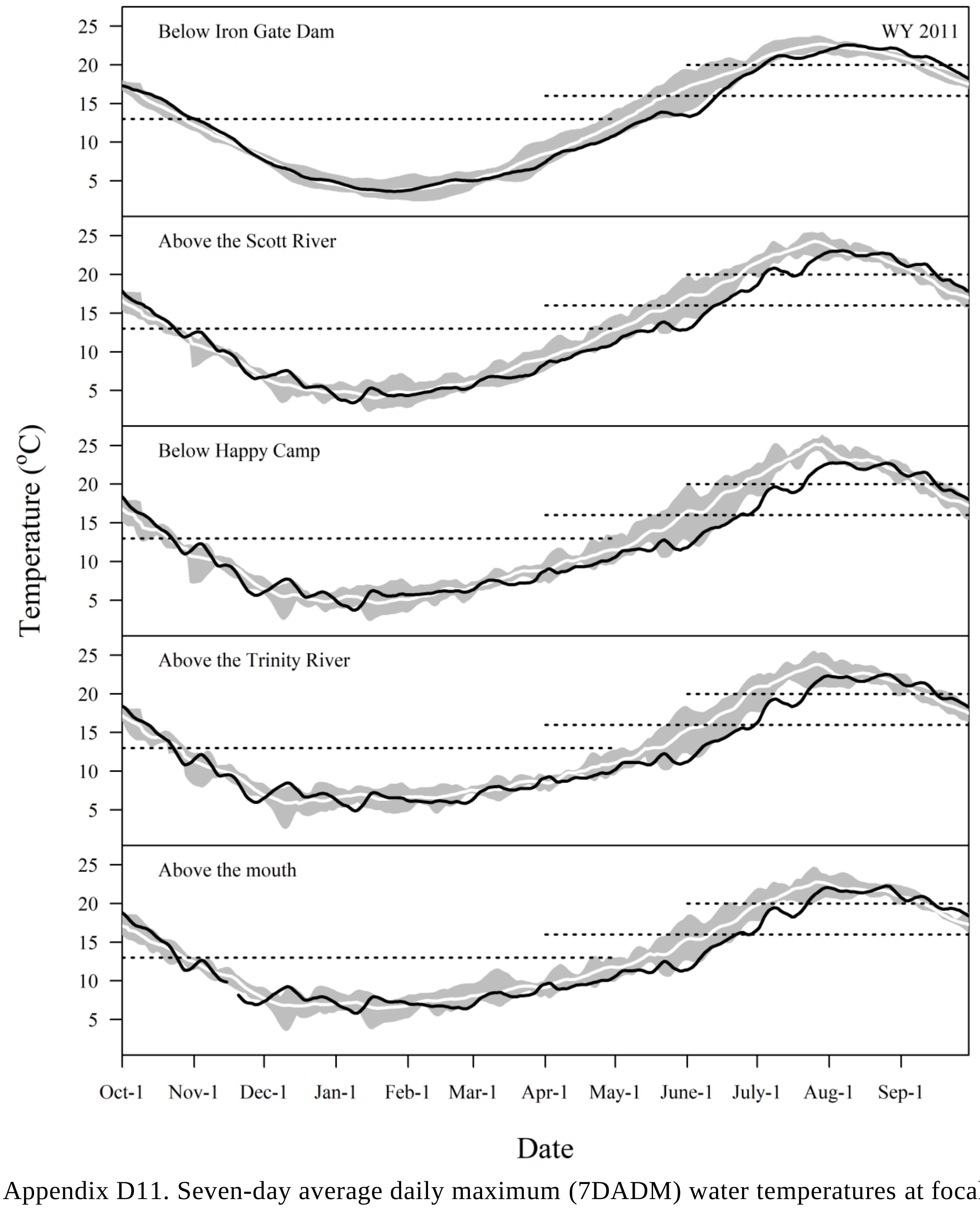
Appendix D8. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2007 – September 30, 2008, with historical summaries from water years (WYs) 2001 to 2007. Black line = 7DADM water temperatures in WY 2008; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



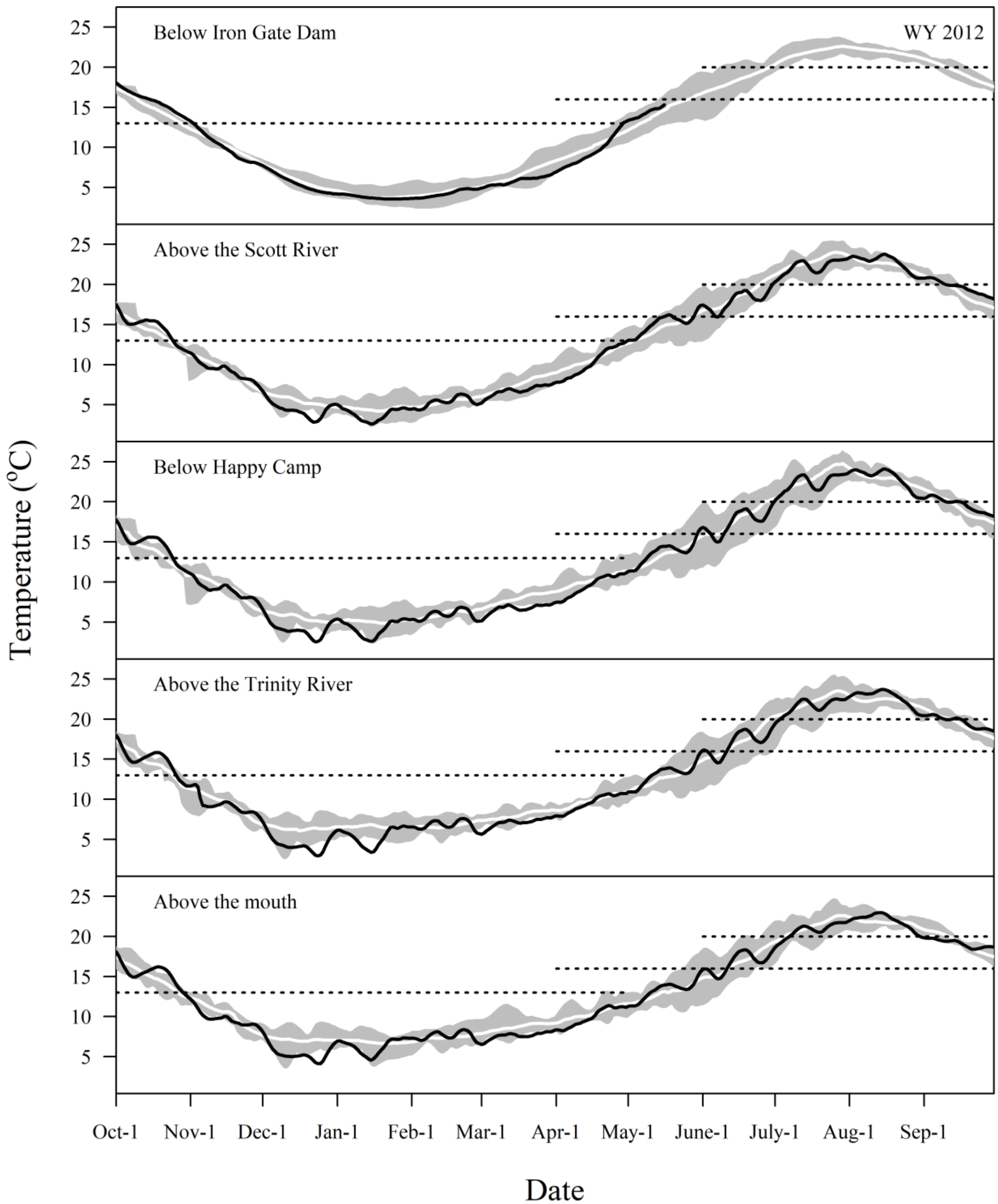
Appendix D9. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2008 – September 30, 2009, with historical summaries from water years (WYs) 2001 to 2008. Black line = 7DADM water temperatures in WY 2009; gray line = historical 7DADM water temperatures; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



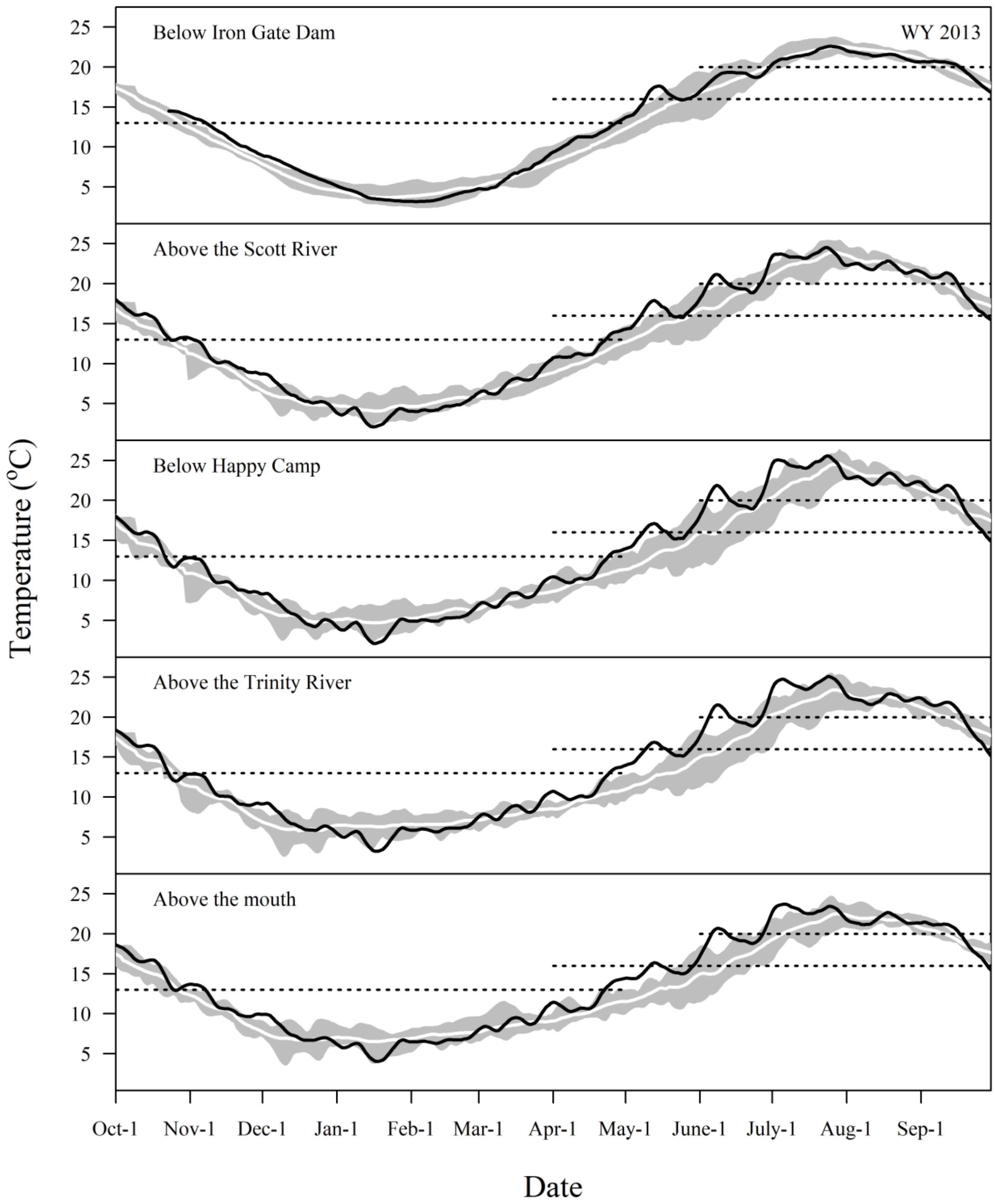
Appendix D10. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2009 – September 30, 2010, with historical summaries from water years (WYs) 2001 to 2009. Black line = 7DADM water temperatures in WY 2010; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



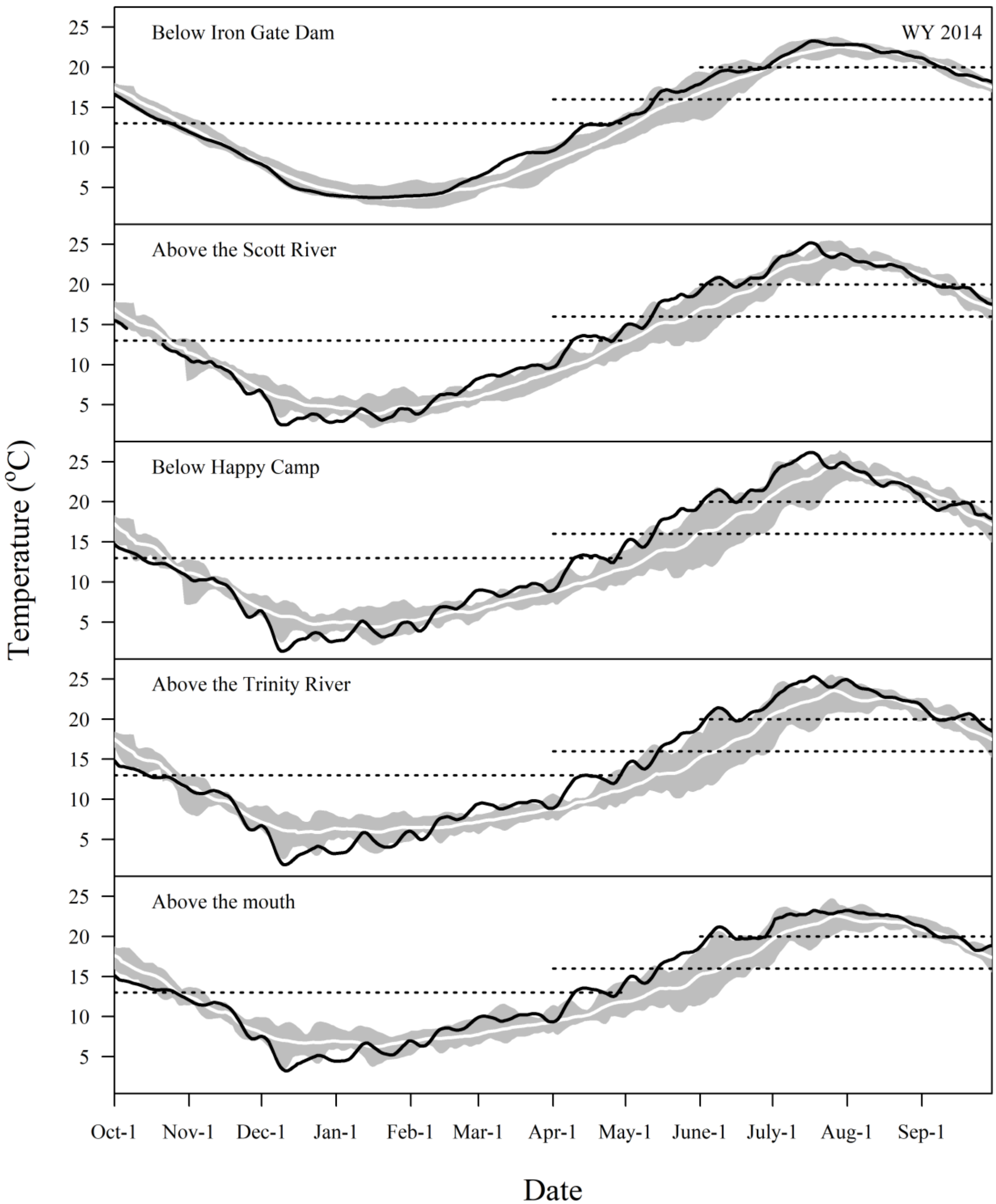
Appendix D11. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2010 – September 30, 2011, with historical summaries from water years (WYs) 2001 to 2010. Black line = 7DADM water temperatures in WY 2011; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



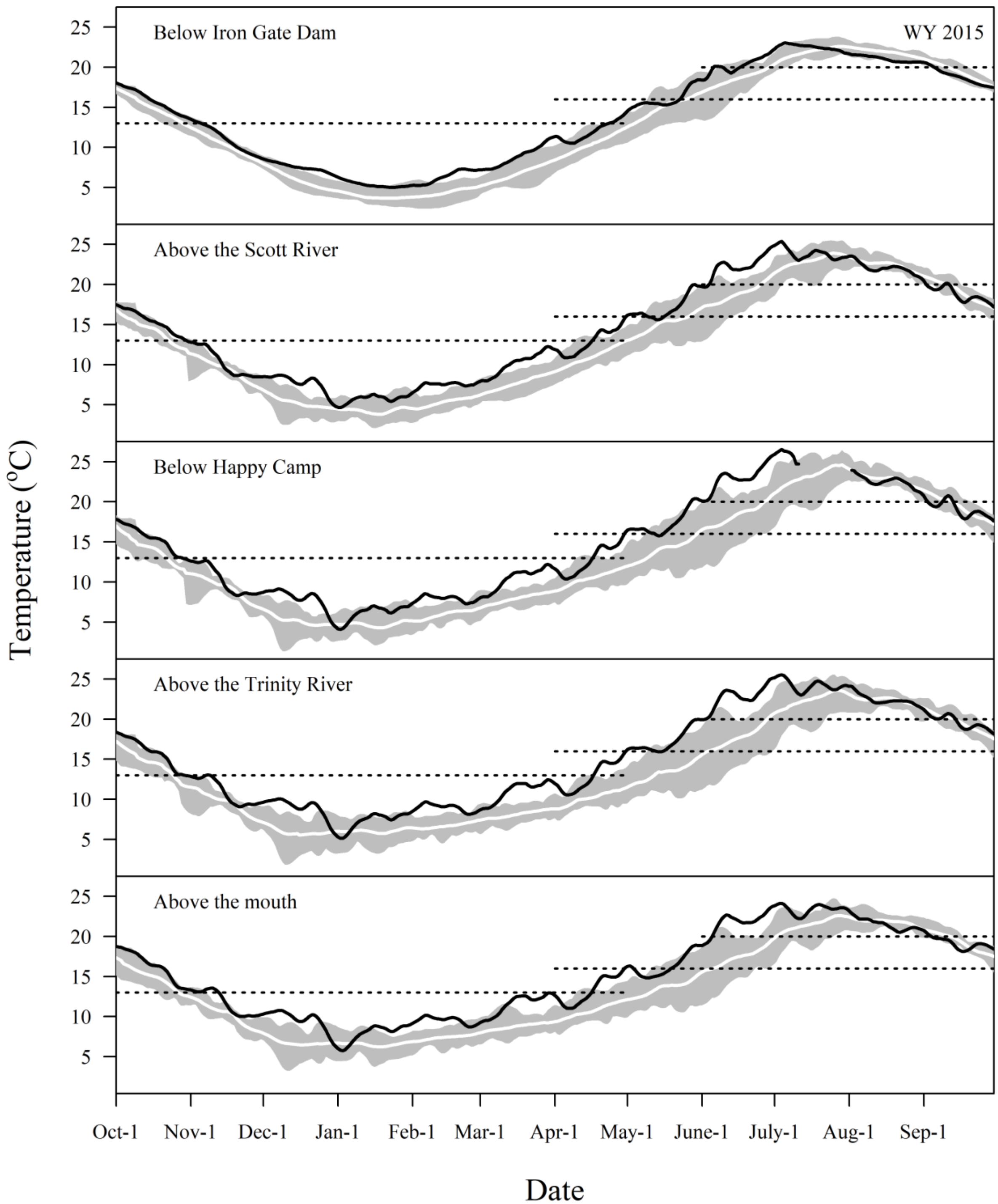
Appendix D12. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2011 – September 30, 2012, with historical summaries from water years (WYs) 2001 to 2011. Black line = 7DADM water temperatures in WY 2012; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



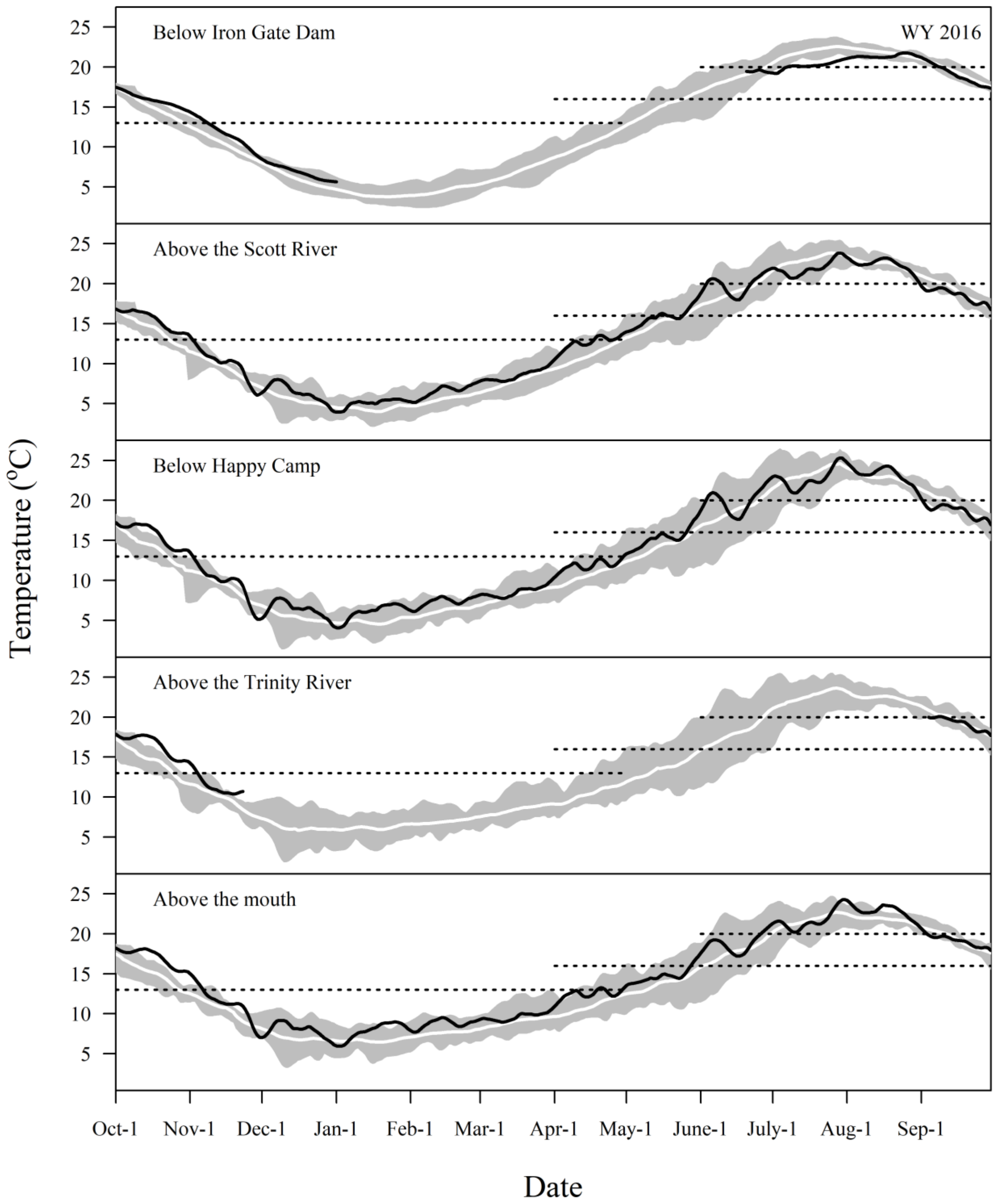
Appendix D13. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2012 – September 30, 2013, with historical summaries from water years (WYs) 2001 to 2012. Black line = 7DADM water temperatures in WY 2013; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



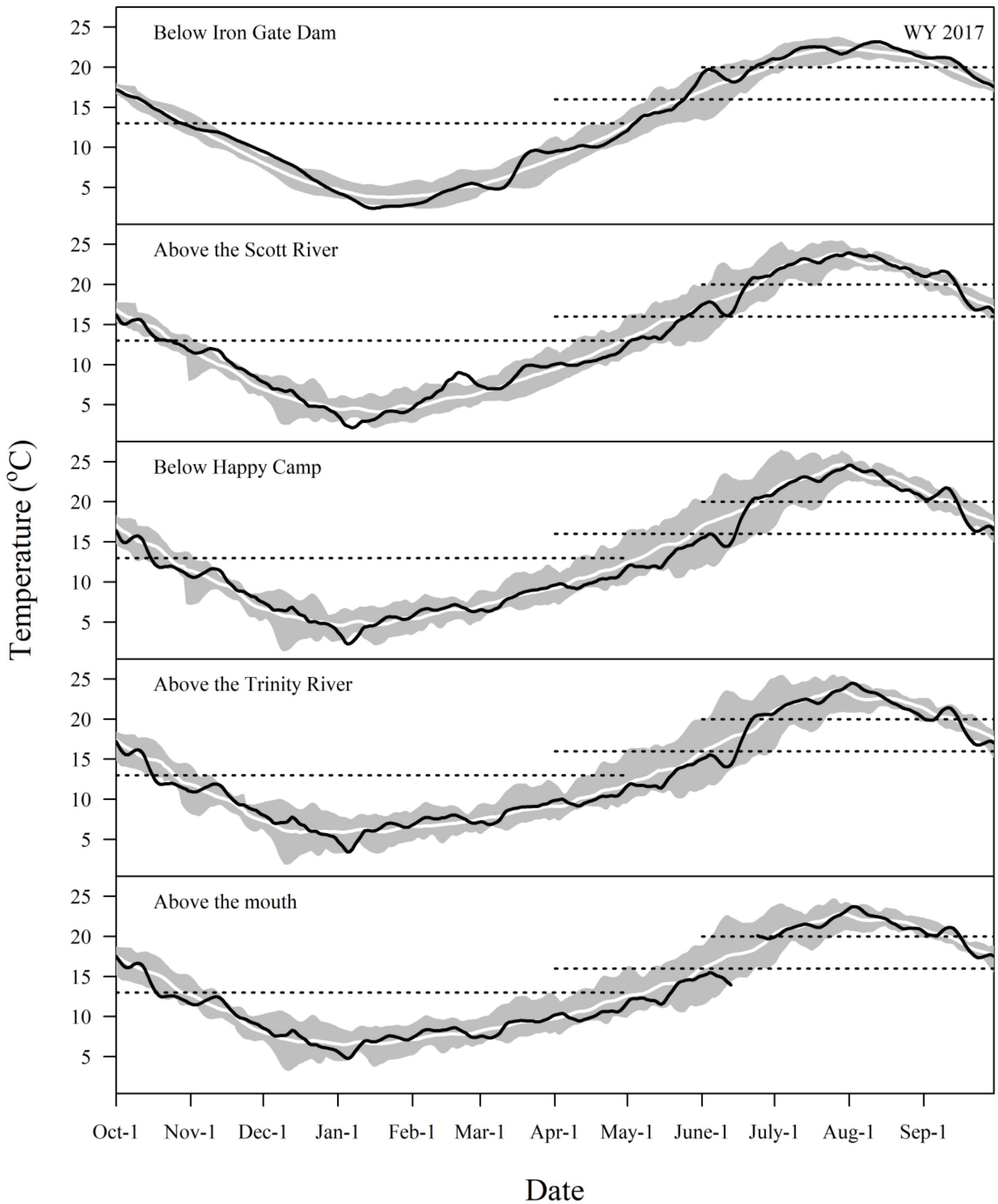
Appendix D14. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2013 – September 30, 2014, with historical summaries from water years (WYs) 2001 to 2013. Black line = 7DADM water temperatures in WY 2014; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



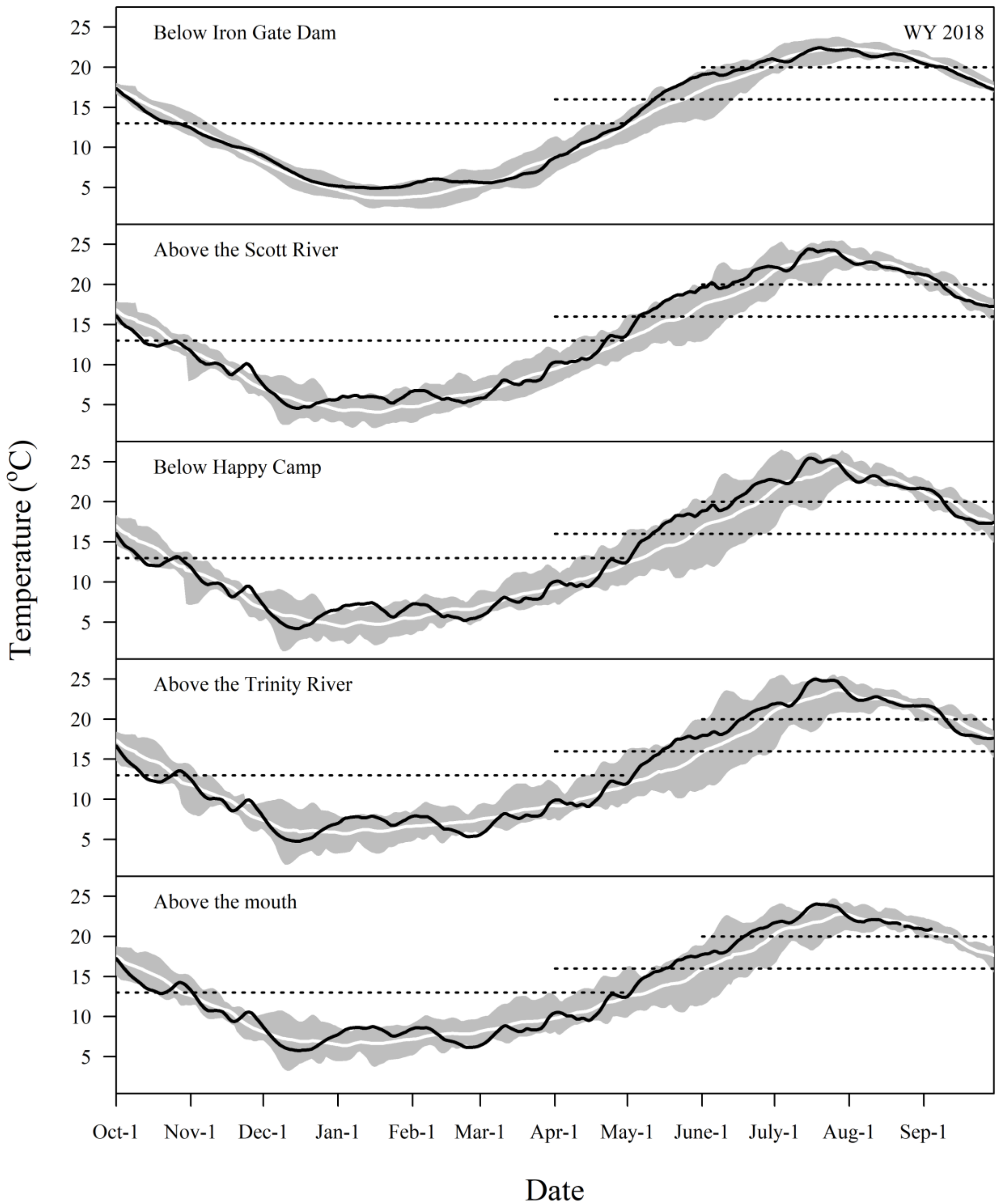
Appendix D15. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2014 – September 30, 2015, with historical summaries from water years (WYs) 2001 to 2014. Black line = 7DADM water temperatures in WY 2015; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.



Appendix D16. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, April 15 – October 31, 2016, with historical summaries from water years (WYs) 2001 to 2015. Black line = 7DADM water temperatures in WY 2016; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.

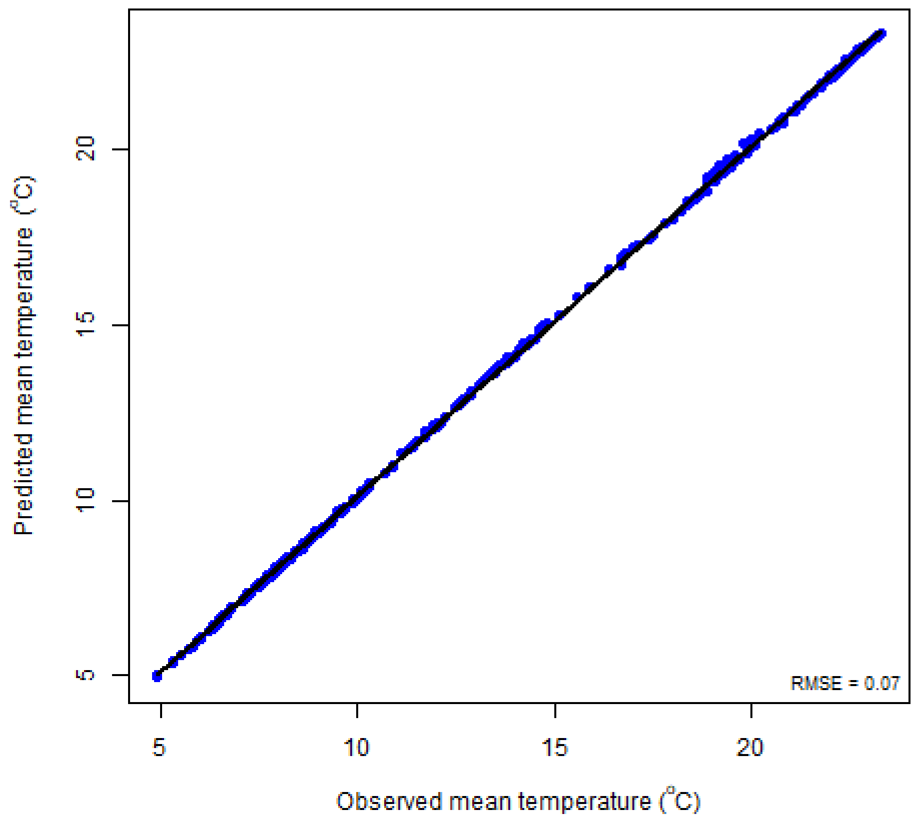


Appendix D17. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2016 – September 30, 2017, with historical summaries from water years (WYs) 2001 to 2016. Black line = 7DADM water temperatures in WY 2017; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.

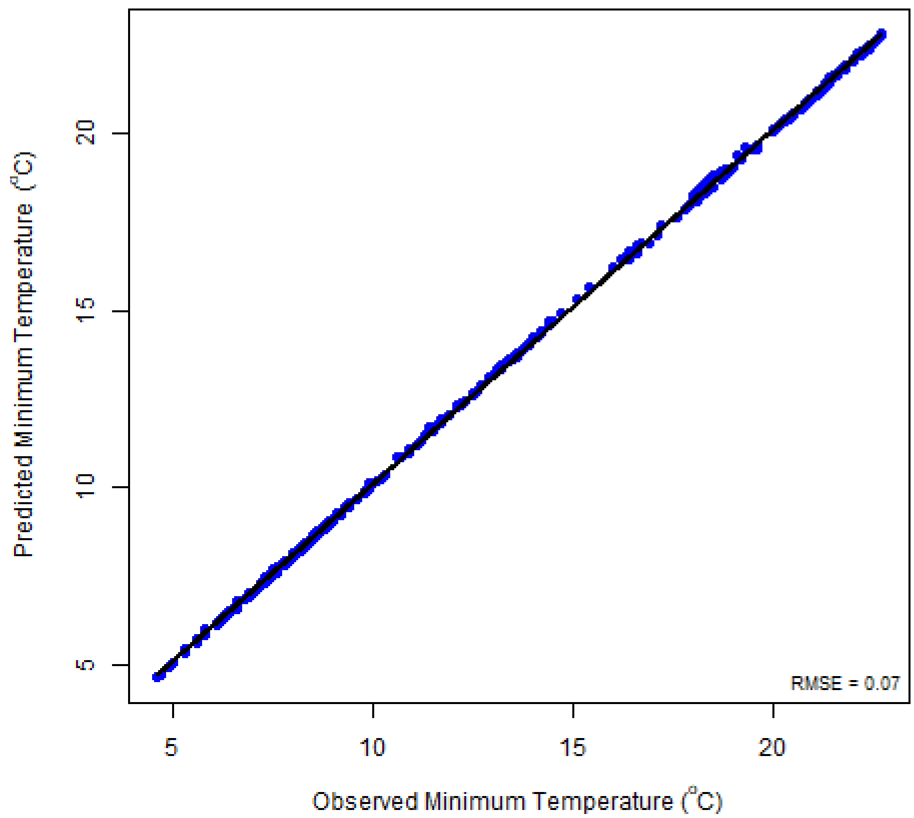


Appendix D18. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, October 1, 2017 – September 30, 2018, with historical summaries from water years (WYs) 2001 to 2017. Black line = 7DADM water temperatures in WY 2018; white line = average historical 7DADM for each day of the year; gray polygon = range of historical 7DADM water temperatures for each day of the year; black dotted line = Environmental Protection Agency Pacific Northwest water temperature criteria.

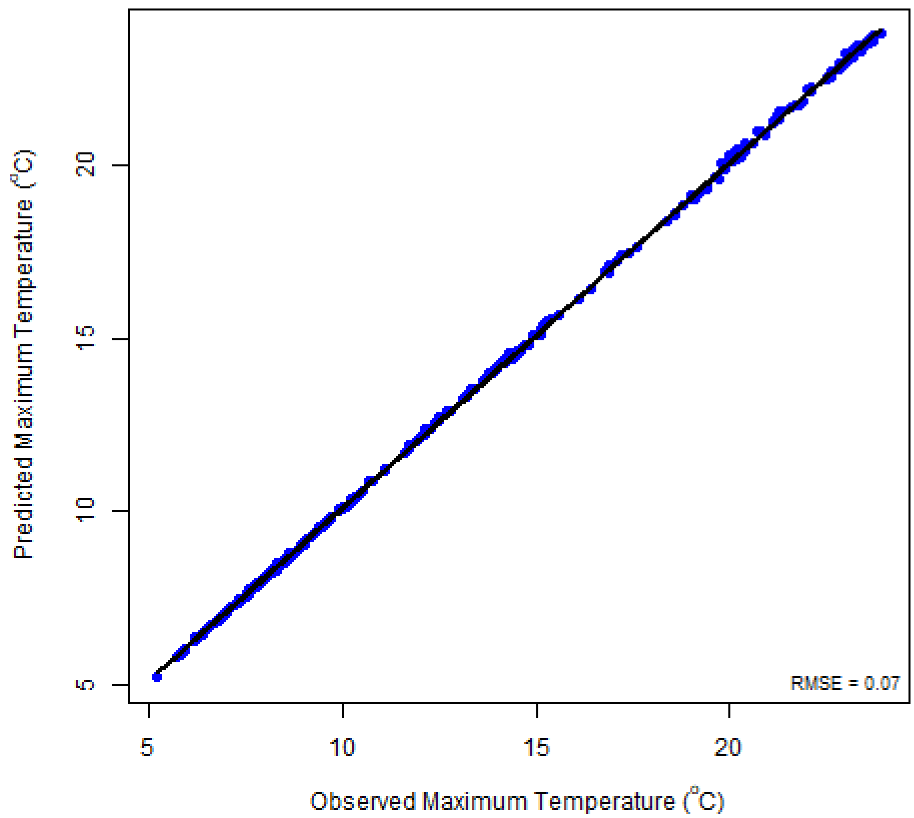
Appendix E. Predicted temperature values vs. observed values used for infilling at focal sites, with root mean square error as a measure for the difference between predicted and observed values.



Appendix E4. Predicted mean water temperature values vs. observed mean water temperature values used for infilling at the Klamath River Blakes Riffle (KRTG) focal site, with observed data at U.S. Geological Survey gage 11530500, with root mean square error (RMSE) as a measure of the difference between the predicted and observed values.



Appendix E5. Predicted minimum temperature values vs. observed minimum temperature values used for infilling at the Klamath River Blakes Riffle (KRTG) focal site, with observed data at USGS gage 11530500, with root mean square error (RMSE) as a measure of the difference between the predicted and reference values.



Appendix E6. Predicted maximum water temperature values vs. observed maximum water temperature values used for infilling at the Klamath River Blakes Riffle (KRTG) focal site, with observed data at USGS gage 11530500, with root mean square error (RMSE) as a measure of the difference between the predicted and reference values.

Appendix F. Secci plot for missing historical data on the Klamath and Trinity rivers 2000-2019. Data from 2000-2018 was not infilled.