U.S. Fish & Wildlife Service

Arcata Fisheries Date Series Report DS 2021-63

Performance of Water Temperature on the Klamath and Trinity Rivers, 2018

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August 2021

Funding for this study was provided by the U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office Fish and Aquatic Habitat Conservation Program.

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key words: Water temperature, Klamath, Trinity, EPA Criteria, dam releases, Chinook

The correct citation for this report is:

Romberger, C. Z. and Daley T. T. 2021. Performance of water temperature management on the Klamath and Trinity Rivers, 2018. U.S. Fish and Wildlife Service. Arcata Fish and Wildlife Office, Arcata Fisheries Date Series Report DS 2021-63, Arcata, California.

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Abstract.—The U.S. Fish and Wildlife Service began 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 salmon. This report summarizes the results of 2018 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 2018 water year was designated as 'Critically Dry', and the Trinity River exceeded temperature criteria for a total of 65 days: 26 days near Douglas City, two days above the confluence with the North Fork Trinity, and 44 days above the confluence with the Klamath River. The Klamath River exceeded temperature criteria at all sites (range from 31 to 160 days). Mean daily water temperatures were < 13.0°C before April 1 at all focal sites. After October 31, mean daily water temperatures were < 13.0°C for three of four Trinity River focal sites and two of five Klamath River focal sites. A majority of locations saw an increase in days exceeding temperature criteria from 2017, as well as their respective long-term averages, on both the Trinity and Klamath Rivers. At all sites combined, there were 120 days that exceeded the observed historical range (n=18) of daily average temperature in the Trinity River and 204 days that exceeded the observed historical range (n=18) of daily average temperature on the Klamath River. Supplemental flow was released from Lewiston Reservoir as part of emergency operations in response to the Carr Fire and then to reduce water temperatures. Supplemental releases began on July 26 and concluded September 20 and reduced temperatures to the management target of < 23℃ below the confluence, in the Lower Klamath River. Temperatures below the confluence, in the lower Klamath River, remained below 23℃ for the remainder of the study period.

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; DOI et al. 2013). However, native fish have dramatically declined over the past century as a result of 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 central tendencies of optimal temperature are important for salmonids. 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), seeking thermal refugia (Sullivan et al. 2000; Goniea et al. 2006), etc. 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 that are 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 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 salmon and concern that elevated water temperatures in the Klamath basin could be impacting salmon populations. The primary intent of this report is to inform water management decisions in the Klamath basin and compare instream monitoring to established criteria, which focuses on exceeding high temperatures. 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 on fish populations. 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), as a foundational driver in the Stream Salmonid Simulator (S3) salmon production model (Perry et al. 2018), the assessment of watershed restoration program criteria (Polos 2016), and the prediction of juvenile salmon outmigration timing (Som and Hetrick 2017).

In response to the fish die-off in the lower Klamath River in 2002, supplementation of flow from the Lewiston Reservoir was implemented based upon triggering criteria as a preventative measure. 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). 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's (ROD) and incorporates the water year type and restoration needs (USDOI 2000).

These supplemental flow releases are used to reduce high temperatures in the lower Klamath River and aid adult salmonid upstream migration in the fall. Supplemental flow triggering criteria are a combination of discharge levels and river temperature. This report evaluates the Supplemental flows based on the described temperature criteria. 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), and Hetrick and Polos (2015).

This report summarizes Klamath basin water temperature data collected by the USFWS between November 1, 2017 and October 31, 2018 and within the context of the period of record at each location to facilitate numerical evaluation of criteria set for the Trinity and Klamath Rivers. Reporting focuses on the warm half of the year for all summaries and analyses, the period when water temperatures are most likely to negatively impact salmonid populations (USEPA 2003).

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 (TRBL1; Figure 1; Table 1) to the confluence with the Klamath River (TRWE1). Klamath River monitoring locations extend from Iron Gate Dam (KRIG1) to near the mouth (KRTG2).

Data Sources and Protocols

The USFWS monitored water temperatures at 19 sites in the Klamath basin in 2018 and acquired data from two locations monitored by the U.S. Bureau of Reclamation (Figure 1; Table 1). Of these 21 locations, eight were on the Trinity River and its tributaries and 11 were on the mainstem Klamath River and its tributaries. These locations were selected to be representative of different reaches in their respective rivers and not to be inadvertently influenced by local conditions such as a spring, tributary, or other thermal anomalies.

All USFWS monitoring locations were fitted with digital data loggers (HOBO Water Temp Pro v2, Onset Computer Corporation) and standardized protocols (Dunham et al. 2005) were used to monitor water temperatures. Loggers were set to record at 30-minute intervals and were typically swapped out twice a 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℃. The two sites monitored by the U.S. Bureau of Reclamation were located at Douglas City (DGC) and above the North Fork Trinity (NFH). These data were examined for discrepancies, and any data determined to be erroneous were removed. Data from USFWS monitoring locations are stored in a Microsoft Access 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 River. 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 (TRBL1), the upper limit to anadromy. The focal sites are located at Douglas City (DGC), above the North Fork Trinity (NFH), and above the Klamath River (TRWE1) 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 (KRIG1), which marks the upper limit to anadromy. The other four focal sites are above the Scott River (KRSC1), below Happy Camp (KRHC1), above the Trinity River (KRWE1), and above the mouth of the Klamath (KRTG2). The KRSC1 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 KRHC1site 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). The KRWE1 site was chosen because it is upstream of the confluence with the Trinity River. Finally, KRTG2 was chosen as it is the terminus of the river.

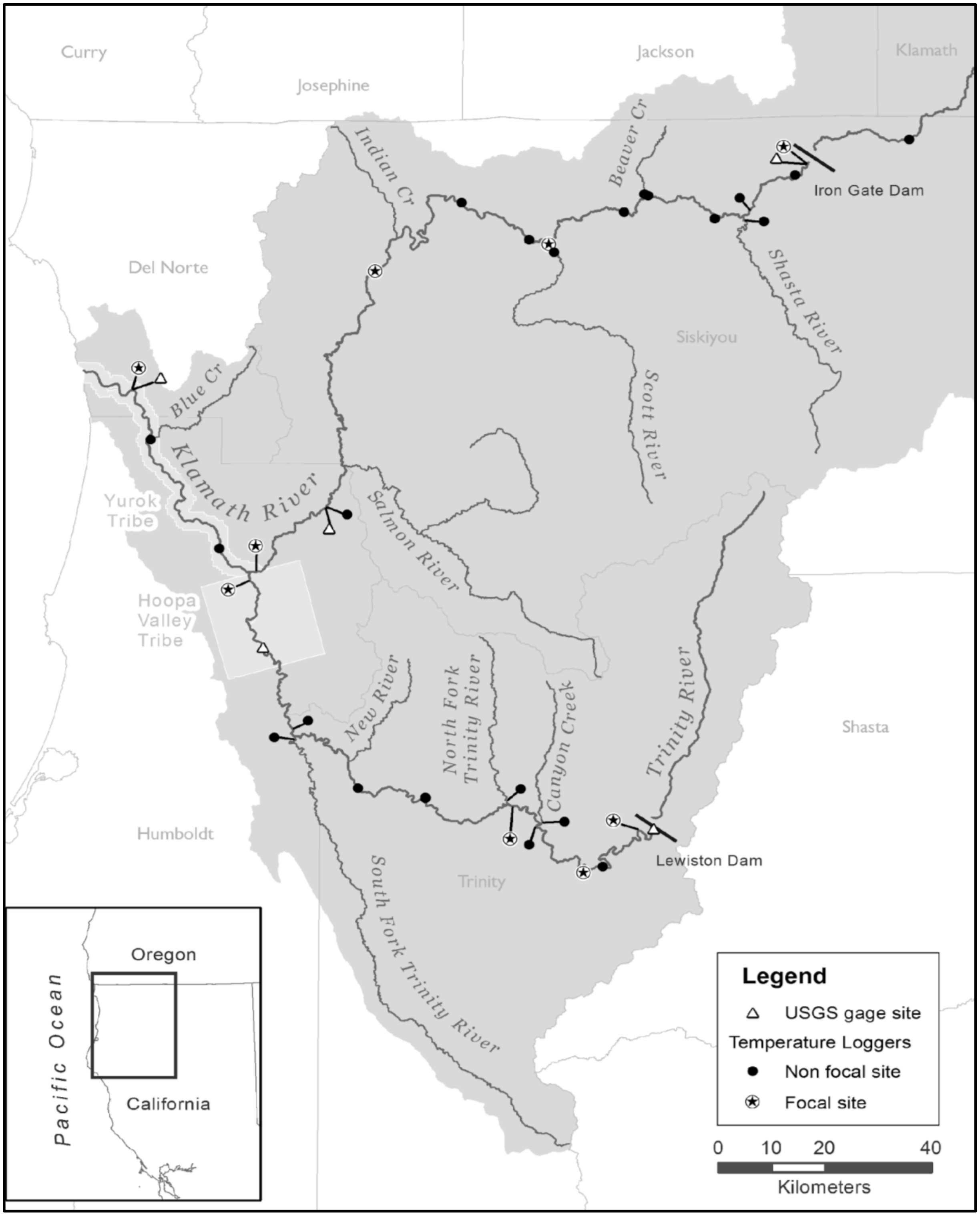

Figure 1. The lower Klamath basin with the locations that water temperature were monitored in 2018. Anadromy is limited to below Iron Gate Dam on the Klamath River and below Lewiston Dam on the Trinity River.

Table 1. Temperature monitoring locations in the Klamath basin operated by the U.S. Fish and Wildlife Service and the U.S. Bureau of Reclamation in 2018. 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.

River/Creek	Location	Location Code	rkm	Latitude	Longitude	Years Operated[†]
Klamath River	Above Copco I	KRCO1	334.3	41.966054	-122.217349	2007-2018
Klamath River	Below Iron Gate Dam	KRIG1	309.7	41.931049	-122.441397	2001-2018
Klamath River	Below R-Ranch	KRRR1	304.3	41.90378	-122.476295	2001-2002, 2005-2018
Klamath River	Above Shasta River	KRSH1	288.5	41.83124	-122.593382	2002-2018
Shasta River	Near mouth	SHKR1	0.8	41.824759	-122.593916	2001-2003, 2005-2018
Klamath River	At Trees of Heaven	KRTH1	281.0	41.825055	-122.658796	2005-2018
Klamath River	Fisher's RV Park	KRBV2	263.4	41.867436	-122.809451	2002-2018
Beaver Creek	Near mouth	BVKR1	0.1	41.870299	-122.817513	2002-2018
Klamath River	At Walker Creek Bridge	KRWB1	254.8	41.837708	-122.864627	2005-2018
Klamath River	Above Scott River	KRSC1	233.2	41.779236	-123.033245	2002-2018
Scott River	At Johnson Bar	SCKR1	2.5	41.765479	-123.022657	2004, 2006-2018
Klamath River	Below Scott River	KRSC2	227.8	41.78791	-123.078927	2005-2018
Klamath River	At Seiad Valley	KRSV1	209.3	41.854087	-123.231469	2001-2018
Klamath River	Below Happy Camp	KRHC1	164.2	41.729647	-123.425579	2002-2018
Klamath River	At Orleans	KROR1	95.5	41.303576	-123.534386	2001-2006, 2008-2018
Klamath River	Above Trinity River	KRWE1	70.2	41.185991	-123.702282	2002-2018
Klamath River	Below Weitchpec	KRBW2	61.7	41.227666	-123.772591	2004, 2007-2018
Klamath River	above Blue Creek	KRBC1	26.2	41.423077	-123.929328	2003-2018
Klamath River	Above mouth	KRTG2	12.7	41.511184	-123.978439	2004-2018
Trinity River	Below Lewiston Dam	TRBL1[a]	180.6	40.717945	-122.803133	2017-2018
Trinity River	Below Lewiston Dam	TRRC1	173.0	40.720869	-122.829122	2002-2003, 2005-2017
Indian Creek	Near mouth	ICTR1	0.2	40.656452	-122.913884	2002-2018
Trinity River	At Douglas City	DGC*	148.5	40.645278	-122.956665	2005-2018
Trinity River	Above Canyon Creek	TRCN1	127.4	40.731506	-123.056993	2001-2016
Canyon Creek	Near mouth	CNTR1	0.3	40.731906	-123.053819	2001-2018
Trinity River	Above North Fork	NFH*	119.7	40.766532	-123.114479	2005-2018
N.F. Trinity River	Near mouth	NFTR1	0.1	40.770324	-123.127484	2001-2018
Big French Creek	Near mouth	BFTR1	0.1	40.780475	-123.308896	2001-2018
Trinity River	Above Big French Creek	TRBF1	96.8	40.779208	-123.3085	2001-2018
Trinity River	At Burnt Ranch	TRBR1	77.2	40.797284	-123.458798	2001-2018
Trinity River	Above South Fork	TRSF1	50.8	40.88981	-123.602038	2001-2003, 2005-2018
S.F. Trinity River	Near mouth	SFTR1	0.1	40.889434	-123.602214	2001-2018
Trinity River	Above Klamath	TRWE1	0.8	41.181077	-123.705809	2002-2018

*The locations at Douglas City and above the North Fork on the Trinity River are monitored by the Bureau of Reclamation. These data were obtained from the California data exchange center website (https://cdec.water.ca.gov/index.html).

[†]Years operated does not include infilled data.

[a] The site 'Below Lewiston Dam' was relocated upstream in 2017 and the coordinates for TRBL1 have replaced TRRC1 as the location for this site.

Data Analysis

Analyses for 2018 was focused on the period of data recorded between April 1 and October 31, because water temperatures were monitored less consistently outside these dates, and exploratory analyses covering the period of record at each site indicated that water temperatures were usually within the optimal range for Pacific salmon outside these dates. Mean daily water temperatures were < 13.0°C on April 1 at all focal sites in 2018, and were < 13.0°C by October 31 for three of four Trinity River focal monitoring sites and for two of five Klamath River focal monitoring sites. After September 30, 2018, the water year designation changes to 2019, which does not affect any conclusions in this report.

Trinity River Evaluation Criteria

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 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 by the Trinity River Flow Evaluation Study (TRFES; Table 2; 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). Adult salmon temperature criteria are the same in summer and fall regardless of water year. To simplify reporting the water year goes through October 31 (Table 2). Spring and summer juvenile salmon outmigration temperature criteria differ depending on the water year type for the Trinity River and begin in early April and go through 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 usual water year type determination of April 1st.

A water year is defined as the amount of precipitation and other hydrological phenomena that occurred during a 12-month period between October 1 and September 30 of the next calendar year (Paulson et al. 1985). Trinity River water year is further described by type: 'Normal', 'Wet', 'Extremely Wet', 'Dry', and 'Critically Dry' (USDOI 2000). During 'Normal', 'Wet', and 'Extremely Wet' water years, 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' water years, flows out of Trinity and Lewiston dams are managed to facilitate outmigration and provide thermal conditions conducive to juvenile survival.

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).

Water year type	**Locations**	**Period**	**Days criteria is in effect**	**Temperature criteria (mean daily °C)**
		Adult salmonid holding and spawning temperature criteria		
All types	Lewiston to Douglas City	July 1 - Sept. 14	92	≤ 15.6
		Sept. 15 - Sept. 30		≤ 13.3
	Lewiston to North Fork Trinity River	Oct. 1 - Dec. 31	92	≤ 13.3
		Outmigrant salmonid temperature criteria		
Normal, Wet, and Extremely Wet	Lewiston to Weitchpec	April 1 - May 22	100	< 13.0
		May 23 - June 4		< 15.0
		June 5 - July 9		< 17.0
Dry and Critically Dry	Lewiston to Weitchpec	April 1 - May 22	100	< 15.0
		May 23 - June 4		< 17.0
		June 5 - July 9		< 20.0

Klamath River Evaluation Criteria

A set of numeric water temperature criteria comparable to the Trinity River's does 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 the use of science-based, peer-reviewed criteria as a measure of the degree to which water temperatures may be impairing Pacific salmon populations in the Klamath River.

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. The EPA guidelines also recommend different criteria for each of the life history stages of Pacific salmon (Table 3; USEPA 2003; Carter 2006). Adult migration (20°C 7DADM) and juvenile rearing (16°C 7DADM) criteria were applied to the Klamath River year round, due to overlapping run timing and life history strategies (Leidy and Leidy 1984; Shaw et al. 1997). Spawning, incubation, and emergence criteria (13°C 7DADM) were applied to the period of October 1 through April 30, the time frame when the majority of these reproductive activities occur in the Klamath basin (Leidy and Leidy 1984; Shaw et al. 1997). This spawning, incubation, and emergence criteria is utilized for the portion of data that is analyzed in this report: October 1-31 and April 1-30.

Table 3. EPA criteria for Pacific Northwest water temperatures to protect Pacific salmon (USEPA 2003). These criteria were interpreted using the EPA recommended metric of seven-day average daily maximum temperatures (7DADM) and were used in the evaluation of Klamath River water temperatures.

Temperature criteria (°C)	Period	Life history focus
< 13.0	Oct. 1 - April 30	Spawning, incubation, and emergence
< 16.0	Year round	Rearing juvenile salmonids
< 20.0	Year round	Migrating adult salmonids

General Analysis

For each day of the year at each Trinity River focal monitoring location, the long-term mean, minimum, and maximum of mean daily water temperatures were calculated across all years of available data. Identical calculations were implemented for the Klamath River focal monitoring sites using 7DADM temperatures instead of mean daily temperatures. These values provided the context (mean and range of observed values) for which to compare 2018 water temperatures. The number of days that exceeded the associated water temperature criteria were calculated for each focal monitoring location in each year with complete or sufficient data to encompass the period of time a criterion was exceeded. Finally, for each focal location, the long-term mean, 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 2015).

Infilling Data

Water temperature time series at some focal sites contained gaps due to the loss of loggers due to high flow events or theft, corruption of logger data, or exposure of loggers to air temperatures during low-flow periods. When available, data from other loggers at the same or nearby locations was used to infill time series gaps. Sources of supplemental data include additional USFWS monitoring locations and data collected by the U.S. Forest Service (USFS), U.S. Geological Survey (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 predict 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 nature of the data and the strong thermal inertia of water. The GLS regressions were implemented using the nlme R package (Pinheiro et al. 2017).

In 2018 there were no days infilled for the Trinity River data. On the Klamath River there were 39 total days infilled. Temperature data was infilled for one day at Klamath River site near Weitchepec (KRWE1) and 38 days at Klamath River site near the mouth (KRTG2). Data from USGS gage 11523000 was used to model and infill KRWE1, approximately 25.3 km upstream of the site, and data from USGS gage 11530500 was used to model and infill KRTG2, which was at approximately the same location.

Plots of the regression used and root mean square error values (RMSE) can be found in Appendix E.

Supplemental Flow Evaluation Criteria

The temperature objective (Logomarsino and Hetrick 2013) of the supplemental flows is to reduce mean daily temperature below 23℃, the migration threshold for adult Chinook Salmon in the lower Klamath River (Strange 2010). Temperature below the Trinity confluence (KRBW2) represents the upstream extent of supplemental flow effects on the Klamath River, while temperature near the mouth of the Klamath (KRTG2) represents the most downstream.

To evaluate these supplemental flows, mean daily water temperatures were compared from five monitoring locations, four of which are focal sites (TRBL1; KRIG1; KRWE1; KRTG2) and remaining site is located on the Klamath River below the confluence with the Trinity River (KRBW2). Daily mean discharge values were gathered from five USGS gaging stations to assess the scale and influence of the supplemental flow on the lower Klamath River. USGS stations were located on the Klamath 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 these 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. In July 2018, the Carr Fire in northern California impacted the release schedule from Lewiston Reservoir, and emergency flows were instituted due to fire proximity to the operations center.

Results

Trinity River

In 2018, a ‘Critically Dry’ water year, there were temperature criteria exceedances at all focal sites, with a total of 72 days of exceedance across all sites. The number of days exceeded in 2018 is more than the long-term mean number of days exceeded per year (x = 38.2; Appendix A). Daily criteria exceedances were two days at NFH, 26 days at DGC, and 44 days at TRWE1 (Table 4; Figure 2). The number of days exceeded at both DGC and TRWE1 were more than their respective long-term mean number of days exceeded at each site (DGC, x = 6.4; TRWE1, x = 29.9; Appendix A).

Outmigrant criteria, April 1 through July 9, was exceeded in all three periods at TRWE1. Temperatures were recorded at 15℃ for fifteen days, 17℃ for seven days, and 20℃ for twenty-two days. Neither DGC nor NFH exceeded outmigrant criteria (Table 4).

Adult holding and spawning criteria, July 1 through October 31, was exceeded in two periods, at 15.6℃ for 26 days at DGC, and at 13.3℃ for two days at NFH. The 13.3℃ criteria period at DGC was not exceeded (Table 4). During 2018 a total of 120 days exceeded the observed historical range of recorded temperatures: 10 days at TRBL1, 65 days at DGC, 35 days at NFH, and 10 days at TRWE1 (Figure 2).

On April 17 releases from Lewiston Dam into the Trinity River increased from the baseflow of approximately 300 cfs to 1,440 cubic feet per second (cfs). After the initial release, there was a gradual decrease to 350 cfs and then a subsequent increase to 1430 cfs by April 28. Small variations in cfs continued from Lewiston Dam until peak flow was achieved at 1,770 cfs on May 14. After this point, there was a gradual decrease in streamflow until July 25 at 450 cfs. On July 26 in response to the Carr Fire, flow released from Lewiston Dam ascended to 984 cfs and was generally maintained at 800 cfs until August 20. Supplemental flow release began on August 21 and was held at approximately 700 cfs until returning to 450 cfs on September 21 and through the end of the period of observation (Buxton 2019).

Water temperatures at the focal Trinity River monitoring locations for 2000-2017 are found in Appendix B.

Table 4. The number of days exceeded temperature management targets in 2018 at focal sites on the Trinity River, 'Critically Dry' water year criteria. TRBL1 = Trinity River below Lewiston Dam; DGC = Trinity River at Douglas City; NFH = Trinity River below North Fork Trinity; TRWE1 = Trinity River above confluence of Klamath River.

			Outmigrant Criteria			*Adult Holding and Spawning Criteria*		
Site Name	**Location Code**	**rkm**	**4/22-5/22 15℃**	**5/23-6/4 17℃**	**6/5-7/9 20℃**	**7/1-9/14 15.6℃**	**9/15-9/30 13.3℃**	**10/1-10/31 13.3℃**
Below Lewiston	TRBL1[a]	173.0	-	-	-	-	-	-
At Douglas City	DGC [b, c]	148.5	0	0	0	26	0	-
Above North Fork	NFH [b, d]	119.7	0	0	0	-	-	2
Above Klamath	TRWE1[d, c]	0.8	15	7	22	-	-	-

[a] No management criteria were identified for below Lewiston Dam.

[b] Sites operated by USGS, data retrieved from CDEC.

[c] No management criteria identified between Oct. 1 - Oct. 31.

[d] No management criteria identified between July 1 - Sept. 30.

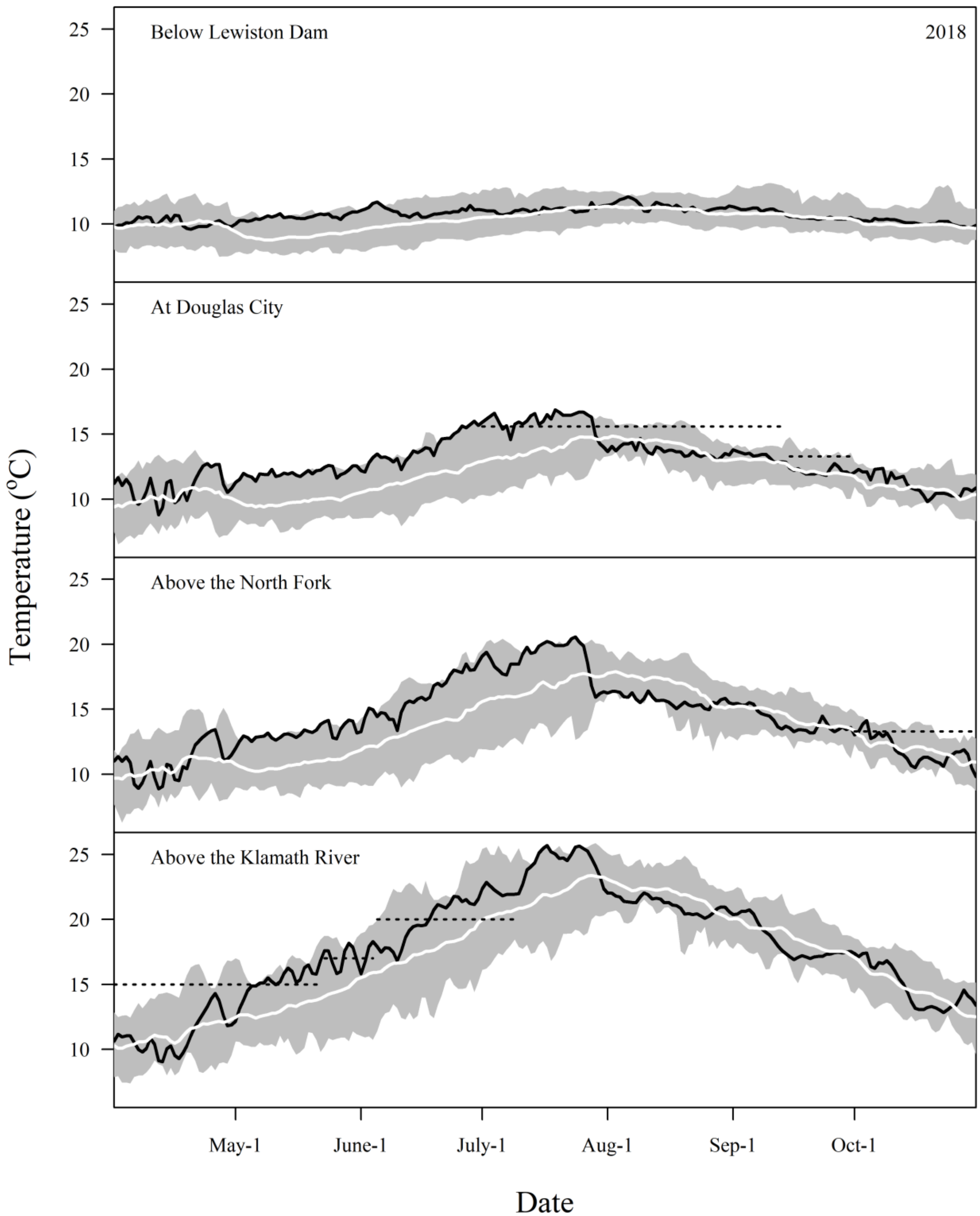

Figure 2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2018, with historical conditions. Black line = mean daily water temperatures in 2018; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature criteria.

Klamath River

In 2018, the number of days exceeding the spawning, incubation, and emergence EPA 13.0℃ 7DADM criteria at focal Klamath River monitoring sites ranged from 31days at KRIG1 and KRWE1, to 38 days at KRSC1(Figure 3; Table 5; Appendix C). The number of days exceeding the spawning, incubation, and emergence criteria were above their respective long-term means at KRSC1, KRHC1, KRWE1, and KRTG2, but did not exceed the range of days exceeding the 13℃ 7DADM criteria in the period of record.

The number of days exceeding the juvenile rearing EPA 16.0℃ 7DADM criteria ranged from 153 days at KRWE1, to 160 days at KRSC1. The number of days exceeding the juvenile rearing criteria were more than their respective long-term means at all sites, but did not exceed the period of record observed number of days exceeding the 16℃ 7DADM criteria.

The number of days exceeding the adult migration EPA 20.0℃ 7DADM criteria ranged from 88 days at KRTG2, to 110 days at KRSC1. The number of days exceeding the adult migration criteria were more than their respective long-term means at KRIG1, KRSC1, KRHC1, and KRTG2, but did not exceed the range of period of record observed number of days exceeding the 20℃ 7DADM criteria.

In 2018, when combing all days across sites, there were a total of 204 days that exceeded period of record observed temperatures at focal sites on the Klamath River: 42 days at KRIG1, 74 days at KRSC1, 45 days at KRHC1, 18 days at KRWE1, and 25 days at KRTG2. These exceedances of observed historical range happened in all months within the analysis timeframe.

Flows from Iron Gate Dam were between 1700 and 1900 cfs from April 1 to April 6 when flows increased to 3890 cfs, and subsequently peaked at 6170 cfs on April 7. From April 8, flows generally decreased from 6000 cfs to 1270 cfs on May 7. On May 8 flows increased to 2140, and stayed at approximately 3000 cfs from May 9 to May 19. From May 20, flows decreased from 2890 cfs to 1000 cfs on June 2. On June 7 flows increased to 1250 cfs, and continued to increase until reaching1670 cfs on June 9. From June 10, flows gradually decreased and stayed at about 900 cfs until August 24, when it increased to 1440 cfs. Flows increased to 1820 cfs on August 25, and decreased to 1000 cfs, varying slightly, for the remainder of the study period.

7DADM water temperatures at the focal Klamath River monitoring locations for 2000-2017 are found in Appendix D.

Table 5. The number of days exceeding the EPA 7DADM criteria for Pacific Northwest water temperatures to protect Pacific salmon at Klamath River focal monitoring sites in 2018. The numbers in parentheses represent the mean, minimum, and maximum number of days exceeding the water temperature criteria across the period of record for each location, respectively. KRIG1 = Klamath below Iron Gate Dam; KRSC1 = Klamath above the Scott River; KRHC1 = Klamath below Happy Camp; KRWE1 = Klamath above the Trinity River; KRTG2 = Klamath above the mouth.

Location code	**rkm**	*Spawning, incubation, and emergence:*	*Juvenile rearing:*	*Adult migration:*
		13.0°C 7DADM	**16.0°C 7DADM**	**20.0°C 7DADM**
KRIG1	309.7	31 (33.6, 26-49)	157 (148.6, 129-163)	100 (89.3, 74-102)
KRSC1	233.2	38 (35.6, 25-52)	160 (147.9, 128-175)	110 (99.2, 98.5-120)
KRHC1	164.2	37 (31.3, 25-51)	157 (140.1, 116-176)	104 (96.7, 73-128)
KRWE1	70.2	31 (30.5, 23-44)	153 (135.6, 110-176)	89 (89.3, 63-119)
KRTG2	12.7	35 (33.9, 27-51)	156 (136.9, 118-171)	88 (85, 64-110)

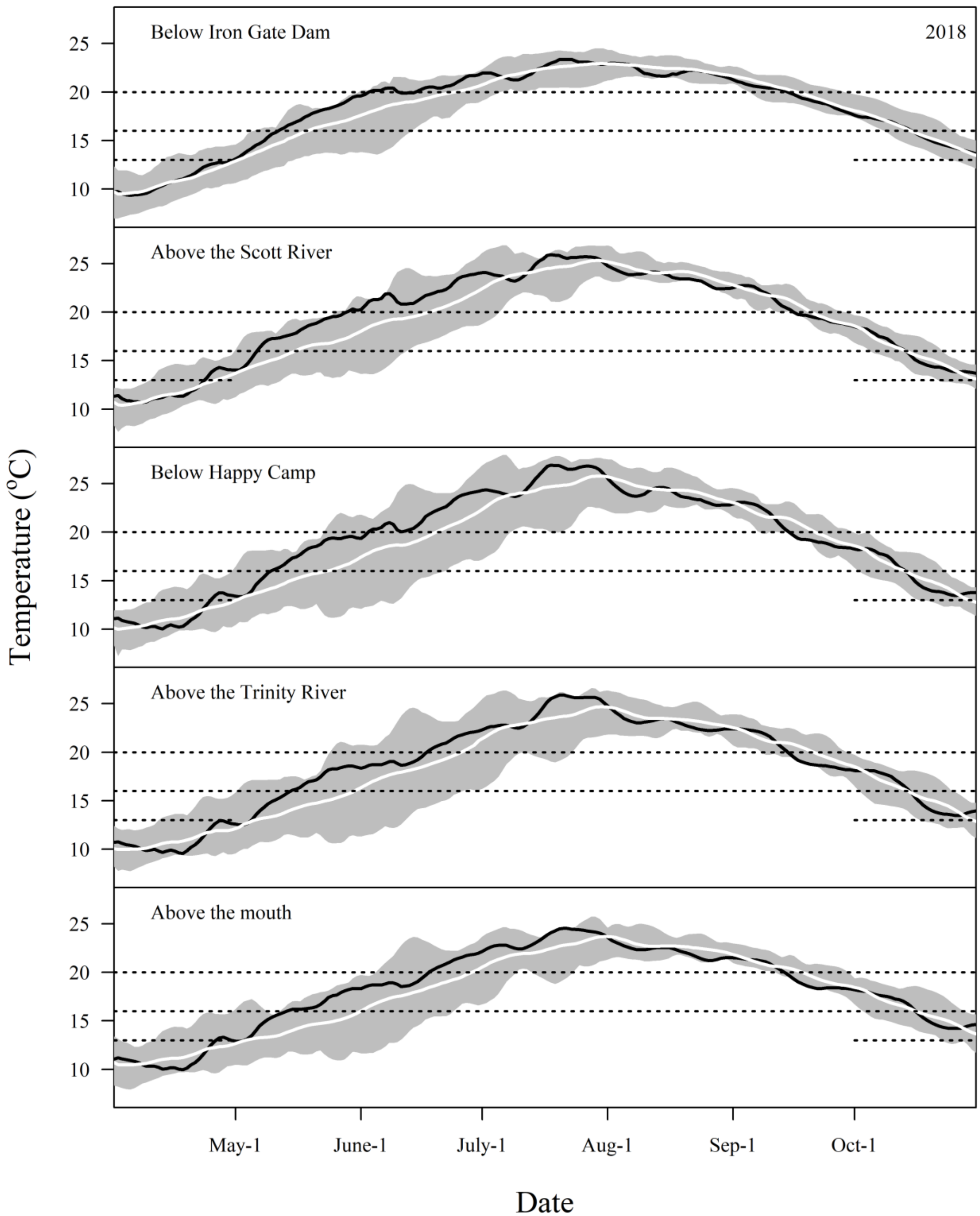

Figure 3. 7DADM water temperatures at focal Klamath River monitoring sites, April 1 – October 31, 2018, with historical conditions. Black line = 7DADM water temperatures in 2018; white line = long-term mean 7DADM for each day of the year; gray polygon = long-

term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

Supplemental Flow

In 2018, increased flow out of Lewiston Dam began on July 26, and returned to base flow on September 21 (Buxton 2019; USDOI and USBOR 2018). This flow incorporated two actions, an emergency release (July 26 to August 20) in response to the Carr Fire near the operations center for Lewiston Dam, and a supplemental flow (August 21 to September 21) to manage temperatures in the lower Klamath River. Due to the similarity in timing and intensity of these actions, they are treated as a single action for analysis purposes.

Mean daily temperature at KRTG2 exceeded 23℃ for 12 days prior to the supplemental flow release, and four days during the supplemental flow release. Mean daily temperature at KRBW2 exceeded 23℃ for 14 days prior to the supplemental flow release, and five days during the supplemental flow release. Mean daily average temperatures at KRTG2 and KRBW2 both were below 23℃ on July 30 and July 31 respectively, and remained below the criteria through the end of the study period.

Prior to the Carr Fire release and supplemental flow period, the temperature in the lower Klamath River peaked at a mean daily temperature of 25.5℃ at KRBW2 and 24.3℃ at KRTG2. By the conclusion of the supplemental flow period on September 20, the mean daily temperature was 17.6℃ at KRBW2 and 17.9℃ at KRTG2. During this period, there was an average decrease in daily temperature of 0.4℃ at KRBW2 and 0.5℃ at KRTG2 when compared to KRWE1 (Appendix F).

During the supplemental flow period, there was a drop in temperature at all focal sites on the Trinity River. Each focal site experienced a decline in temperature prior to the supplemental flow release. At DGC there was a 3.0℃ decline over the course of seven days between July 26 and August 1. At NFH there was a 4.0℃ decline over the course of four days, between July 26 and July 29. At TRWE1 there was a 4.2℃ decline over the course of 14 days between July 26 through August 8 (Figure 2).

Discussion

Trinity River

Water temperature criteria for the Trinity River were exceeded more frequently in 2018 (*n*=65) than in 14 of the previous 17 years. However, there were less exceedances than in 2014, which had the greatest number of exceedances observed to date (*n*=86; Appendix A) and was the only prior year designated as ‘Critically Dry’. While exceedances by location were similar between 2018 and 2014 at DGC and TRWE1, most differences occurred at the NFH site, where 2014 had 15 days and 2018 had two days exceeding criteria. Exceedances above the 15.6℃ criteria occurred at DGC during both years, primarily in early July. Both years’ daily mean temperatures were almost exclusively above the long-term mean for the first half of the study period. Exceedances at TRWE1 also occurred on a similar timeline between years. With small exceptions in 2014, they began exceeding the 15℃ criteria in mid-May, the 17℃ criteria interspersed throughout late-May and early-June, and the 20℃ criteria in mid-June for the remainder of that criteria period (Appendix B; Figure 2).

Water year 2018 was designated as 'Critically Dry'. Precipitation within the Trinity River watershed unit was recorded at 68% of normal in May 2018, and snowpack at 10% of the May 1 average (CDWR 2018a; CDWR 2018b). These factors likely had an influence on the overall temperature criteria exceedances and on the temperatures above the observed historical range (n=18) at all focal sites in 2018.

In early-April there was variation in the mean daily temperature, but from mid-April through late-July the mean daily temperature was almost exclusively above the long-term mean at all focal sites. At DGC and NFH the warmest observed temperatures were reached or close to reaching frequently, while only reaching this mark occasionally at TRWE1. This period of high temperatures and receding discharge from the Lewiston Reservoir is associated with criteria exceedances at DGC, at 15℃, and TRWE1, at 15℃, 17℃, and 20℃. After late-July and until late-August, the mean daily temperature was below the long-term mean at DGC, NFH, and TRWE1. This corresponds to the Carr Fire/Supplemental flow release from the Lewiston Reservoir beginning in the same time period. Through late-August and the end of the period of observation, there are slight variations in temperature at each site. At DGC and NFH there are points where temperature meets or exceeds the observed historical range (n=18) of temperatures, and two days exceeding criteria at NFH in early-October.

Temperature criteria exceedances at DGC, for 15.6℃, happened only from July 1 to July 28, approximately 30% of the location's criteria time period, and did not occur at either criteria period after July 28. These exceedances are associated with summer baseflow levels from Trinity Reservoir of 450 cfs. Of the days in this criteria period, 23 days had the warmest observed daily mean in the period of record. The exceedances at this focal site were likely limited in large part due to the supplemental flow period beginning in late-July.

Temperature criteria exceedances at NFH, for 13.3℃, happened twice, on October 3 and 4, and immediately dropped below the criteria and stayed below for the remainder of the period. There was likely some influence from precipitation levels in October, which were 24% of average (CDWR 2019a; CDWR 2019b).

Temperature criteria exceedances at TRWE1, for 15℃, happened from May 7 to May 22. For the 17℃ criteria, exceedances occurred on seven days throughout the 13-day criteria period. For the 20℃ criteria, exceedances happened from June 18 to July 9. These exceedances at TRWE1 occurred for 44% of the location's criteria time period. Likely influences on these exceedances include the low levels of precipitation and snowpack as described in the California Depart of Water Resources (2018a) report.

Klamath River

According to EPA guidelines, in 2018, the migrating adult salmon and rearing juvenile salmon criteria were exceeded for approximately three months at all sites for the 20.0℃ criteria, approximately five months at all sites for the 16.0℃ criteria, and approximately a month at all locations for the 13.0℃ criteria. The number of days exceeding per location criteria combination were almost exclusively above their respective long-term means, excluding KRWE1 20.0℃ and KRIG1 13.0℃ (Table 5).

Similar to the Trinity, precipitation in the Klamath River watershed unit was 64% of normal by the end of April in 2018, and 10% of the May 1 average snowpack (CDWR 2018a; CDWR 2018b). Precipitation stayed low and was 32% of the October average (CDWR 2019b). These factors likely had an influence on the overall temperature criteria exceedances and on the temperatures above the historical range (*n*=18) at all focal sites in 2018.

In early-April all sites were measured above the long-term 7DADM, but were below the long-term 7DADM for a majority of the month. In late-April, KRSC1, KRHC1, and KRTG2 all had exceedances of the 13.0℃ 7DADM criteria and can generally be associated with a reduction in discharge from Iron Gate Dam during the same period. By mid-May, all sites had surpassed their 16.0℃ 7DADM criteria. Although this time period is associated with an increase in discharge from Iron Gate Dam, it is likely that other environmental factors played a part in influencing the overall increase in temperature. There were some fluctuations in flows throughout early-June, though this seems to have had marginal effects on the overall temperature as KRSC1 surpassed the 20.0℃ 7DADM criteria by May 29 and all other sites by June 18 (Table 5; Figure 3).

Temperatures stayed above 20.0℃ 7DADM at all sites through mid-September, and all sites were below the adult migration criteria between September 14 and 16. There was likely little influence from Iron Gate Dam (IGD) discharge in this contemporaneous shift as there was little variation from late-August through the end of the study period. It is more likely that there were multiple and combining environmental factors including a shift in air temperatures, increased precipitation, and/or the influence of wildfire related smoke (David et al. 2018). There was a short period of time during mid-September where four of the five focal sites were measured at their lowest average daily temperature within the observed historical range (*n*=18) 7DADM (Figure 3; KRSC1, 1 day; KRHC1, 6 days; KRWE1, 5 days; KRTG2, 5 days). All sites reached the juvenile rearing criteria of 16.0℃ 7DADM by mid-October, and all sites again reached these criteria on a very similar timeline between October 14 and 17. This simultaneous shift in mid-October is consistent with the observed period of record 7DADM (Figure 3). No sites met the 13.0℃ 7DADM criteria by the end of the study period.

Comparing 2018 to the previous year, there were more days exceeding criteria for 7DADM at all sites, except at KRTG2 20.0℃ and KRIG1 13.0℃. At the 20.0℃ criteria, sites exceeded nine more days on average than in 2017, excluding KRTG2. At the 16.0℃ criteria, sites exceeded 31.8 more days on average than in 2017. At the 13.0℃ criteria, sites exceeded 7.5 more days on average than in 2017 (Appendix C).

Generally, Klamath River temperatures at all focal sites were above the long-term 7DADM, with slight variations at each site from May to late-July. After late-July there was more variation in the 7DADM, and more days below the long-term 7DADM. This is particularly true when considering the juvenile rearing criteria, 16.0℃, 7DADM for 2018, where all sites were above the long-term number of days exceeding 7DADM criteria. This suggests that there were higher sustained water temperatures in the Klamath in general, and specifically, higher sustained temperatures at KRSC1, KRHC1, and KRTG2, where all site and temperature combinations were above their long-term 7DADM in all criteria periods for 2018 (Table 5).

Supplemental Flow

Previous evaluation of supplemental flows from Lewiston Reservoir have found that this action does lead to decreased temperatures in the lower Klamath River (Zedonis 2003, 2004, 2005; Magneson 2015; David and Goodman 2017). Over the course of the Carr Fire release and supplemental flow period, the mean daily discharge was 750 cfs, averaging 300 cfs above summer baseflow from Lewiston Reservoir (USGS gage 11525500).

There were 19 days in 2018 at KRBW2 where the mean temperature was ≥ 23℃ criteria (Appendix F). There are five days during the period of supplemental flow that also exceeded the 23℃ criteria. At KRTG2 there were 16 days where the mean temperature was ≥ 23℃ criteria (Appendix F). Water temperatures at both sites stayed below the 23℃ criteria after the conclusion of the supplemental flow.

Temperatures were ≥ 23℃ for 21 days at KRWE1, immediately upstream of the Trinity River confluence with the Klamath. These days occurred from July 12 to 31, and again on August 10. This suggests that though the supplemental flow had a cooling influence on temperatures in the lower Klamath River, it's effects were limited in scope, and likely had a greater positive impact on the river discharge level below the confluence in regards to achieving objectives outside of water temperature criteria (Hetrick et al. 2016).

In 2018 the supplemental flow incorporated an emergency release associated with the Carr Fire (USDOI and USBOR 2018). The emergency release in 2018 was on average 25 days earlier than prior supplemental flow releases (David and Goodman 2017). There is evidence to suggest that discharge is an environmental cue for the timing of upriver migration in anadromous salmonids and facilitates upstream movement (Shapovalov and Taft 1954; Jonsson 1991; Keefer et al. 2004; Keefer et al. 2008). It is possible that because of the early timing of this discharge event there was an influence on the timing of both the spring and fall Chinook runs.

Acknowledgements

We thank the Yurok Tribe Environmental Program, especially Kassandra Grimm, for assistance with deploying and retrieving temperature loggers in the lower Klamath and Trinity rivers and for sharing water temperature data for the infilling of gaps in our time series. We would also like to thank USFWS employees Brianna Walsh, Carmen Leguizamon, David Kissling, Greg Gray, Michael Macon, Ryan Bernstein, Shannon Boyle, and Sterling Fulford who assisted with retrieval and deployment of temperature loggers throughout the basin, and Damon Goodman for programmatic support. Finally, we thank Damon Goodman, Nicholas Hetrick, and Kate Wilcox for their editorial efforts and support.

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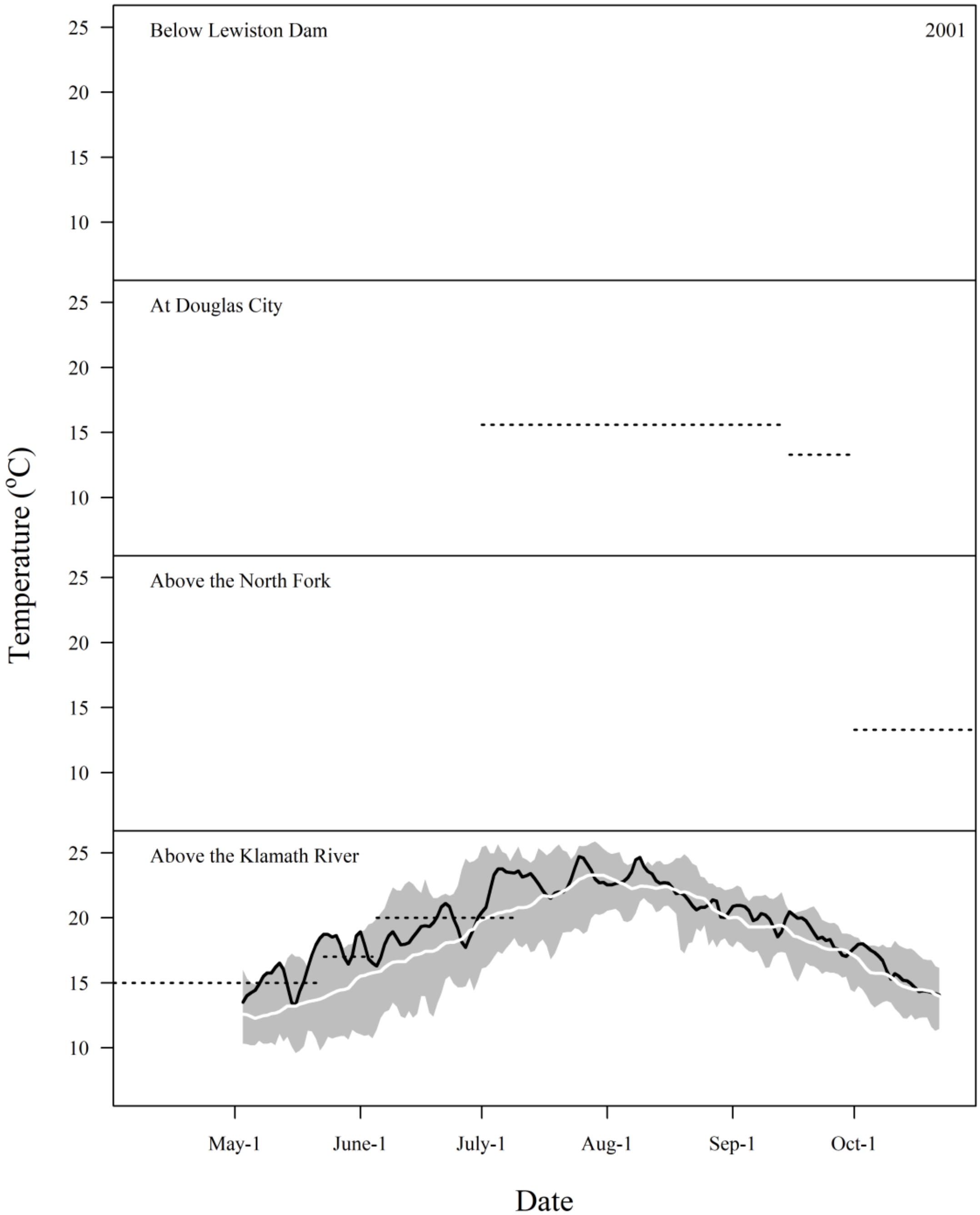
Appendices

Appendix A. Number of days exceeding numeric water temperature criteria for the four focal locations on the Trinity River, 2001-2018. TRRC1 = Trinity River Below Lewiston Dam; DGC = Trinity at Douglas City; NFH = Trinity above the North Fork Trinity; TRWE1 = Trinity above the Klamath.

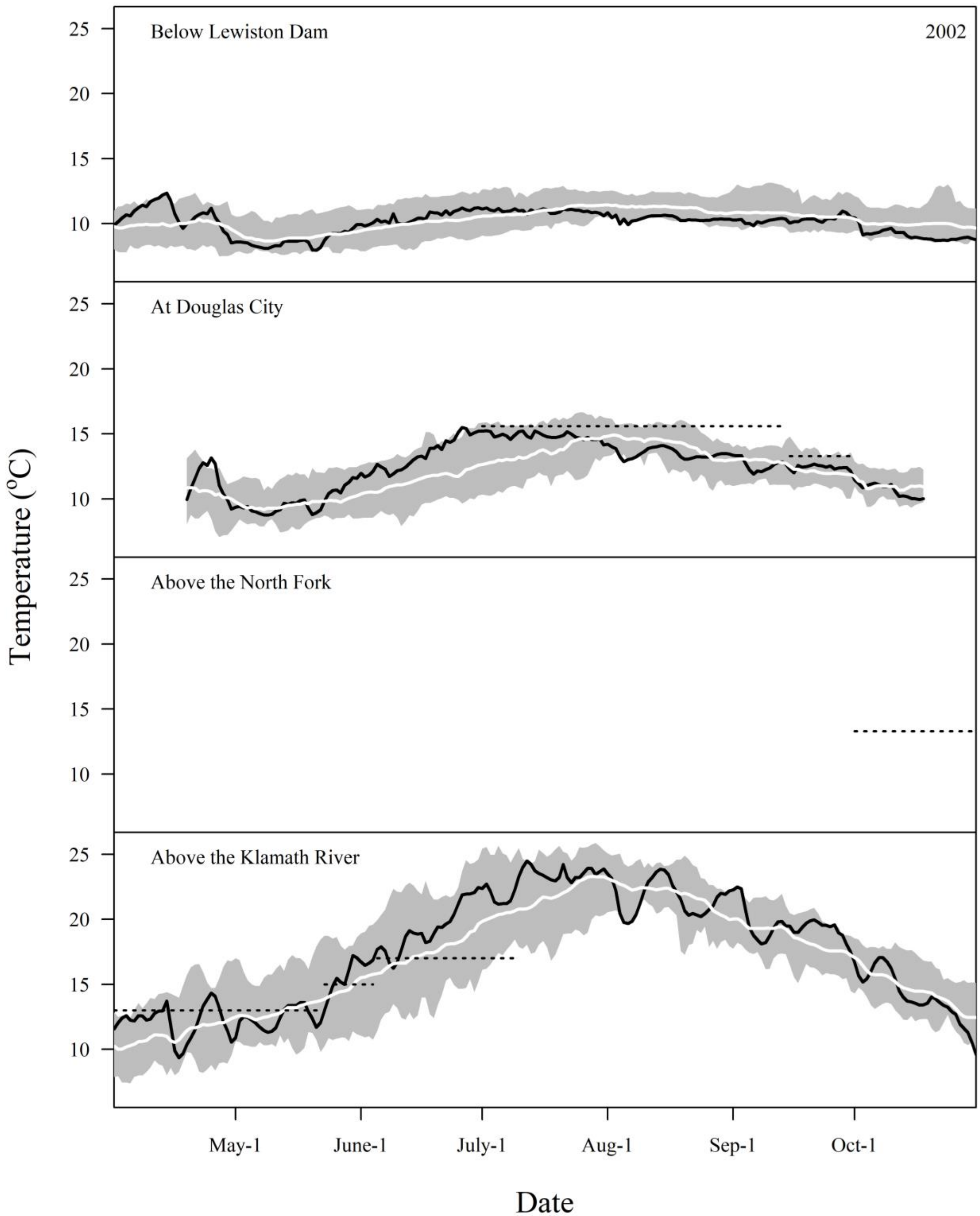
	Criteria locations					
Year	**TRBL1**	**DGC**	**NFH**	**TRWE1**	**Total**	*Water year type*
2001	--	--	--	33[a]	33	Dry
2002	--	0	--	54	54	Normal
2003	--	11	--	34	45	Wet
2004	--	0	--	43	43	Wet
2005	--	--	1	21[b]	22	Wet
2006	--	6	0	18	24	Ex. Wet
2007	--	3	0	19	22	Dry
2008	--	1	4	0	5	Dry
2009	--	31	2	21	54	Dry
2010	--	6	7	10	23	Wet
2011	--	0	0	7	7	Wet
2012	--	0	1	25	26	Normal
2013	--	0	0	26	26	Dry
2014	--	18	15	53	86	Crit. Dry
2015	--	--	18	65	83	Dry
2016	--	14	3	52	69	Wet
2017	--	0	0	27	27	Ex. Wet
2018	--	26	2	44	72	Crit. Dry

[a] Data unavailable prior to 5/3 for TRWE1 in 2001. It was assumed mean daily temperatures did not reach or exceed 15.0 C before this date.

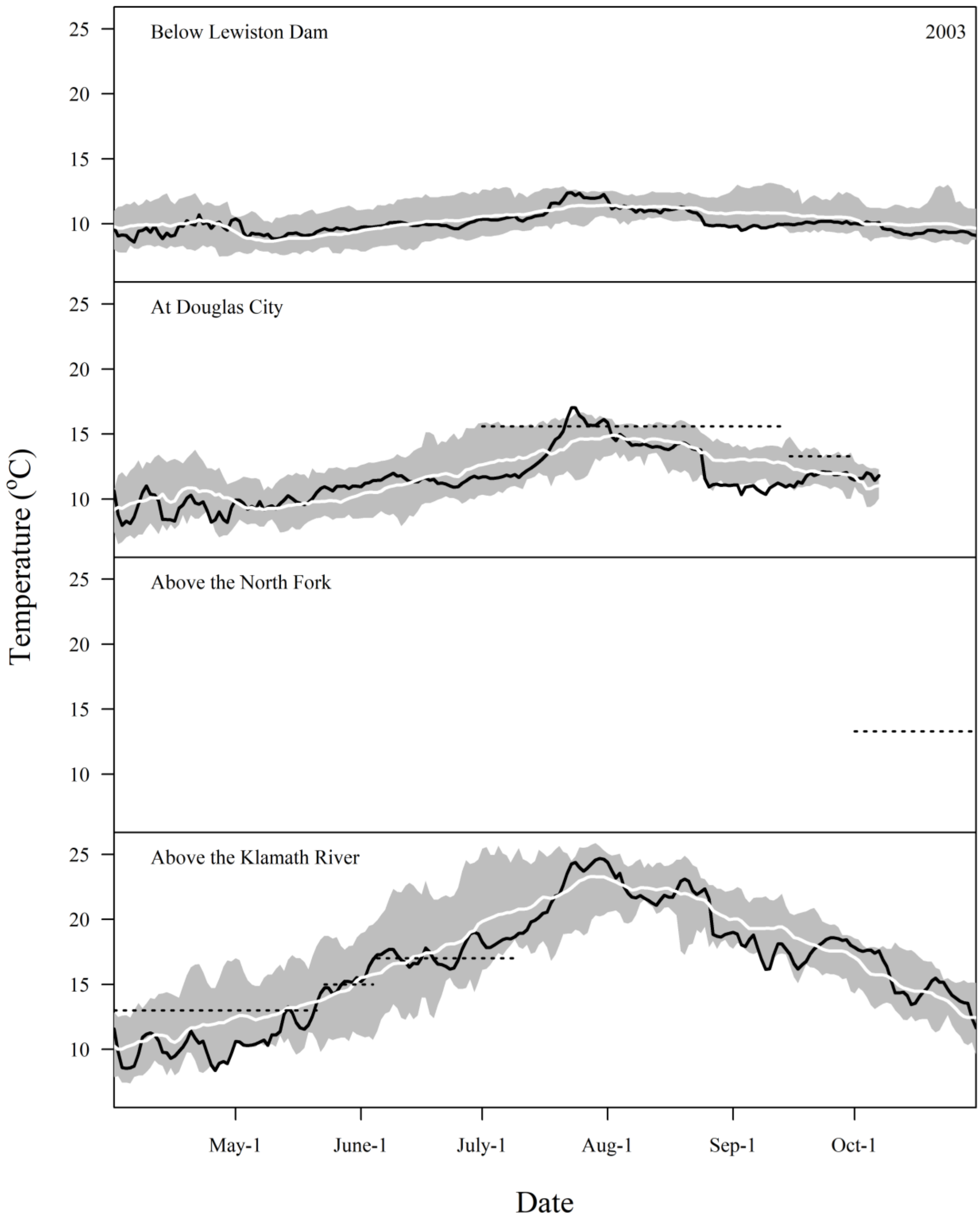
Appendix A. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2001-2017 with historical conditions. Includes both observed and infilled water temperatures.



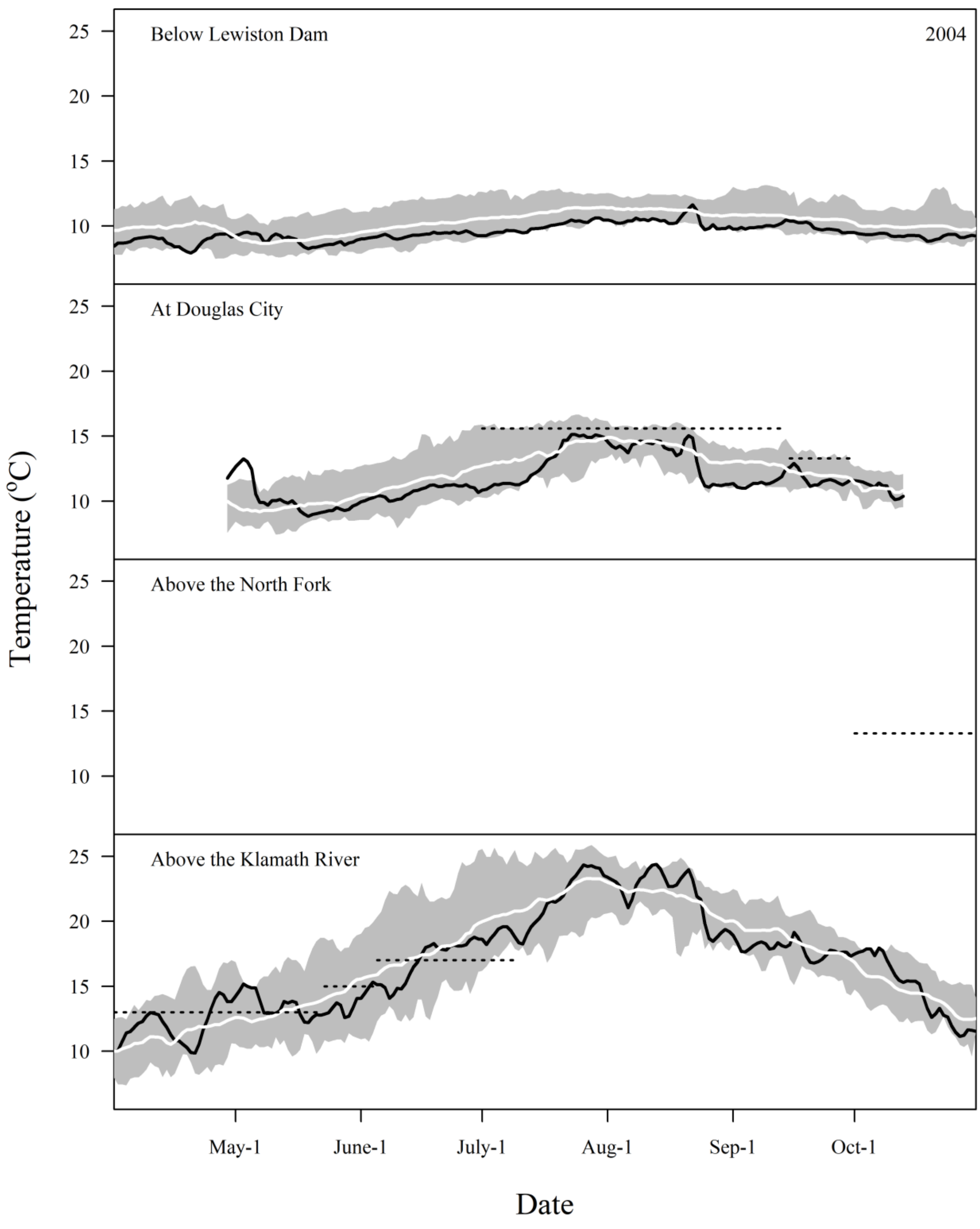
Appendix B1. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = mean daily water temperatures in 2001; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives. Sections that are blank indicates that during that period no data exists for the site.



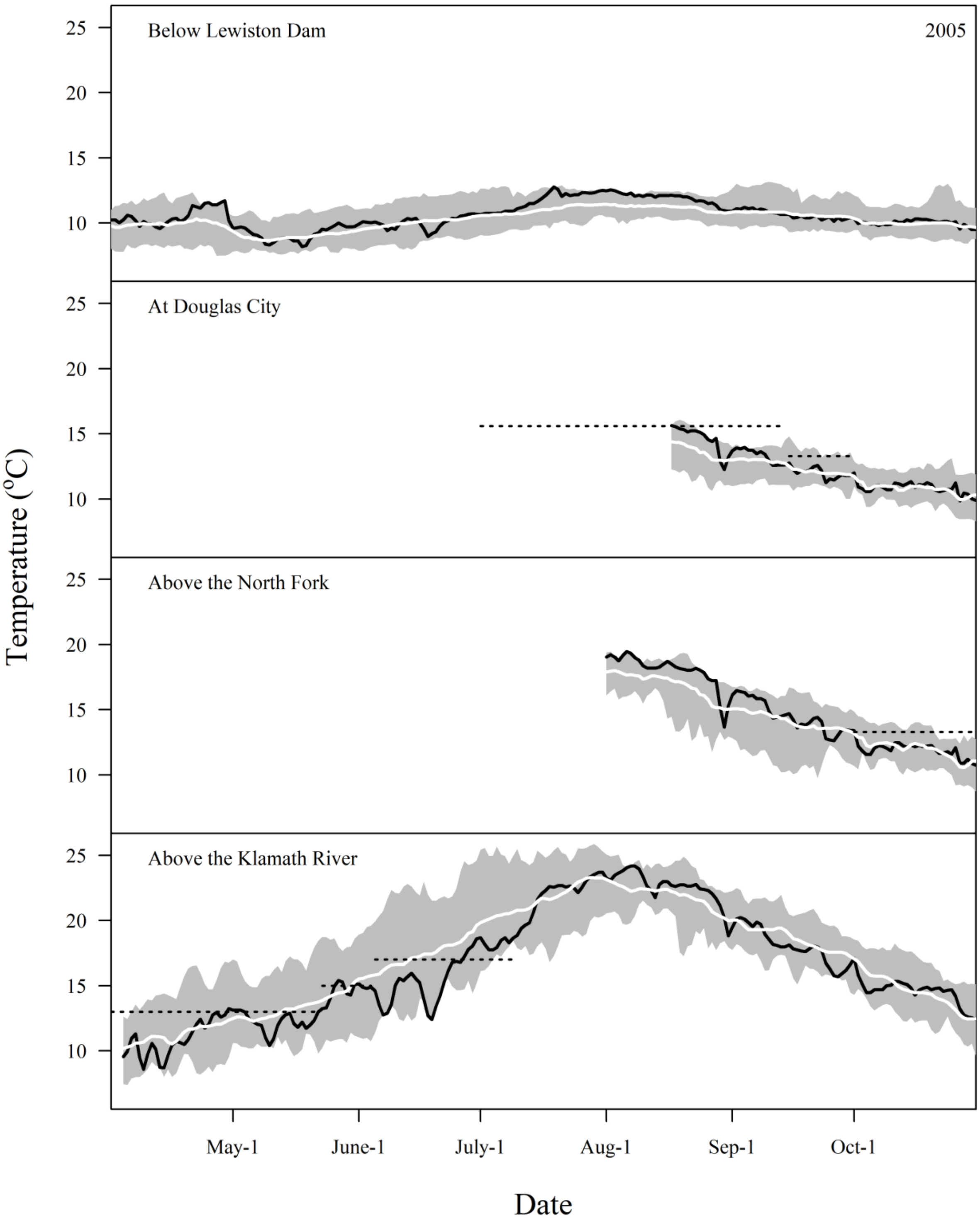
Appendix B2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = mean daily water temperatures in 2002; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives. Sections that are blank indicates that during that period no data exists for the site.



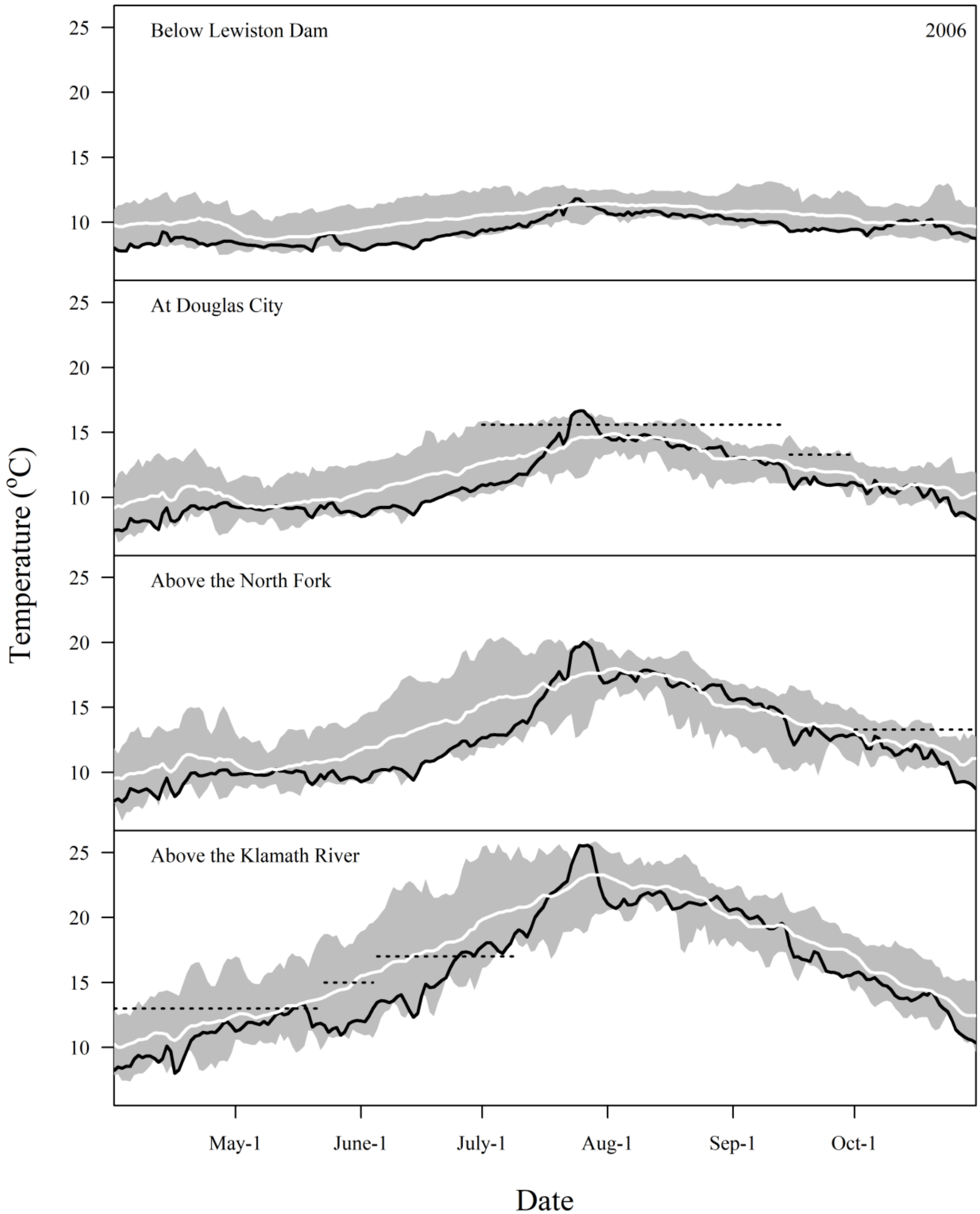
Appendix B3. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = mean daily water temperatures in 2003; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives. Sections that are blank indicates that during that period no data exists for the site.



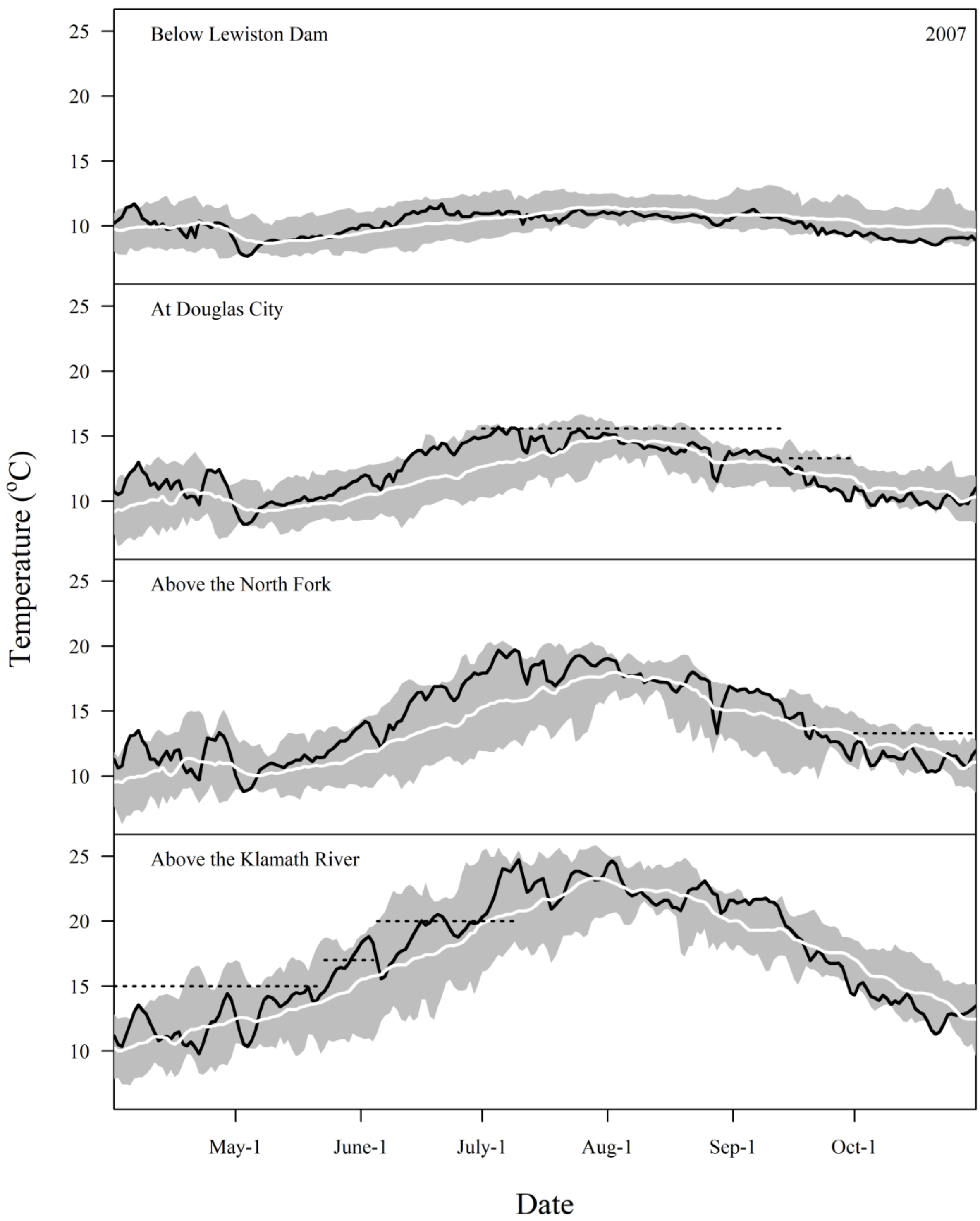
Appendix B4. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = mean daily water temperatures in 2004; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



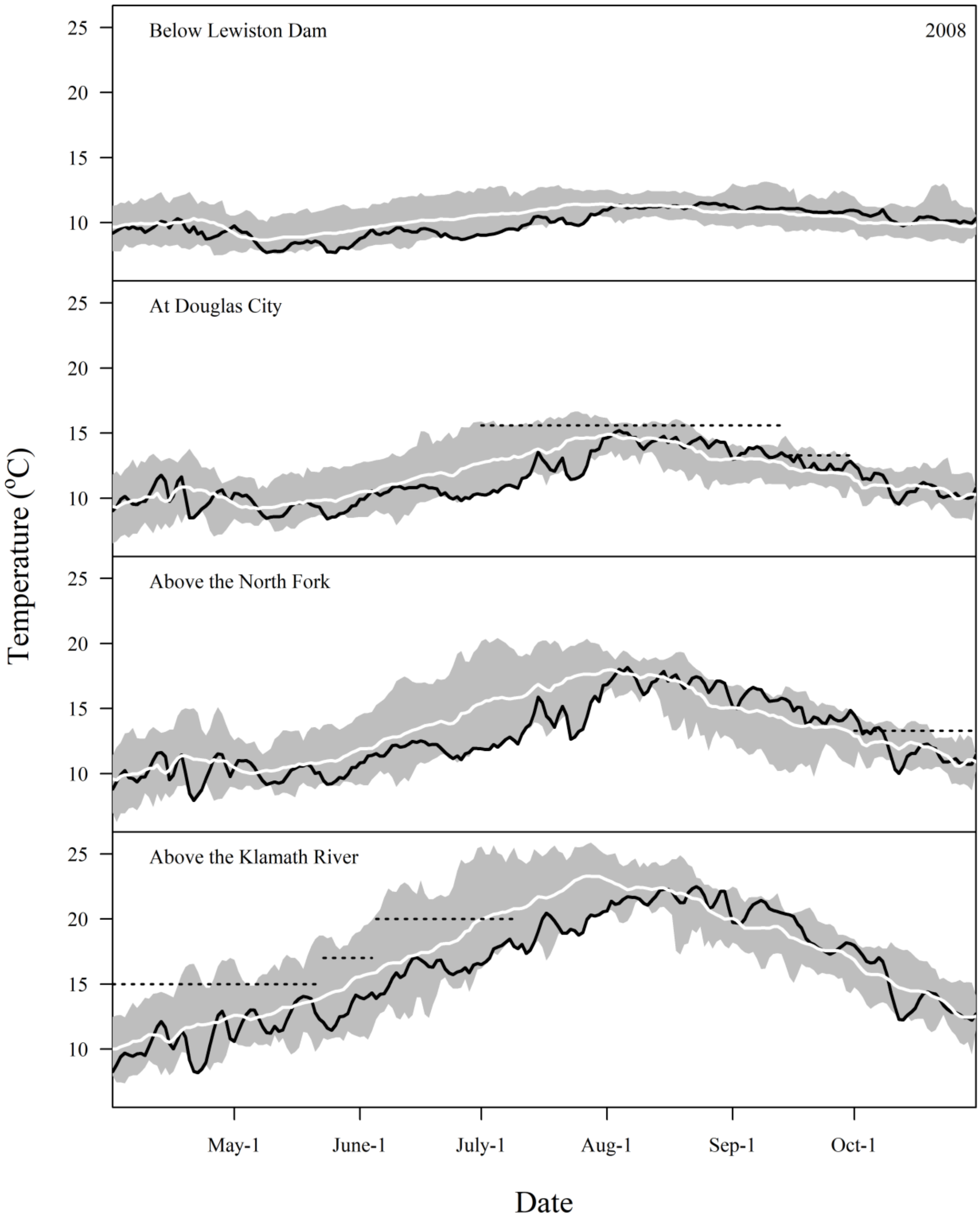
Appendix B5. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = mean daily water temperatures in 2005; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



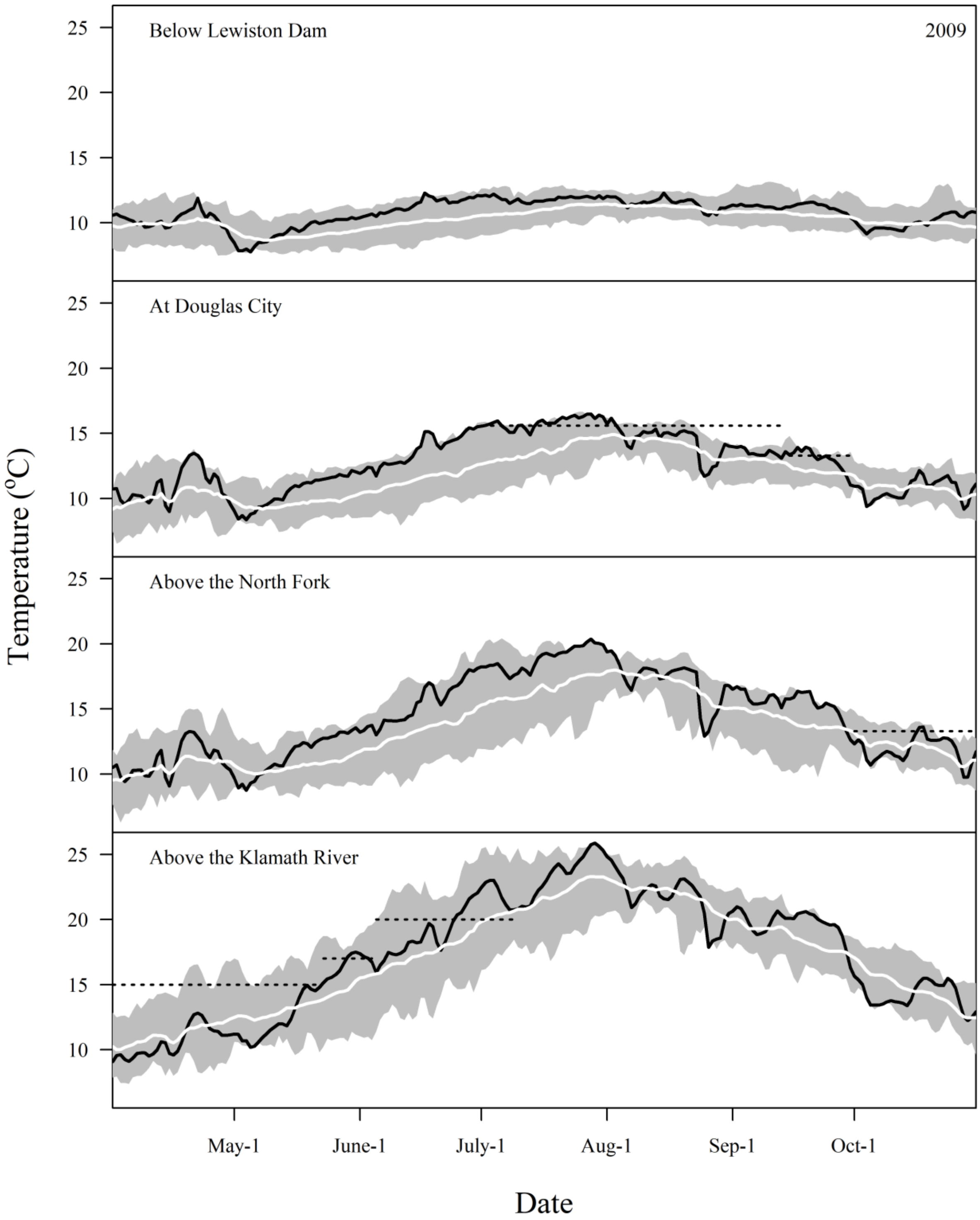
Appendix B6. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = mean daily water temperatures in 2006; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



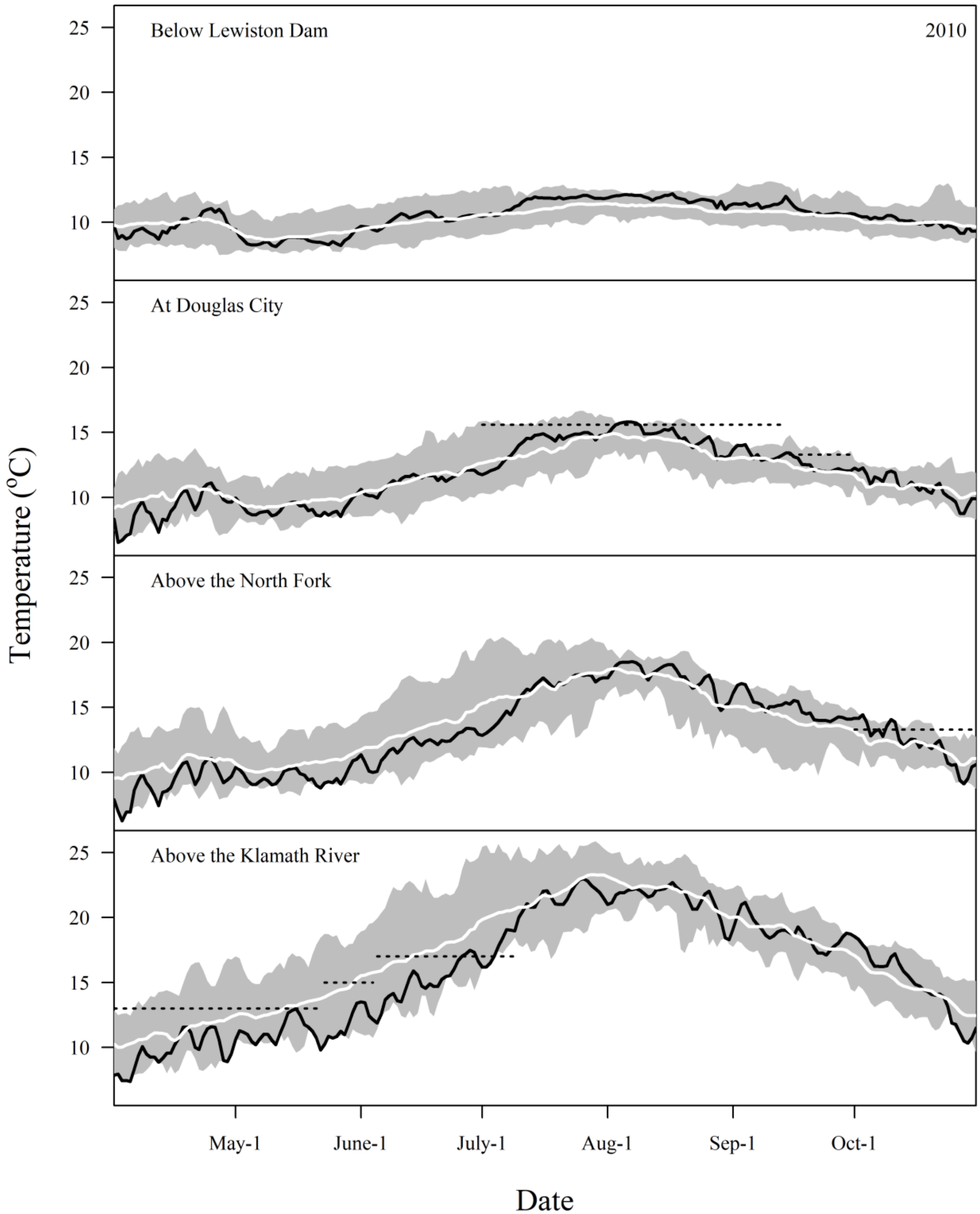
Appendix B7. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = mean daily water temperatures in 2007; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



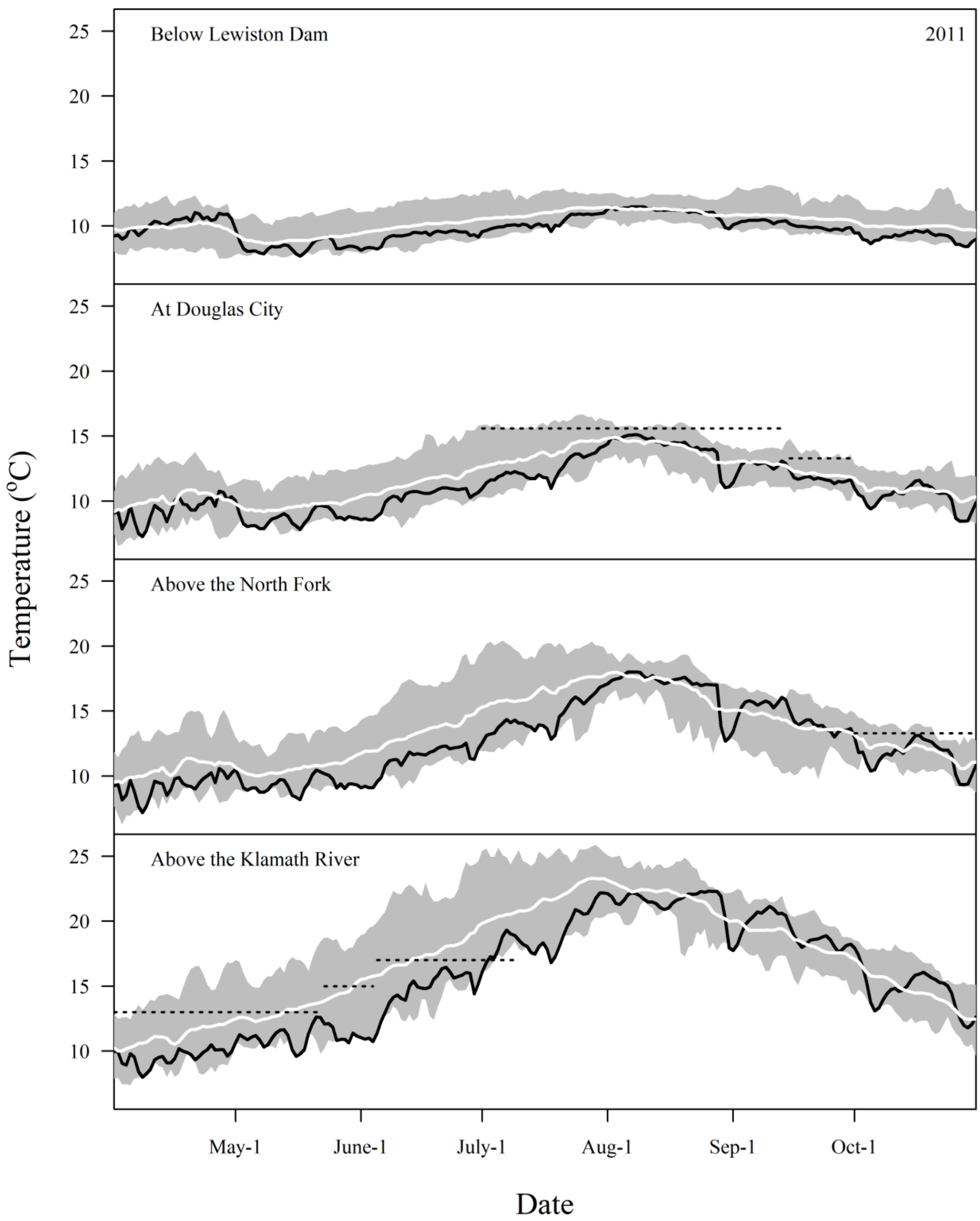
Appendix B8. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = mean daily water temperatures in 2008; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



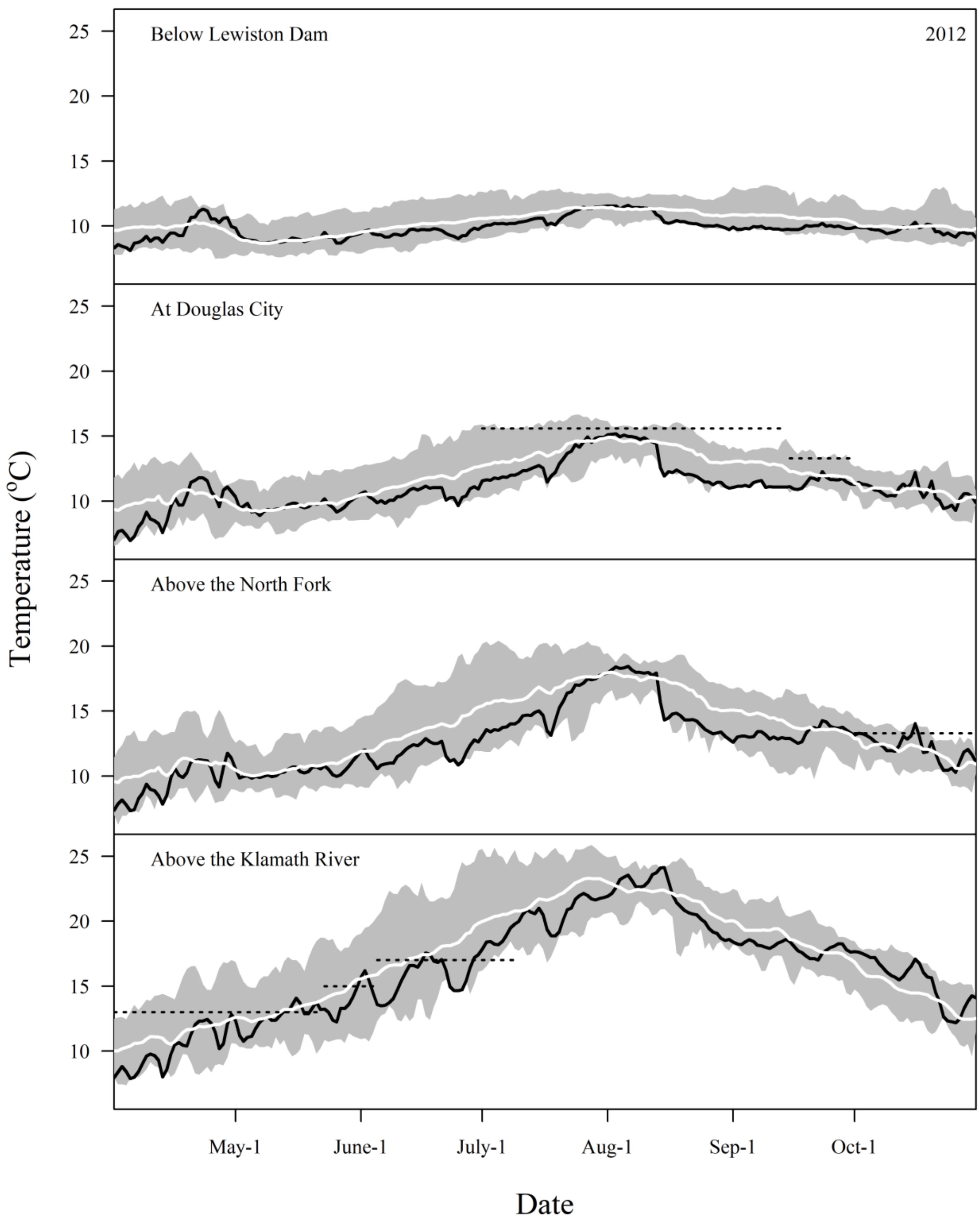
Appendix B9. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = mean daily water temperatures in 2009; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



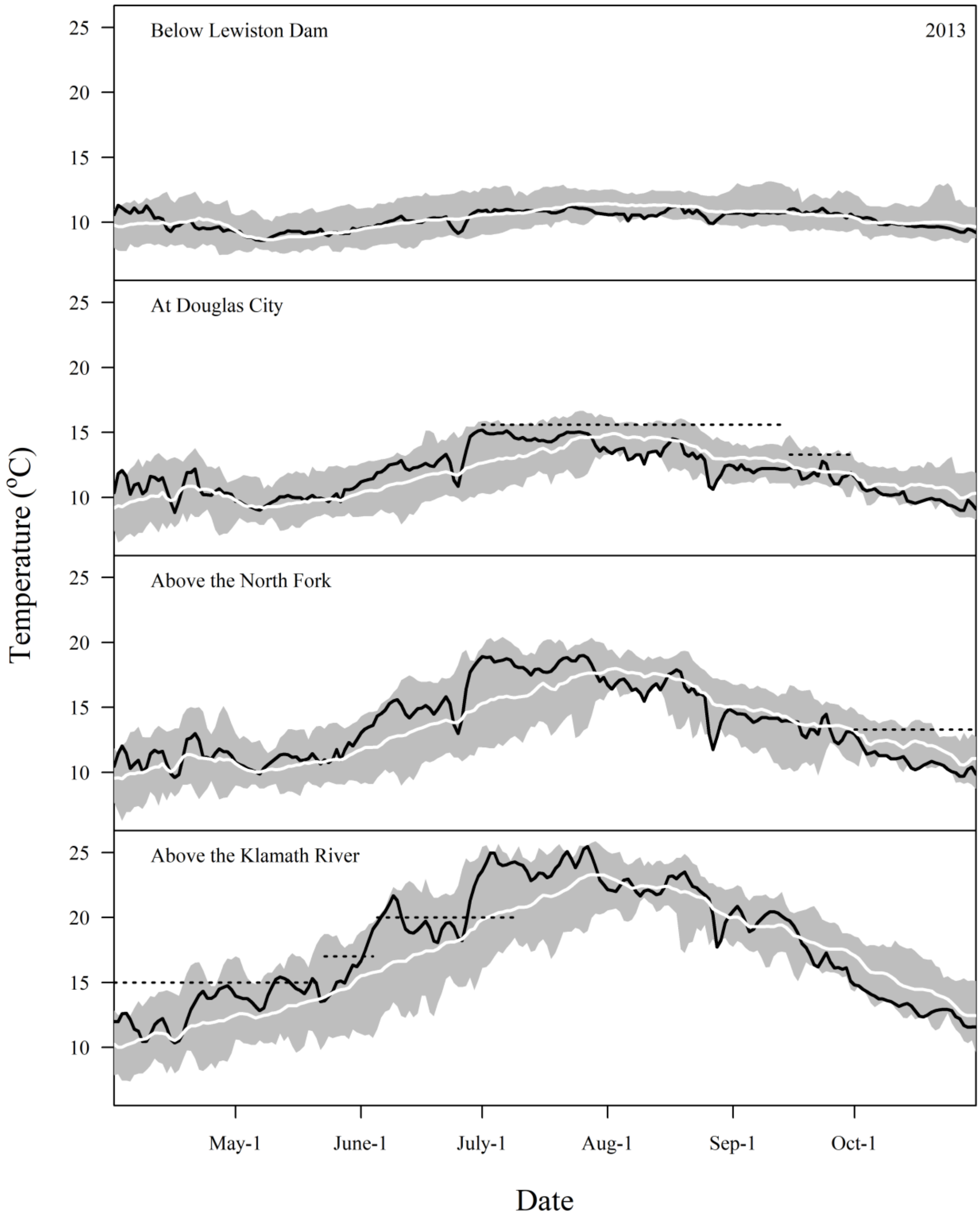
Appendix B10. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = mean daily water temperatures in 2010; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



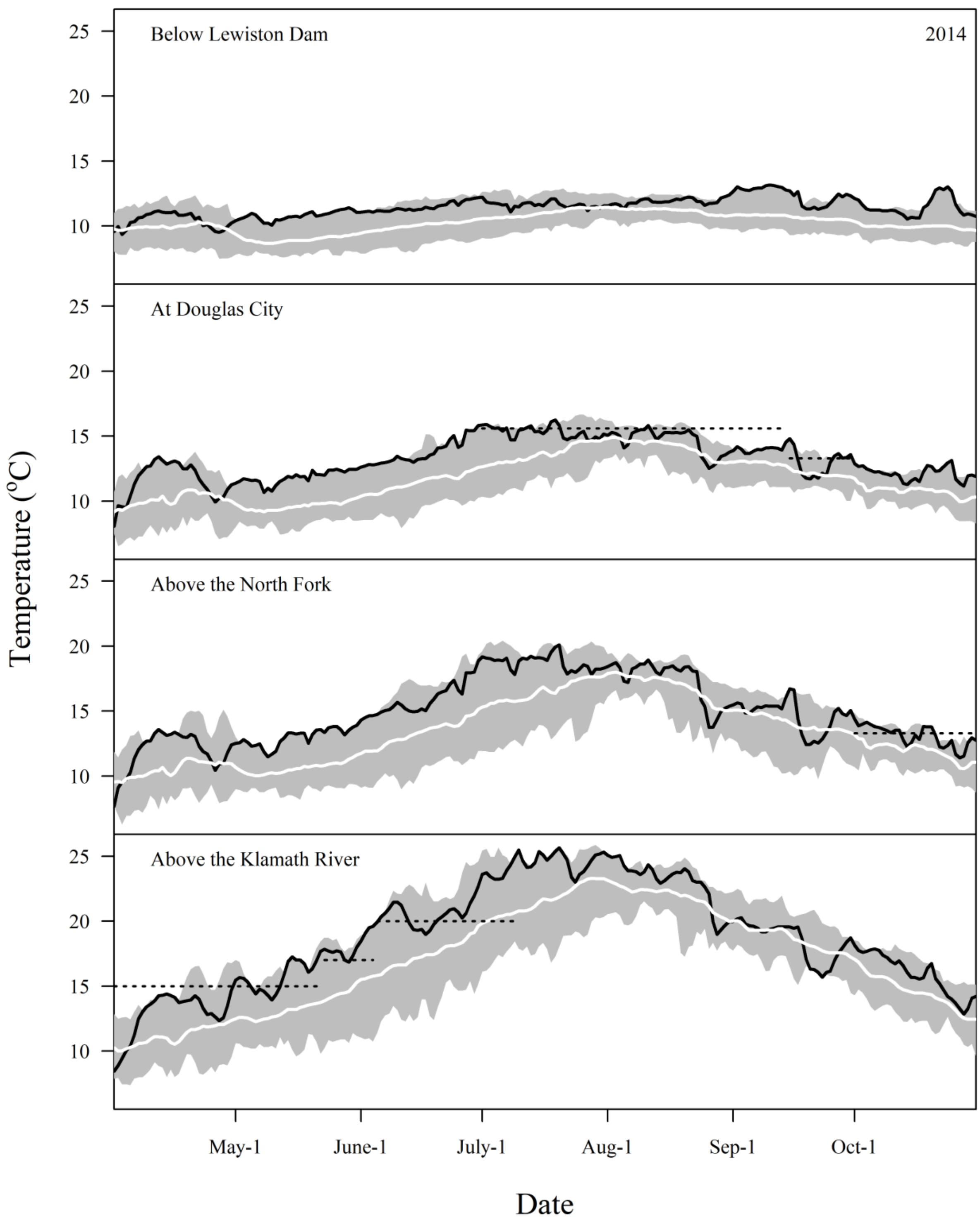
Appendix B11. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = mean daily water temperatures in 2011; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



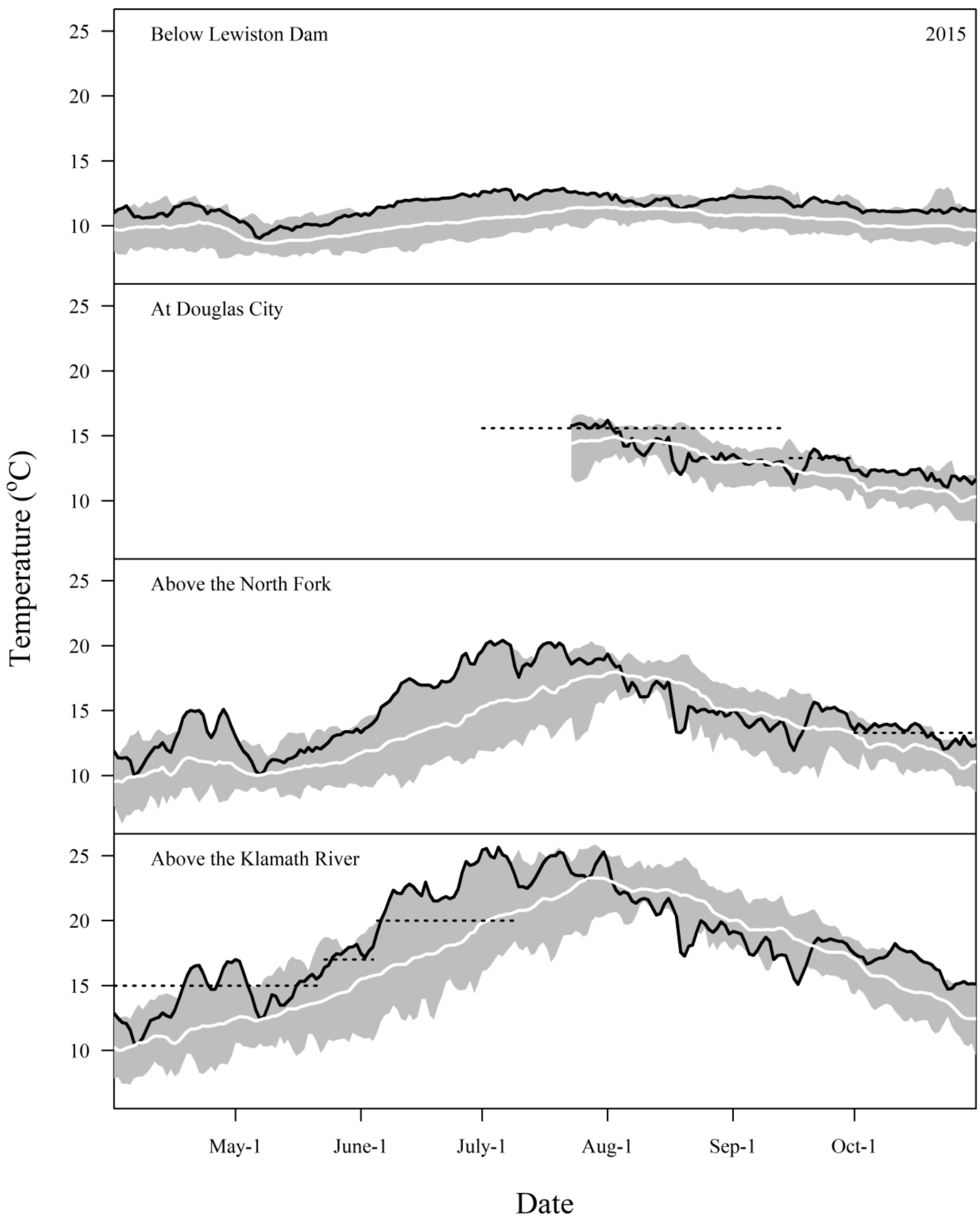
Appendix B12. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = mean daily water temperatures in 2012; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



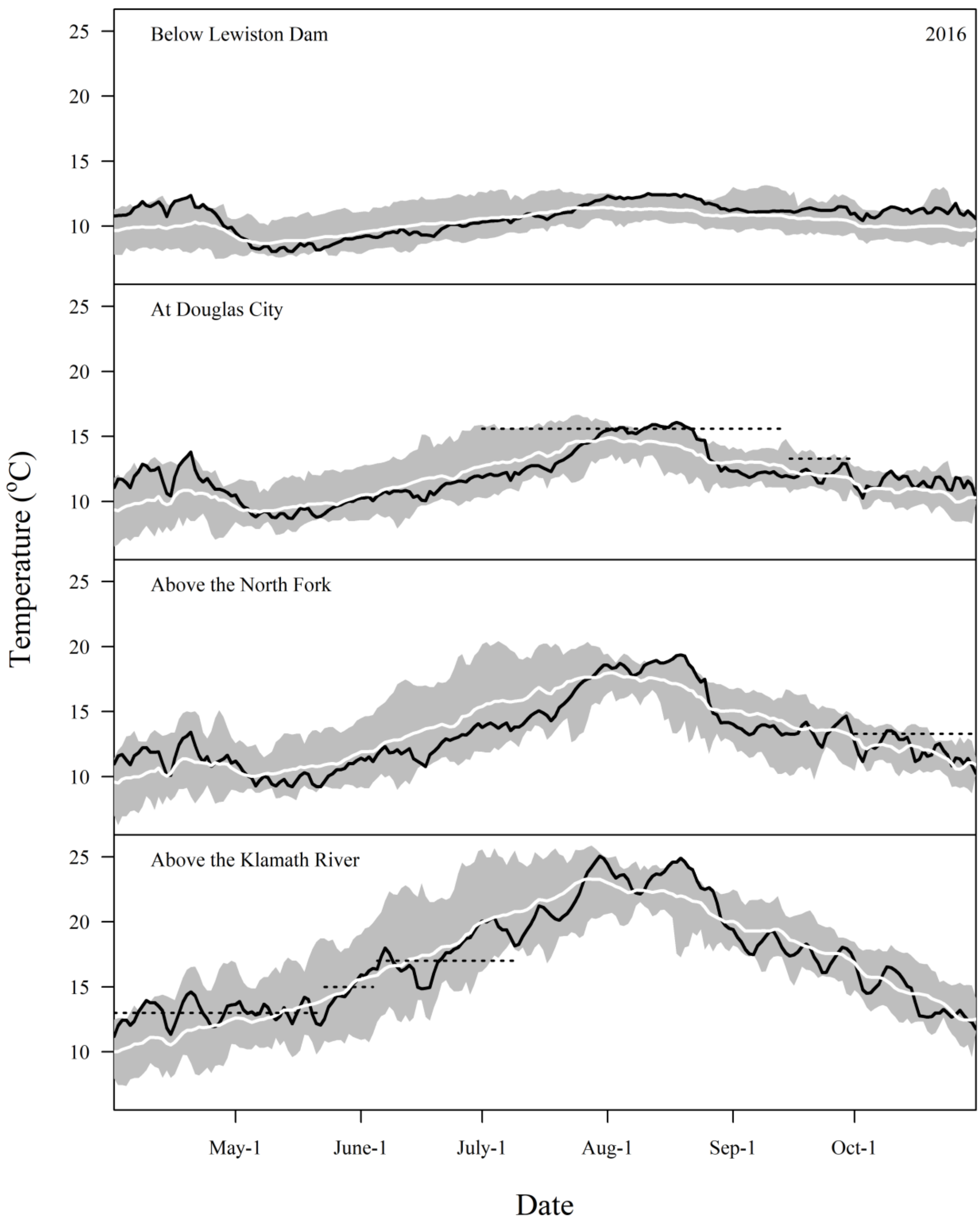
Appendix B13. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = mean daily water temperatures in 2013; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



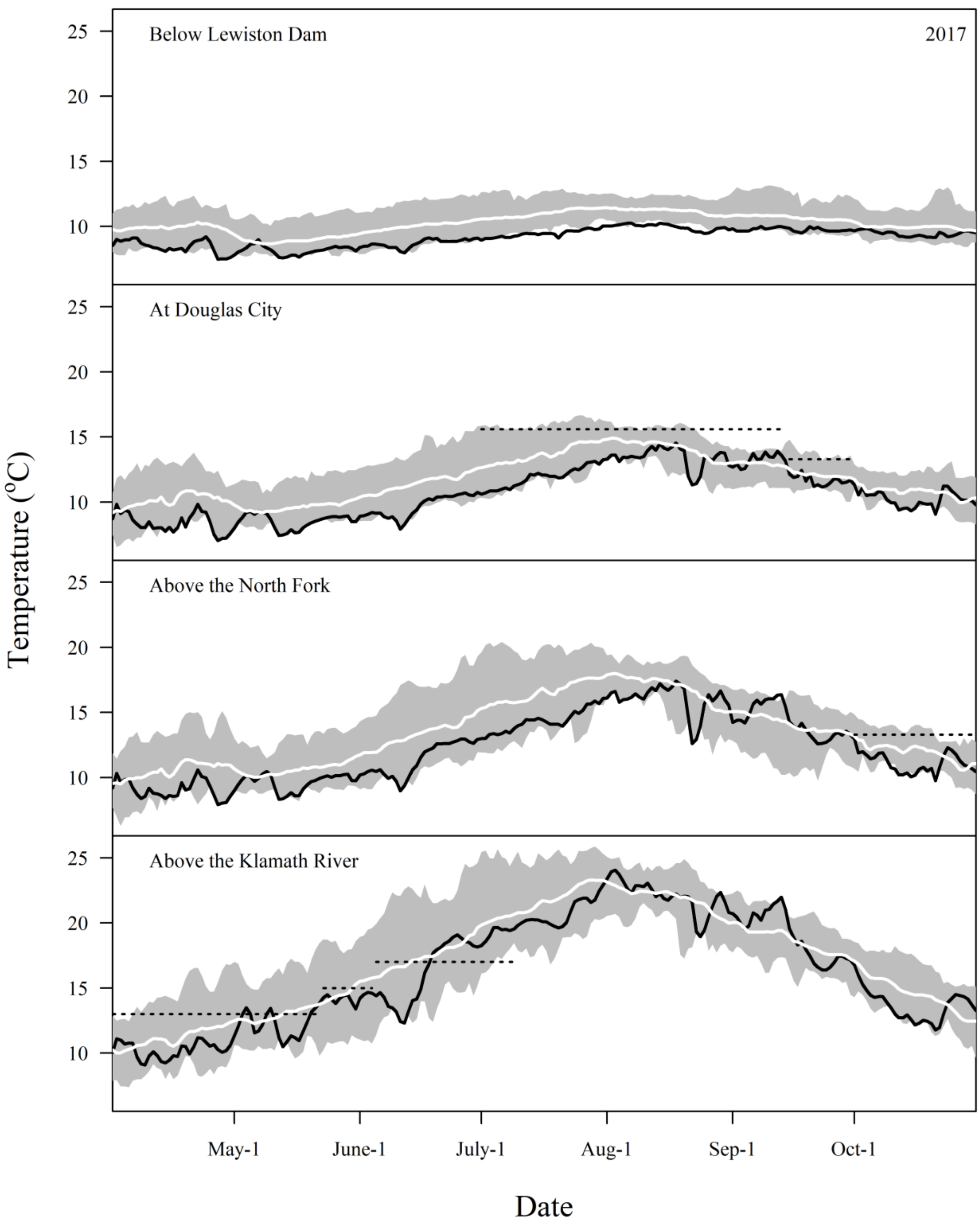
Appendix B14. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2014, with historical conditions. Black line = mean daily water temperatures in 2014; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



Appendix B15. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2015, with historical conditions. Black line = mean daily water temperatures in 2015; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



Appendix B16. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = mean daily water temperatures in 2016; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = water temperature objectives.



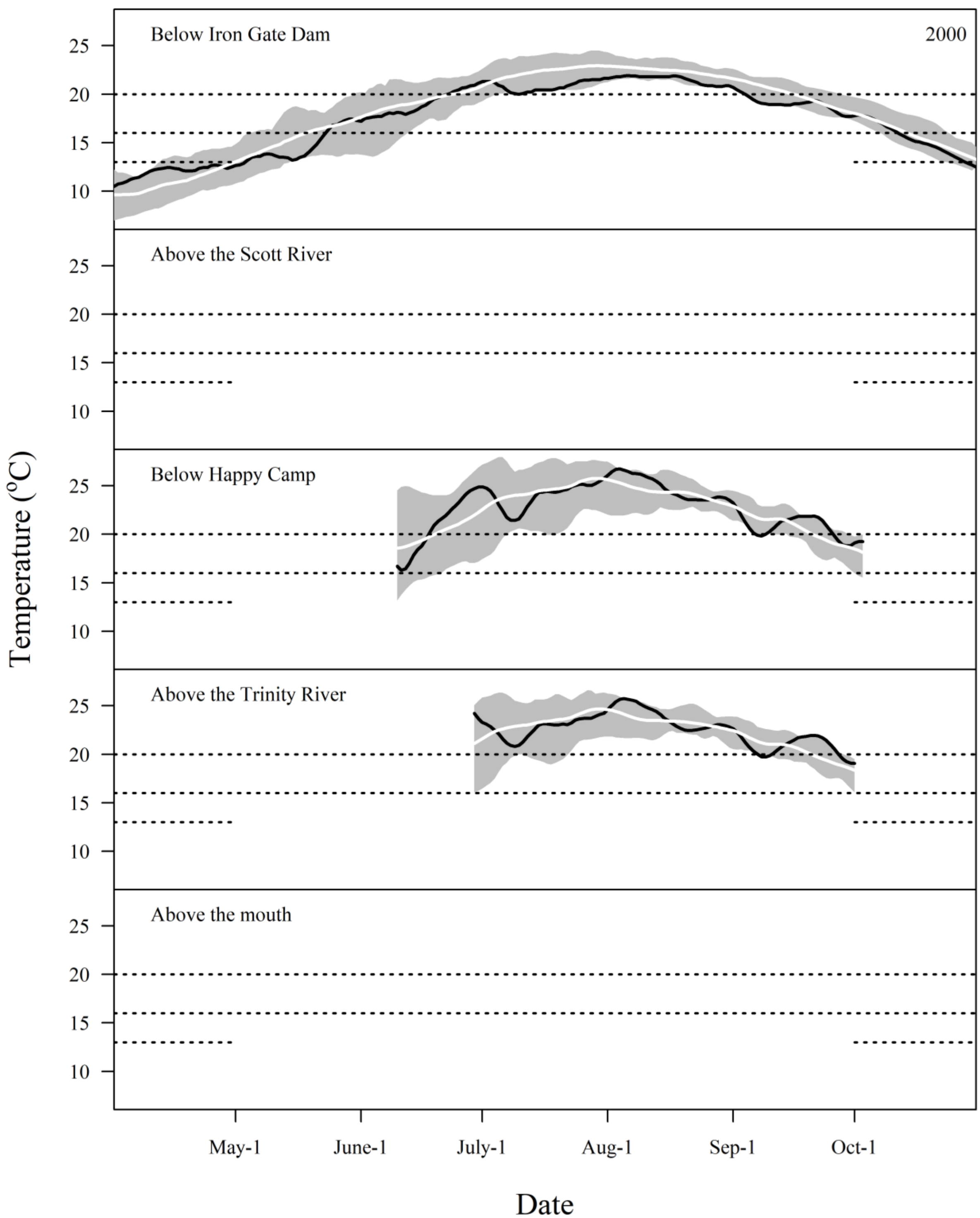
Appendix B17. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2017, with historical conditions. Black line = mean daily water temperatures in 2016; white line = long-term mean for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = 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, April 1 – October 31, 2000-2018. KRIG = Klamath below Iron Gate Dam; KRSC1 = Klamath above the Scott River; KRHC1 = Klamath below Happy Camp; KRWE1 = Klamath above the Trinity River; KRTG2 = Klamath above the mouth.

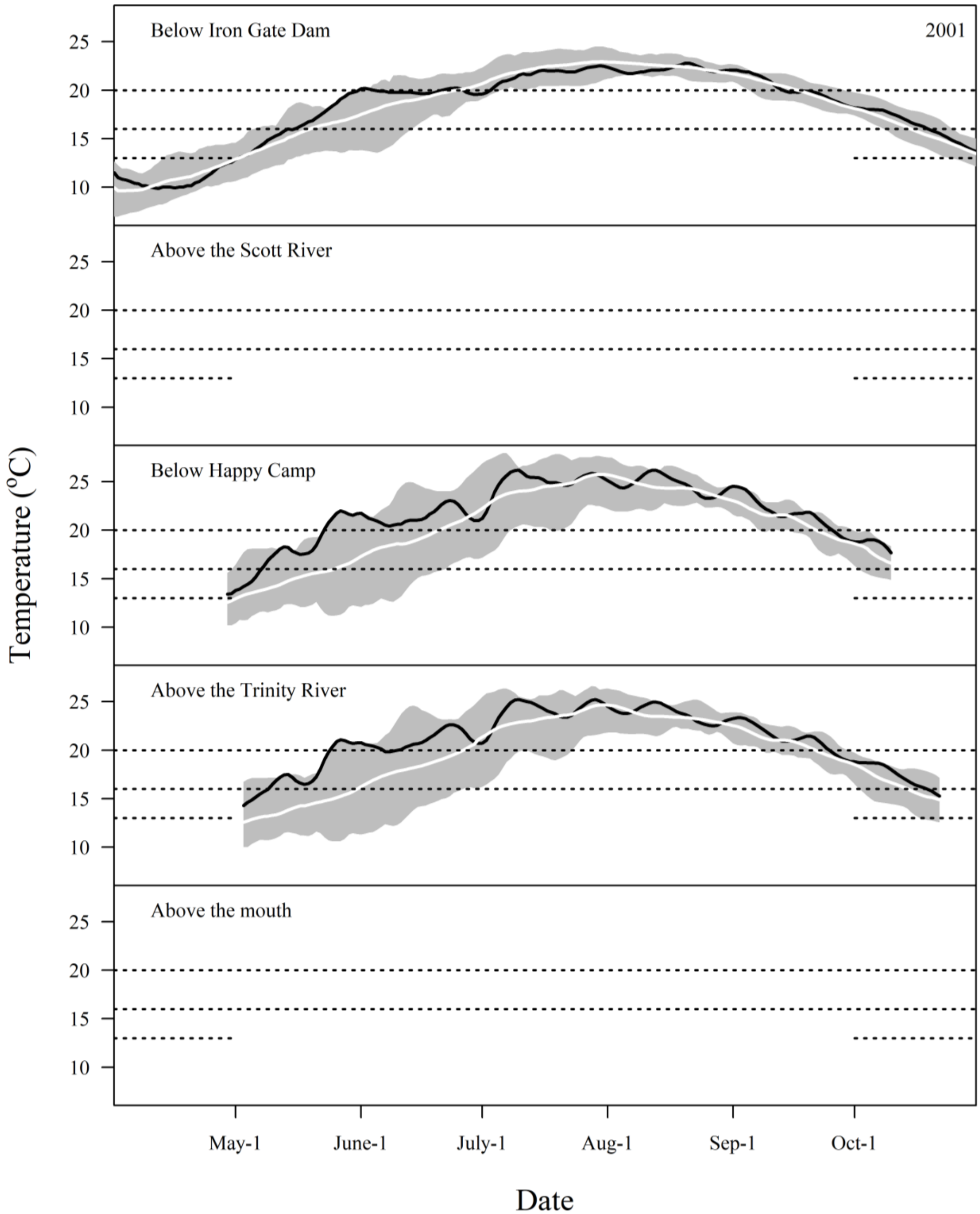
	20°C 7DADM criterion					*16°C 7DADM criterion*					*13°C 7DADM criterion*				
Year	**KRIG1**	**KRSC1**	**KRHC1**	**KRWE1**	**KRTG2**	**KRIG1**	**KRSC1**	**KRHC1**	**KRWE1**	**KRTG2**	**KRIG1**	**KRSC1**	**KRHC1**	**KRWE1**	**KRTG2**
2000	74	-	98[d]	-	-	141	-	-	-	-	28	-	-	-	-
2001	81	-	126[e]	119[f]	-	158	-	-	162[f]	-	31	-	-	-	-
2002	78[a]	-	-	95[g]	-	-	-	-	139[g]	-	-	-	-	-	-
2003	102	102	97	86	83	142	142	136	133	141	31	31	31	31	31
2004	85[b]	94	94	91	84	156[b]	154	146	140	138	-	37	28	26	30
2005	75[c]	83	81	75	74	-	135	128	120	129	-	36	30	31	32
2006	89	90	89	87	83	154	151	130	127	124	31	30	27	27	29
2007	95	106	105	-	95	147	147	146	-	136	26	25	25	-	27
2008	81	87	86	83	74	146	135	122	121	123	30	29	27	29	31
2009	86	120	109	102	99	144	142	139	137	143	35	37	35	33	38
2010	74	84	73	63	64	130	128	118	115	118	31	28	26	26	28
2011	83	84	77	64	64	129	128	116	110	121	31	30	29	30	31
2012	85	92	88	80	67	163	158	142	138	138	32	37	26	26	31
2013	95	110	109	104	99	151	152	147	140	138	33	34	33	34	37
2014	98	118	128	117	110	158	167	168	161	162	48	52	51	44	51
2015	95	112	115	112	101	161	175	176	176	171	40	45	45	43	47
2016	91	104	103	99	86	156	155	149	149	141	49	50	26	23	33
2017	99	91	89	88	89	140	137	121	114	112	31	31	25	24	31
2018	100	110	104	89	88	157	160	157	153	156	31	38	37	31	35

[a] Data unavailable prior to 5/14 for KRIG1 in 2002. It was assumed 7DADM temperatures did not reach or exceed 20.0 C before this date.
[b] Data unavailable prior to 4/20 for KRIG1 in 2004. It was assumed 7DADM temperatures did not reach or exceed 16.0 C before this date.
[c] Data unavailable prior to 6/1 for KRIG1 in 2005. It was assumed 7DADM temperatures did not reach or exceed 20.0 C before this date.
[d] Data unavailable prior to 6/10 and after 10/3 for KRHC1 in 2000. It was assumed 7DADM temperatures did not reach or exceed 20.0 C outside these dates.
[e] Data unavailable prior to 4/29 and after 10/10 for KRHC1 in 2001. It was assumed 7DADM temperatures did not reach or exceed 20.0 C outside these dates.
[f] Data unavailable prior to 5/3 and after 10/22 for KRWE1 in 2001. It was assumed 7DADM temperatures did not reach or exceed 16.0 C outside these dates.
[g] Data unavailable prior to 4/26 for KRWE1 in 2002. It was assumed 7DADM temperatures did not reach or exceed 16.0 C before this date.

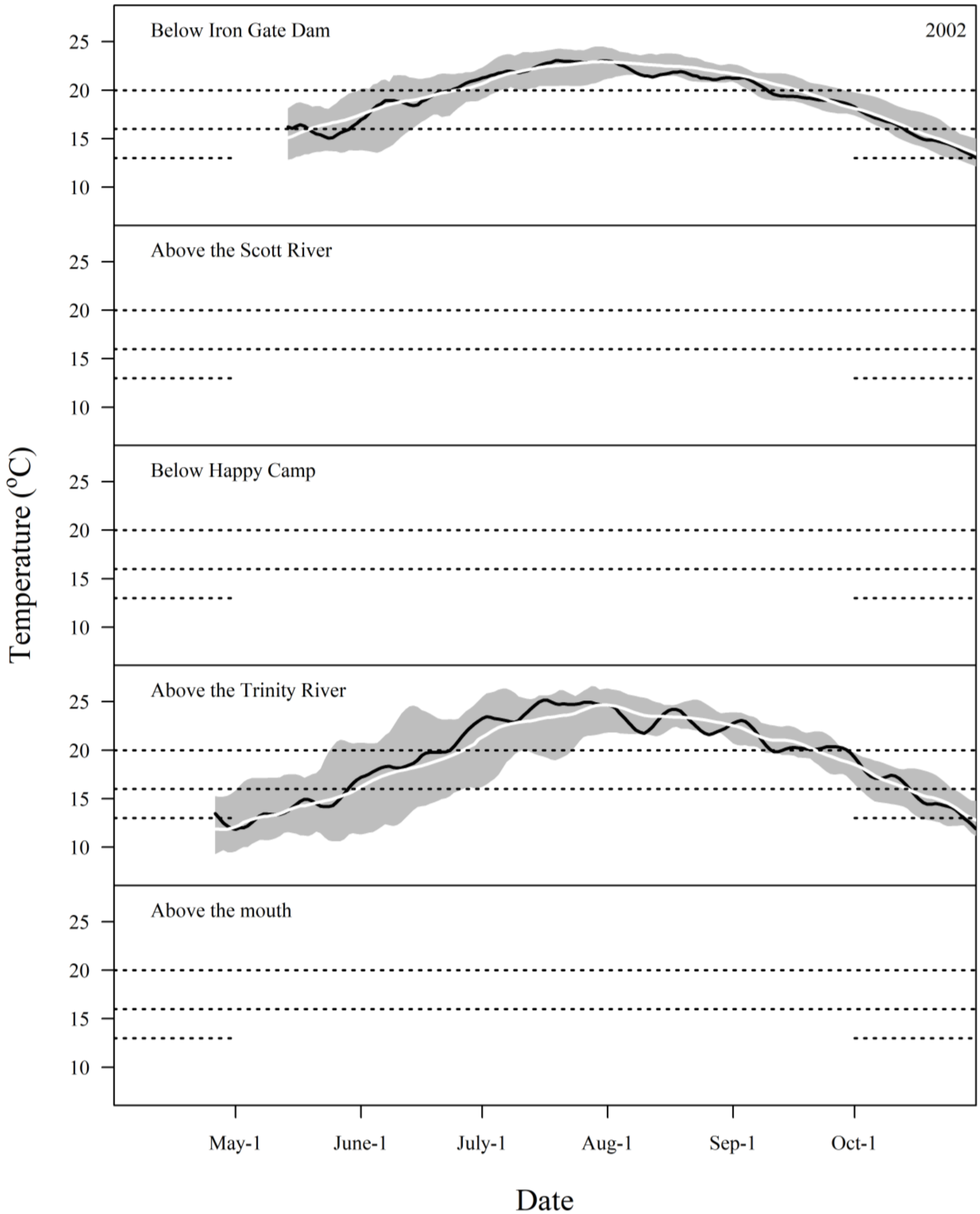
Appendix D. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000-2017, with historical conditions. Includes both observed and infilled water temperatures.



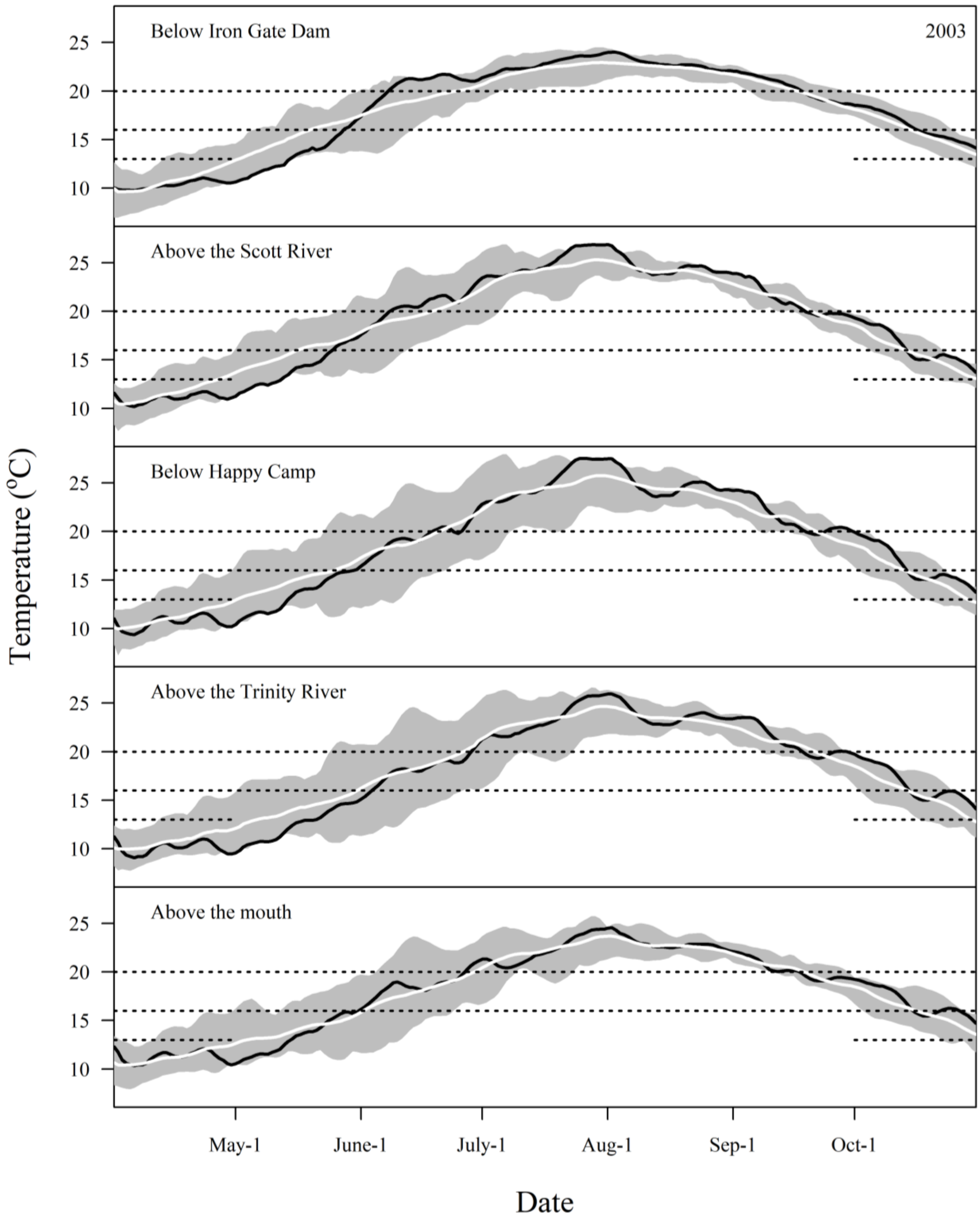
Appendix D1. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000, with historical conditions. Black line = 7DADM water temperatures in 2000; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



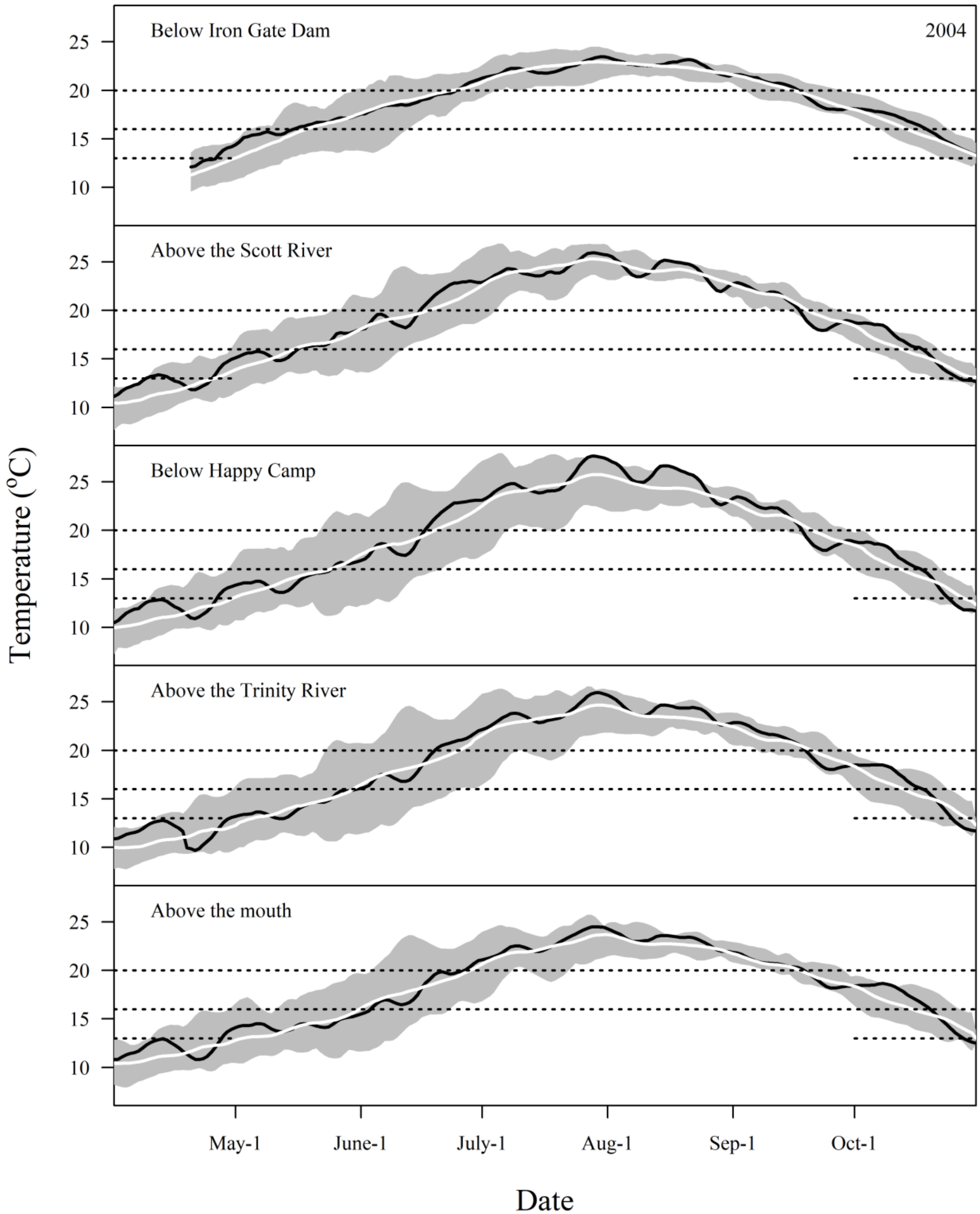
Appendix D2. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = 7DADM water temperatures in 2001; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



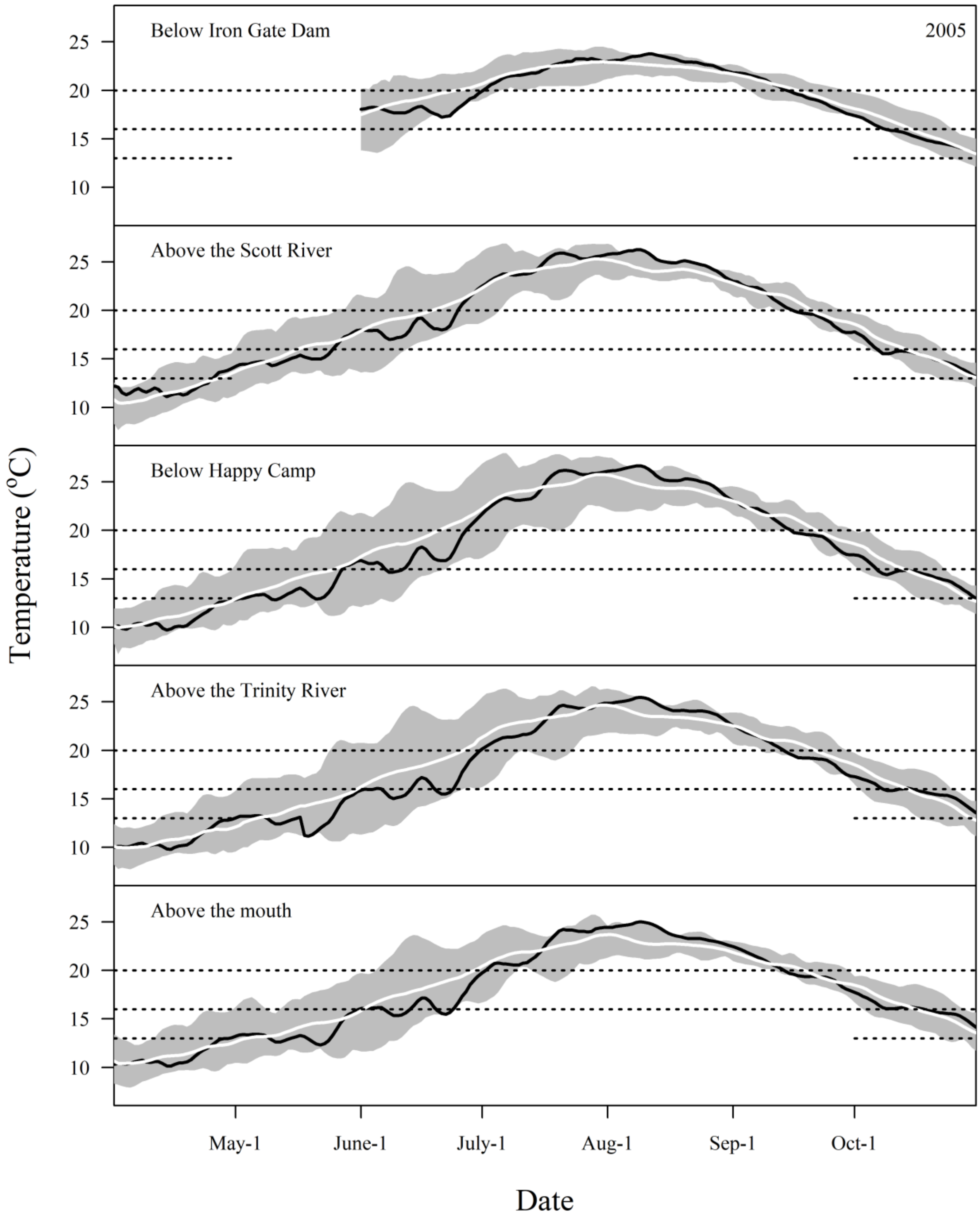
Appendix D3. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = 7DADM water temperatures in 2002; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria. Sections that are blank indicates that during that period no data exists for the site.



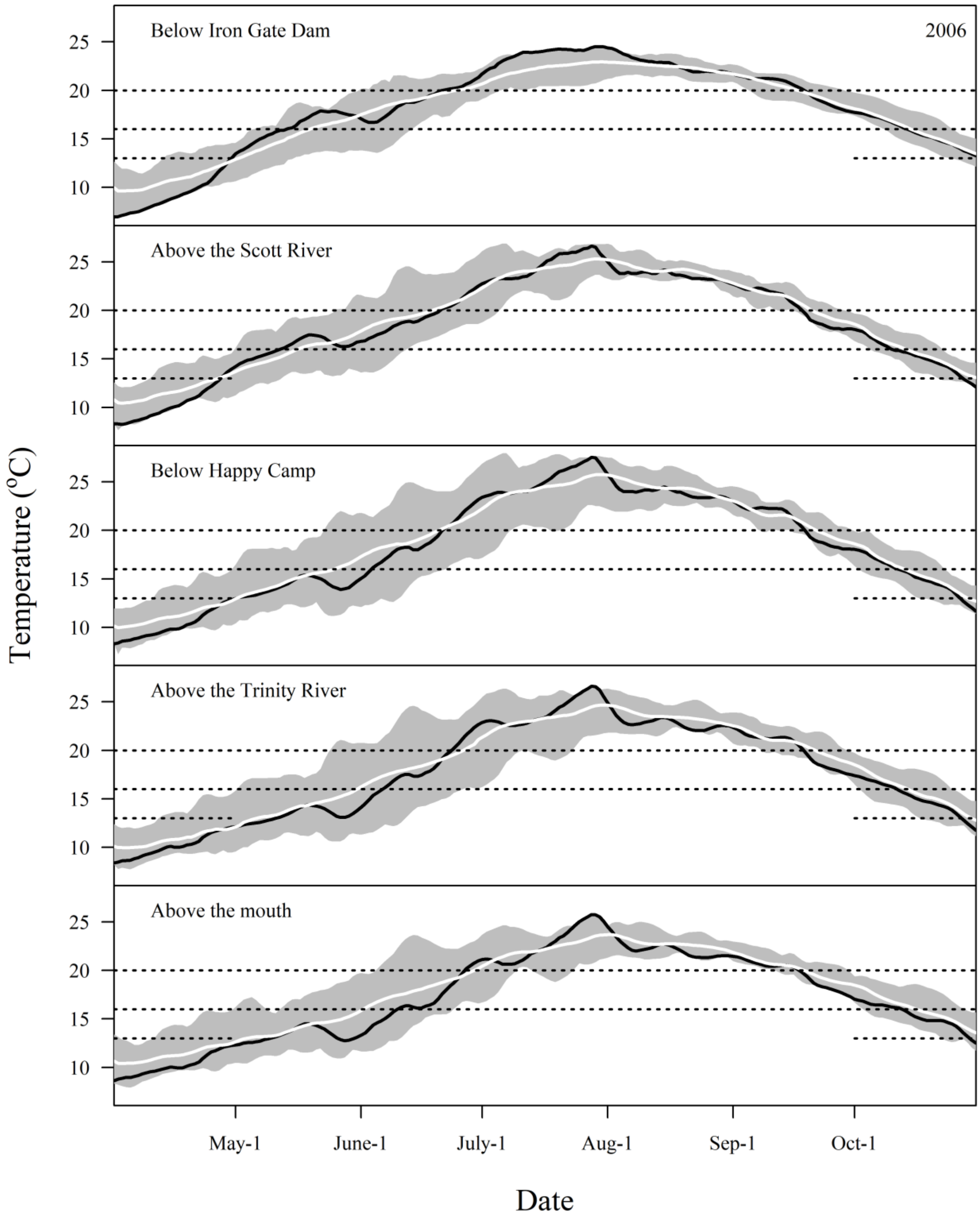
Appendix D4. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = 7DADM water temperatures in 2003; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



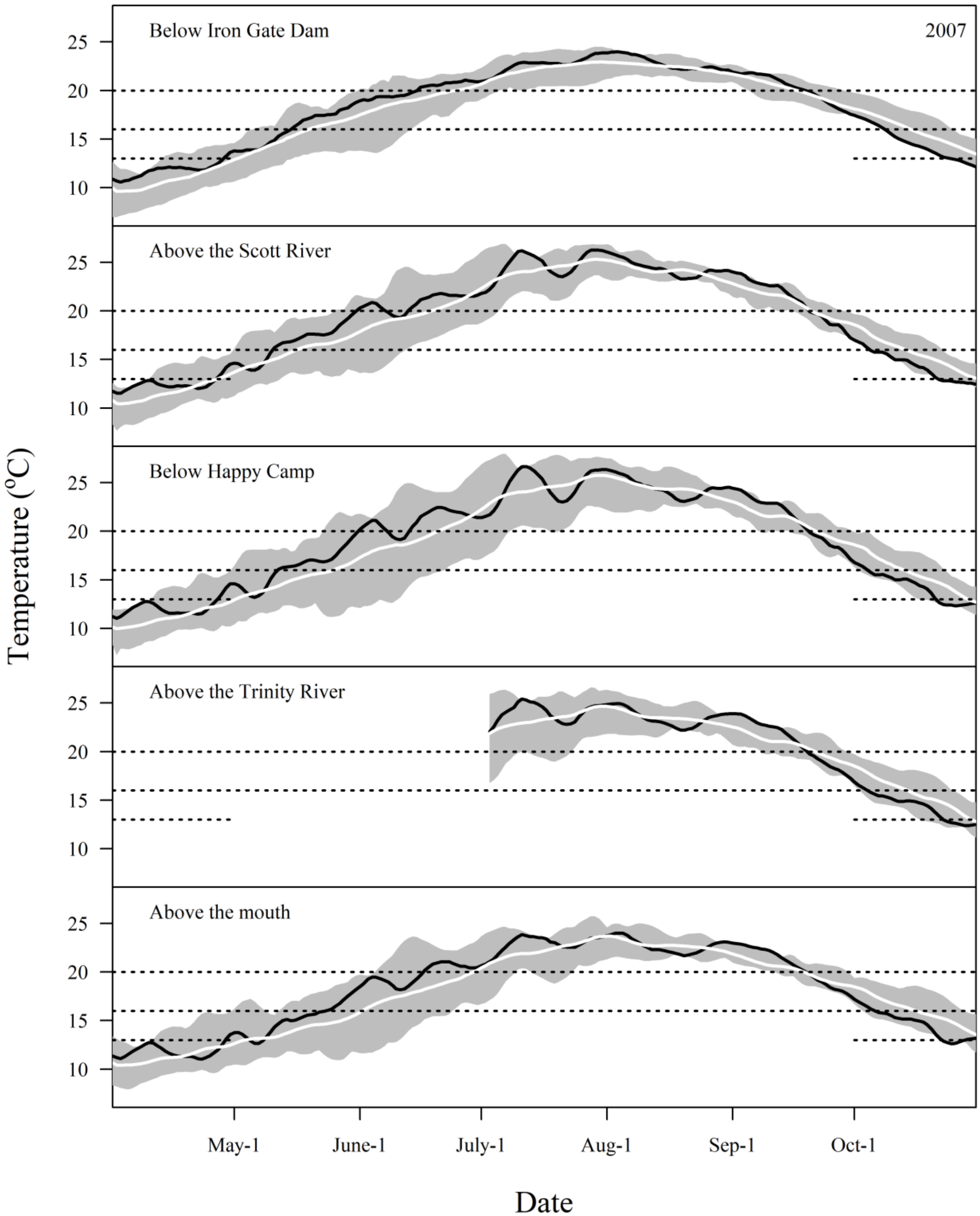
Appendix D5. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = 7DADM water temperatures in 2004; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



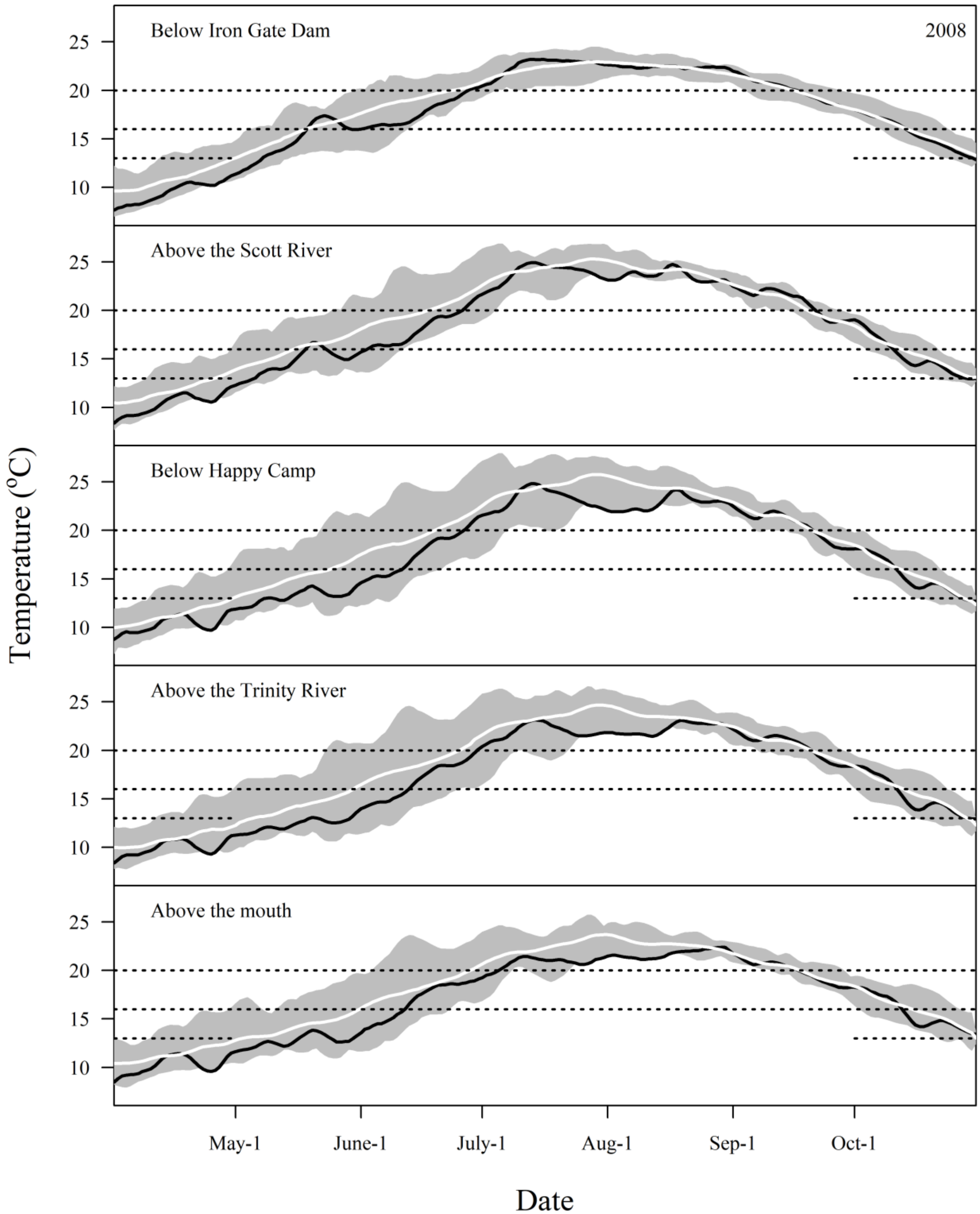
Appendix D6. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = 7DADM water temperatures in 2005; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



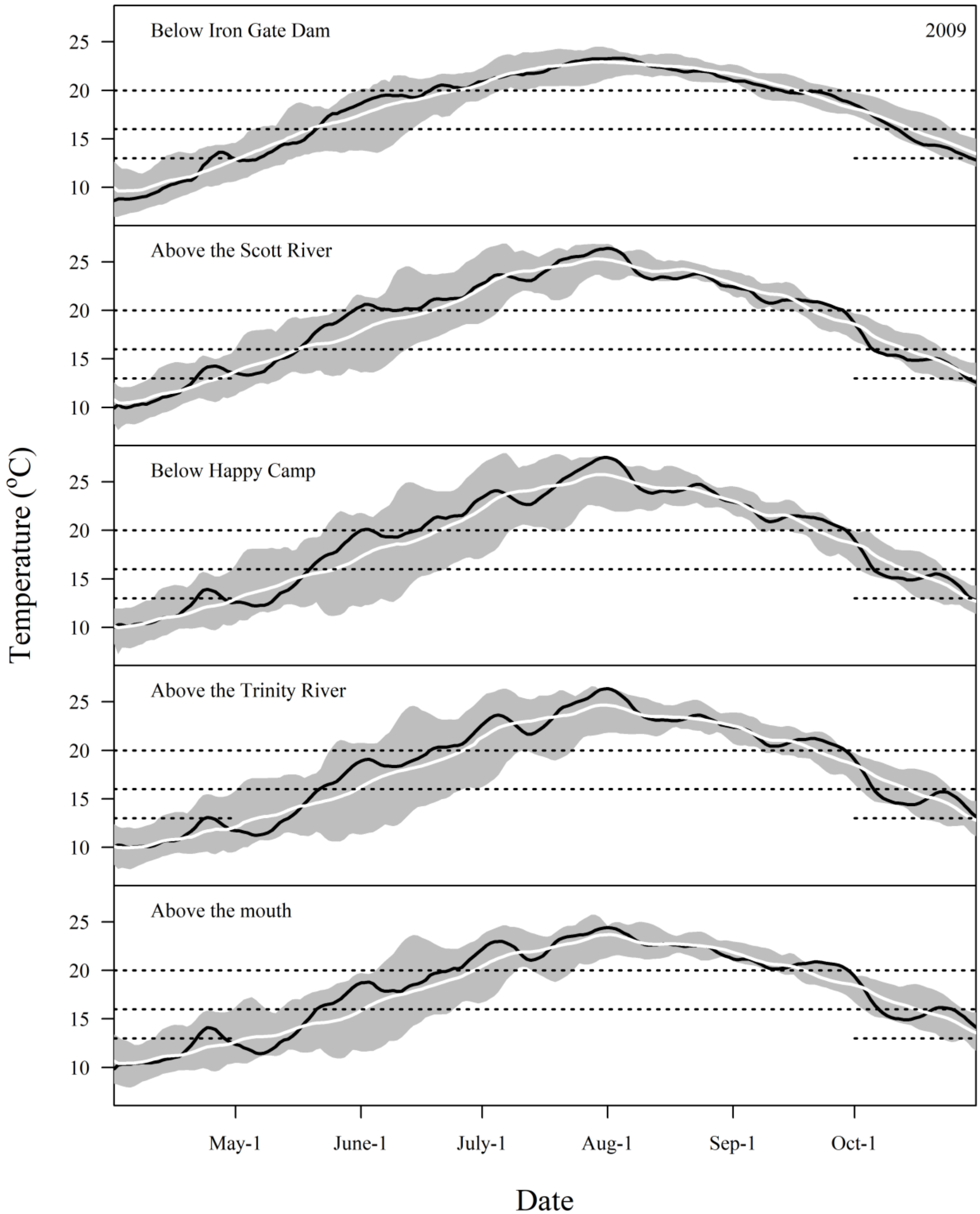
Appendix D7. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = 7DADM water temperatures in 2006; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



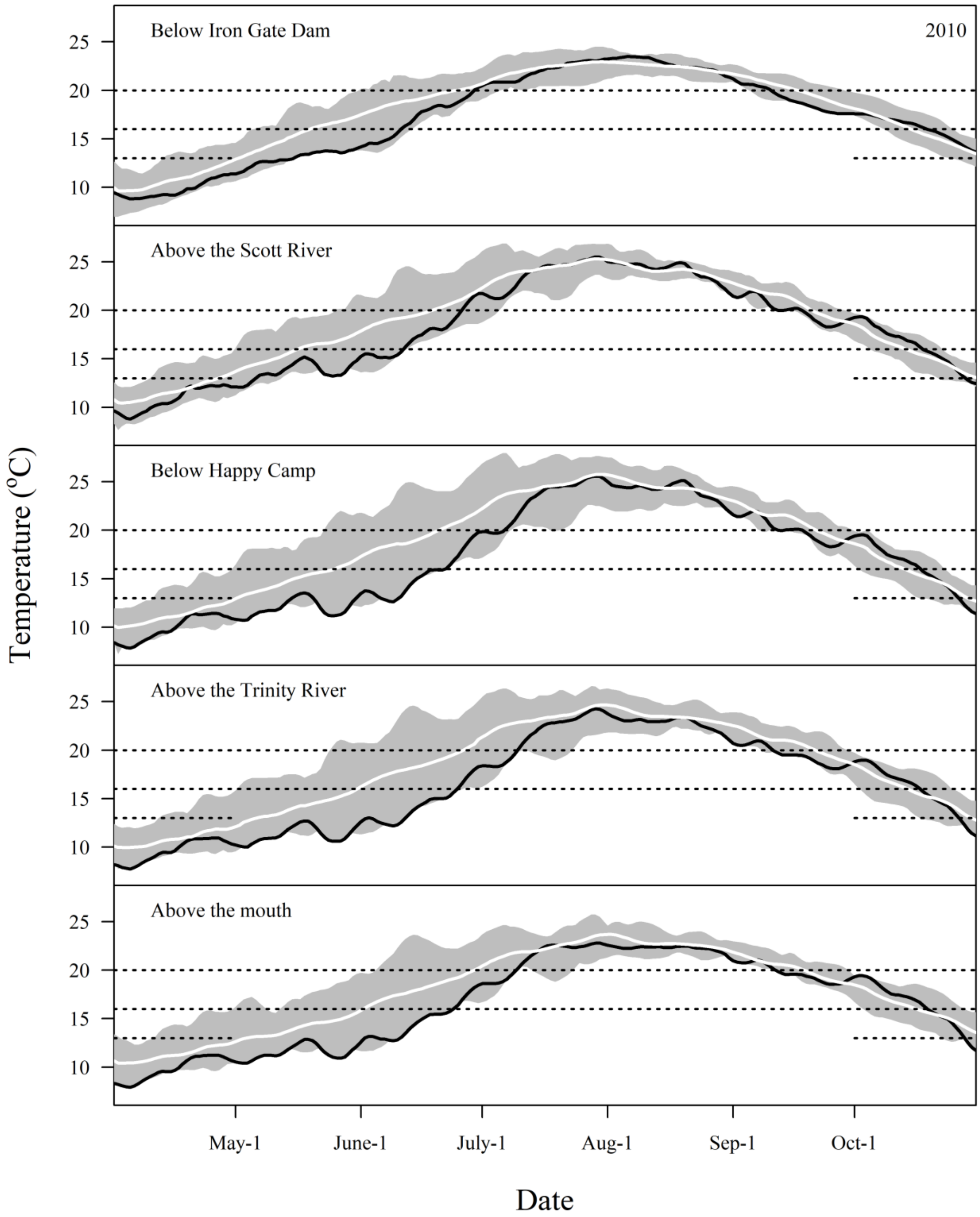
Appendix D8. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = 7DADM water temperatures in 2007; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



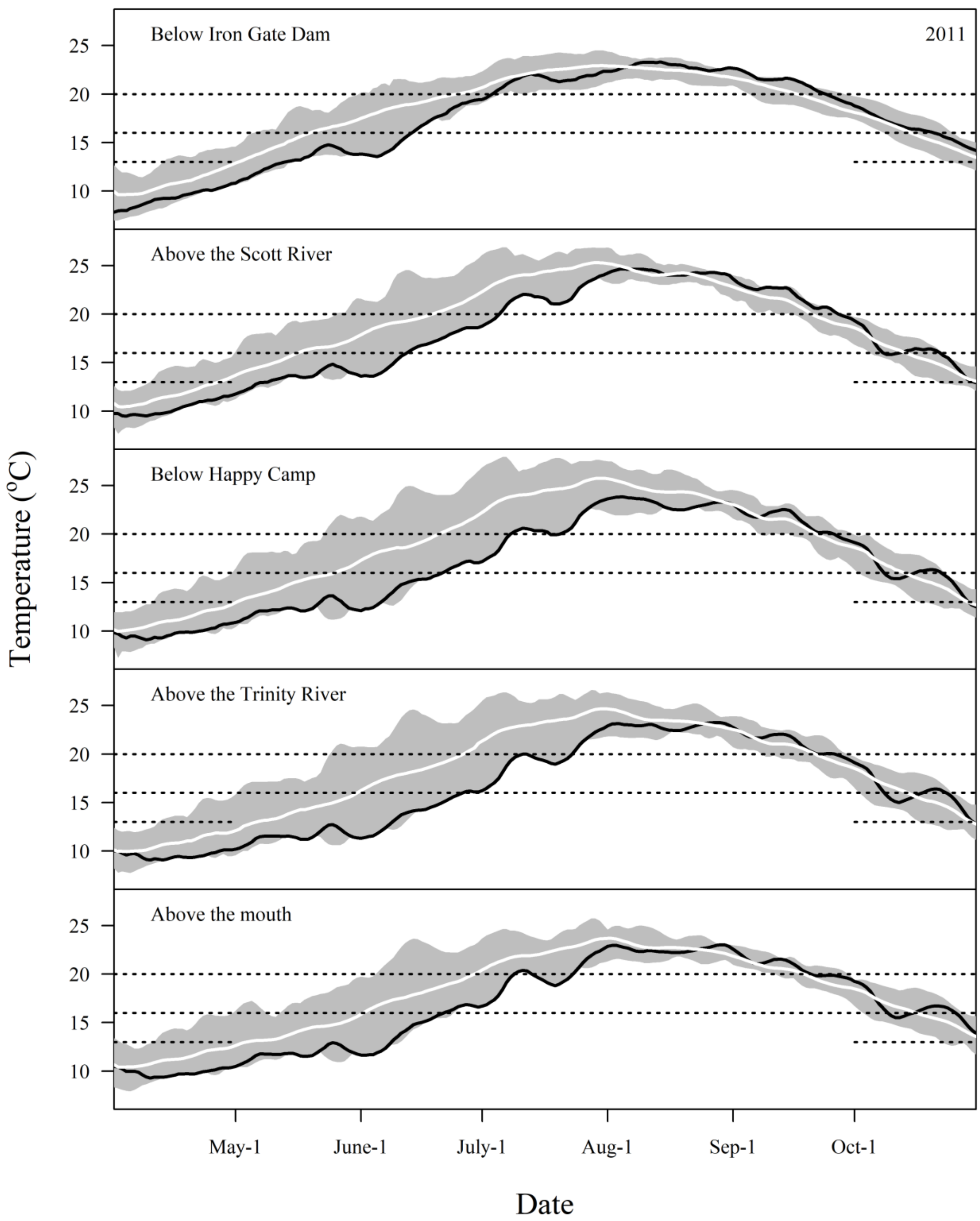
Appendix D9. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = 7DADM water temperatures in 2008; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



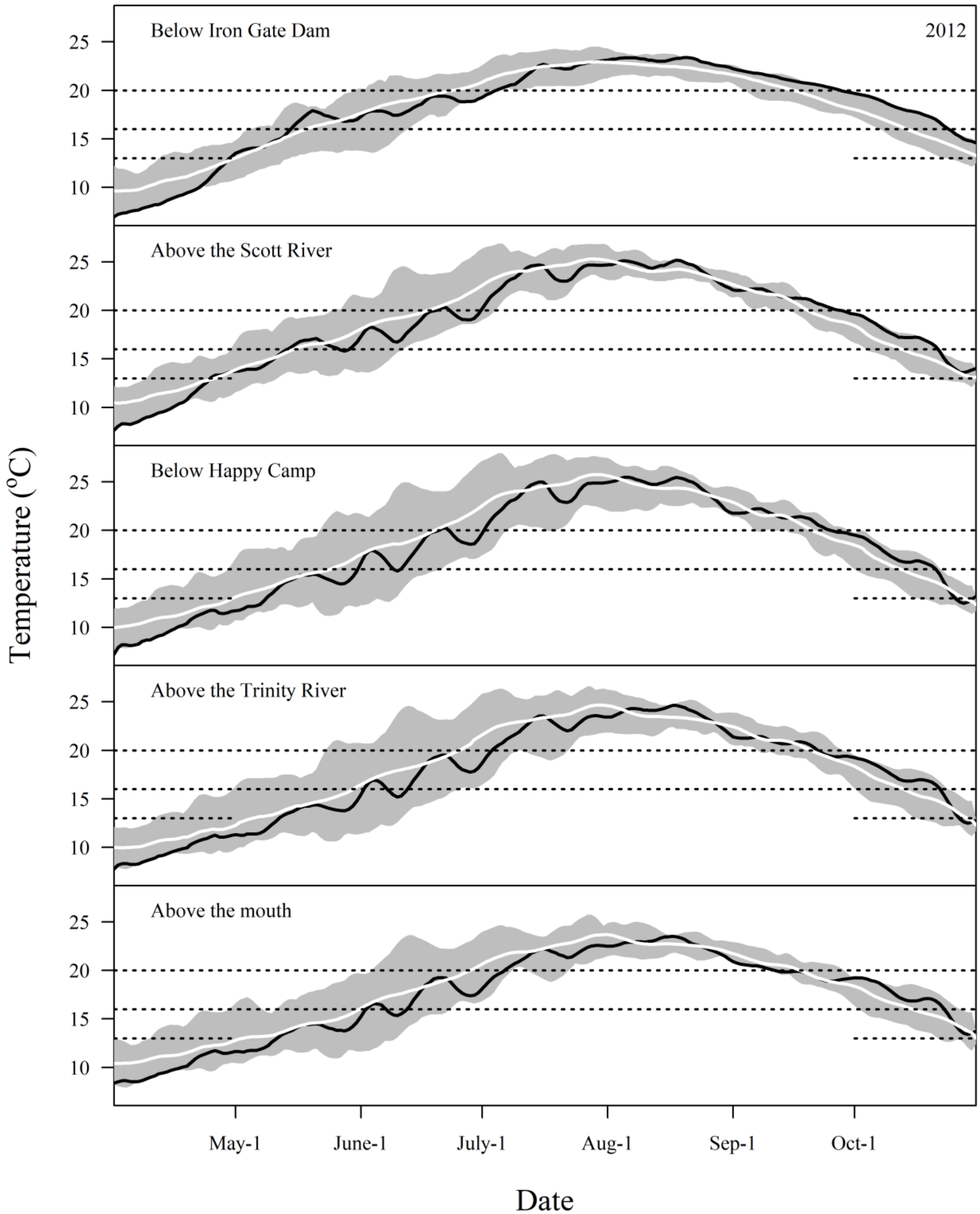
Appendix D10. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = 7DADM water temperatures in 2009; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



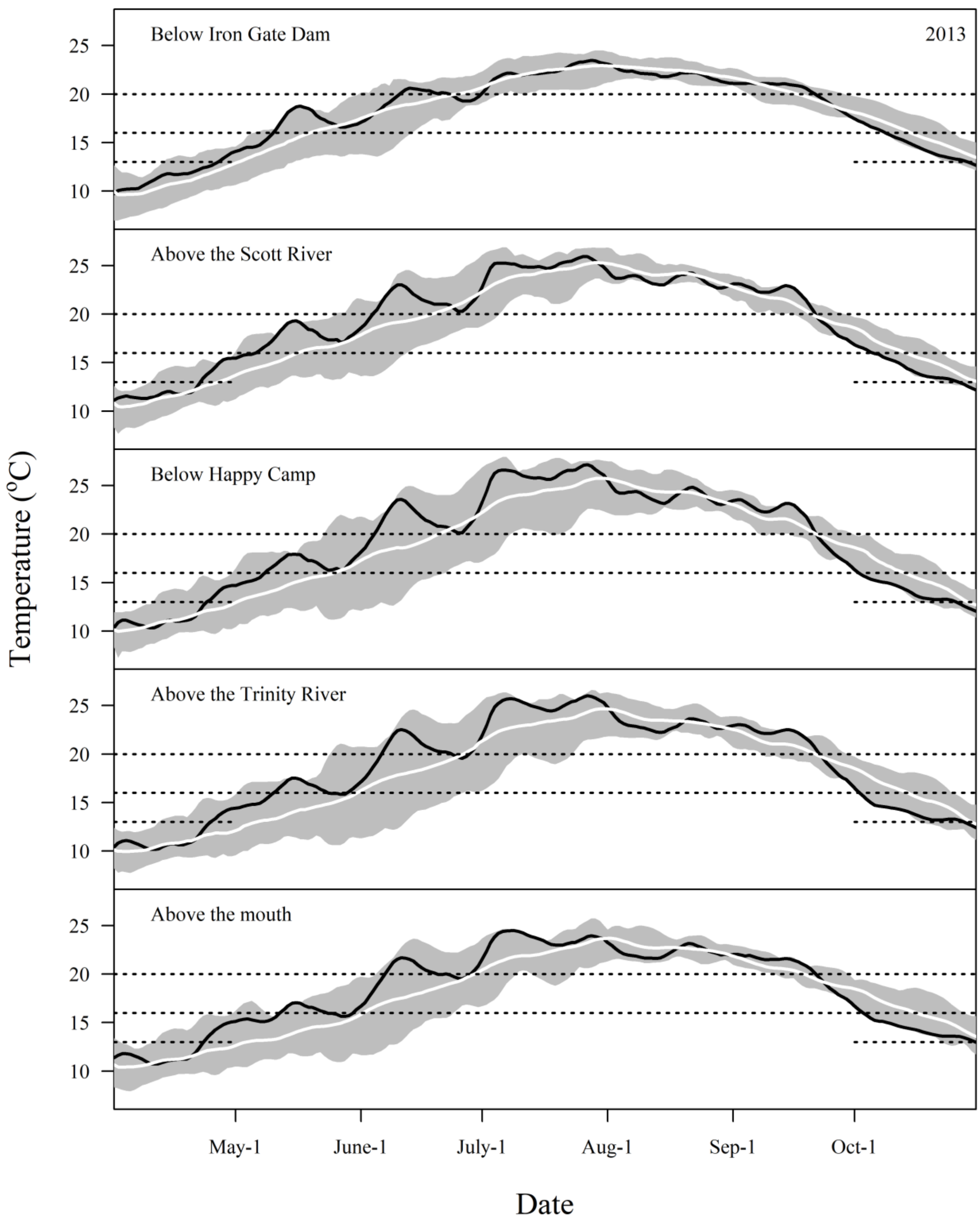
Appendix D11. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = 7DADM water temperatures in 2010; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



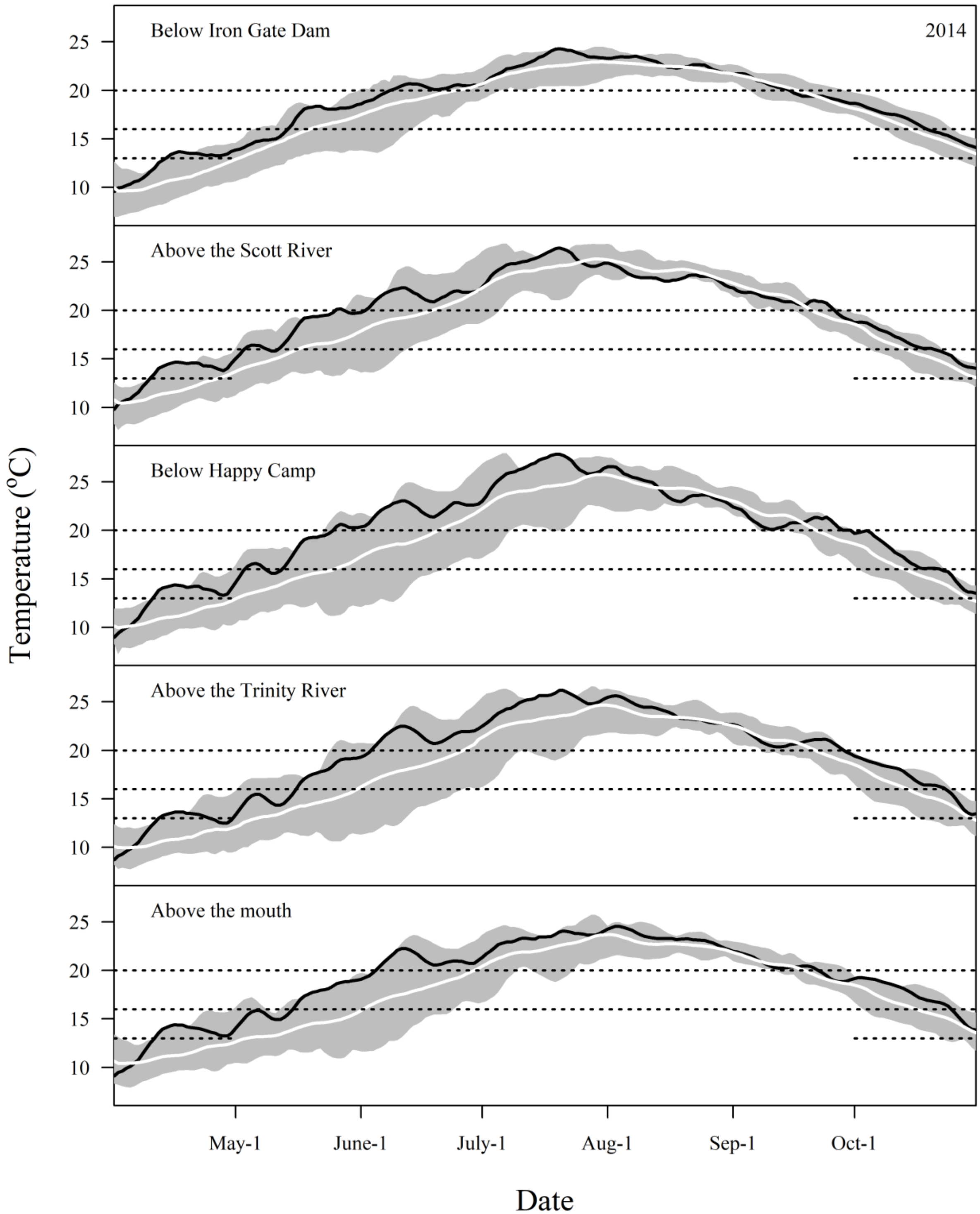
Appendix D12. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = 7DADM water temperatures in 2011; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



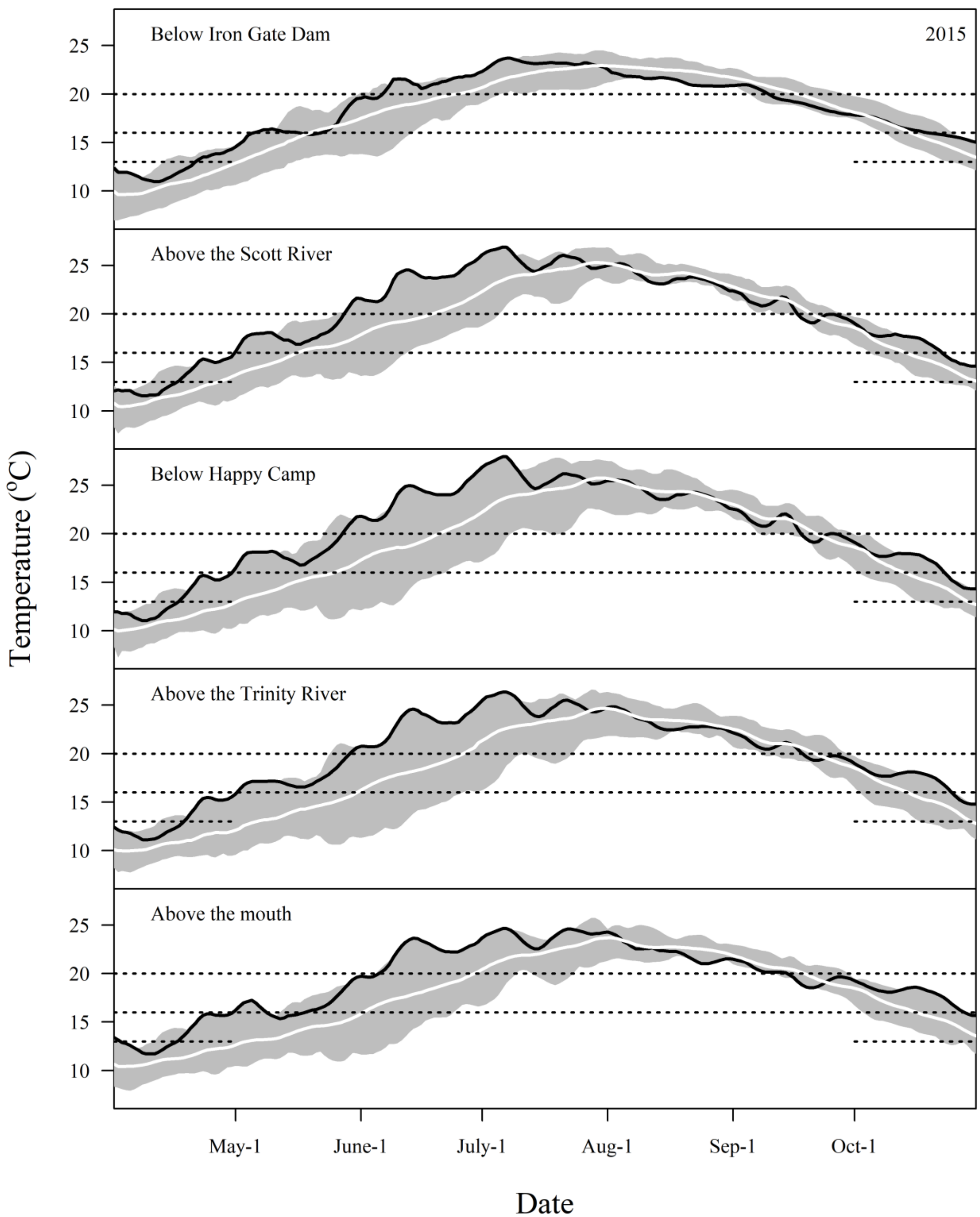
Appendix D13. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = 7DADM water temperatures in 2012; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



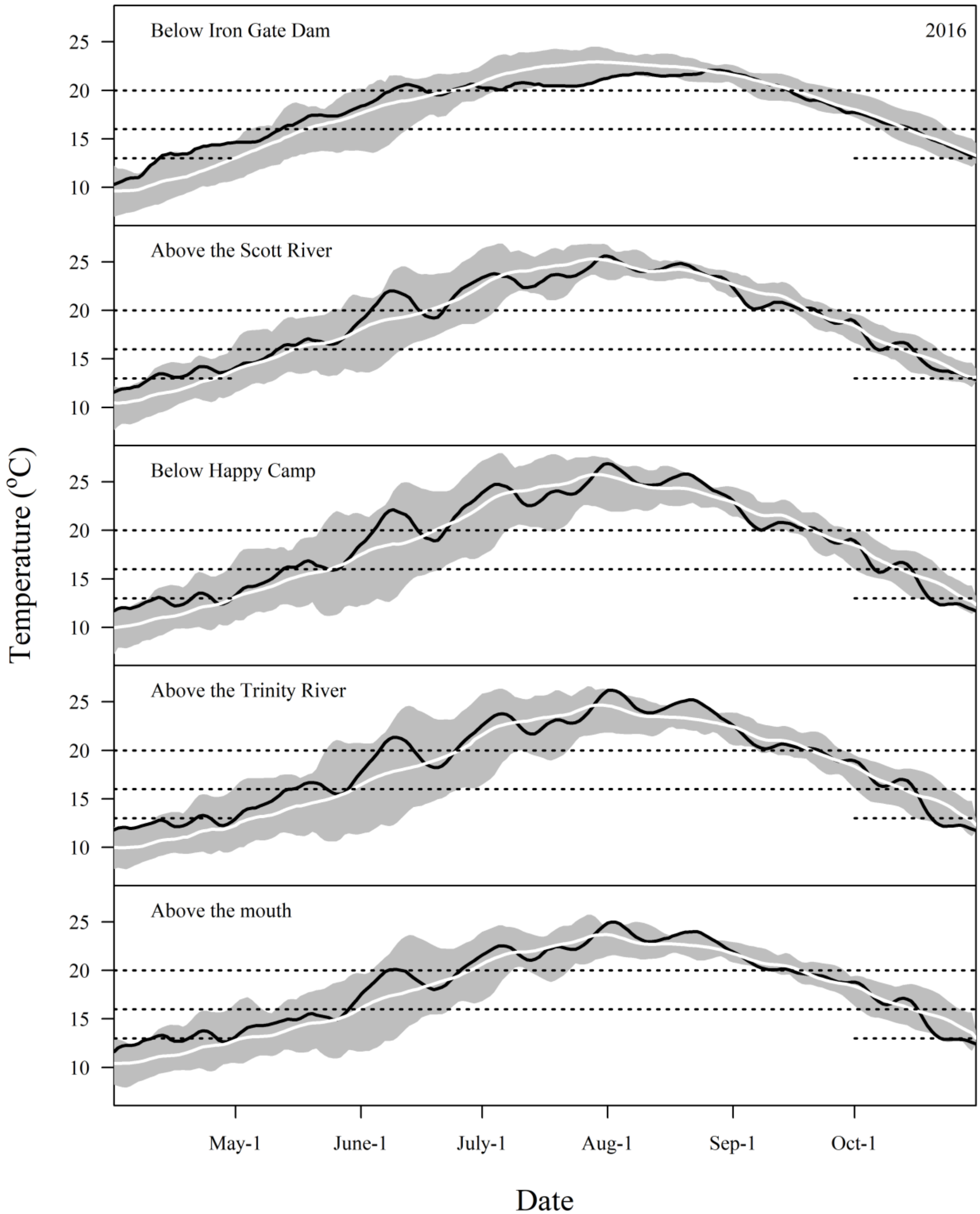
Appendix D14. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = 7DADM water temperatures in 2013; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



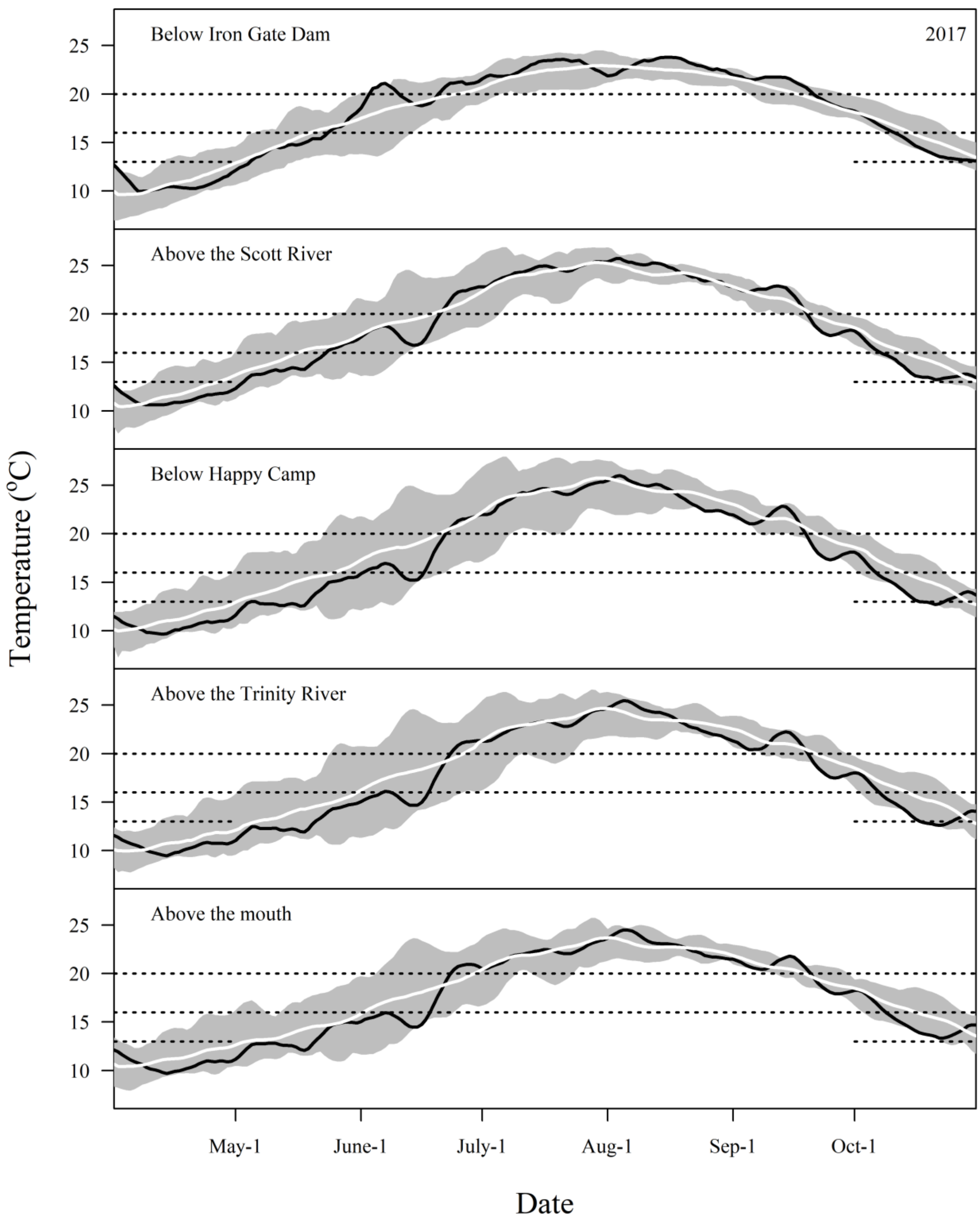
Appendix D15. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2014, with historical conditions. Black line = 7DADM water temperatures in 2014; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



Appendix D16. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2015, with historical conditions. Black line = 7DADM water temperatures in 2015; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

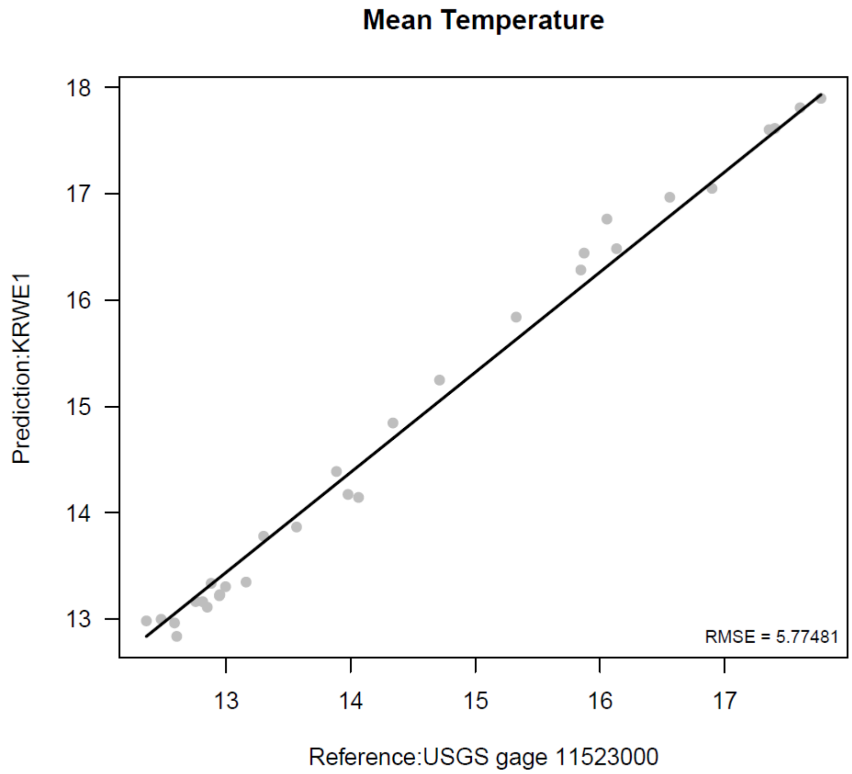


Appendix D17. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = 7DADM water temperatures in 2016; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

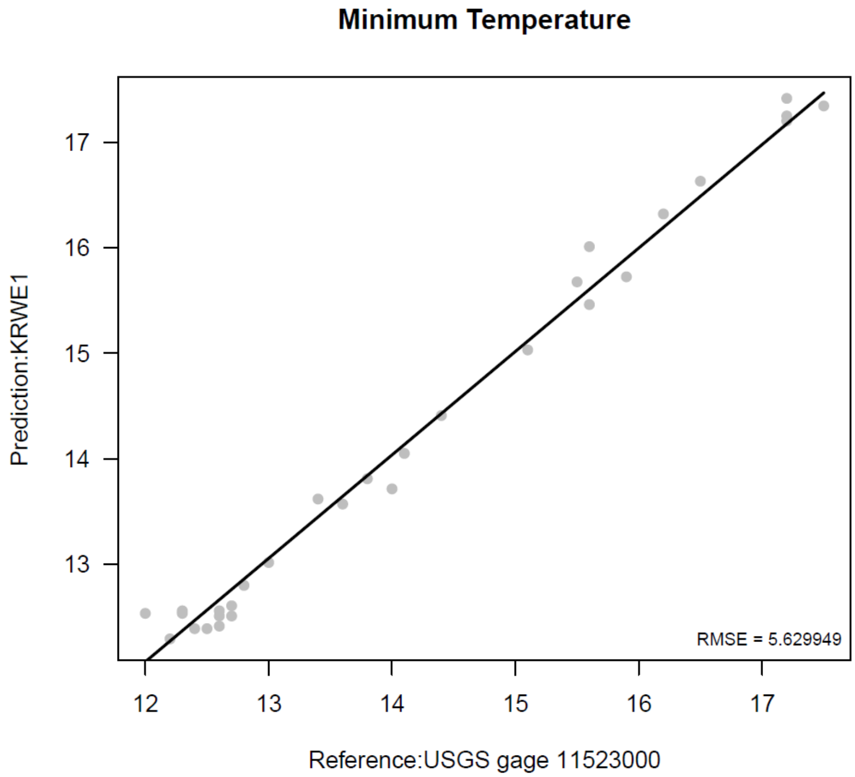


Appendix D17. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2017, with historical conditions. Black line = 7DADM water temperatures in 2016; white line = long-term mean 7DADM for each day of the year; gray polygon = long-term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

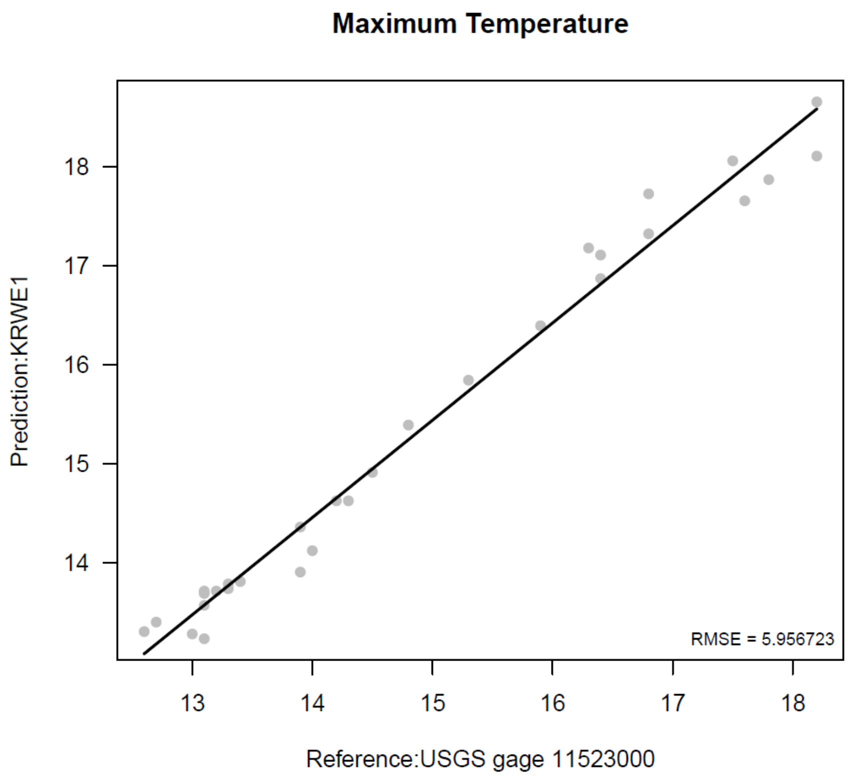
Appendix E. Predicted temperature values vs. reference values used for infilling at focal sites, with root mean square error (RMSE) as a measure for the difference between predicted and reference values.



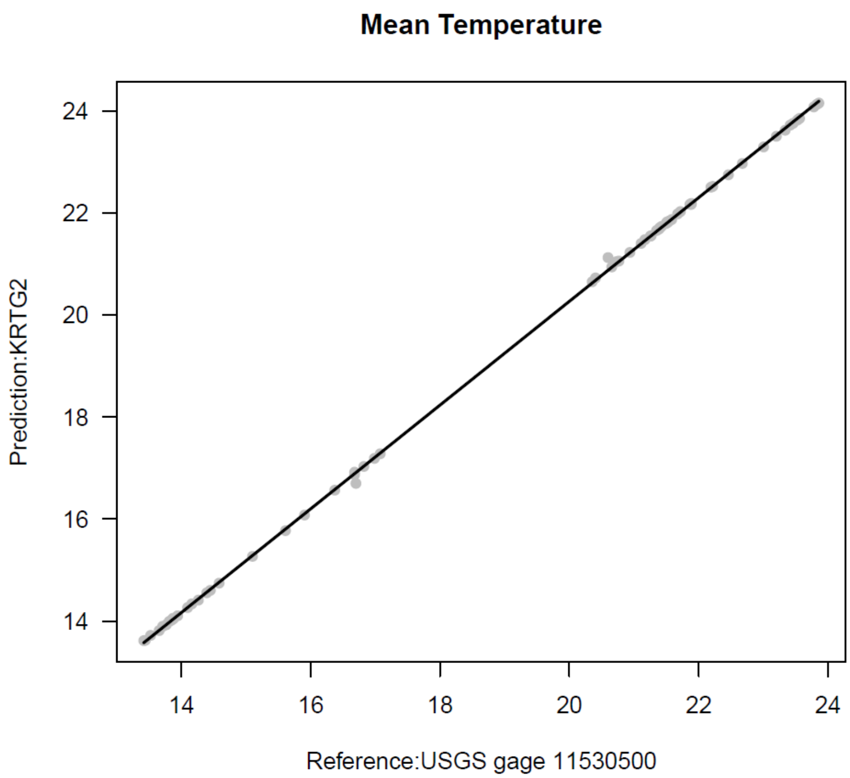
Appendix E1. Predicted mean temperature values vs. reference values used for infilling at the KRWE1 focal site, with observed data at USGS gage 11523000, with RMSE as a measure of the difference between the predicted and reference values.



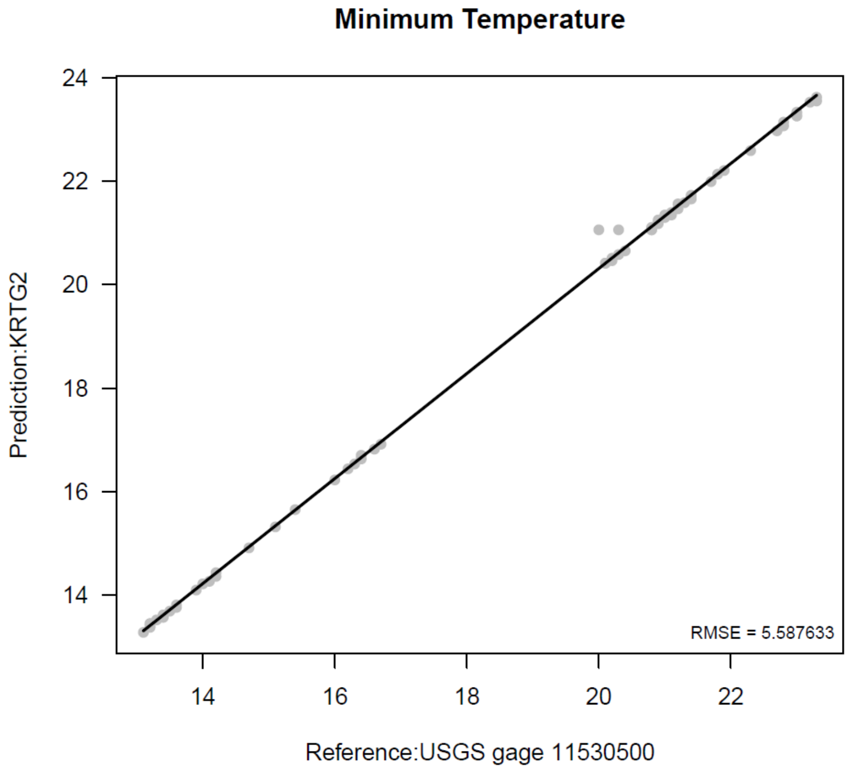
Appendix E2. Predicted minimum temperature values vs. reference values used for infilling at the KRWE1 focal site, with observed data at USGS gage 11523000, with RMSE as a measure of the difference between the predicted and reference values.



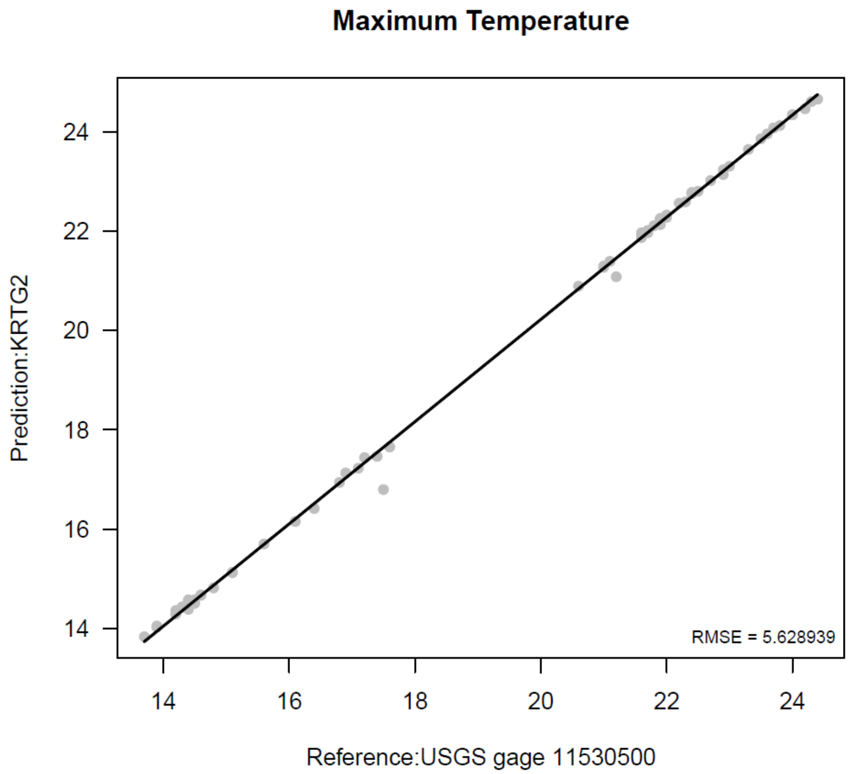
Appendix E3. Predicted maximum temperature values vs. reference values used for infilling at the KRWE1 focal site, with observed data at USGS gage 11523000, with RMSE as a measure of the difference between the predicted and reference values.



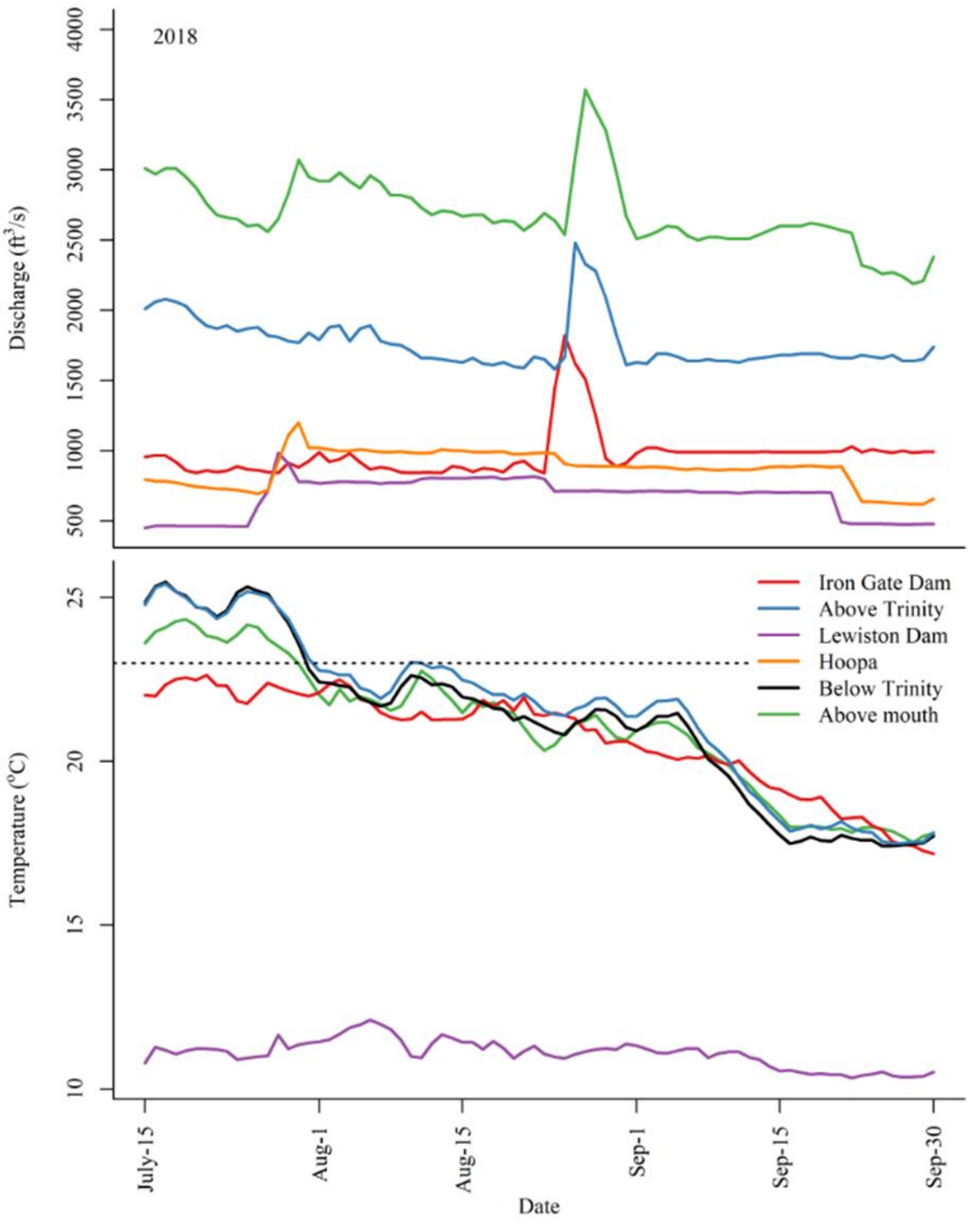
Appendix E4. Predicted mean temperature values vs. reference values used for infilling at the KRTG2 focal site, with observed data at USGS gage 11530500, with RMSE as a measure of the difference between the predicted and reference values.



Appendix E5. Predicted minimum temperature values vs. reference values used for infilling at the KRTG2 focal site, with observed data at USGS gage 11530500, with RMSE as a measure of the difference between the predicted and reference values.



Appendix E6. Predicted maximum temperature values vs. reference values used for infilling at the KRTG2 focal site, with observed data at USGS gage 11530500, with RMSE as a measure of the difference between the predicted and reference values.



Appendix F. Mean daily water temperature and river flows at five locations in the Klamath and Trinity Rivers before, during, and after supplemental releases from Trinity Reservoir, July 15 – September 30, 2018. Dotted line represents 23℃ criteria.