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Performance of water temperature management on the Klamath and Trinity Rivers, 2017

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Abstract.– Water temperature is an important factor in riverine environments, influencing the physiology and life history expression for salmonids and other aquatic organisms. Understanding the thermal regime of a river is a crucial component of successful environmental flow management, especially on rivers with dams and other anthropogenic influences. 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 on Pacific salmon. This report summarizes the results of 2017 water temperature monitoring for a set of focal locations within the anadromous portion of the Klamath Basin from April 1 to October 31. Temperature criteria for the Trinity River have been recommended by the Trinity River Restoration Program (TRRP) and are based upon the Trinity River Flow Evaluation Study and the Trinity River Mainstem Fishery Restoration: Final Environmental Impact Statement/Environmental Impact Report. On the Klamath River the U.S. Environmental Protection Agency's (EPA) Pacific Northwest salmonid life history stage temperature criteria are used, as they are the best science-based and peer-reviewed criteria available. In 2017, designated an 'Extremely Wet' water year, the Trinity River exceeded temperature criteria for 27 days at the monitoring location above the confluence with the Klamath. The Klamath River exceeded temperature criteria at all sites (range of 24 to 140 days), but only exceeded the long-term mean daily water temperatures at two sites, at Klamath River below Iron Gate Dam and at Klamath River above the mouth. Mean daily water temperatures were < 13.0°C before April 1 at all focal sites and were < 13.0°C after October 31 for 3 of 4 Trinity River focal sites and for 3 of 5 Klamath River focal sites. Most locations saw a decrease in days exceeding temperature criteria from 2016, as well as their respective long-term averages. Despite the overall decrease in number of days exceeding temperature criteria in 2017, elevated warm-season water temperatures likely remain a factor limiting the recovery of salmon populations as well as the expression of salmon life history strategies. Meeting water temperature threshold criteria in late spring and summer will likely require adaptive changes to water management as well as additional watershed restoration actions in future years.

Introduction

The Klamath River basin historically supported large runs of Chinook Salmon *Oncorhynchus tshawytscha*, Coho Salmon *O. kisutch*, and steelhead *O. mykiss* that contribute to economically and culturally important subsistence, sport, and commercial fisheries (Leidy and Leidy 1984; KRBFTF 1991; NAS 2004; DOI et al. 2013). Populations of Chinook Salmon in the Klamath basin have dramatically declined over the past century as a result of various anthropogenic or anthropogenic linked factors, including a series of dams on the mainstem Klamath and Trinity Rivers (KRBFTF 1991; West Coast Chinook Salmon Biological Review Team 1997; Ayres Associates 1999; Poole and Berman 2001; USEPA 2003; NAS 2004; Caissie 2006; Heard et al. 2007; Moyle et al. 2008, 2011; Thorsteinson et al. 2011; Hester and Doyle 2011; USDOI and NMFS 2012; USDOI et al. 2013). 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). Influences on life stages can be significant during spawning and early stages of life, which have a greater effect on overall population survivability (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 (e.g. reduction in feeding [Brett 1971] and seeking thermal refugia [Sullivan et al. 2000; Goniea at al. 2006]). Effects on eggs and alevin can be more acute, with elevated temperatures directly affecting survival (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).

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 significance of water temperatures on salmon and concern that elevated water temperatures in the Klamath basin could be impacting salmon populations. These water temperature data are used for a variety of purposes, including the development and validation of physical water temperature models (Perry et al. 2011; Jones et al. 2016), driving salmon production models, assessment of watershed restoration program criteria (Polos 2016), and prediction of juvenile salmon outmigration timing (Som and Hetrick 2017).

This report summarizes Klamath basin water temperature data collected by the USFWS in 2017 within the context of the period of record at each location and facilitates numerical evaluation of criteria set for the Trinity and Klamath Rivers. Reporting is focused on the warm half of the year for all summaries and analyses because that is the period when water temperatures are most likely to negatively impact salmon populations (USEPA 2003). It is the intent of this report to inform and be utilized by managers within the Klamath basin, to increase understanding of the areas of concern within the basin and the consequences of high water temperatures on salmonid populations.

Methods

Study Area

This report focuses on the lower Klamath basin, incorporating the area where anadromy is present: the Trinity River and tributaries and the Klamath River and tributaries. Monitoring locations on the Trinity River extend from below Lewiston Dam (TRRC1; rkm 180.6; see Figure 1; see Table 1) to the confluence with the Klamath River (TRWE1; rkm 0.8; see Figure 1). On the Klamath River monitoring locations extend from above Iron Gate Dam (KRCO1; rkm 334.3; see Figure 1; see Table 1) to near the mouth (KRTG2; rkm 12.7; see Figure 1; see Table 1).

Data Sources and Protocols

The USFWS monitored water temperatures at 30 locations in the Klamath basin in 2017 and acquired data from 2 locations monitored by the U.S. Bureau of Reclamation (Figure 1; Table 1). Of these 32 locations, 16 were on the mainstem Klamath River and 16 were on Klamath River tributaries. The mainstem Trinity River holds 8 of the 16 Klamath tributary monitoring locations. These locations were selected to be representative of different reaches in their respective rivers and to not be inadvertently influenced by local conditions. All water temperature monitoring locations were situated in the lower Klamath basin except one, which was located in an un-impounded reach of the mainstem Klamath River upstream of Copco Reservoir within PacifiCorp's Klamath Hydroelectric Project. Data from all USFWS monitoring locations are stored in a Microsoft Access relational database and are available upon request.

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-min 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°C.

Water temperature data were also acquired from two sites monitored by the U.S. Bureau of Reclamation, Douglas City (DGC) and above North Fork Trinity (NFH). These data were examined for suspicious observations and any data determined to be erroneous were removed.

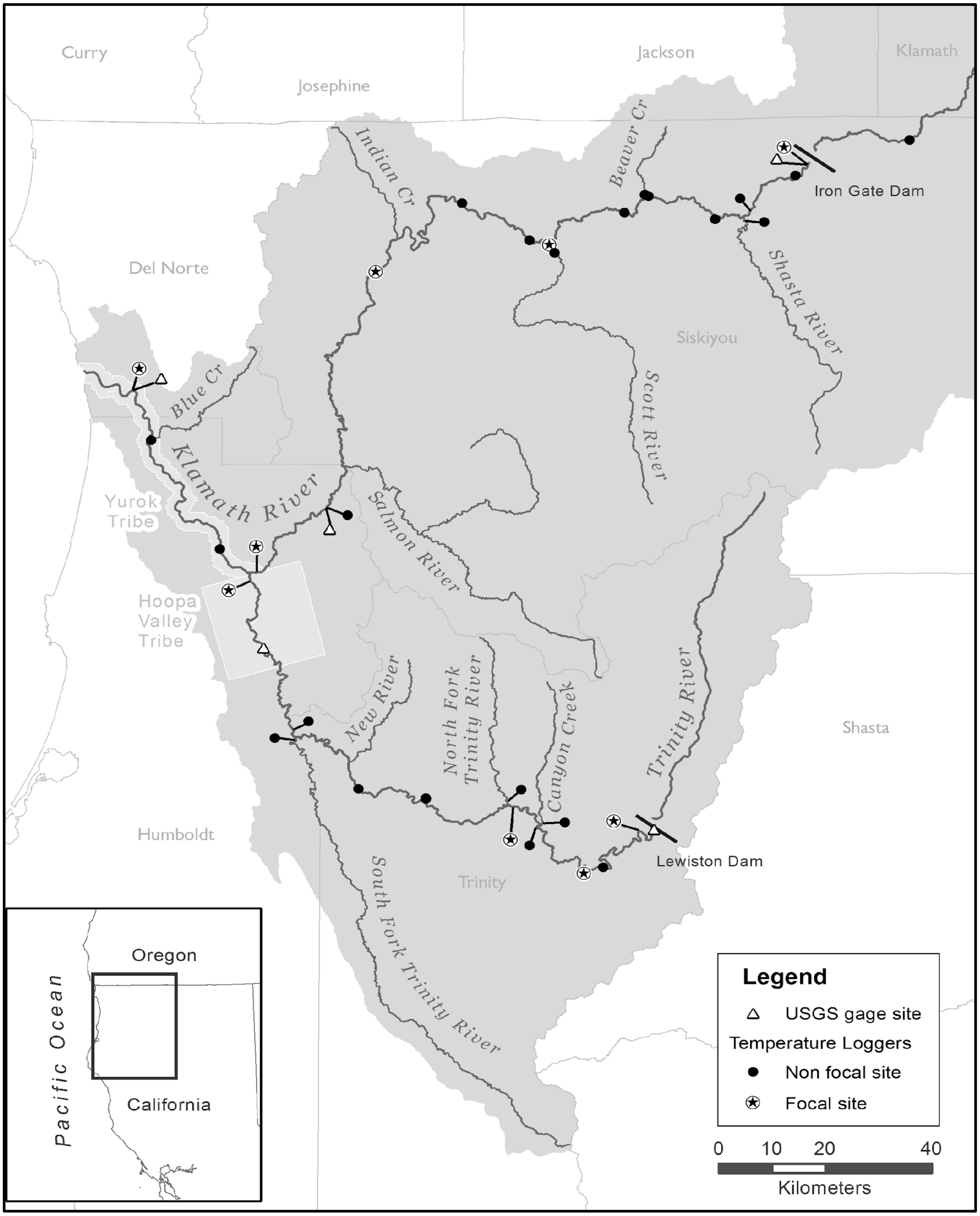

Figure 1. The lower Klamath basin with the locations that water temperature were monitored in 2017. Anadromy is limited to below Iron Gate Dam on the Klamath River and below Lewiston Dam on the Trinity River.

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 2017. Locations are ordered from upstream to downstream by river kilometer (rkm) along the Klamath and Trinity Rivers, with tributaries arranged by their entrance to 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	2007-2017
Klamath River	Below Iron Gate Dam	KRIG1	309.7	41.931049	-122.441397	2001-2017
Klamath River	Below R-Ranch	KRRR1	304.3	41.90378	-122.476295	2001-2002, 2005-2017
Klamath River	Above Shasta River	KRSH1	288.5	41.83124	-122.593382	2002-2017
Shasta River	Near mouth	SHKR1	0.8	41.824759	-122.593916	2001-2003, 2005-2017
Klamath River	At Trees of Heaven	KRTH1	281.0	41.825055	-122.658796	2005-2017
Klamath River	Fisher's RV Park	KRBV2	263.4	41.867436	-122.809451	2002-2017
Beaver Creek	Near mouth	BVKR1	0.1	41.870299	-122.817513	2002-2017
Klamath River	At Walker Creek Bridge	KRWB1	254.8	41.837708	-122.864627	2005-2017
Klamath River	Above Scott River	KRSC1	233.2	41.779236	-123.033245	2002-2017
Scott River	At Johnson Bar	SCKR1	2.5	41.765479	-123.022657	2004, 2006-2017
Klamath River	Below Scott River	KRSC2	227.8	41.78791	-123.078927	2005-2017
Klamath River	At Seiad Valley	KRSV1	209.3	41.854087	-123.231469	2001-2017
Klamath River	Below Happy Camp	KRHC1	164.2	41.729647	-123.425579	2002-2017
Klamath River	At Orleans	KROR1	95.5	41.303576	-123.534386	2001-2006, 2008-2017
Klamath River	Above Trinity River	KRWE1	70.2	41.185991	-123.702282	2002-2017
Klamath River	Below Weitchpec	KRBW2	61.7	41.227666	-123.772591	2004, 2007-2017
Klamath River	above Blue Creek	KRBC1	26.2	41.423077	-123.929328	2003-2017
Klamath River	Above mouth	KRTG2	12.7	41.511184	-123.978439	2004-2017
Trinity River	Below Lewiston Dam	TRBL1[a]	180.6	40.717945	-122.803133	2017
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	2002-2017
Trinity River	At Douglas City	DGC*	148.5	40.645278	-122.956665	2005-2017
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	2001-2017
Trinity River	Above North Fork	NFH*	119.7	40.766532	-123.114479	2005-2017
N.F. Trinity River	Near mouth	NFTR1	0.1	40.770324	-123.127484	2001-2017
Big French Creek	Near mouth	BFTR1	0.1	40.780475	-123.308896	2001-2017
Trinity River	Above Big French Creek	TRBF1	96.8	40.779208	-123.3085	2001-2017
Trinity River	At Burnt Ranch	TRBR1	77.2	40.797284	-123.458798	2001-2017
Trinity River	Above South Fork	TRSF1	50.8	40.88981	-123.602038	2001-2003, 2005-2017
S.F. Trinity River	Near mouth	SFTR1	0.1	40.889434	-123.602214	2001-2017
Trinity River	Above Klamath	TRWE1	0.8	41.181077	-123.705809	2002-2017

*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 will replace TRRC1 as the location for this site in future reports.

Focal Sites

Focal site selection was based on points influential to temperature within the mainstem Klamath or Trinity River, these points usually correspond to a landmark, e.g., a dam or large tributary. Four focal sites were chosen on the Trinity River and five focal sites were selected on the Klamath River. The data gathered from these sites are used for further analysis.

On the Trinity the furthest upstream focal site is just below Lewiston Dam, the upper limit to anadromy on the Trinity River. In 2017 the location used for monitoring below Lewiston (TRRC1) was relocated upstream and replaced by a new location (TRBL1). The other three focal sites; 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 uppermost focal site is below Iron Gate Dam (KRIG1), which marks the upper limit to anadromy on the Klamath River. The other four focal sites were above the Scott River (KRSC1), below Happy Camp (KRHC1), above the Trinity River (KRWE1), and above the mouth of the Klamath (KRTG2). KRSC1 was chosen because it is the first tributary that can substantially influence water temperatures in the Klamath River downstream of Iron Gate Dam. KRHC1 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). KRWE1 was chosen because it is upstream of the Trinity River. Finally, KRTG2 was chosen as it is the terminus of the river.

Data Analysis

Analyses were limited to data recorded between April 1 and October 31. 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. Additionally, water temperatures were monitored less consistently outside these dates. Mean daily water temperatures were < 13.0°C on April 1 at all focal locations in 2017, and were < 13.0°C by October 31 for 3 of 4 Trinity River focal monitoring sites and for 3 of 5 Klamath River focal monitoring sites. After September 30, 2017 the water year designation changes to 2018, 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). Spring and summer juvenile salmon outmigration temperature criteria differ depending on the water year type for the Trinity River basin, while summer and fall adult salmon temperature criteria are the same regardless of water year type (Table 2). Water year is generally described as a 12-month period, between October 1st to September 30th the next calendar year, and the precipitation and other hydrological phenomena that occurred during the period (Paulson et al. 1985). Trinity River water year is further described by type, the amount of precipitation and hydrological phenomena: 'Normal', 'Wet', 'Extremely Wet', 'Dry', and 'Critically Dry' (DOI 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 provide at least marginal thermal conditions for outmigrating juvenile salmon and to facilitate early outmigration.

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		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 similar to the Trinity River's does not exist for the Klamath River. Instead, the EPA's 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, identified as the time frame when the vast majority of these reproductive activities occur in the Klamath basin (Leidy and Leidy 1984; Shaw et al. 1997). This 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. These criteria were interpreted using the EPA recommended metric of seven-day average daily maximum temperatures (7DADM) and used in the evaluation of Klamath River water temperatures.

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

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 locations using 7DADM temperatures instead of mean daily temperatures. These values provided the context (mean and range of observed values) for which to compare 2017 water temperatures. For each focal monitoring location in each year with complete data, or sufficient data to encompass the period of time a criterion was exceeded, the number of days that exceeded the associated water temperature criterion was calculated. Finally, for each focal location, the long-term mean, minimum, and maximum number of days exceeding the associated water temperature criterion 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 locations contained gaps due to the loss of loggers as a result of 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, U.S. Geological Survey (USGS), and the Yurok Tribe Environmental Program. 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).

Results

Trinity River

In 2017, an 'Extremely Wet' water year, the focal sites DGC and NFH did not exceed water temperature criteria on any day during the period of reporting, which was fewer than the number of days the criteria were exceeded at these location for 8 of 13 and 8 of 12 previous years, respectively (Figure 2; Table 4; Appendix A). The TRWE1 criteria was exceeded during 27 days, which was fewer than the number of days the criteria was exceeded at this location for 7 of 16 previous years. Exceedances happened during two criteria phases. From April 1 – May 22, the criteria (≤ 13.0°C) were exceeded 6 days, and from June 5 – July 9, the criteria (≤ 17.0°C) were exceeded 21 days. The number of days exceeding the criteria were fewer than the long-term average number of days per year (x = 39; see Appendix A) exceeding the criteria at these sites. The number of days exceeded were also fewer than the long-term average of days exceeding criteria set for TRWE1 (x = 30; See Appendix A).

In regards to days above the long-term average at each location, there was an increase in number of days as the sites became located further downstream. Some of these observations did occur in concert with exceedances of temperature criteria at the TRWE1 site, but also occurred at every focal site (Figure 2; days above long-term average by location, TRRC1 = 1, DGC = 27, NFH = 36, TRWE1 = 66).

At TRRC1 and DGC no days exceeded the historical range of temperatures. At NFH and at TRWE1, 2 and 4 days exceeded the historical range, respectively. These exceedances of historical range happened in mid-September, the 12th and 13th at NFH and from the 11th to the 14th at TRWE1 (see Figure 2).

Water temperatures at the focal Trinity River monitoring locations for 2000-2016 are found in Appendix B.

Table 4. Number of days exceeded temperature management targets in 2017 at focal locations on the Trinity River, 'Extremely Wet' water year criteria. TRRC1 = 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.

		Juvenile Outmigrant Criteria			*Adult Holding and Spawning Criteria*		
Location Code	**rkm**	**April 1-May 22 13°C**	**May 23-June 4 15°C**	**June 5-July 9 17°C**	**July 1- Sept. 14 15.6°C**	**Sept. 15-Sept. 30 13.3°C**	**Oct. 1-Oct. 31 13.3°C**
TRRC1[a]	173.0	-	-	-	-	-	-
DGC [b,c]	148.5	0	0	0	0	0	-
NFH [b,c]	119.7	0	0	0	0	0	-
TRWE1[d]	0.8	6	0	21	-	-	0

[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.

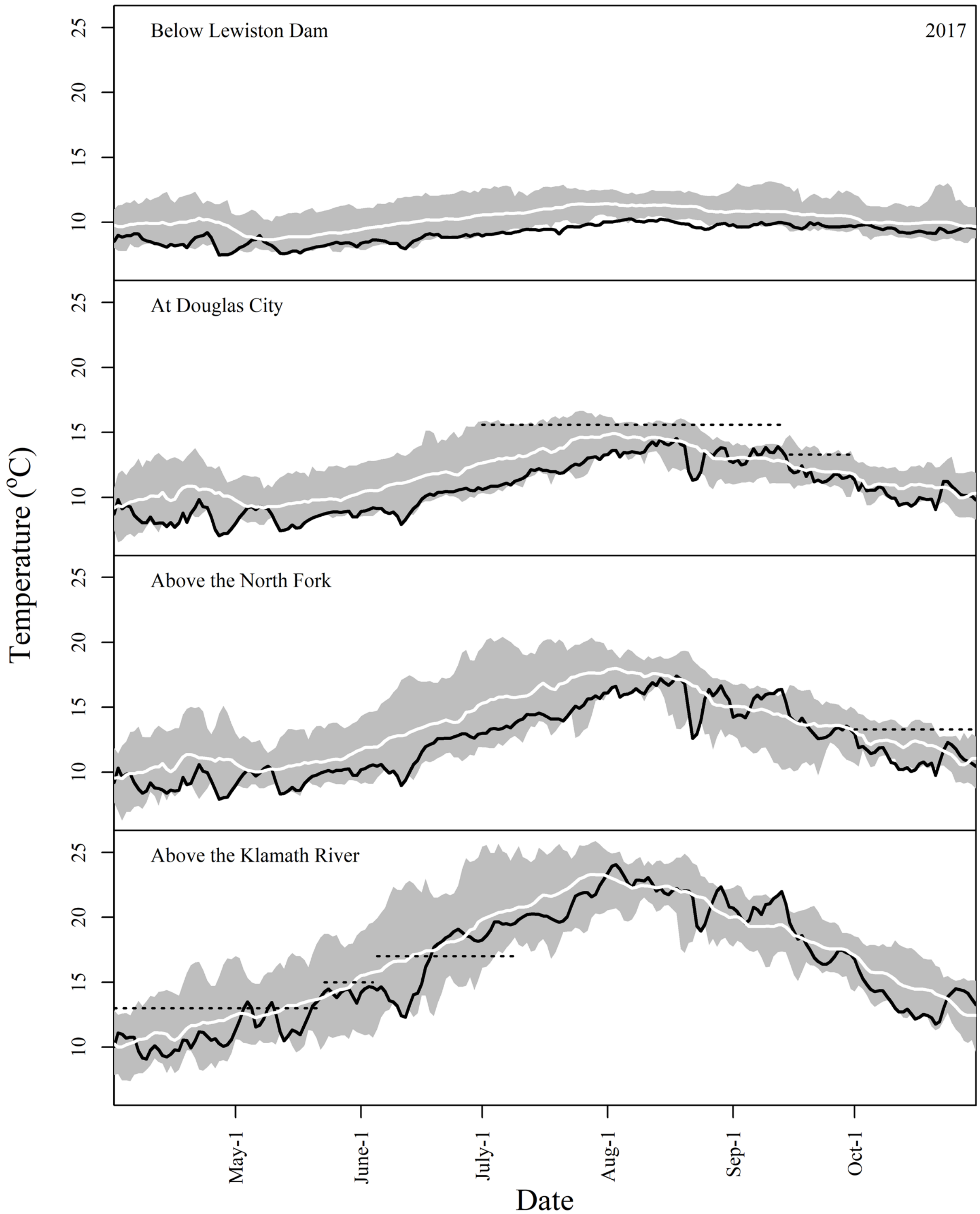

Figure 2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2017, with historical conditions. Black line = mean daily water temperatures in 2017; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature criteria.

Klamath River

In 2017, the number of days exceeding the migrating adult salmon EPA 7DADM criterion at focal Klamath River monitoring locations (Figure 3; Table 5; Appendix C) ranged from 88 days (KRWE1) to 99 days (KRIG1). The number of days exceeding the criterion at Klamath below KRIG1 and KRTG2 was greater than the long-term mean for each location, 99 (x=88.5) and 89 (x=84.8) respectively.

The number of days exceeding the rearing juvenile salmon EPA 7DADM criterion ranged from 112 days, at KRTG1, to 140 days, at KRIG1. These numbers of days exceeding the rearing juvenile salmon criterion were less than their respective long-term means.

The number of days exceeding the spawning, incubation, and emergence EPA 7DADM criterion ranged from 24 days, at KRWE1, to 31 days, at KRIG1, KRSC1, and KRTG2. These numbers of days exceeding the spawning, incubation, and emergence criterion were below their respective long-term mean.

No temperatures at any site exceeded the historical range, but at KRIG1, KRSC1, and KRTG1, 18, 6, and 4 days respectively, were equal to the historical high for that day at the site.

7DADM water temperatures at the focal Klamath River monitoring locations for 2000-2016 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 locations in 2017. 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°C 7DADM	**16°C 7DADM**	**20°C 7DADM**
KRIG1	309.7	31 (33.8, 26-49)	140 (148.0, 129-163)	99 (88.5, 74-102)
KRSC1	233.2	31 (35.5, 25-52)	137 (147.1, 128-175)	91 (98.5, 83-120)
KRHC1	164.2	25 (30.9, 25-51)	121 (138.9, 116-176)	89 (96.2, 73-128)
KRWE1	70.2	24 (30.5, 23-44)	114 (134.4, 110-176)	88 (89.4, 63-119)
KRTG2	12.7	31 (33.8, 27-51)	112 (135.7, 118-171)	89 (84.8, 64-110)

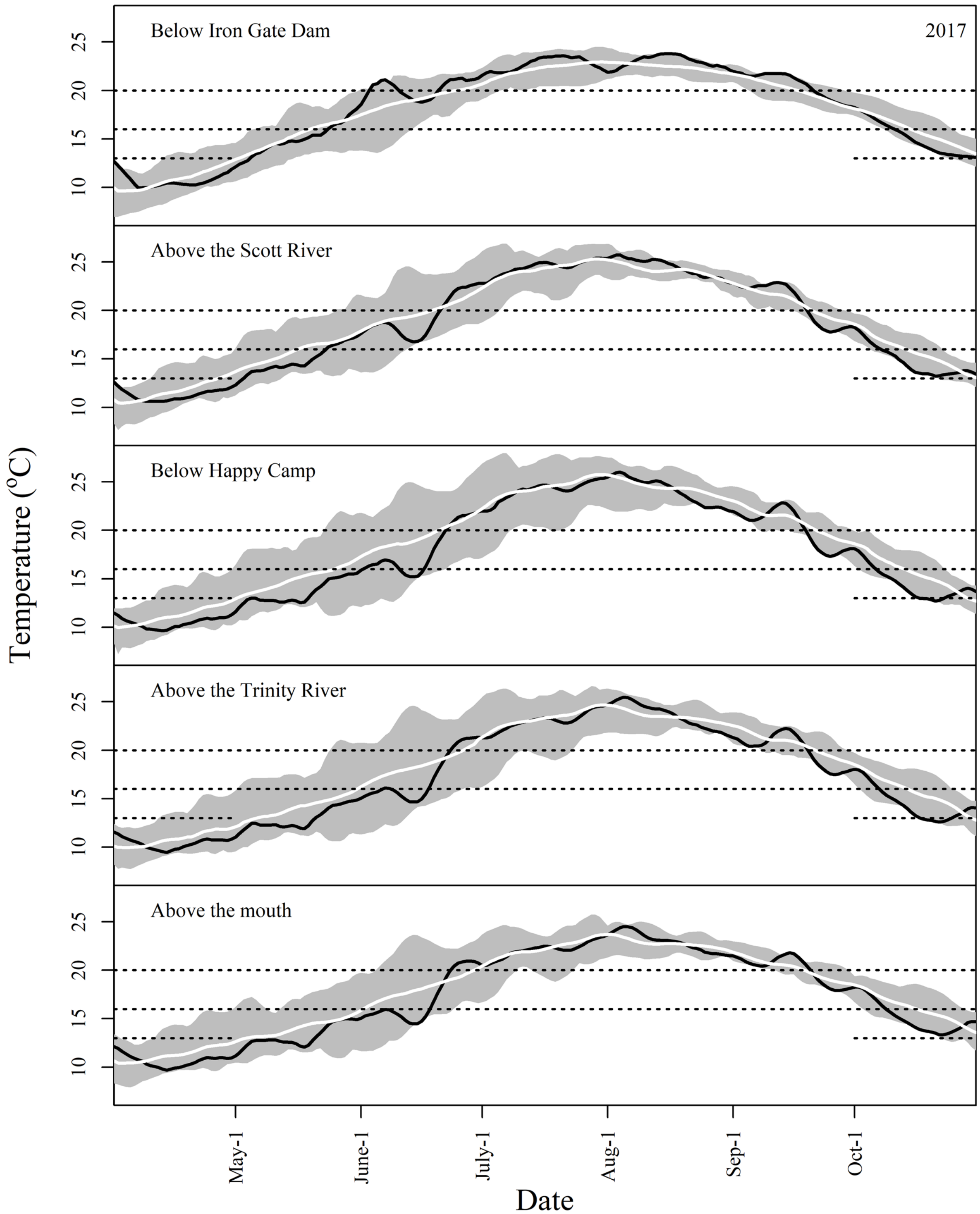

Figure 3. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2017, with historical conditions. Black line = 7DADM water temperatures in 2017; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.

Infilled Data

In 2017 the total number of days infilled on the Trinity River were 29 at the North Fork Trinity (NFH) Site, data from Trinity River Above Big French Creek (TRBF1; see Figure 1; See Table 1) was used to model and infill this site, which was 22.9 km downstream of NFH. On the Klamath there were 16 infilled days at Klamath River near the mouth (KRTG2), data from USGS gage 11530500 was used to model and infill this site, 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.

Discussion

Trinity River

Water temperature criteria for the Trinity River were exceeded less frequently in 2017 than in any year since 2013. There were 42 fewer days that exceeded temperature criteria in 2017 than the previous year. The effects of the latest multi-year drought in California were likely minimized after an ‘Extremely Wet’ water year in 2017, with above average precipitation and snowpack. Exceedances still occurred in late spring and early summer at the TRWE1 site (See Figure 1; See Table 1), the furthest downstream focal site from Lewiston Dam. These exceedances occurred in late spring and early summer, alluding to the challenges associated with managing a river’s thermal regime, even in a year with abundant precipitation. Comparisons can be drawn from 2006, the only other recorded ‘Extremely Wet’ water year since the inception of the TRRP and enhanced streamflows for restoration purposes. Like in 2017, exceedances primarily happened at the TRWE1 site, with 18 of the total 24 exceeding days occurring at the TRWE1 site (see Appendix A). These exceedances occurred on a similar timeframe as well, in late May, above the 13°C threshold, and in late June through early July, exceeding the 17°C threshold (see Appendix B).

The annual flow release schedule for the Trinity River is established based on the recommendations of the December 2000 Trinity River Mainstem Fishery Restoration Record of Decision’s (ROD), incorporating the water year type and restoration needs (USDOI 2000). On April 28, releases from Lewiston Dam into the Trinity River were decreased from a peak of approximately 11,000 cubic feet per second (cfs) to 2,050 cfs on May 2 before increasing again to 5,400 cfs on May 10 (USDOI and USBOR 2017). The first day that exceedances were recorded at TRWE1 occurred on May 4, during this brief period of lowered flows. On June 4, flows began ramping down to the 450 cfs summer base flow, which was reached on August 11 (USDOI and USBOR 2017). The second period of exceedances at TRWE1 were recorded during this period of decreasing flows, starting June 5 and continuing for 21 days. The highest daily average of 19.6°C occurred on July 5 at this site location. These events illustrate how water temperatures in the lower Trinity River are dependent on maintaining flows and that the juvenile outmigrant criteria are not being met based on the current management recommendations. Temperature exceedances occur consistently at TRWE1, with 16 out of the past 17 years on record experiencing them for at least 7 days in a given year during varying life stage temperature criteria.

Tributaries are known to influence mainstem temperatures, particularly during low-flow conditions, and understanding their relationship to dam impacted thermal regimes is crucial (NAS 2004; Olden and Naiman 2010). The influence of major tributaries to the lower Trinity River could be a significant factor affecting temperatures, especially the South Fork Trinity River, which has been one of the warmest tributaries monitored in previous studies done by the USFWS (Zedonis 2003). Examination of data collected from the South Fork Trinity and Above the South Fork (SFTR1 and TRSF1 respectively; See Figure 1; See Table 1) show that the average daily temperature for all years recorded (2001-2003, 2005-2017) in the South Fork Trinity River is 2.59 °C higher (SFTR1, x = 15.28°C; TRSF1, x = 12.68°C). However, when the data was limited to the years of 2013-2017, SFTR1 was an average of 4.57 °C higher than from TRSF1 (SFTR, x = 17.23°C; TRSF1, x = 12.66°C; See Appendix B). Considering data from 2017 for the South Fork Trinity River was incomplete, due to a loss of that logger, temperatures at SFTR1 were still an average of 1.21°C higher than what was measured at TRSF1.

Temperature is a critical environmental cue for smolt development, and higher temperatures can influence morphological and behavioral changes, potentially resulting in premature smolting or desmoltification when they occur during periods of outmigration (Wedmeyer et al. 1980; McMahon and Hartman 1988; Hoar and Randall 1988; McCullough 1999). Migration survival is linked to conditions in the freshwater and ocean environments, and if warming is occurring more rapidly in rivers, smolts migrating to the ocean may have a narrower window to respond and adapt to changing conditions (Björnsson et al. 2011). Temperature also influences residence time of juveniles in river, and can lead to early downstream migration (NMFS 2002).

As long as there are multiple competing objectives for flow regime on the Trinity River there are likely to be exceedances in temperature criteria. These objectives might include creating habitat for multiple life history stages, mimicking natural flow events to produce a variable hydrograph, or encouraging geomorphic change (USFWS and HVT 1999). The process of managing flows can lead to a prioritization of goals and make it more difficult to manage temperature criteria, especially in a large river system. A change in the hydrograph may keep exceedances under control in one location but can lead to exceedances further downstream, where the thermal regime is more difficult to mitigate and manage. The implementation of a dynamic hydrograph, with dramatic peaks following storm events that mimic the pattern of natural variation can help maintain the interconnected geomorphic and ecological processes that riverine species, including anadromous salmonids, are adapted to (Poff et al. 1997).

Klamath River

Using EPA guidelines, in 2017 and for the long-term averages, the migrating adult salmon and rearing juvenile salmon criteria were exceeded for approximately three months and more than four months, at all five focal monitoring locations. This illustrates a recurring concern about the long term effects of elevated water temperatures in the Klamath River. The numbers of days exceeding all EPA criteria in 2017 were fewer than the respective long-term averages at all five Klamath River focal sites, with the exception of the migrating adult salmon criterion below Iron Gate dam (KRIG1; See Figure 1; See Table 1) and near the mouth (KRTG2; See Figure 1; See Table 1). Although overall 2017 water temperatures were slightly lower than average for the period of April through October, exceedances at certain locations increased. The number of days exceeding criteria increased at KRIG1 >20°C; KRWE1 >13°C; and KRTG1 >20 (See Table 5) when compared to 2016 (David and Goodman 2017). These results correspond with trends observed on the Trinity River, even as thermal management on the Klamath River proves to be a unique challenge.

During 2017 flows from IGD were above the base flow, of 1000 cfs, between April 1 – June 22, beginning at 5590 cfs on April 1, peaking at 6910 cfs on April 15 and generally decreasing over time until the return to approximate base flows on June 22. These base flows were held from June 23 through September 7, varying slightly, and corresponded with a general increase in days above long term 7DAM at all sights. The highest temperatures recorded at each site for 2017 also occurred during this period of base flows (>23.0°C at KRIG1; >25.0°C at KRHC1; >26.0°C at KRHC1; >25.0°C at KRWE1; and >24.0°C at KRTG2). On September 8, flows increased to approximately 1200 cfs and varied at around 1200 cfs for the remainder of the study period.

The Klamath River has several large dams in its upper basin that store water and sediment and disrupt the seasonal fluctuations in temperature and flow present in a free flowing river (Doyle et al. 2003). The reservoirs created by these dams are mostly shallow, i.e., the average depth in Upper Klamath Lake is 3 m, and have limited ability to influence temperature, which may explain the perpetual elevated water temperature recorded during the spring and summer months. The outlets in these reservoirs are located in the epilimnion and the quantity of stratified cool water is limited. More recently PacifiCorp has taken steps to try to improve water quality from IGD, and noted that their installation of a barrier curtain helped to isolate warmer near surface water under some conditions, and allows the release of more seasonally lower temperature water (PacifiCorp 2017).

The effects of an elevated thermal regime on salmonids has been continually monitored throughout the basin, including the effects these changes have on salmonid behavioral thermoregulation by exploiting spatial and temporal thermal refugia in the Klamath basin (e.g., Sutton et al. 2007; Strange 2010; Sutton and Soto 2012; Brewitt and Danner 2014). Salmonids do show some capacity to acclimate to higher water temperatures, but as cold-water adapted organisms, this is limited and has effects on other ecological factors that influence survivability (Brett 1952; Cherry at al. 1975; Magnuson et al. 1979; Dickerson and Vinyard 1999).

The prevalence of disease outbreaks in salmon is a management concern relating to water temperature on the Klamath. The myxozoan parasites *Ceratonova shasta* and *Parvicapsula minibicornis* can be influenced by environmental factors such as streamflow and water temperatures due in part to their complex life cycle. Both parasites alternate between a myxospore and actinospore spore stage that infect different hosts. Actinospores develop in the polychaete worm *Manayunkia speciosa* after they ingest and are infected by myxospores present in the water. The actinospores released by the worms may then infect juvenile and adult salmonids, particularly Chinook and Coho salmon, leading to a necrosis of internal tissue that can result in death for the host (ESSA 2017). In 2017, a wetter and cooler year than the previous two years, the prevalence of *C. shasta* infection in Chinook salmon collected in the Klamath above the Trinity River confluence during peak outmigration was 26%, which was lower than the 48% observed in 2016 and 91% in 2015 (True et al. 2017). The physiological stress of sustained high water temperatures on fish corresponds with higher rates of infection and disease, which can contribute significantly to juvenile salmonid mortality in the Klamath basin (Benson 2014).

Despite the overall decrease in number of days exceeding all temperature criteria in 2017, elevated warm-season water temperatures likely remain a factor limiting the size of salmon populations and the expression of salmon life history strategy (KRBFTF 1991; NAS 2004; Bartholow 2005; NCRWQCB 2010; NMFS 2014). The impact of high summer water temperatures varies depending on the timing and extent of the freshwater stage of anadromous species' life histories (NMFS 2002). Water temperature throughout the mainstem should continue to be a primary management concern as current water temperatures impair multiple beneficial uses (NCRWQCB 2010). The ability of salmonids to adapt to an anthropogenically influenced thermal regime is limited and thermal change is likely to be more rapid than is possible to genetically acclimate or adapt to (Quinn and Adams 1996; Isaak et al. 2011)

Conclusion

In the lower portions of the Trinity River and in the Klamath River, water temperatures have frequently been higher than management targets recommended to protect salmon populations. In the upper monitored area of the Trinity River, cold-water releases have kept water temperatures from reaching stressful levels, but these releases have not had the same effects further downstream. In 2017, the implications of when exceedances occurred suggests there may have been negative effects on outmigrating juveniles.

The extended high water temperatures of multiple preceding years in the Klamath have likely resulted in behavioral and physiological shifts in salmonids, causing them to seek thermal refugia and alter migration timing. There are also implications for disease infection and transmission that are likely to remain a factor of great concern for basin managers, which can have long-term impacts on smolt survival and abundance and possibly population viability.

Improving thermal regimes is an important component of restoration efforts in the Klamath basin as well as rivers throughout the Pacific Northwest. These efforts are challenging due to the dynamic nature of large river systems as well as competing objectives and goals regarding water management. Management decisions that are made cooperatively and incorporate basin wide trends will likely have the most success. Watershed restoration actions and adaptive changes to water management are likely necessary to meet late spring and summer water temperature criteria in future years. Such actions could help to ensure the viability of imperiled salmon populations in the basin, as well as the greater aquatic community that depends on and inhabits rivers.

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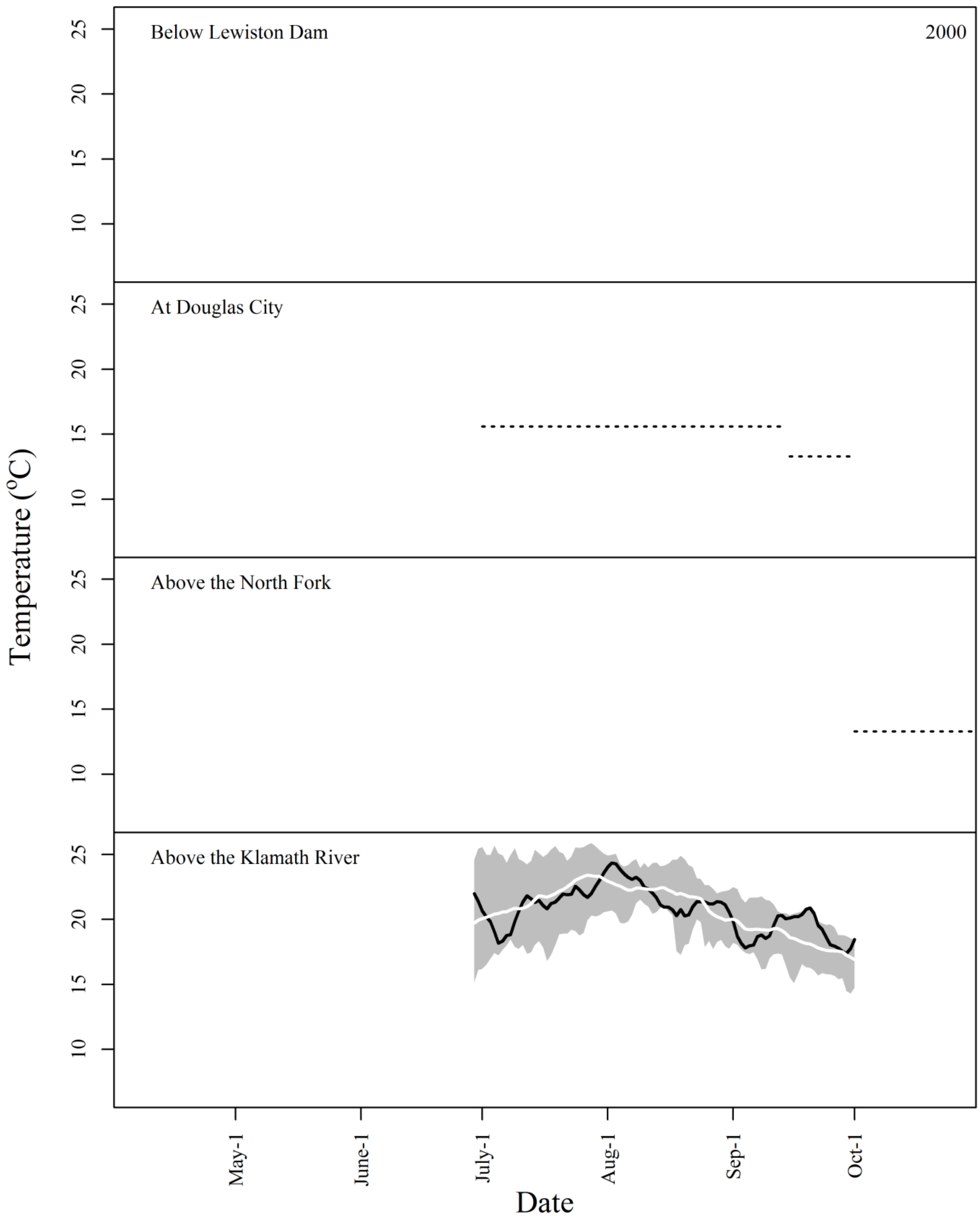
Appendix A. Number of days exceeding numeric water temperature criteria for the four focal locations on the Trinity River, 2001-2017. TRRC1 = Trinity River Below Lewiston Dam; DGC = Trinity at Douglas City; NFH = Trinity above the North Fork Trinity; TRWE1 = Trinity above the Klamath.

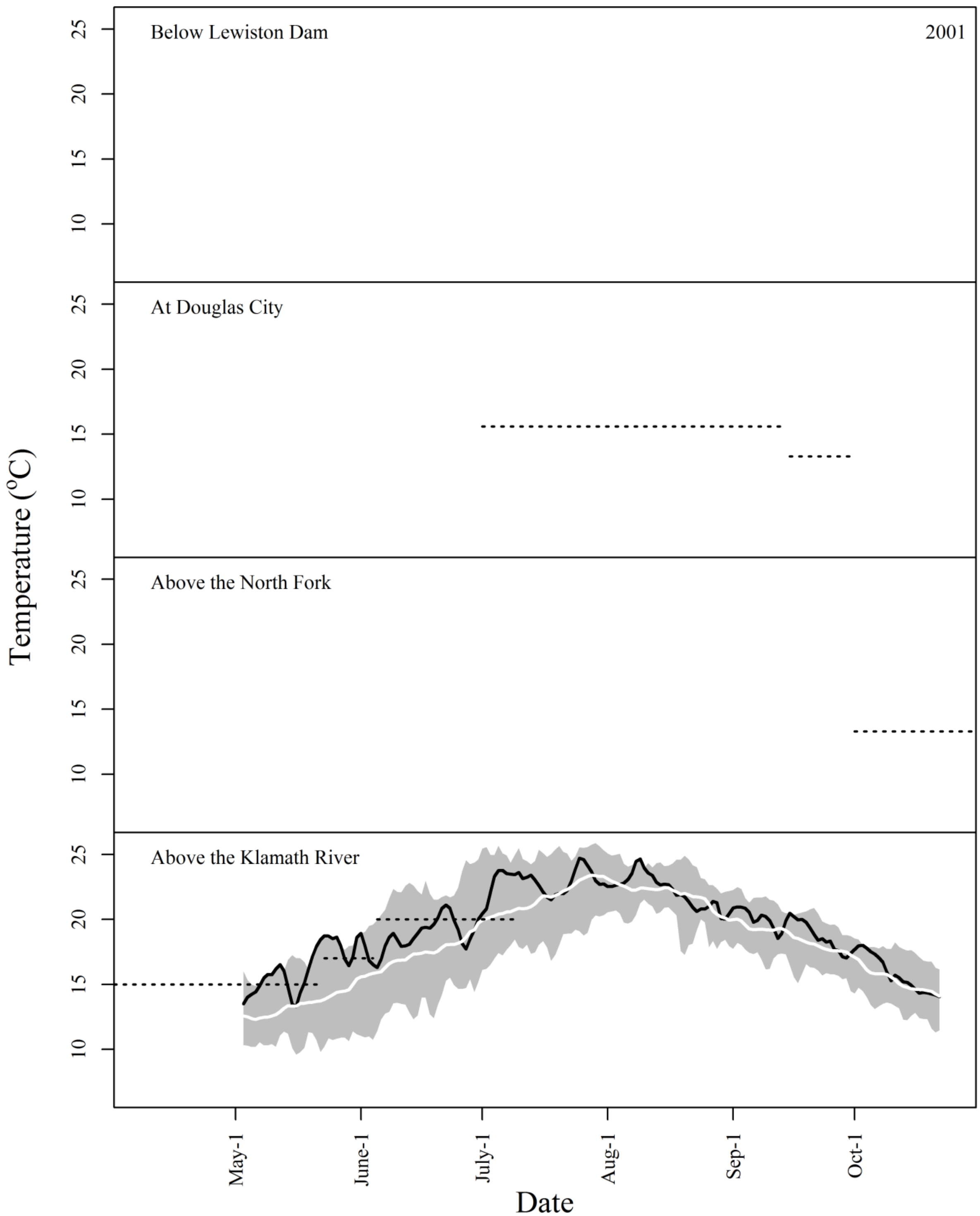
	Criteria locations				Forecast water year	Actual water year
Year	**TRRC1**	**DGC**	**NFH**	**TRWE1**	**type**	**type**
2001	--	--	--	33[a]	Dry	Dry
2002	--	0	--	54	Normal	Normal
2003	--	11	--	34	Wet	Wet
2004	--	0	--	43	Wet	Wet
2005	--	--	1	21[b]	Normal	Wet
2006	--	6	0	18	Ex. Wet	Ex. Wet
2007	--	3	0	19	Dry	Dry
2008	--	1	4	0	Normal	Dry
2009	--	31	2	21	Dry	Dry
2010	--	6	7	10	Normal	Wet
2011	--	0	0	7	Wet	Wet
2012	--	0	1	25	Normal	Normal
2013	--	0	0	26	Dry	Dry
2014	--	18	15	53	Crit. Dry	Crit. Dry
2015	--	--	18	65	Dry	Dry
2016	--	14	3	52	Wet	Wet
2017	--	0	0	27	Ex. Wet	Ex. Wet

[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.
[b] Data unavailable prior to 4/4 for TRWE1 in 2005. It was assumed mean daily temperatures did not reach or exceed 13.0 C before this date.

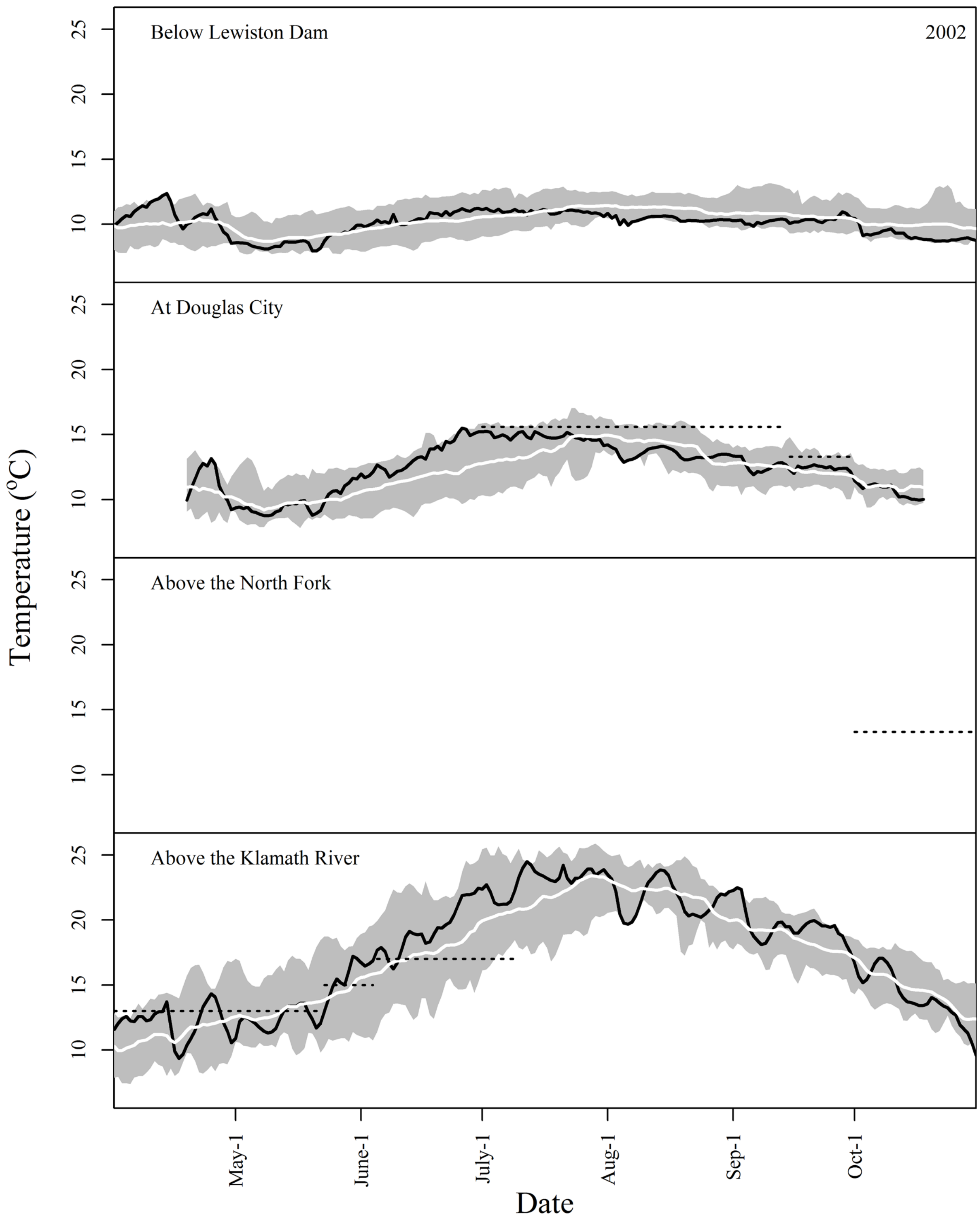
Appendix B. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2000-2016, with historical conditions. Includes both observed and infilled water temperatures.



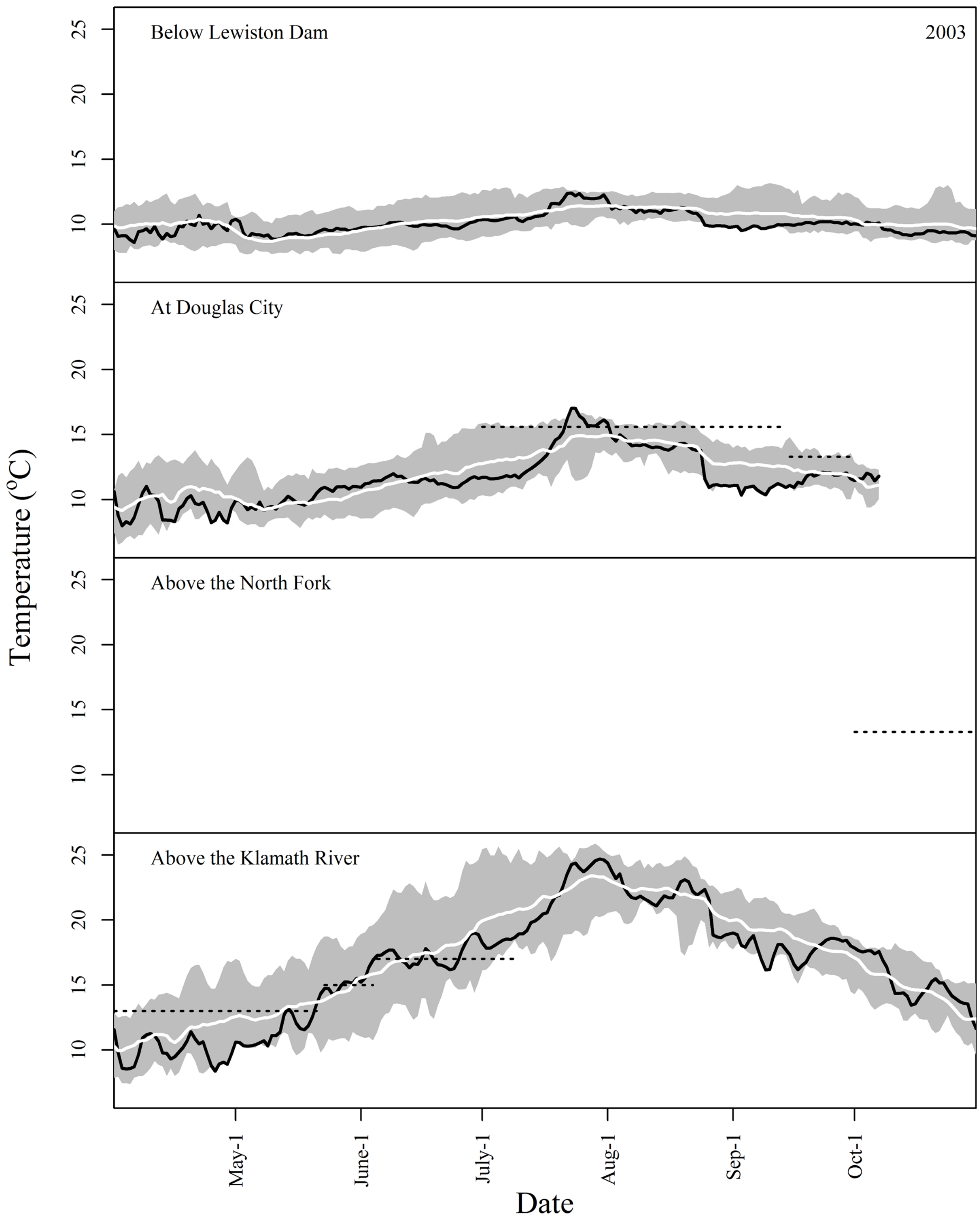
Appendix B1. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2000, with historical conditions. Black line = mean daily water temperatures in 2000; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



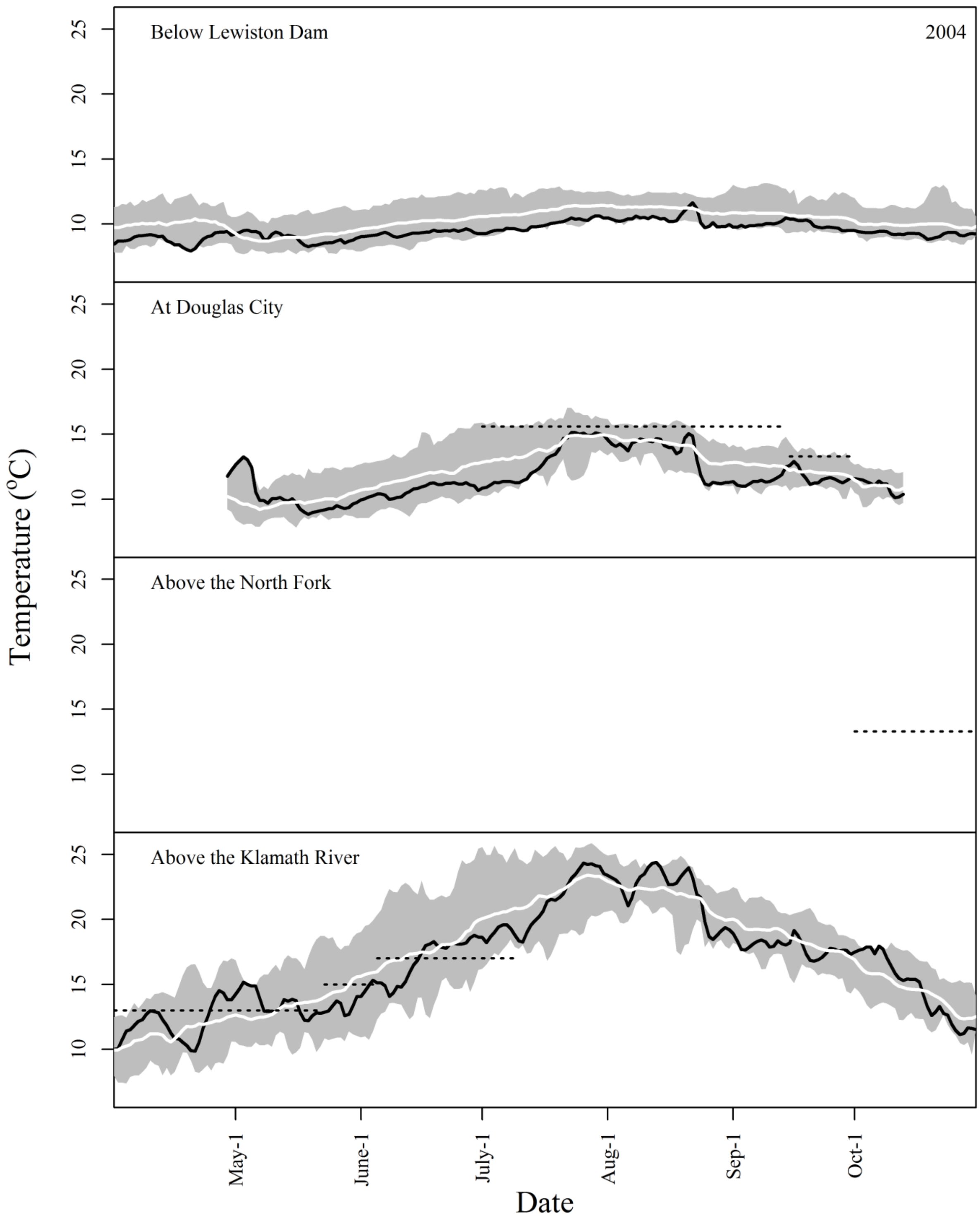
Appendix B2. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = mean daily water temperatures in 2001; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



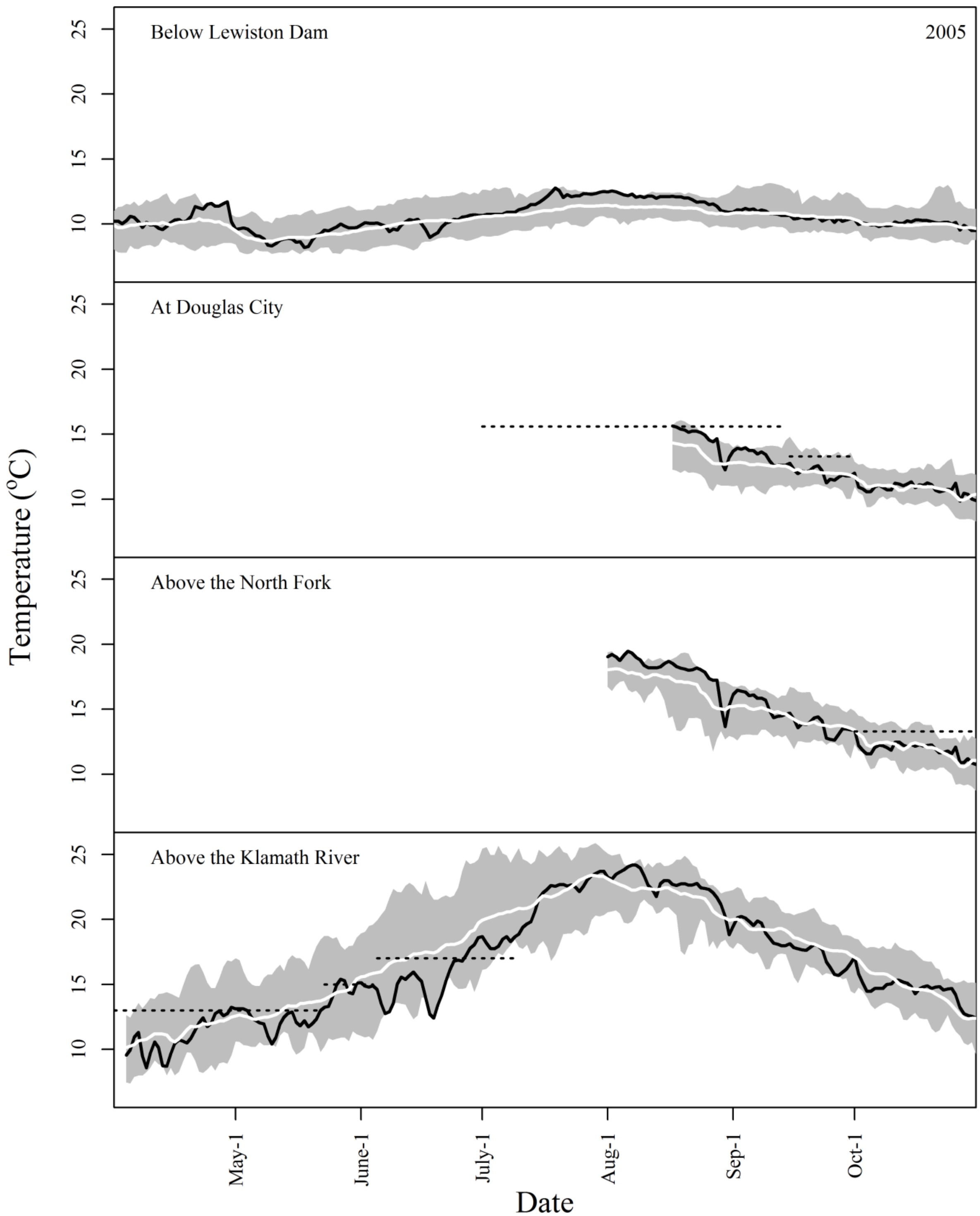
Appendix B3. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = mean daily water temperatures in 2002; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



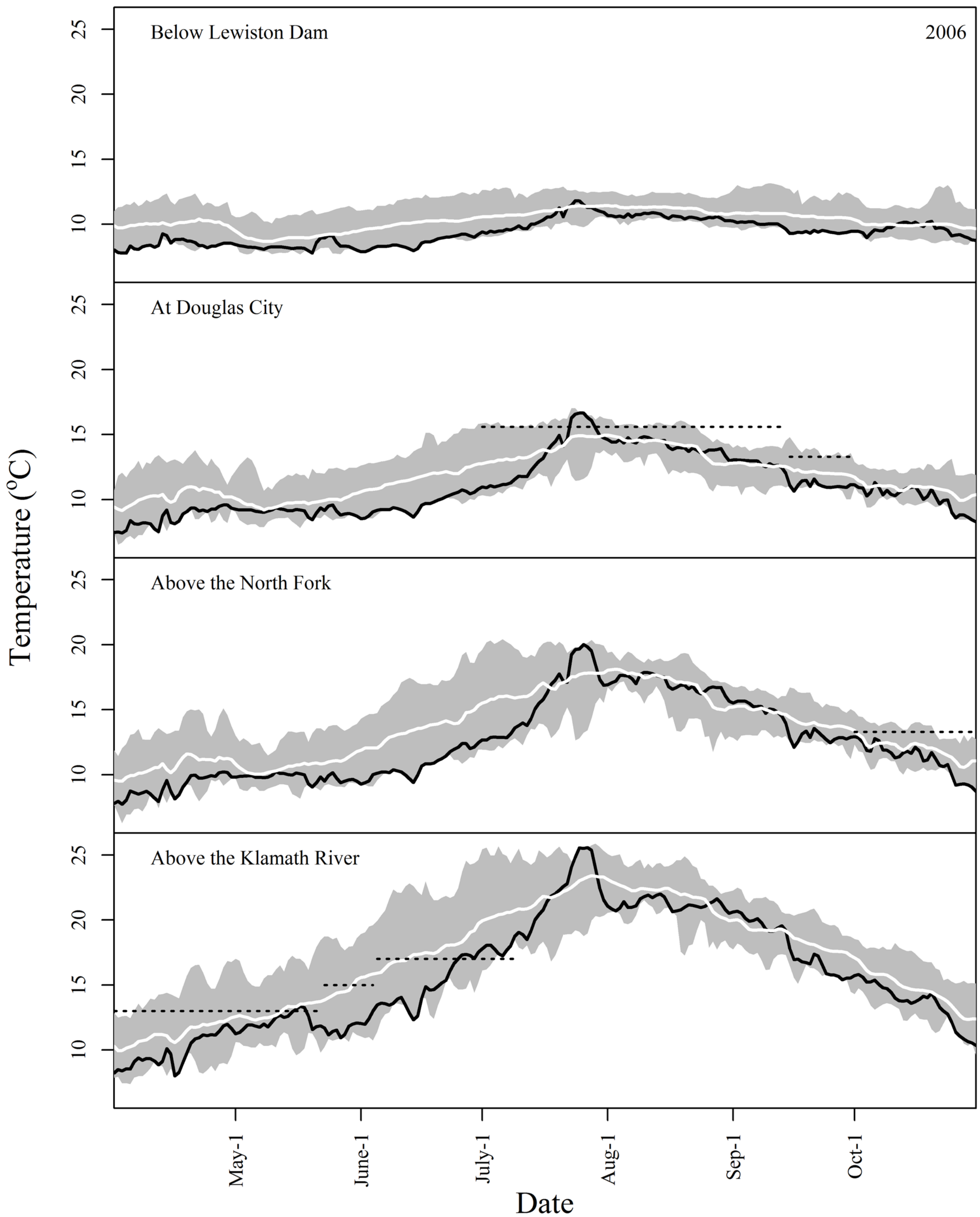
Appendix B4. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = mean daily water temperatures in 2003; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



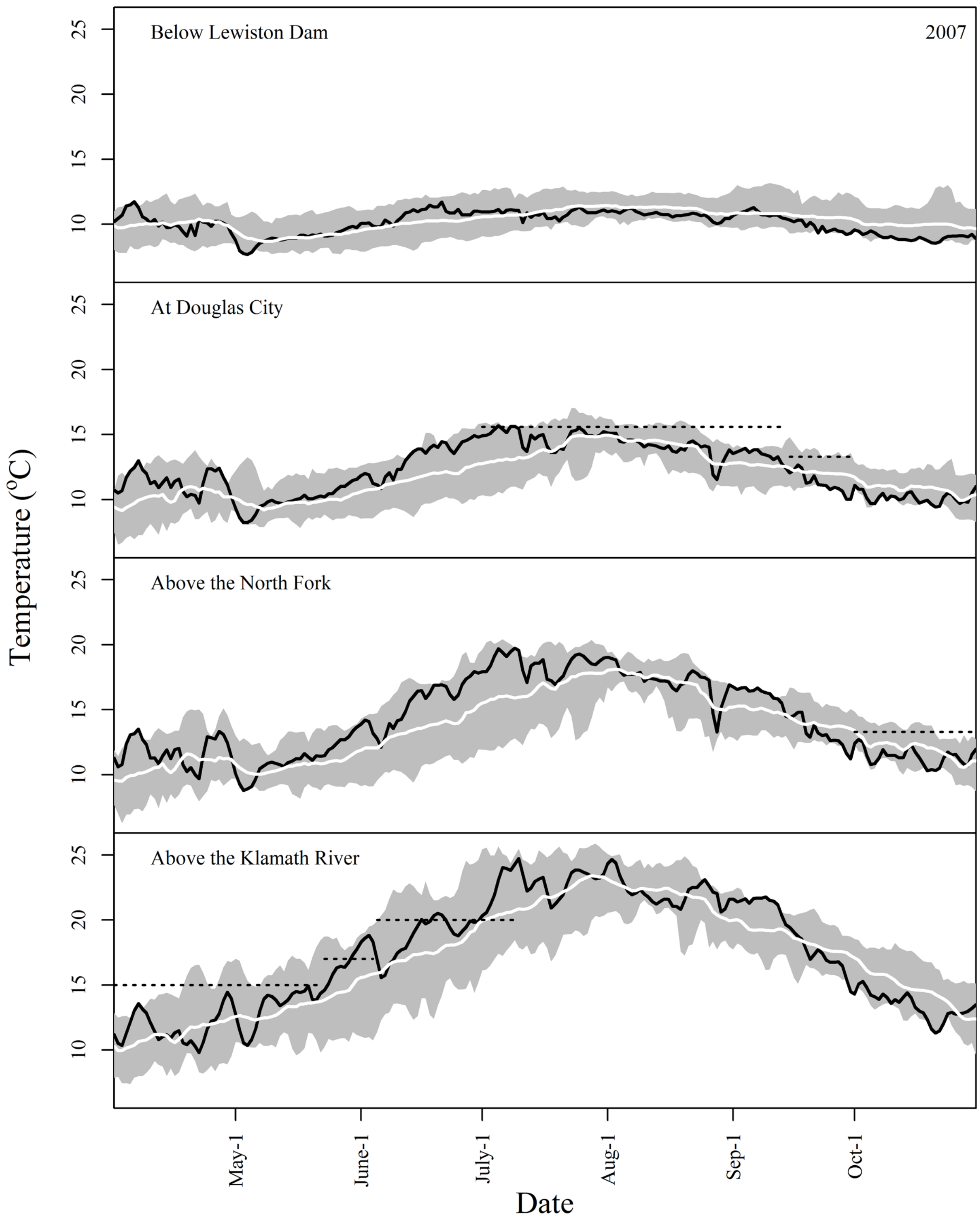
Appendix B5. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = mean daily water temperatures in 2004; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



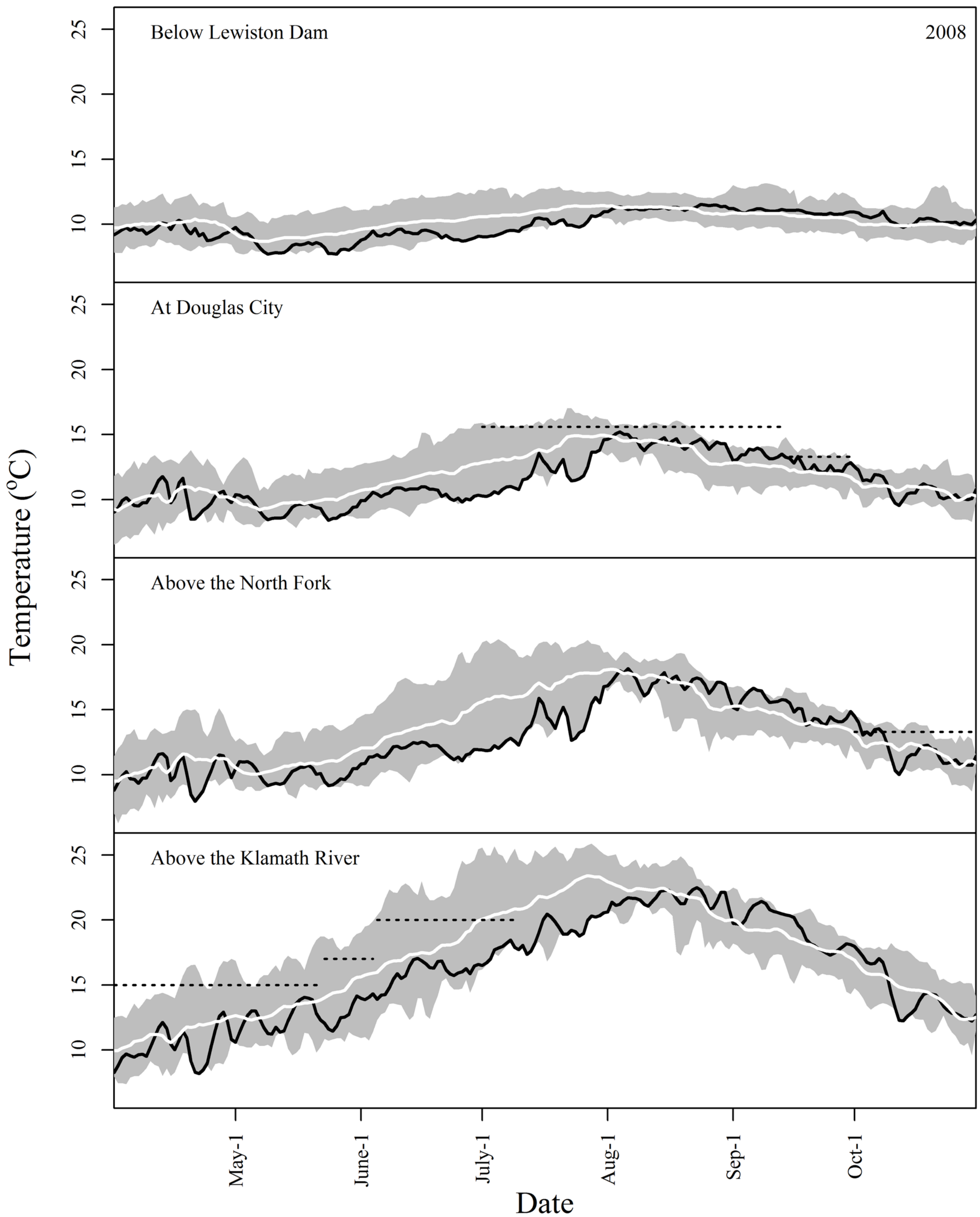
Appendix B6. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = mean daily water temperatures in 2005; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



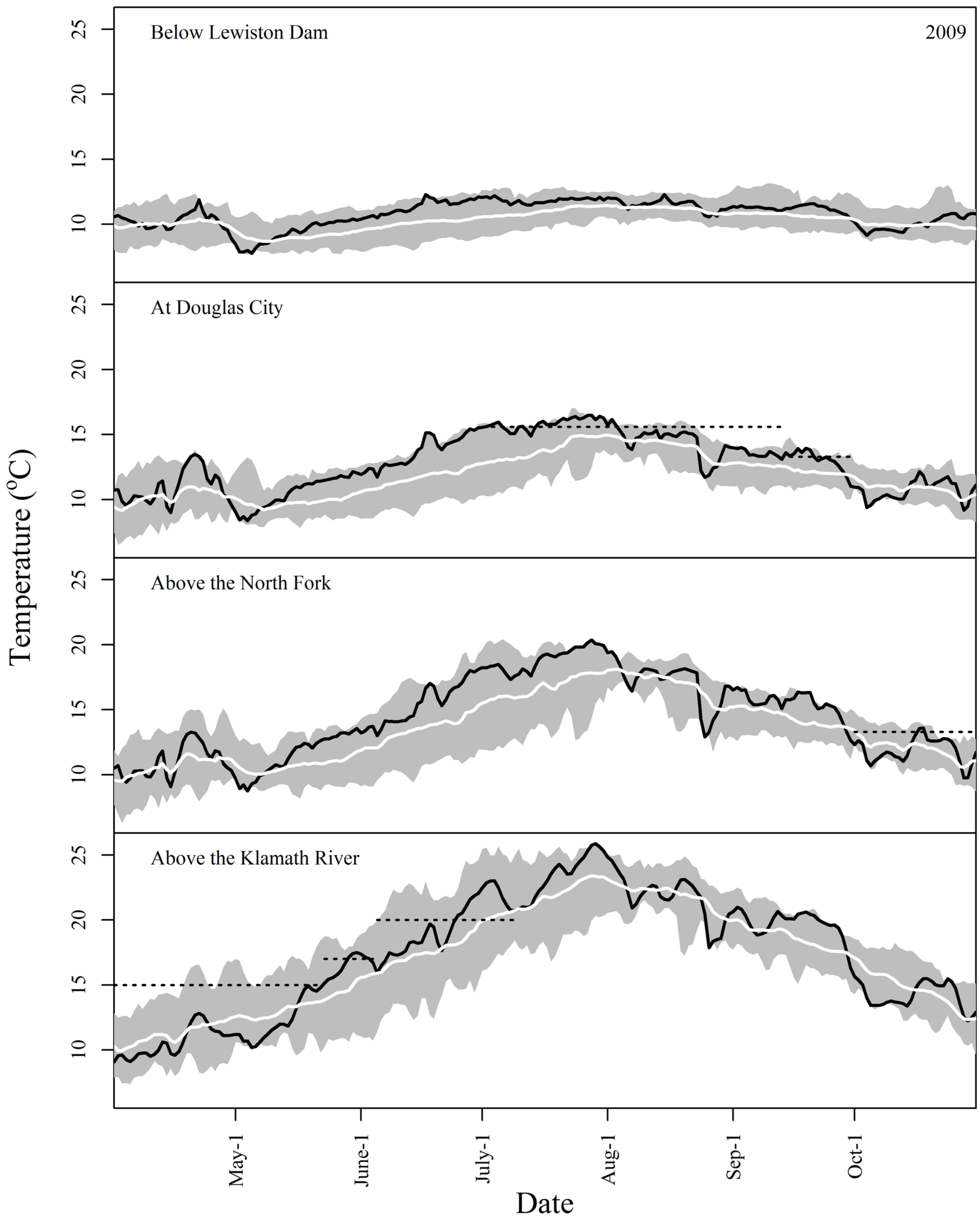
Appendix B7. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = mean daily water temperatures in 2006; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



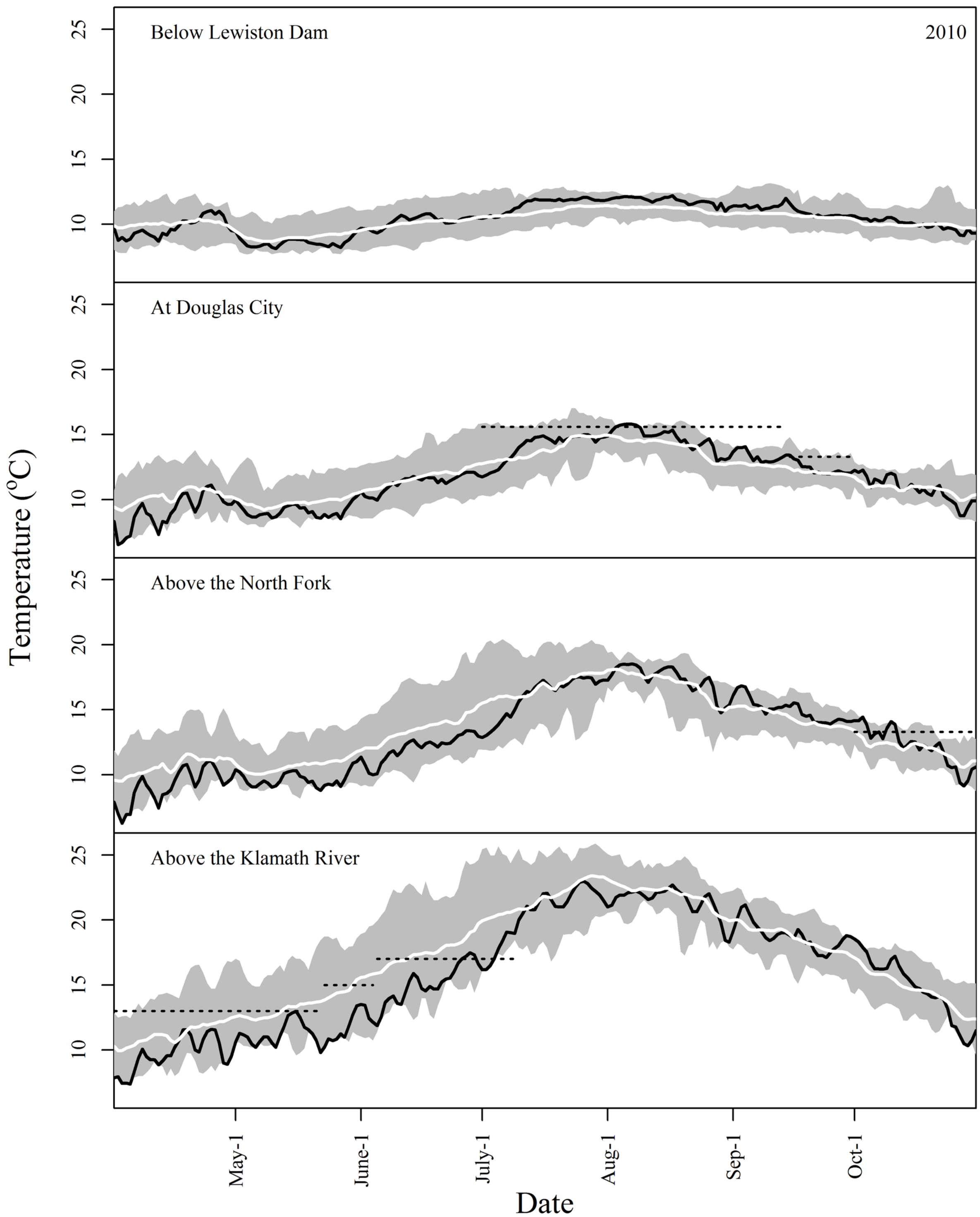
Appendix B8. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = mean daily water temperatures in 2007; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



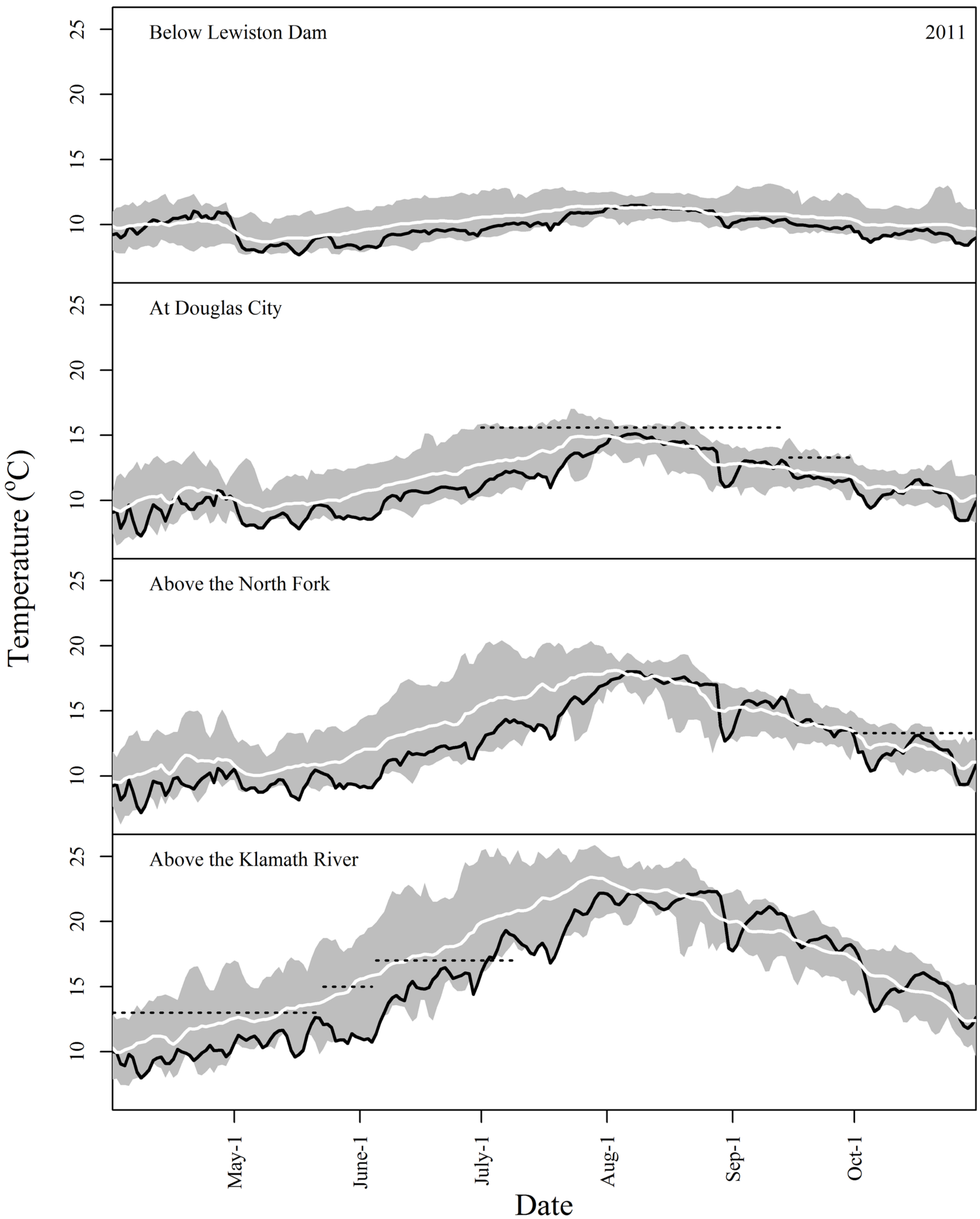
Appendix B9. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = mean daily water temperatures in 2008; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



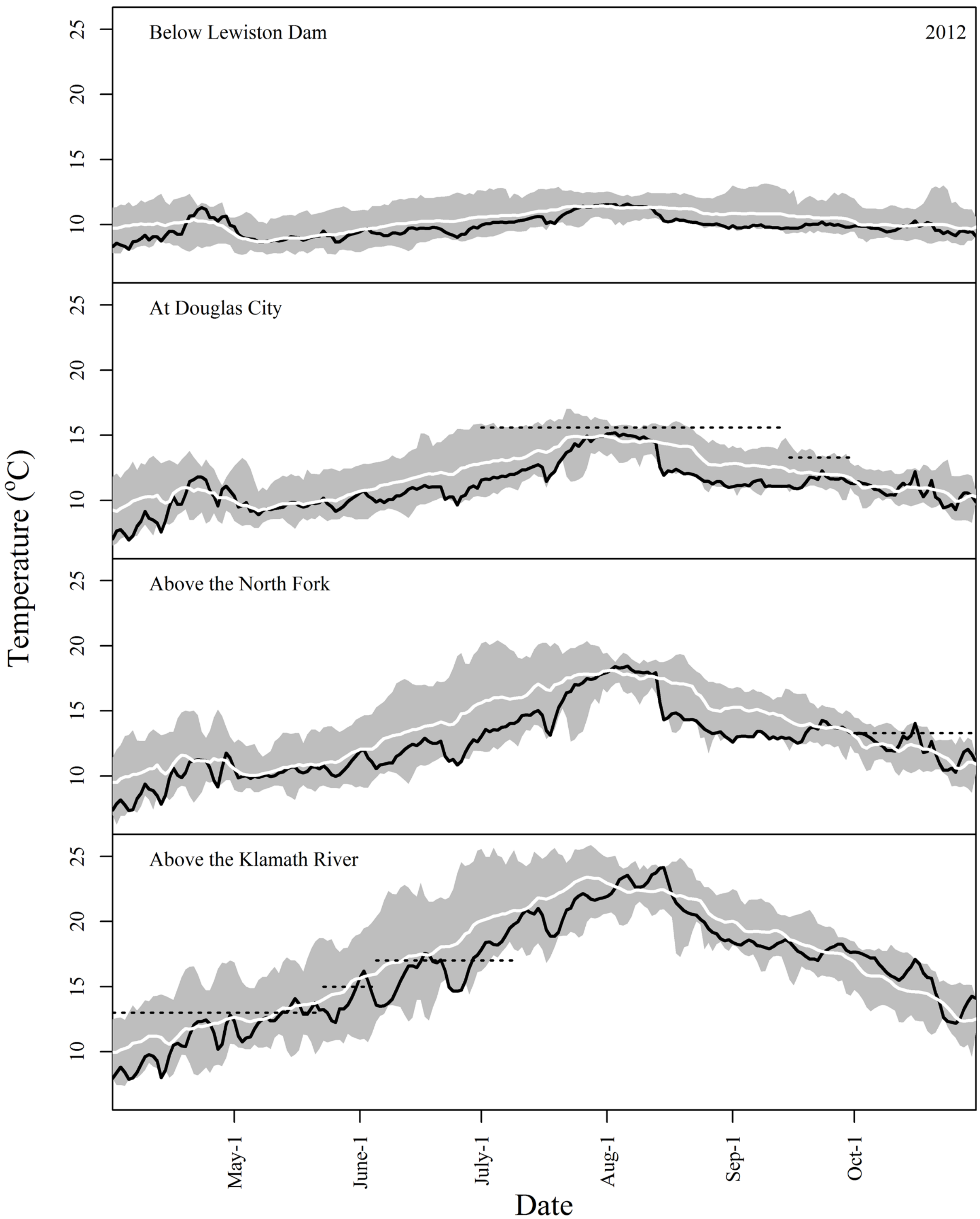
Appendix B10. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = mean daily water temperatures in 2009; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



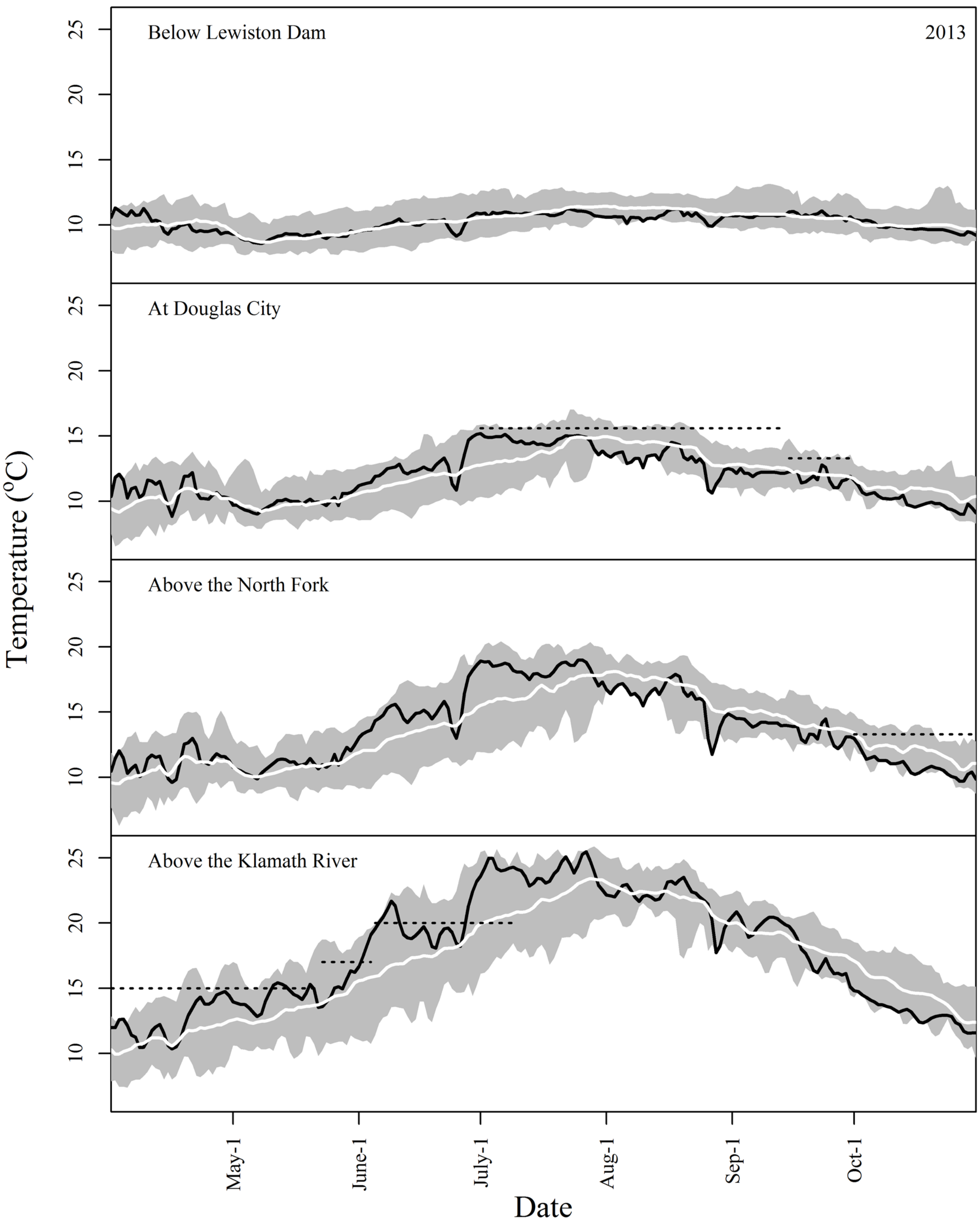
Appendix B11. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = mean daily water temperatures in 2010; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



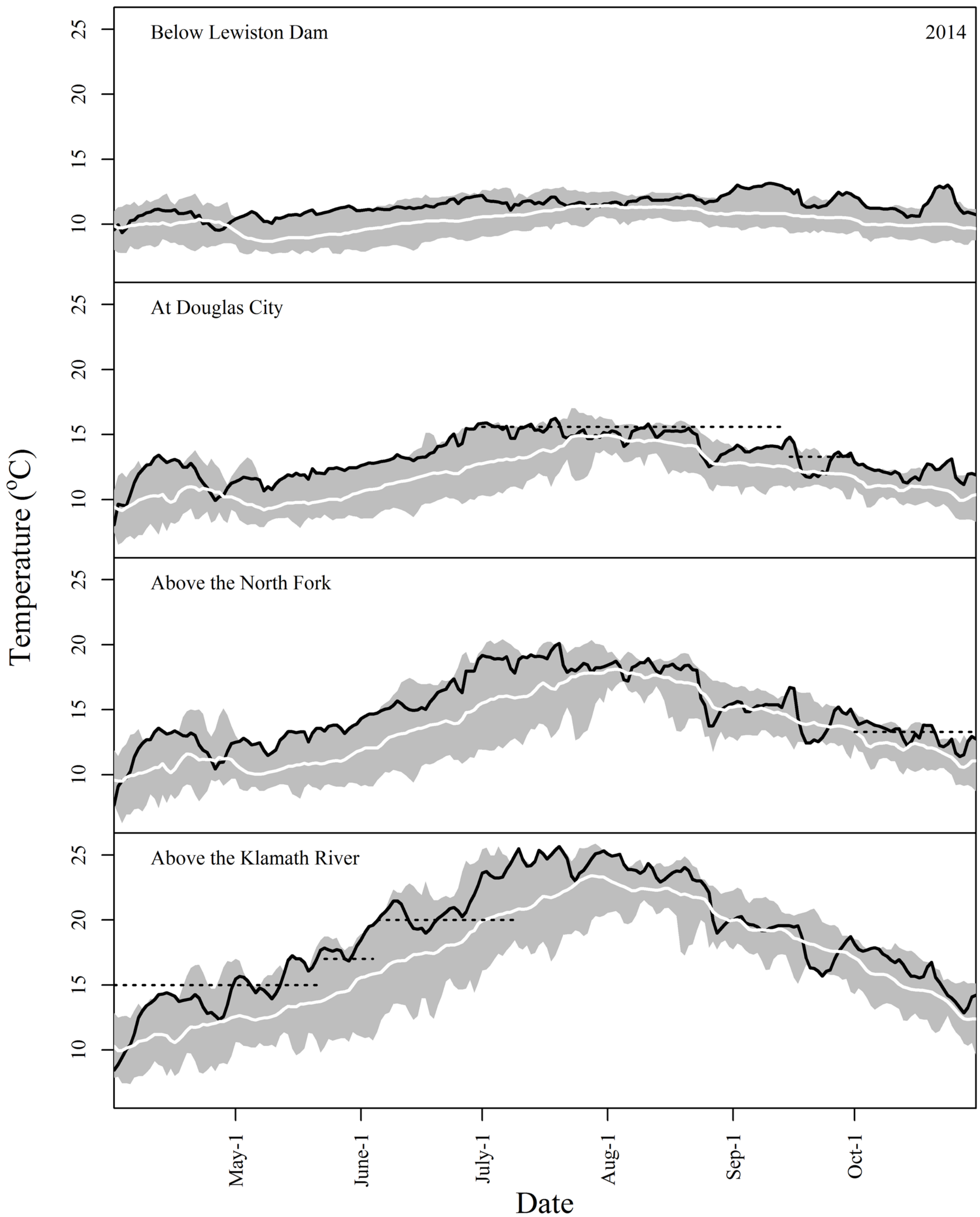
Appendix B12. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = mean daily water temperatures in 2011; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



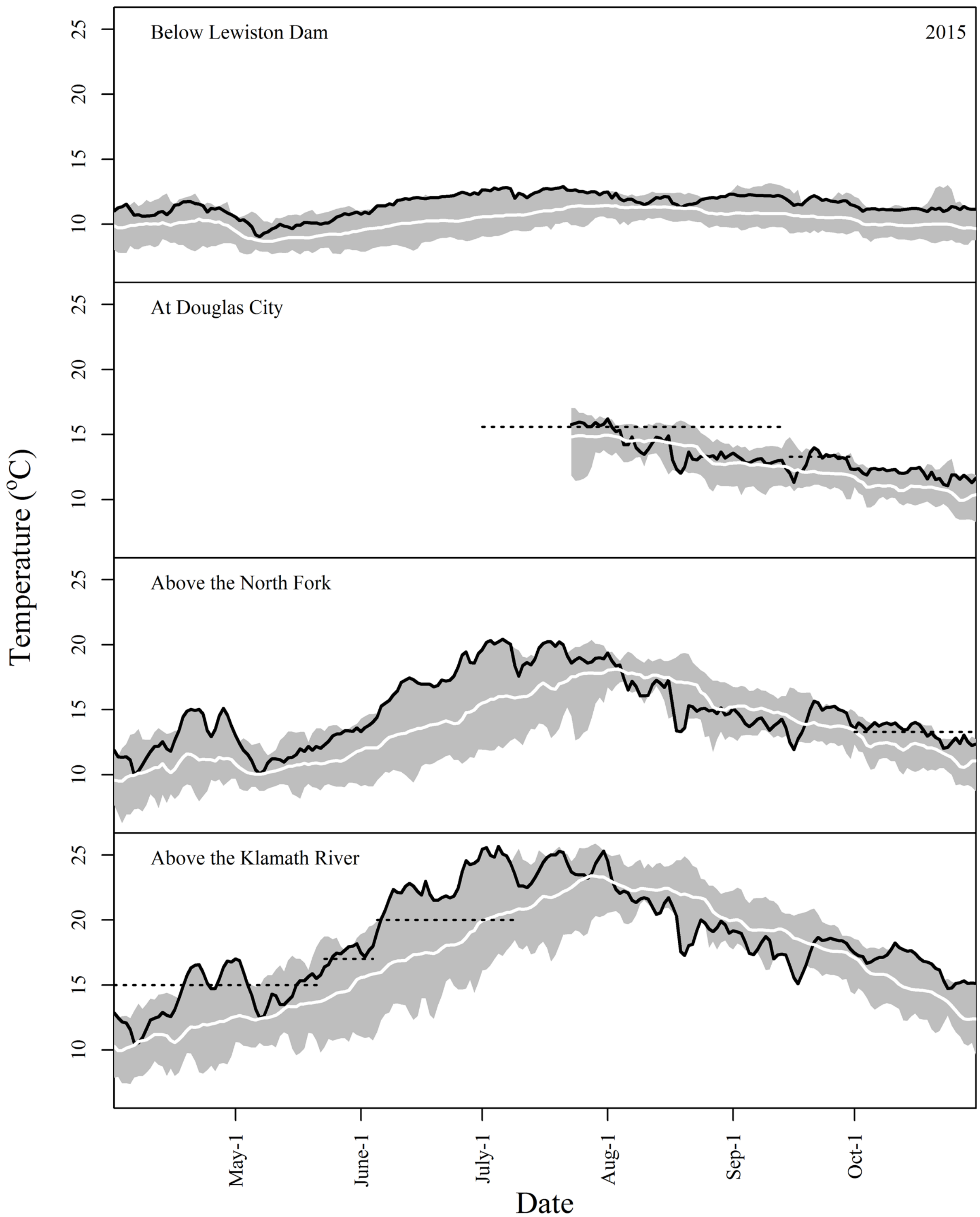
Appendix B13. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = mean daily water temperatures in 2012; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



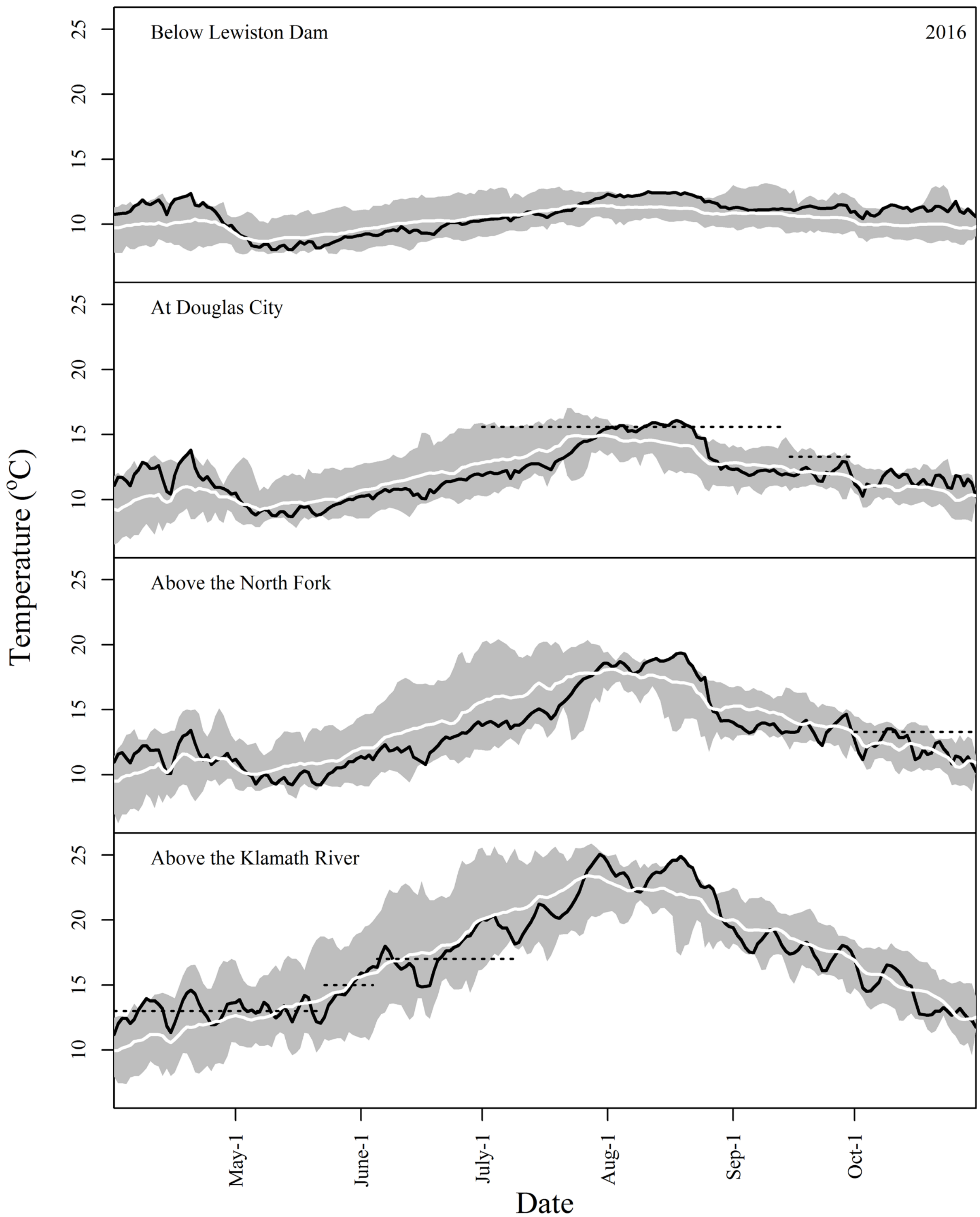
Appendix B14. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = mean daily water temperatures in 2013; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.



Appendix B15. 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 B16. 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.



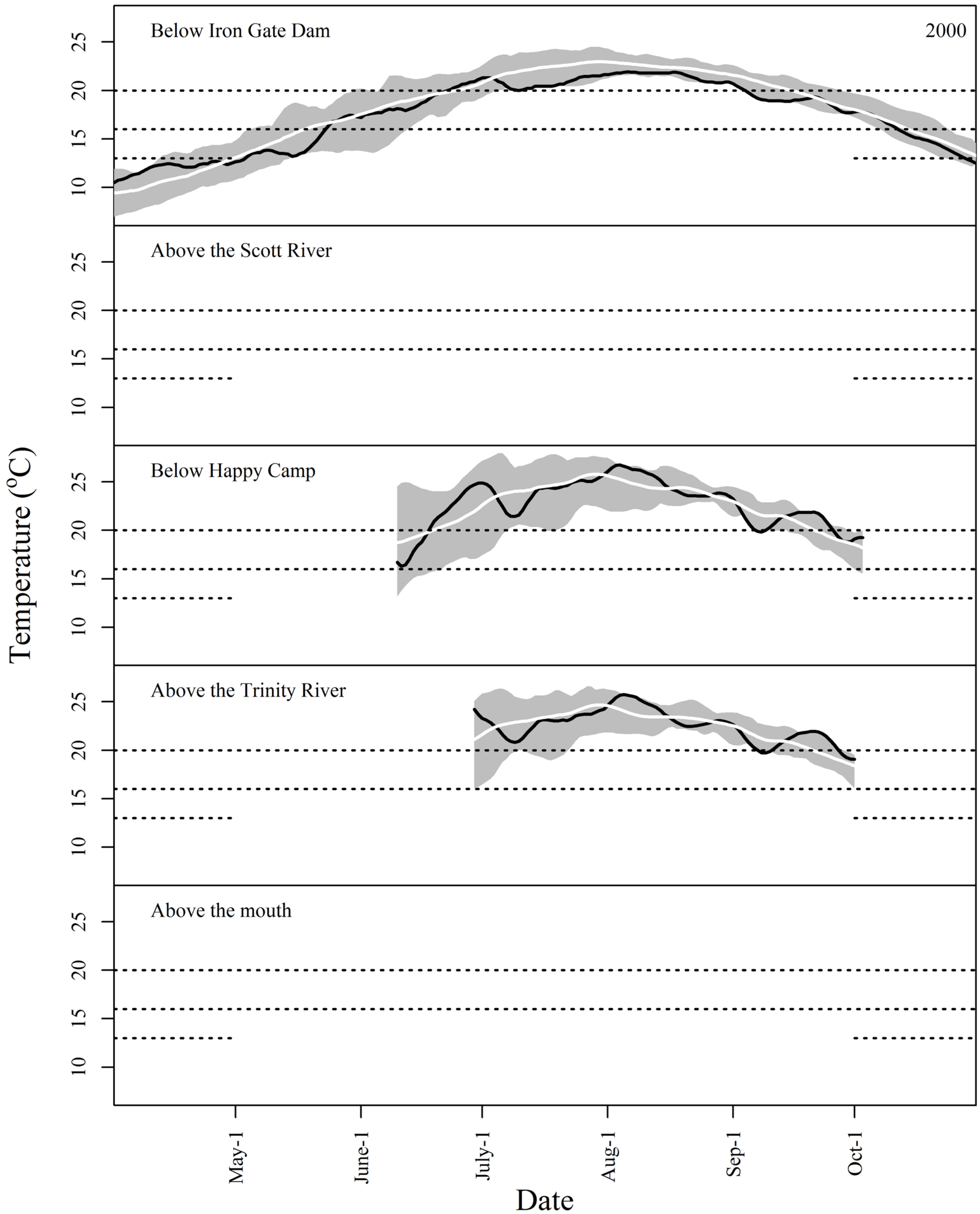
Appendix B17. Mean daily water temperatures at focal Trinity River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = mean daily water temperatures in 2016; white line = long term mean for each day of the year; gray polygon = long term range for each day of the year; dotted lines = water temperature objectives.

Appendix 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, 2000-2017. 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.

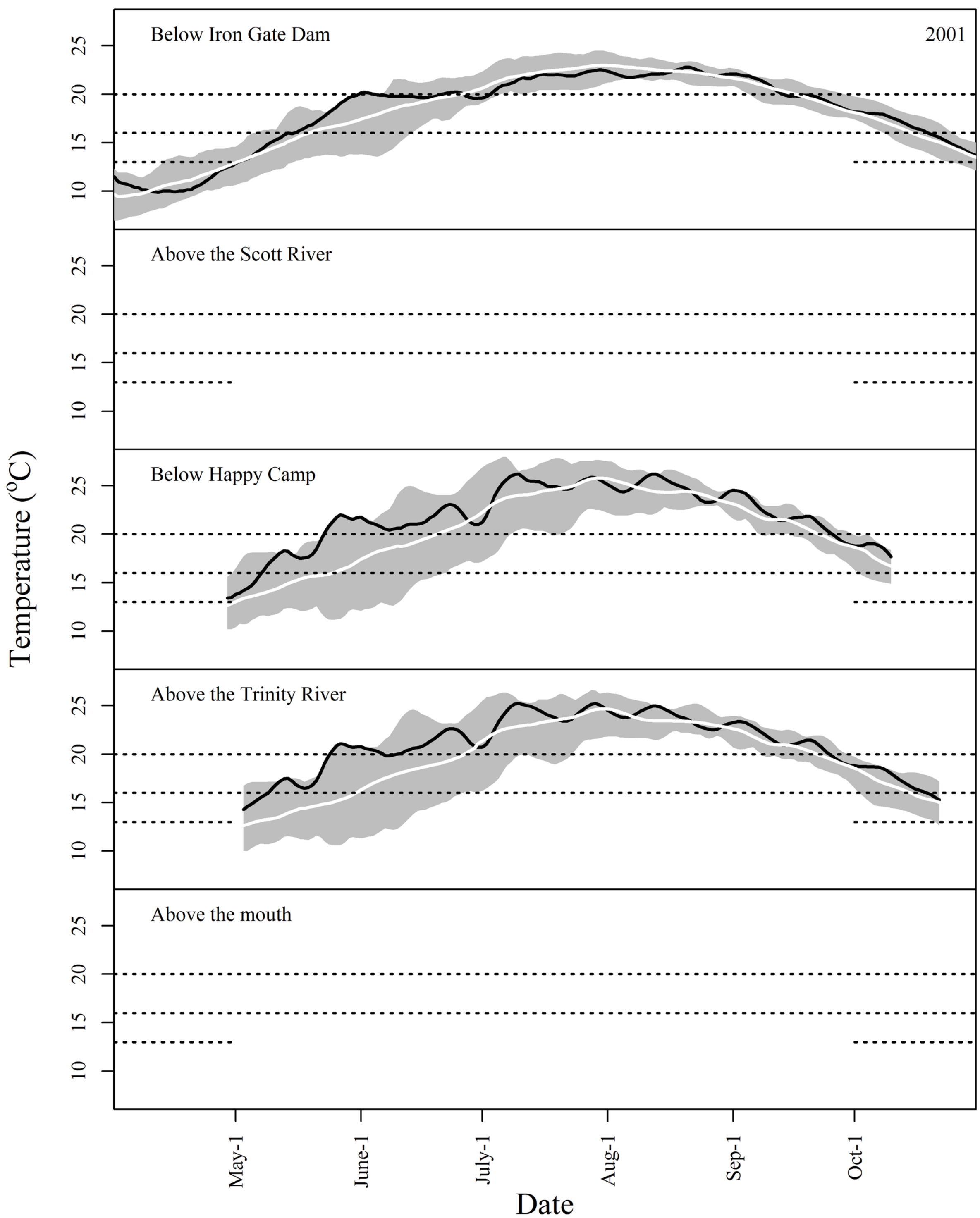
	20°C 7DADM criterion					16°C 7DADM criterion					13°C 7DADM criterion				
Year	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2	KRIG1	KRSC1	KRHC1	KRWE1	KRTG2
2000	74	-	98[d]	-	-	141	-	-	-	-	28	-	-	-	-
2001	81	-	126[e]	119[f]	-	158	-	-	162[f]	-	31	-	-	-	-
2002	78[a]	-	-	95[g]	-	-	-	-	139[g]	-	-	-	-	-	-
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

[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.

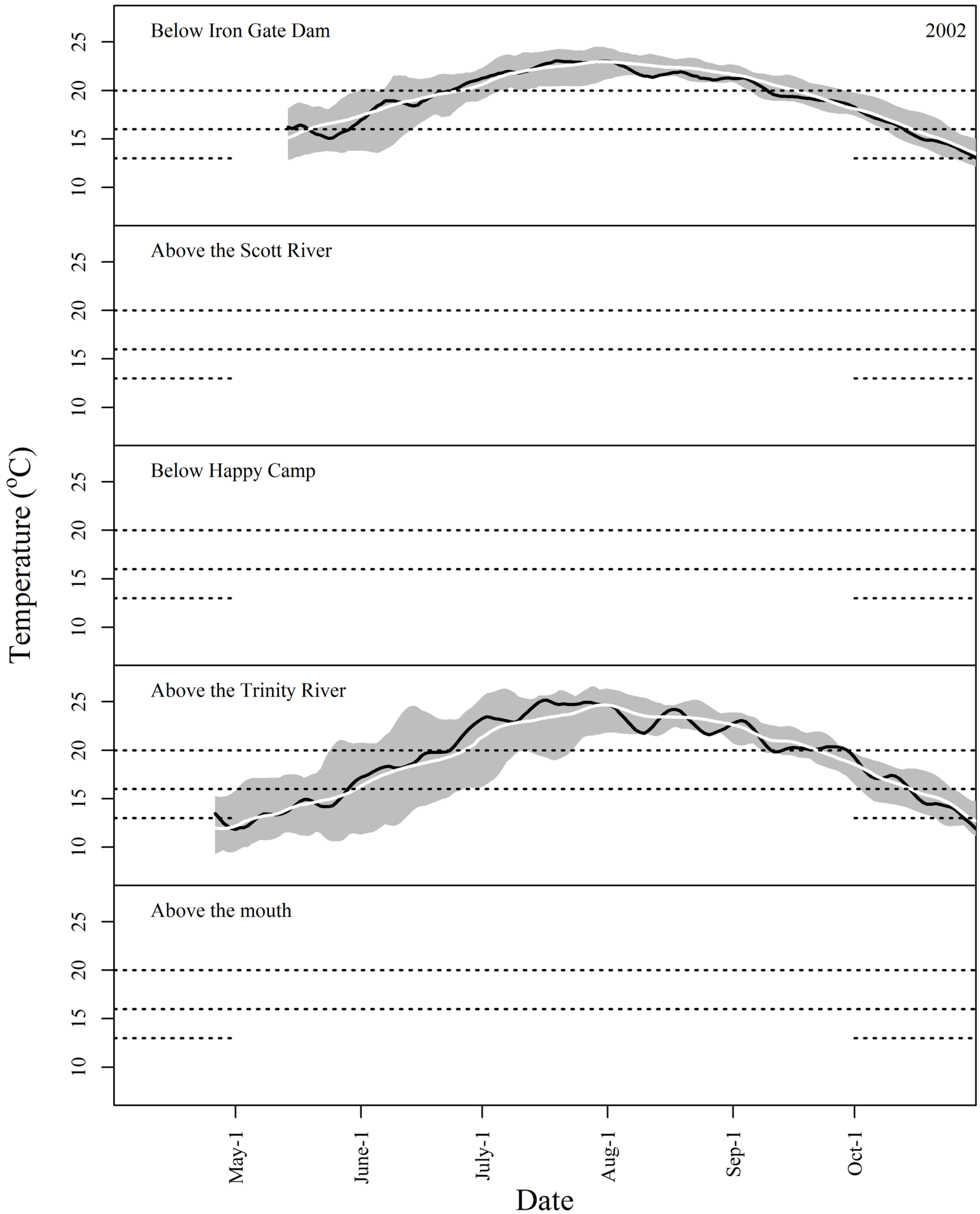
Appendix D. Seven-day average daily maximum (7DADM) water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000-2016, with historical conditions. Includes both observed and infilled water temperatures.



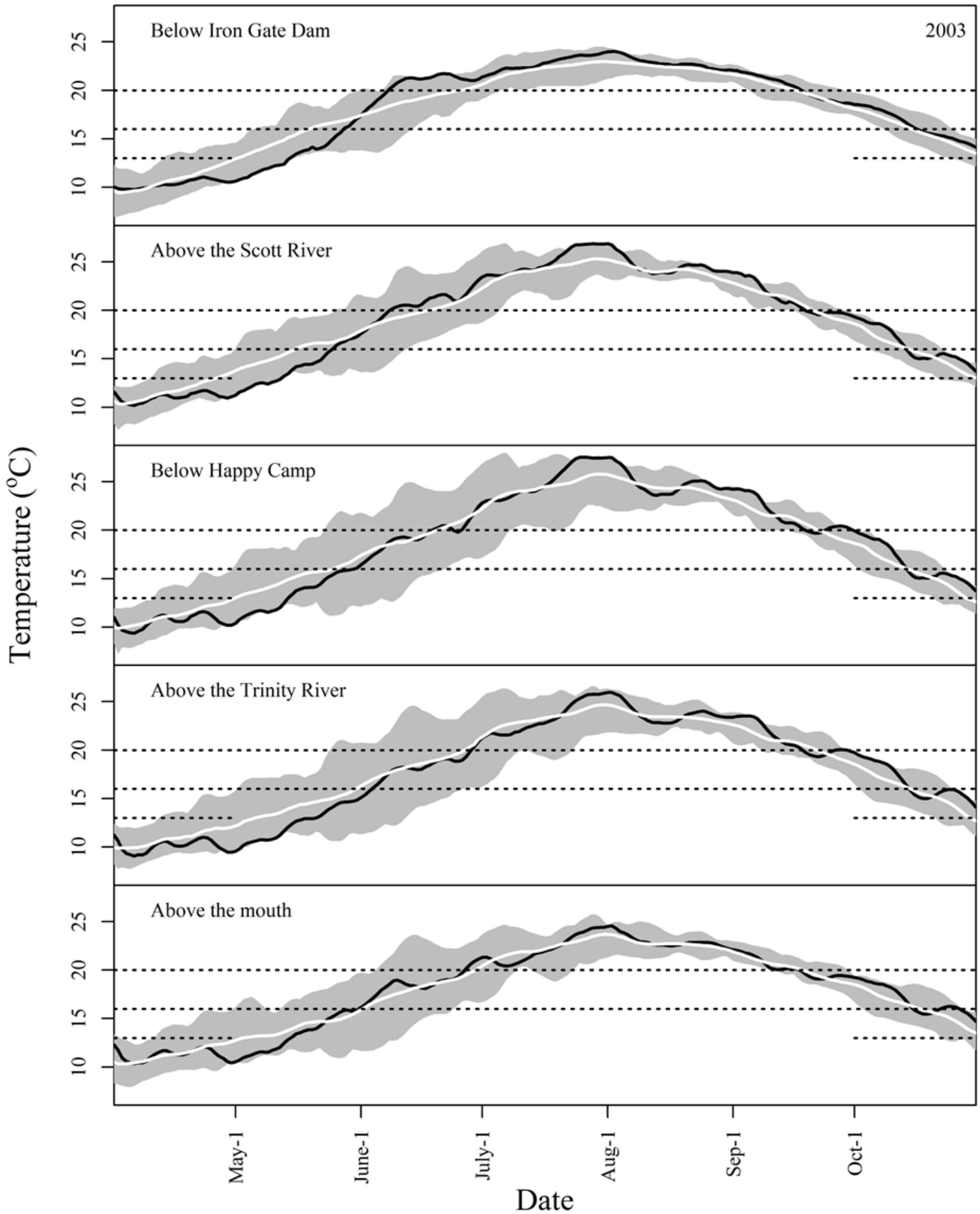
Appendix D1. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2000, with historical conditions. Black line = 7DADM water temperatures in 2000; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



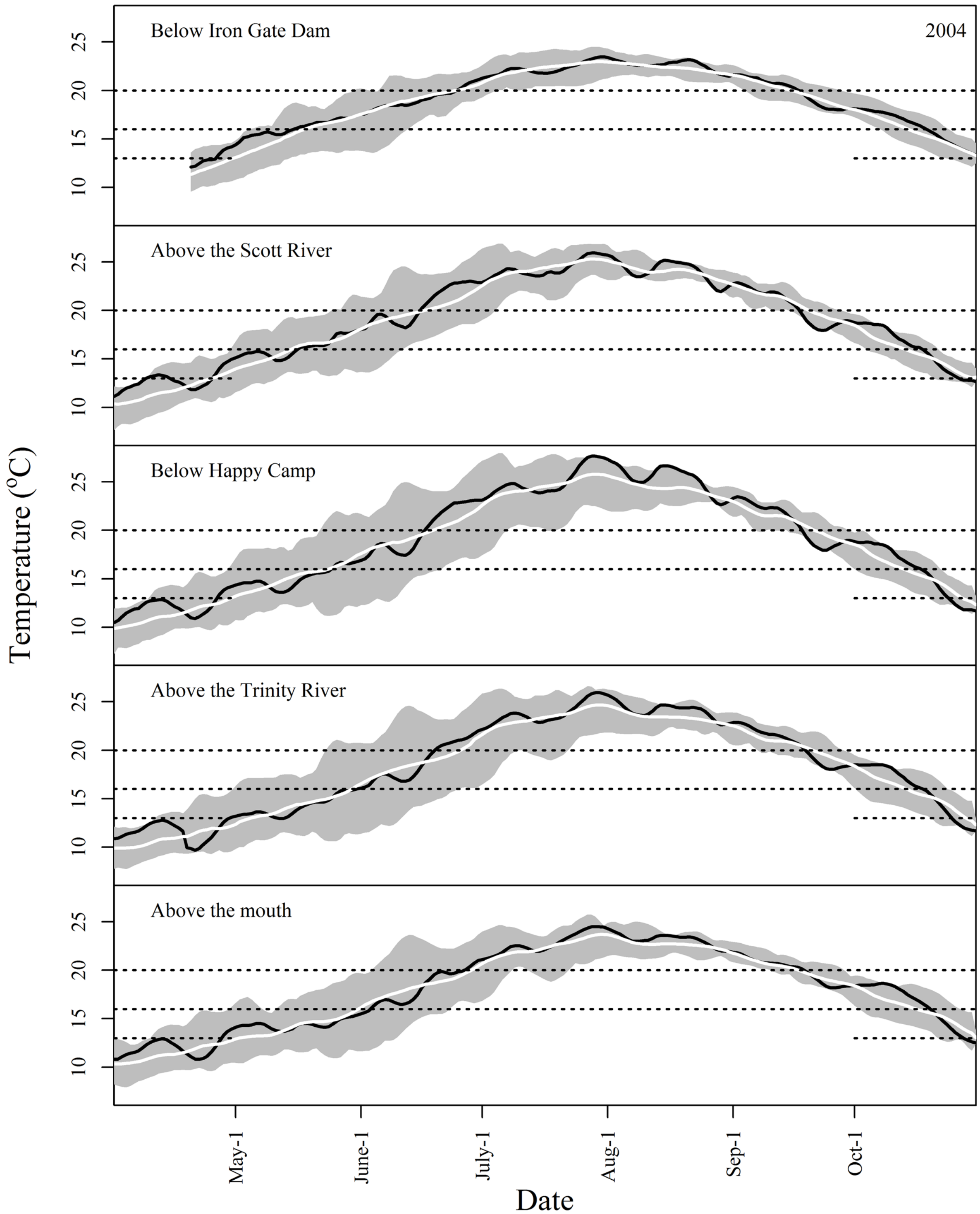
Appendix D2. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2001, with historical conditions. Black line = 7DADM water temperatures in 2001; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



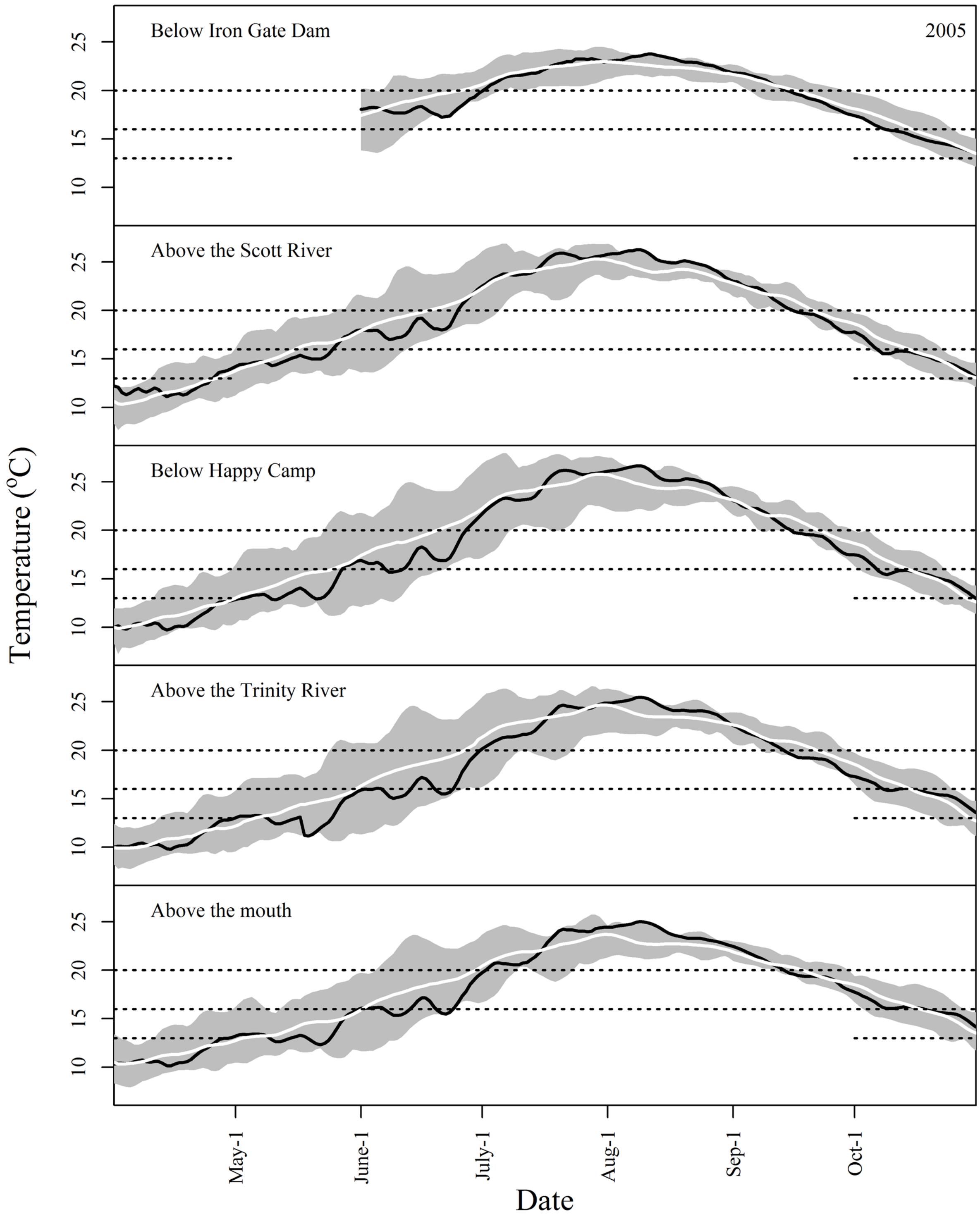
Appendix D3. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2002, with historical conditions. Black line = 7DADM water temperatures in 2002; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year; dotted lines = EPA Pacific Northwest water temperature criteria.



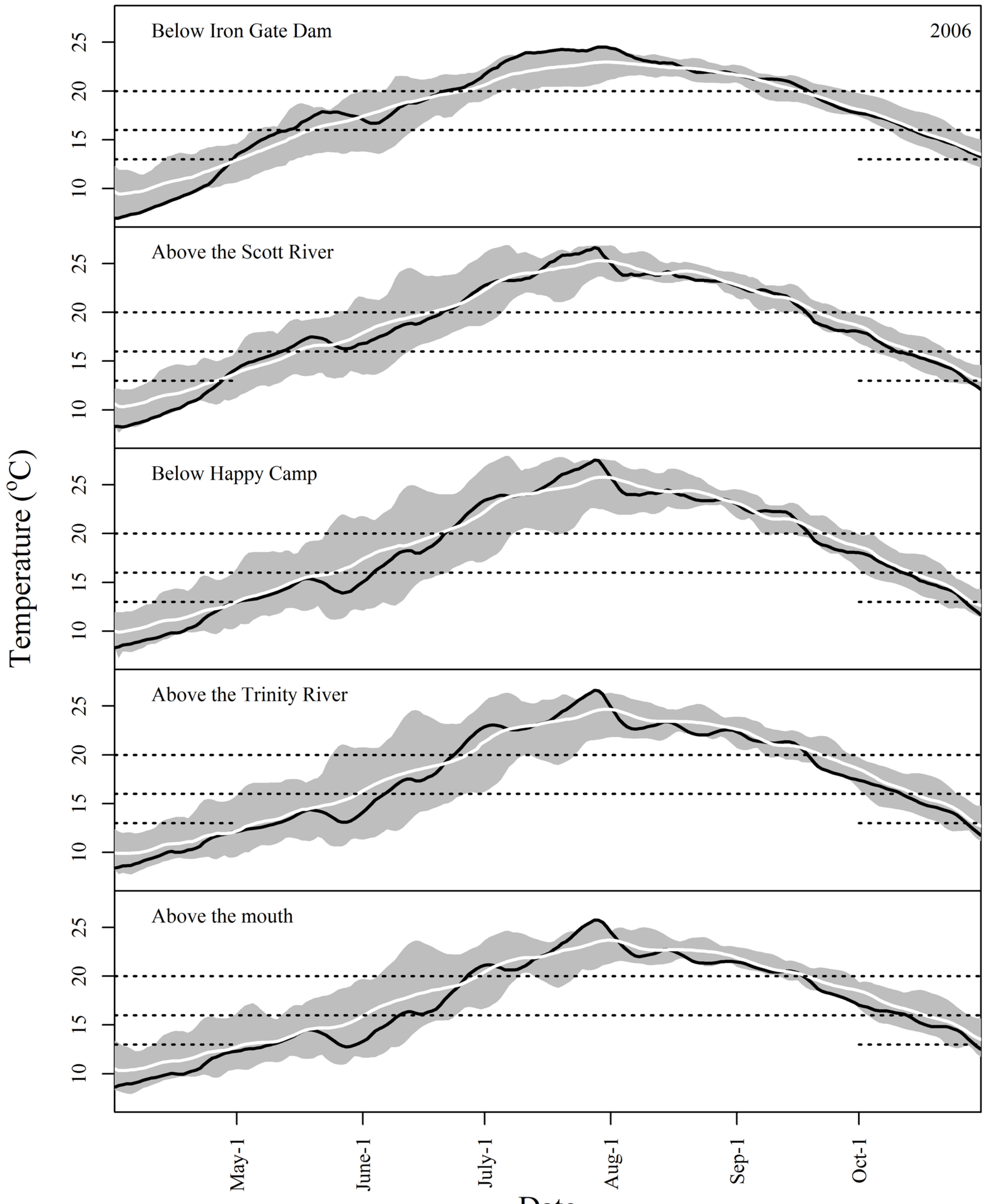
Appendix D4. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2003, with historical conditions. Black line = 7DADM water temperatures in 2003; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



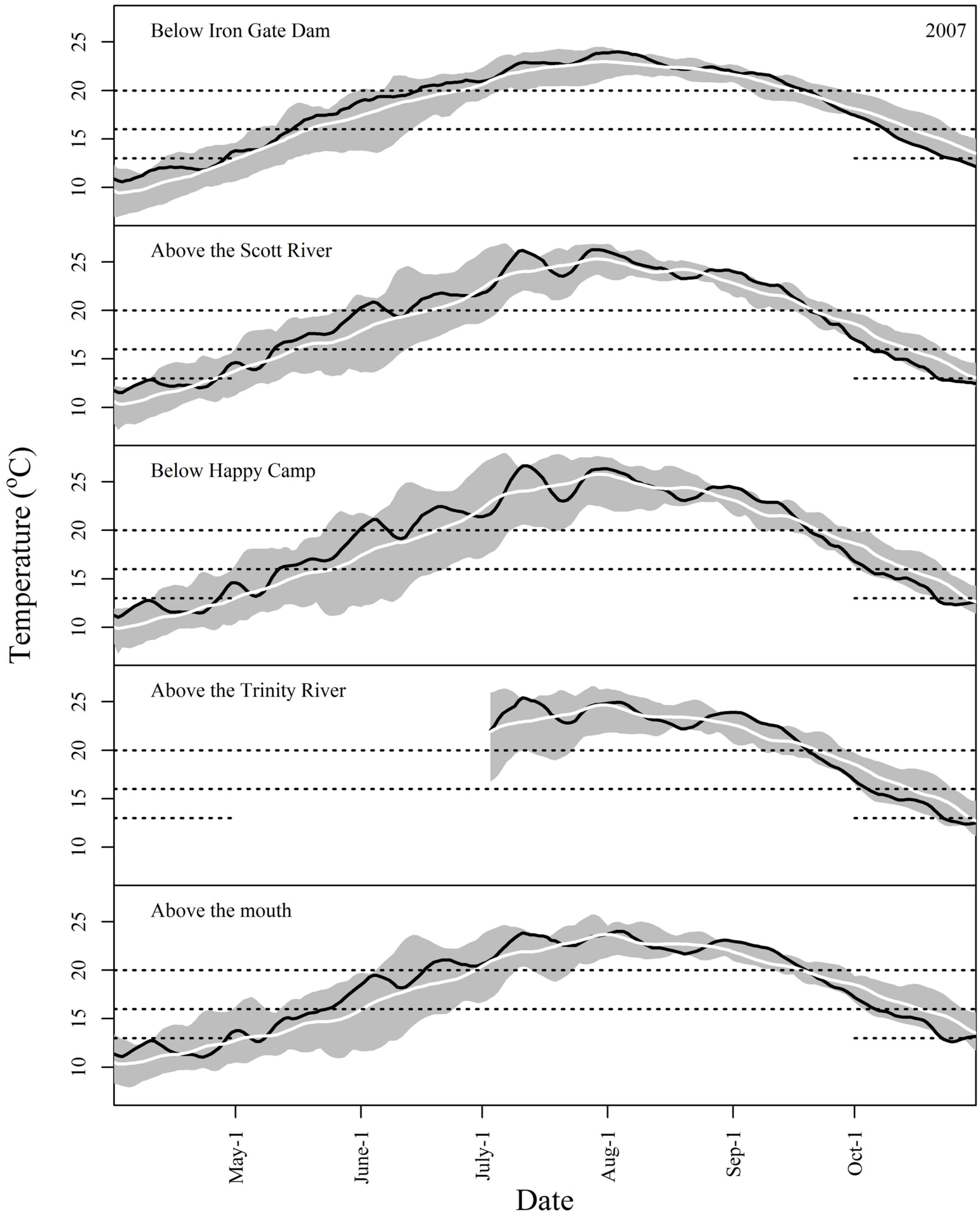
Appendix D5. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2004, with historical conditions. Black line = 7DADM water temperatures in 2004; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



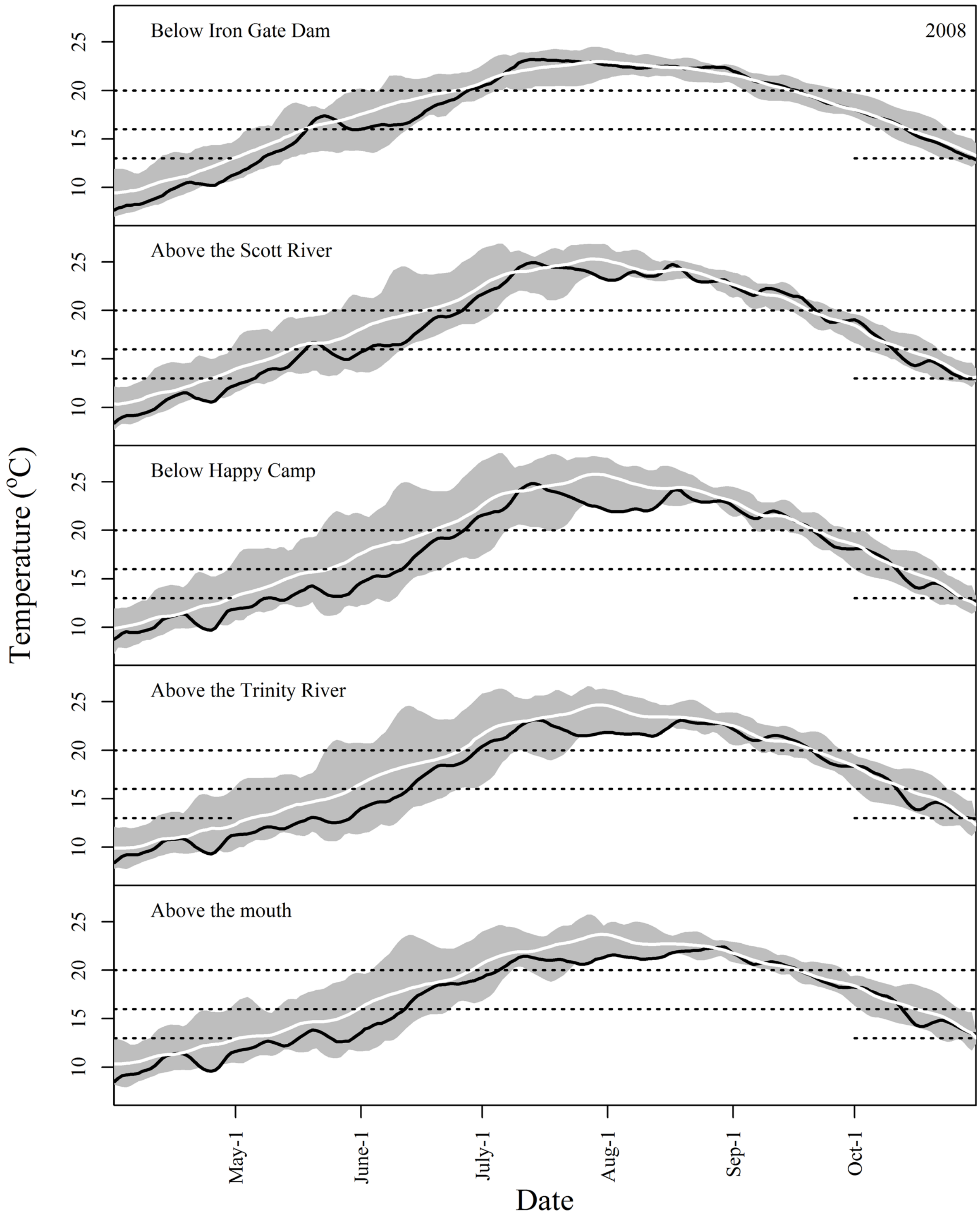
Appendix D6. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2005, with historical conditions. Black line = 7DADM water temperatures in 2005; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



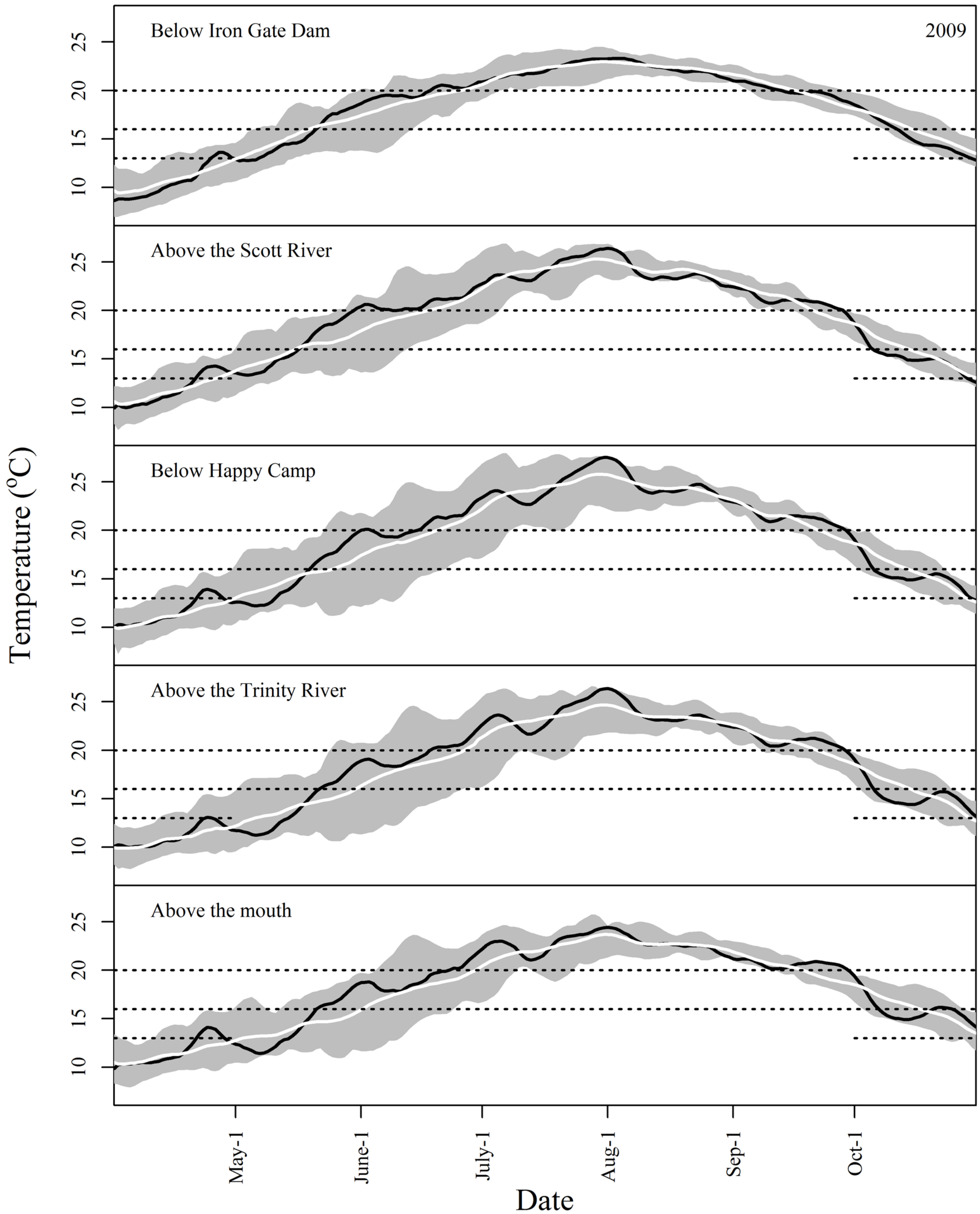
Appendix D7. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2006, with historical conditions. Black line = 7DADM water temperatures in 2006; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



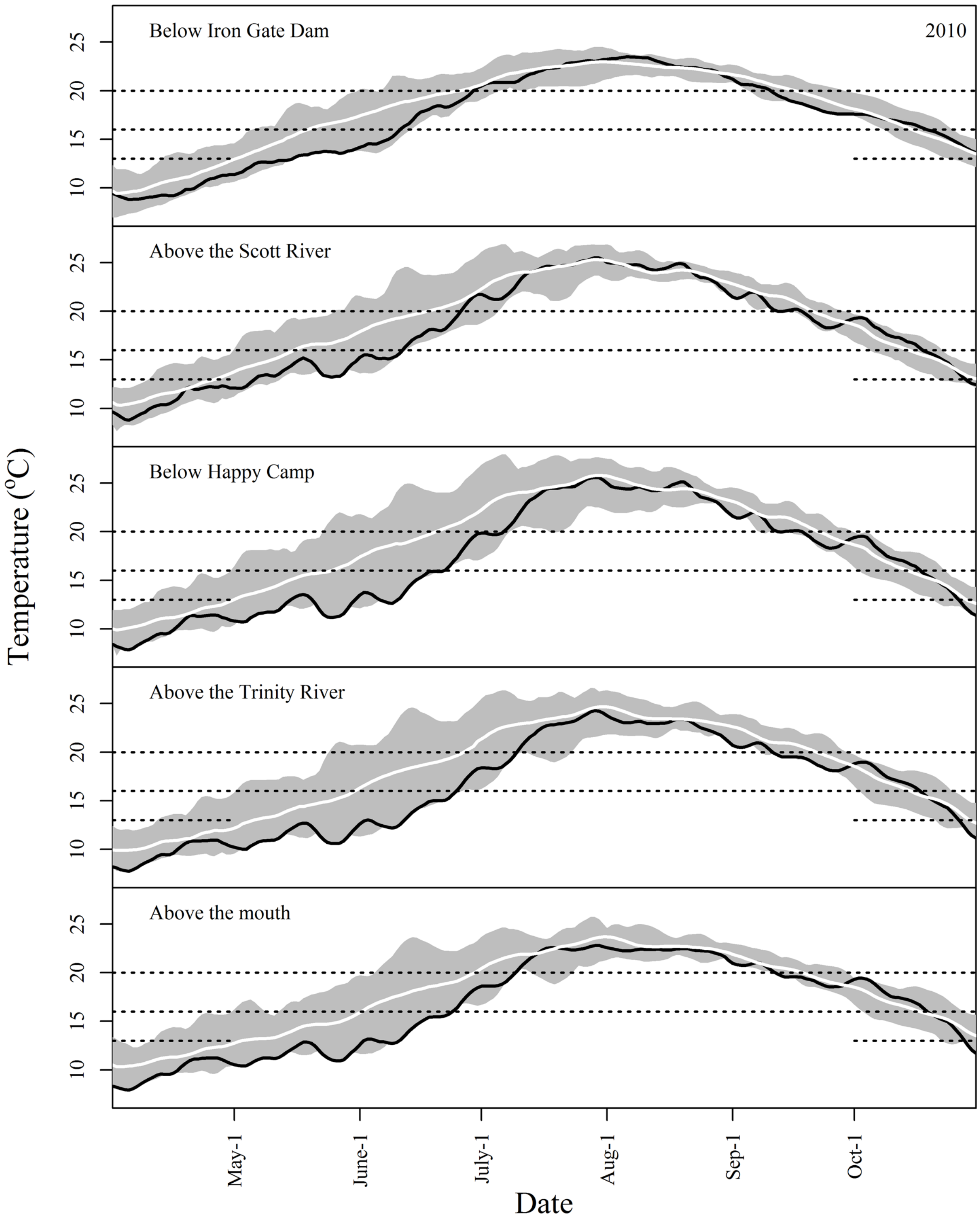
Appendix D8. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2007, with historical conditions. Black line = 7DADM water temperatures in 2007; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



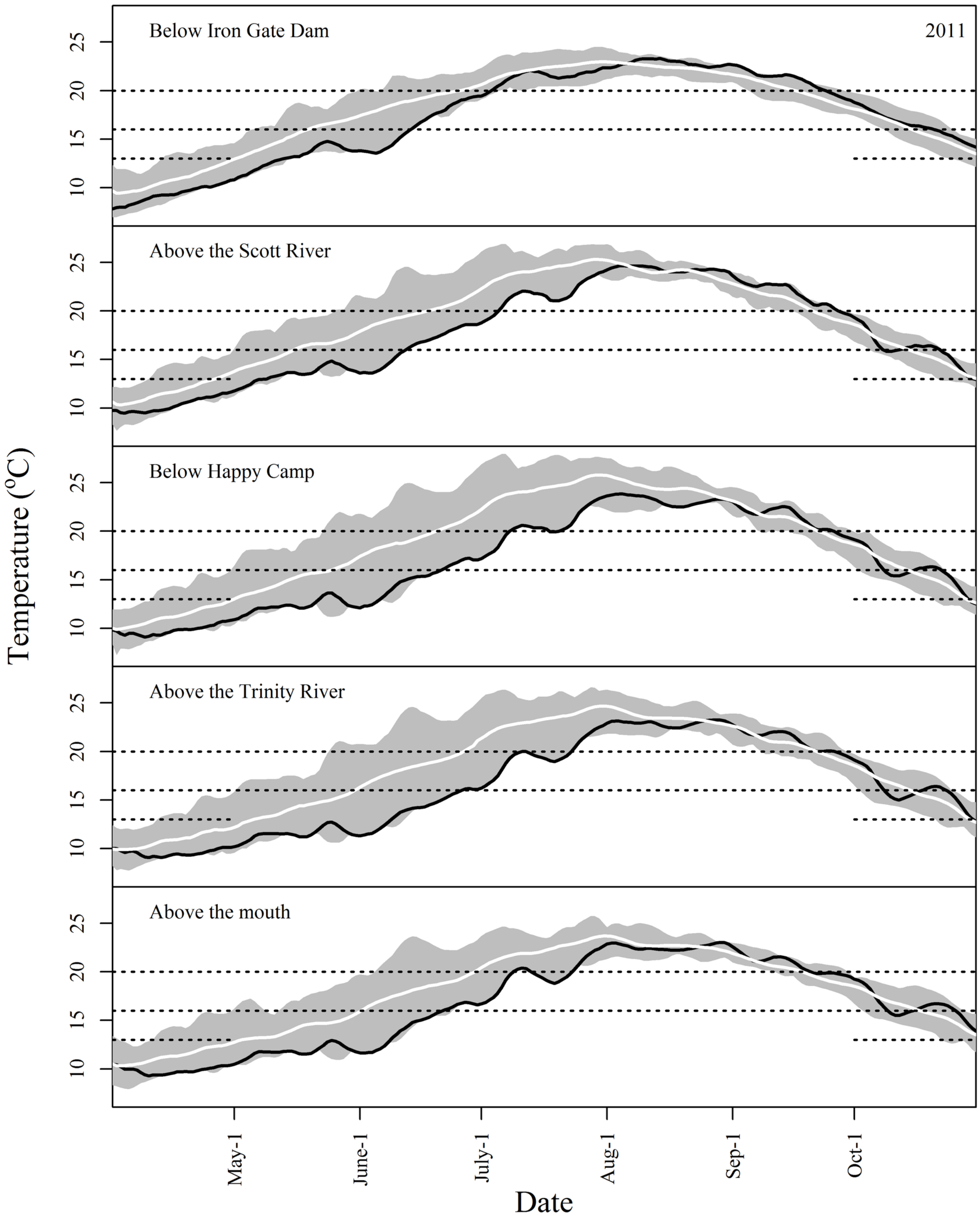
Appendix D9. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2008, with historical conditions. Black line = 7DADM water temperatures in 2008; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



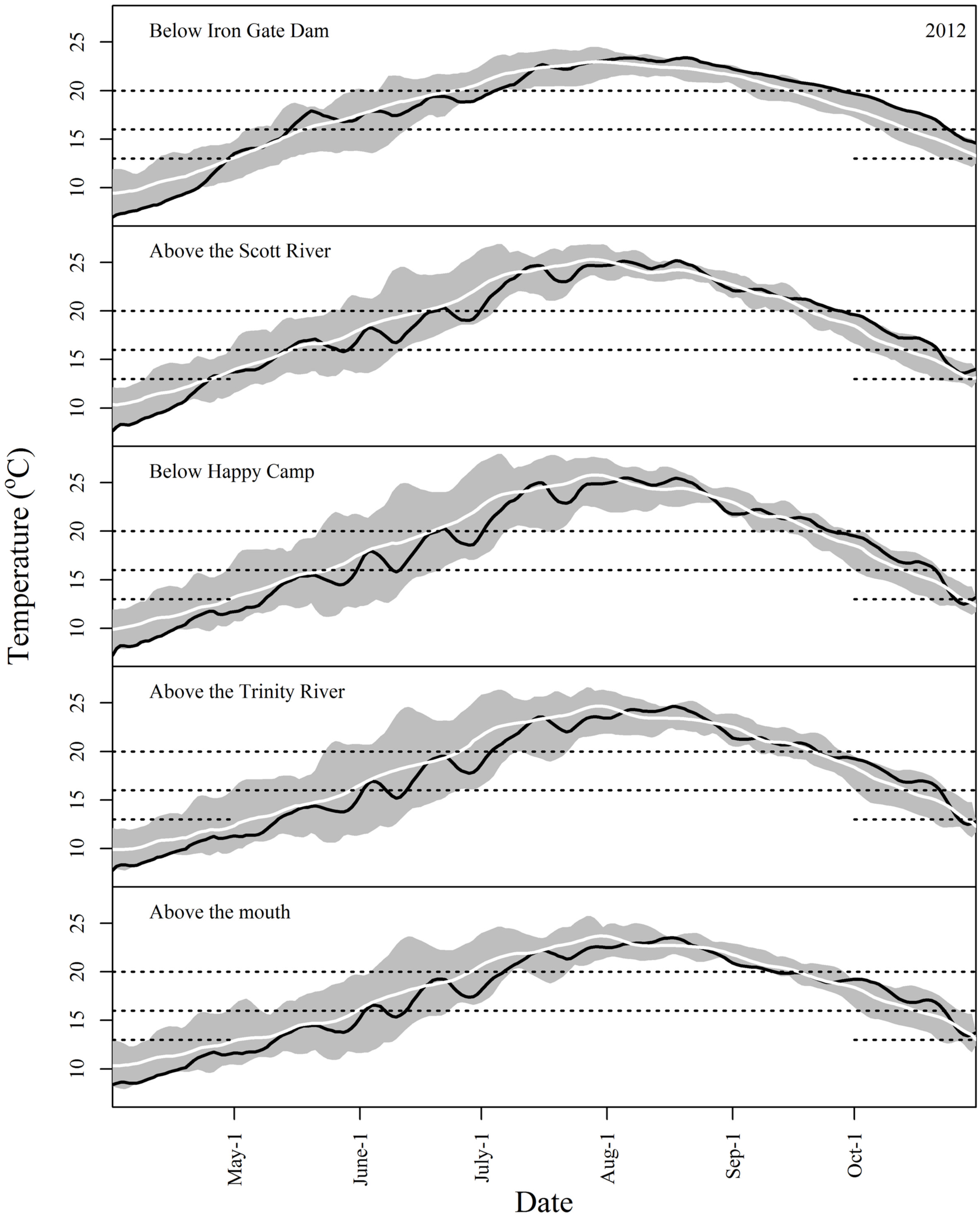
Appendix D10. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2009, with historical conditions. Black line = 7DADM water temperatures in 2009; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



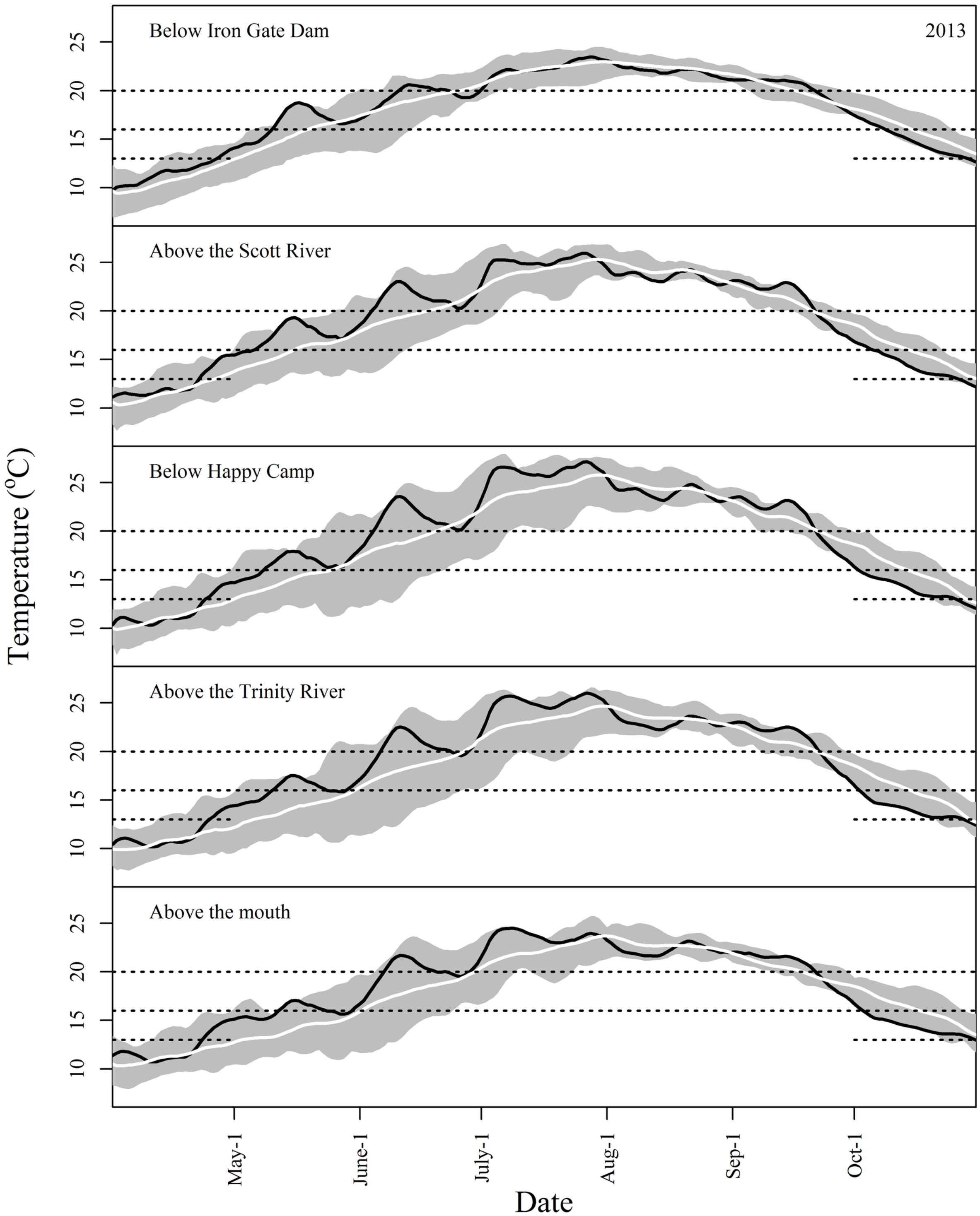
Appendix D11. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2010, with historical conditions. Black line = 7DADM water temperatures in 2010; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



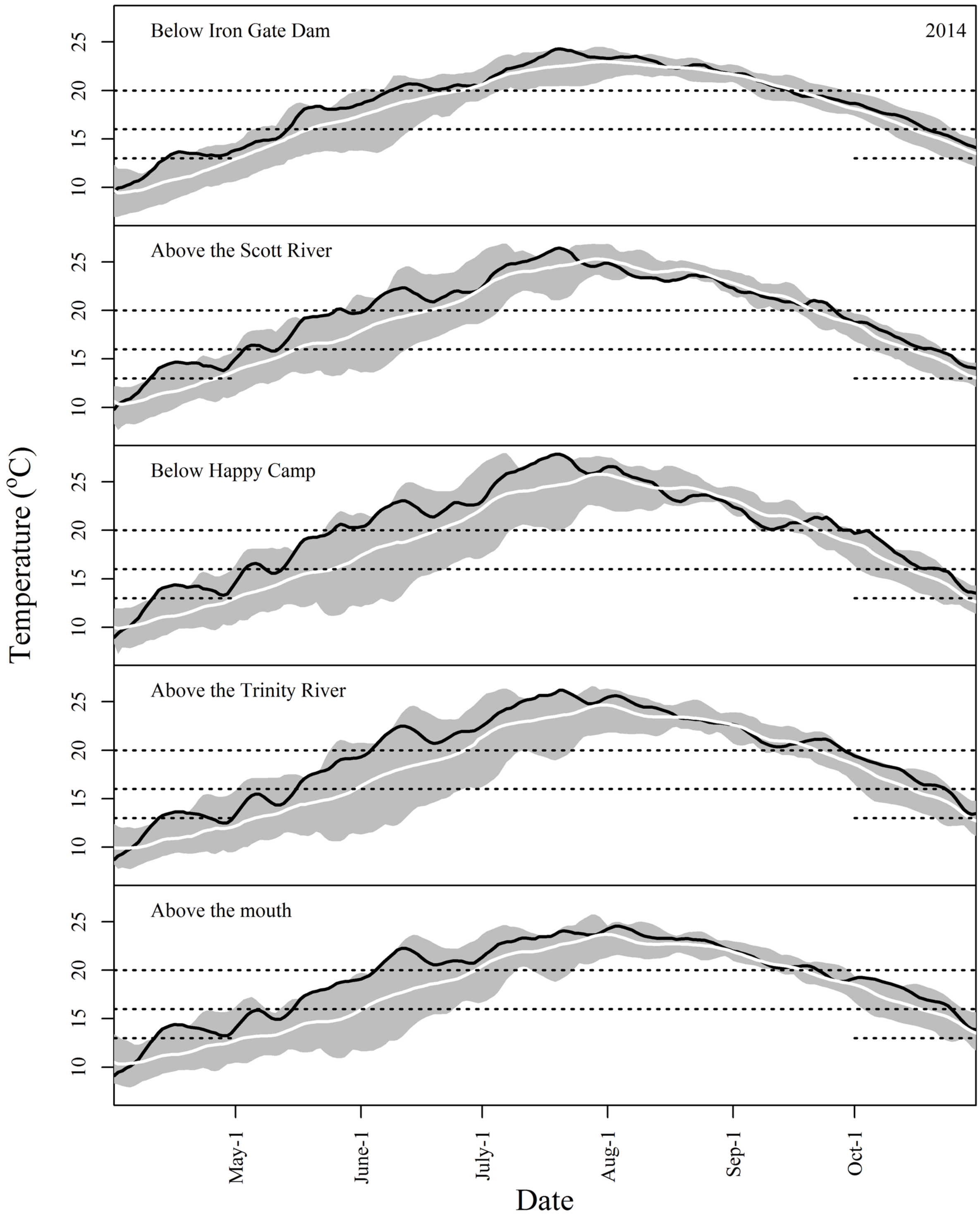
Appendix D12. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2011, with historical conditions. Black line = 7DADM water temperatures in 2011; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



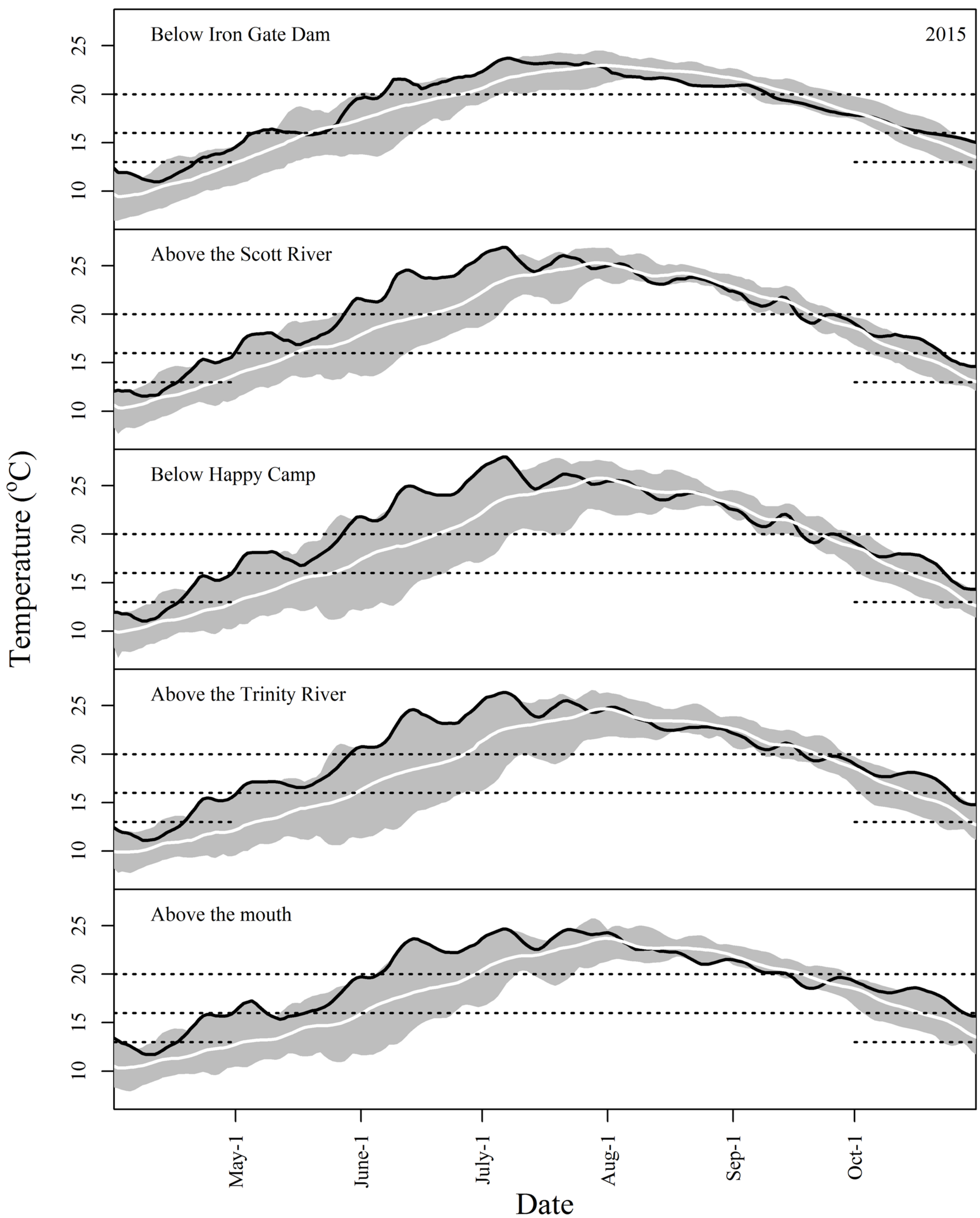
Appendix D13. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2012, with historical conditions. Black line = 7DADM water temperatures in 2012; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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



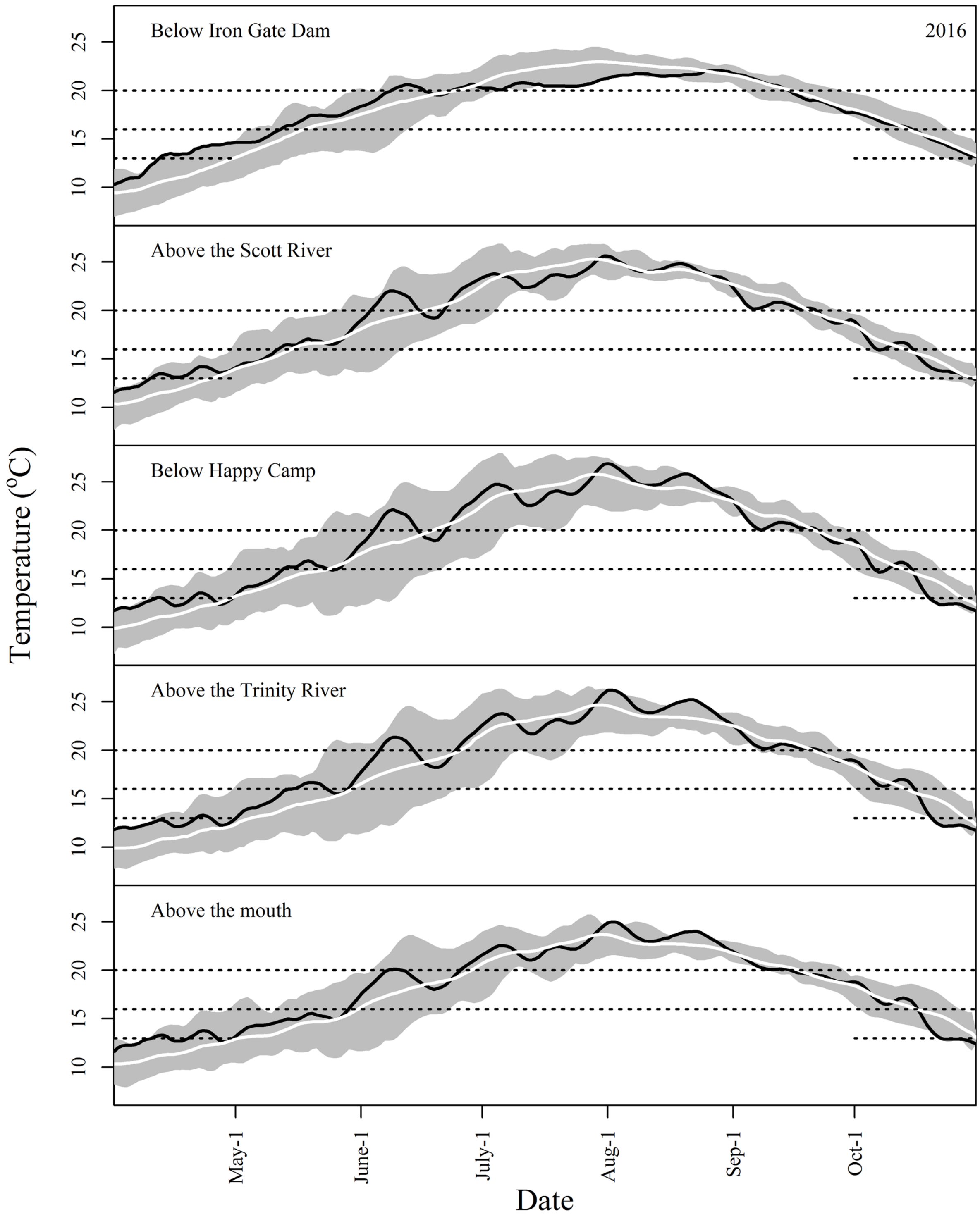
Appendix D14. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2013, with historical conditions. Black line = 7DADM water temperatures in 2013; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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

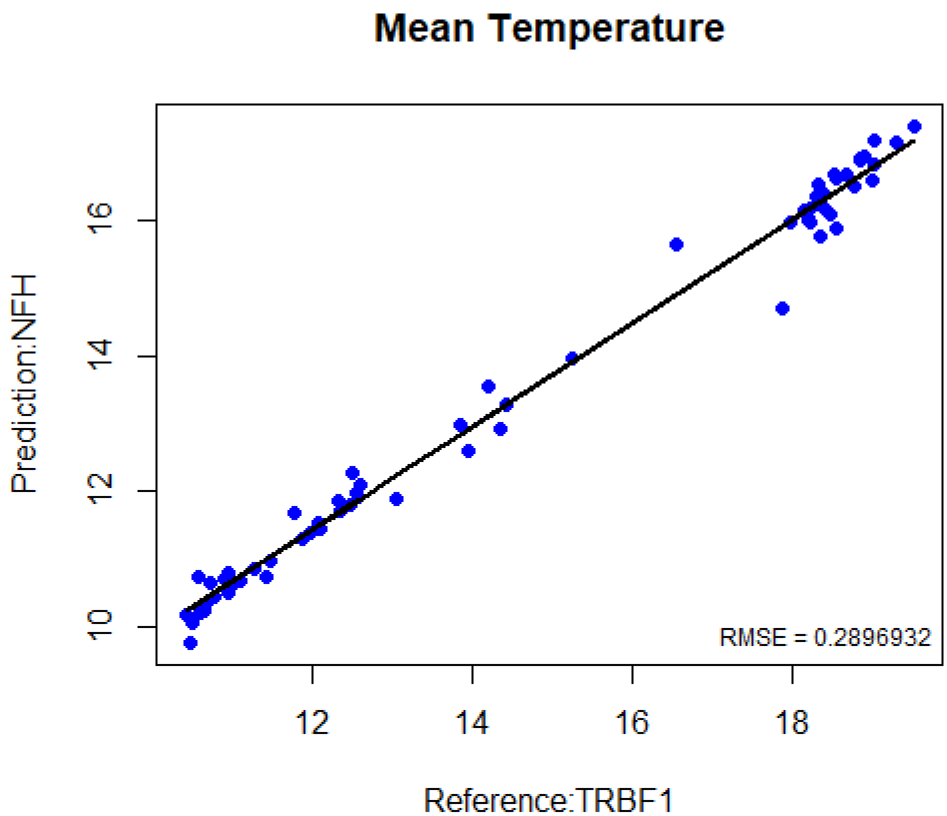


Appendix D16. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2015, with historical conditions. Black line = 7DADM water temperatures in 2015; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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

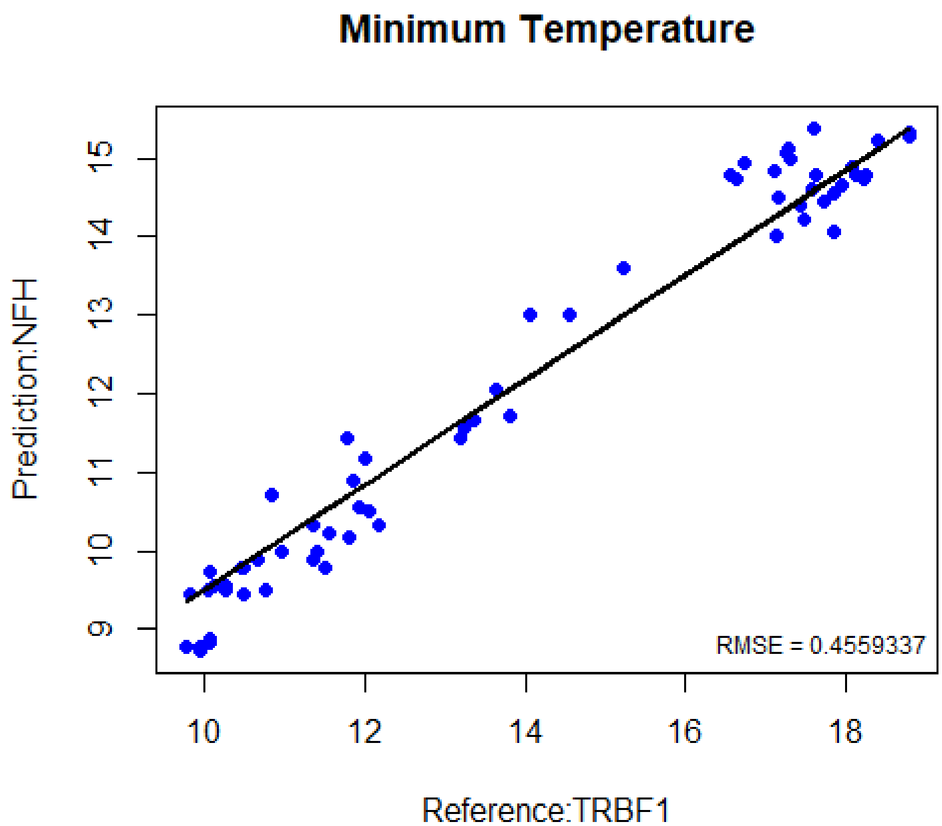


Appendix D17. 7DADM water temperatures at focal Klamath River monitoring locations, April 1 – October 31, 2016, with historical conditions. Black line = 7DADM water temperatures in 2016; white line = long term mean 7DADM for each day of the year; gray polygon = long term range for each day of the year;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

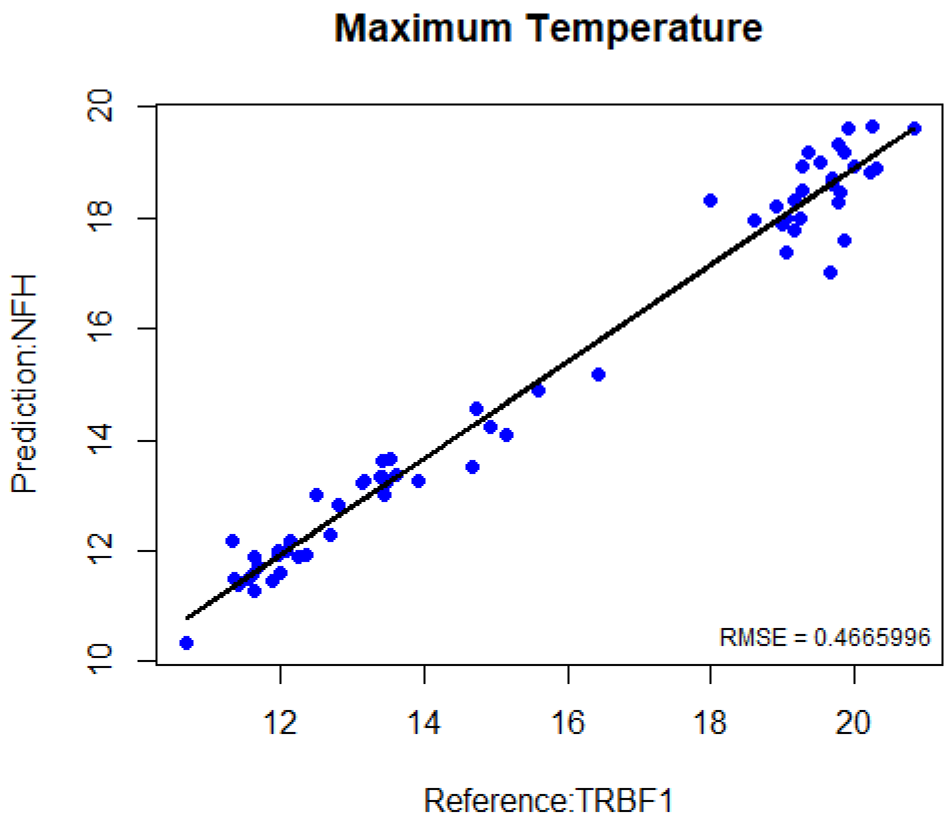
Appendix E. Predicted temperature values vs. reference values used for infilling at focal sites, with root mean square error (RMSE) as a measure for the difference between predicted and reference values.



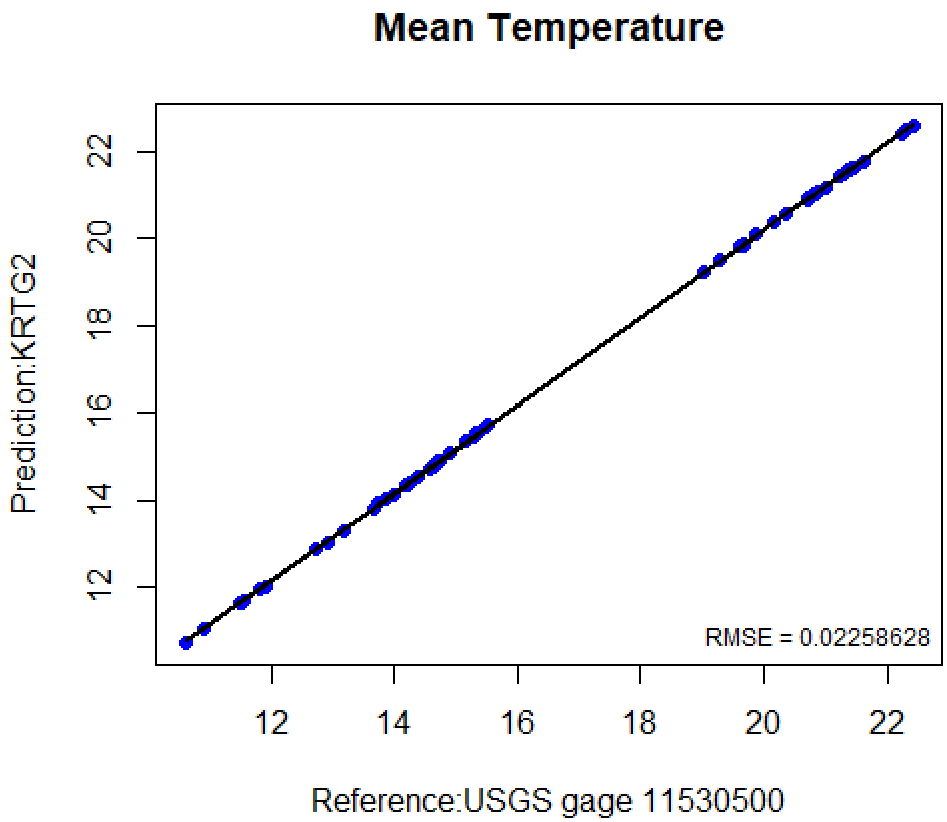
Appendix E1. Predicted mean temperature values vs. reference values used for infilling at the NFH focal site, with observed data at TRBF1, with RMSE as a measure of the difference between the predicted and reference values.



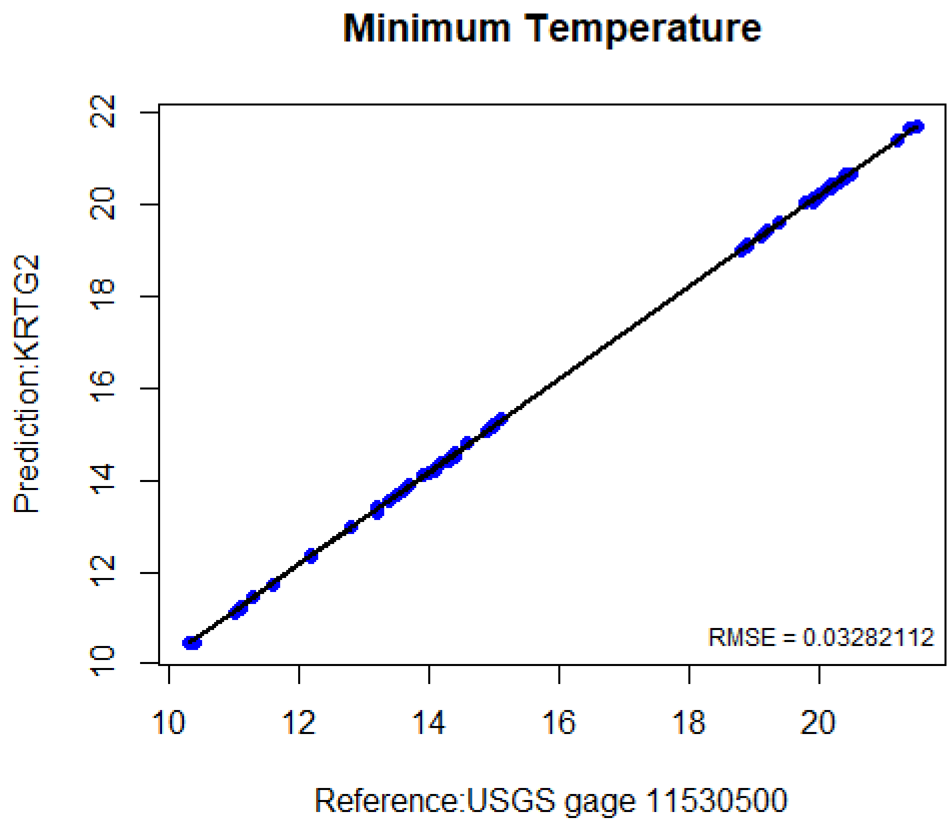
Appendix E2. Predicted minimum temperature values vs. reference values used for infilling at the NFH focal site, with observed data at TRBF1, with RMSE as a measure of the difference between the predicted and reference values.



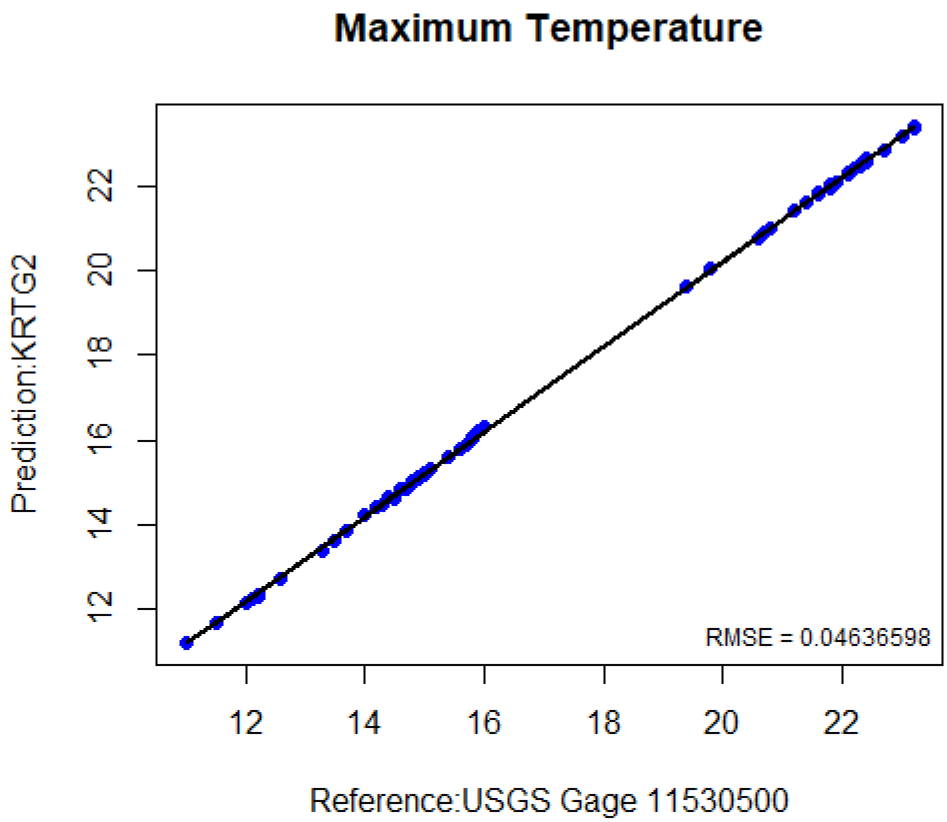
Appendix E3. Predicted maximum temperature values vs. reference values used for infilling at the NFH focal site, with observed data at TRBF1, with RMSE as a measure of the difference between the predicted and reference values.



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 E4. 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 E4. 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.