Stream Temperature Monitoring on the

Klamath National Forest, 2010 to 2011

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ABSTRACT

Summer stream temperatures were measured near the mouth of 87 watersheds representing most of the major tributary streams on the Klamath National Forest. The Maximum Weekly Maximum Stream Temperature (MWMT) exceeded the 16^{o}C threshold for core juvenile salmonid rearing in 85% of all streams on the Forest. Stream temperatures exceed 16^{o}C in 15 out of 20 reference streams, indicating that the natural receiving temperature of most streams is warmer than the threshold used to measure support of the beneficial use. A comparison of temperatures in managed and reference streams shows no significant increase in the managed streams. A weak but significant correlation was found between stream temperature and stream shade, mean July air temperature, drainage area, and elevation. The model estimates that the maximum temperature increase due to human-caused shade loss is 1.0^{o}C. Compliance with the Basin Plan standards was evaluated in each watershed using the Regional Water Board's outline for interpreting temperature standards. In total there are 33 watersheds that do not meet the Basin Plan temperature standards, and 54 watersheds that are in compliance.

INTRODUCTION

This report is an analysis of stream temperature data collected in tributary streams on the Klamath Nation Forest in 2010 and 2011. This assessment meets the Forest Service temperature monitoring requirements of Klamath, Scott, Shasta, and Salmon River TMDLs, two memorandums of understanding between the Forest Service and the Regional Water Quality Control Board (NCWQCB 2009a,b), and a Waiver of Waste Discharge Requirements (NCRWQCB 2010).

COMPLIANCE CRITERIA

Water quality standards for stream temperature are specified in the Water Quality Control Plan for the North Coast Region, referred to as the Basin Plan (NCRWQCB 2007). Compliance with the temperature objective requires an assessment of whether the natural water temperature has been altered (Table 1). Steam shade is used as a surrogate for water temperature as described in the load allocations for the Klamath River TMDL (NCRWQCB 2010b). In streams where the natural shade has been altered, compliance can still be demonstrated if the existing stream temperatures are cold enough to support beneficial uses. Support of beneficial uses can be assessed by comparing measured stream temperatures to the TMDL thresholds for adverse effects (Table 2). Watersheds with altered shade must also demonstrate that temperatures have not increased by more than 5^{o}F (2.8^{o}C).

METHODS

Sample sites are located near the mouth of 87 watersheds that represent all of the major tributary streams on the Klamath National Forest (Figures 1 and 2). Another 21 sites are located along the main channels of the Klamath, Salmon, and Scott Rivers but are not evaluated in this report. Each stream is designated as either a managed or reference stream depending on the level of human disturbance in the watershed (Table 3). Reference streams are well distributed across the forest and have a similar range of physical characteristics as the managed streams (Table 4). Details on the selection of reference streams can be found in the sediment monitoring report (USFS 2012). The sample sites on tributary streams are the same as those monitored for sediment, except for three sites that were added where only temperature is measured.

At each sample site, stream temperature is measured using digital dataloggers sampling at half hour intervals. The dataloggers are deployed in well-mixed zones during the low flow summer months. An air temperature monitoring site is paired with each of the stream temperature sites. The procedures used for temperature sampling, data processing, and quality control are provided in USFS (2010b). A quality assurance project plan has been developed by the Forest Service and approved by the North Coast Regional Water Board.

Table 1. Narrative water quality objectives for temperature from the Basin Plan (NCRWQCB 2011).

Temperature	The natural receiving water temperature of intrastate waters shall not be altered unless it can be demonstrated to the satisfaction of the Regional Water Board that such alteration in temperature does not adversely affect beneficial uses. At no time or place shall the temperature of any COLD water be increased by more than 5° F above natural receiving water temperature.

Table 2. Chronic effects thresholds used to interpret the narrative water quality objectives for temperature from the Basin Plan. From: Table 2-8 of the Klamath TMDL (NCRWQCB 2010b). Most tributary streams on the Klamath National Forest are located in the mid to upper reaches of the Klamath Basin where the core juvenile rearing threshold applies.

Life Stage	Maximum Weekly Maximum Temperature (MWMT, ^{o}C)
Adult Migration	20
Adult Migration plus Non-Core Juvenile Rearing[1]	18
Core Juvenile Rearing[2]	16
Spawning, Egg Incubation, and Fry Emergence	13

1 The Adult Migration plus Non-Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of migrating adult and juvenile salmonids and moderate to low density salmon and trout juvenile rearing during the period of summer maximum temperatures," usually occurring in the mid to lower part of the basin. The phrase "moderate to low density" is not specifically defined.

2 The Core Juvenile Rearing designation is recommended by USEPA (2003) for the "protection of moderate to high density summertime salmon and trout juvenile rearing" locations, usually occurring in the mid to upper reaches of the basin. The phrase "moderate to high density" is not specifically defined.

Table 3. Reference watershed criteria

Disturbance	Criteria
Stream shade	No evidence of human-caused reduction in stream shade is apparent in aerial photos
Road density	Less than 0.19 km/km^2 (0.30 mi/mi^2) with no significant road failures. Most have no roads
Grazing	Less than 10% of the drainage area grazed, and no BMP violations. Most have no grazing.
Mining	No significant sediment input or point sources (metals or pH). Most have only prospects.
Timber harvest	A road density of less than 0.19 km/km^2 is used as surrogate for past harvest intensity.
Wildfire and other natural disturbance	Natural disturbance is included in the reference pool as of component of natural variability.

Table 4. Characteristics of reference and managed watersheds.

	Reference Streams (n = 20)			Managed Streams (n = 67)		
Watershed Characteristics	Average	Maximum	Minimum	Average	Maximum	Minimum
Drainage Area (km^2)	64	291	13	72	310	12
Elevation at sample site (m)	726	1300	400	675	1801	234
Precipitation (Mean Annual) (in)	74	100	55	56	87	29
Road Density (km/km^2)	0.03	0.19	0.0	1.62	3.58	0.14
Stream Shade (watershed ave. %)	88	97	76	89	97	54
Stream Shade reduction by human activities (watershed ave. %)	0	0	0	0.6	8.2	0
Channel Gradient (%)	3.3	6.5	1.1	3.4	6.6	0.5

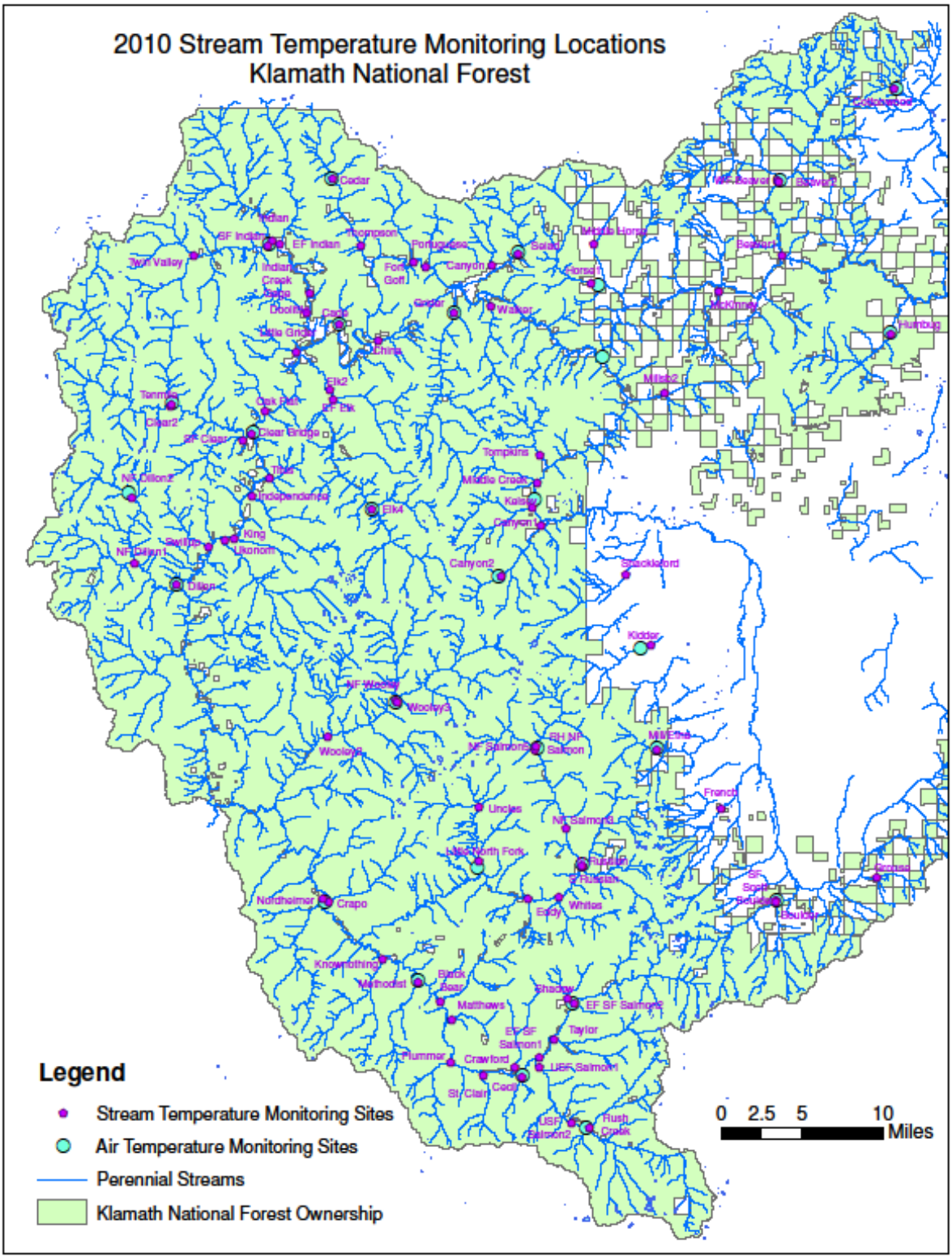

Figure 1. Temperature monitoring sites on the west side of the Klamath National Forest

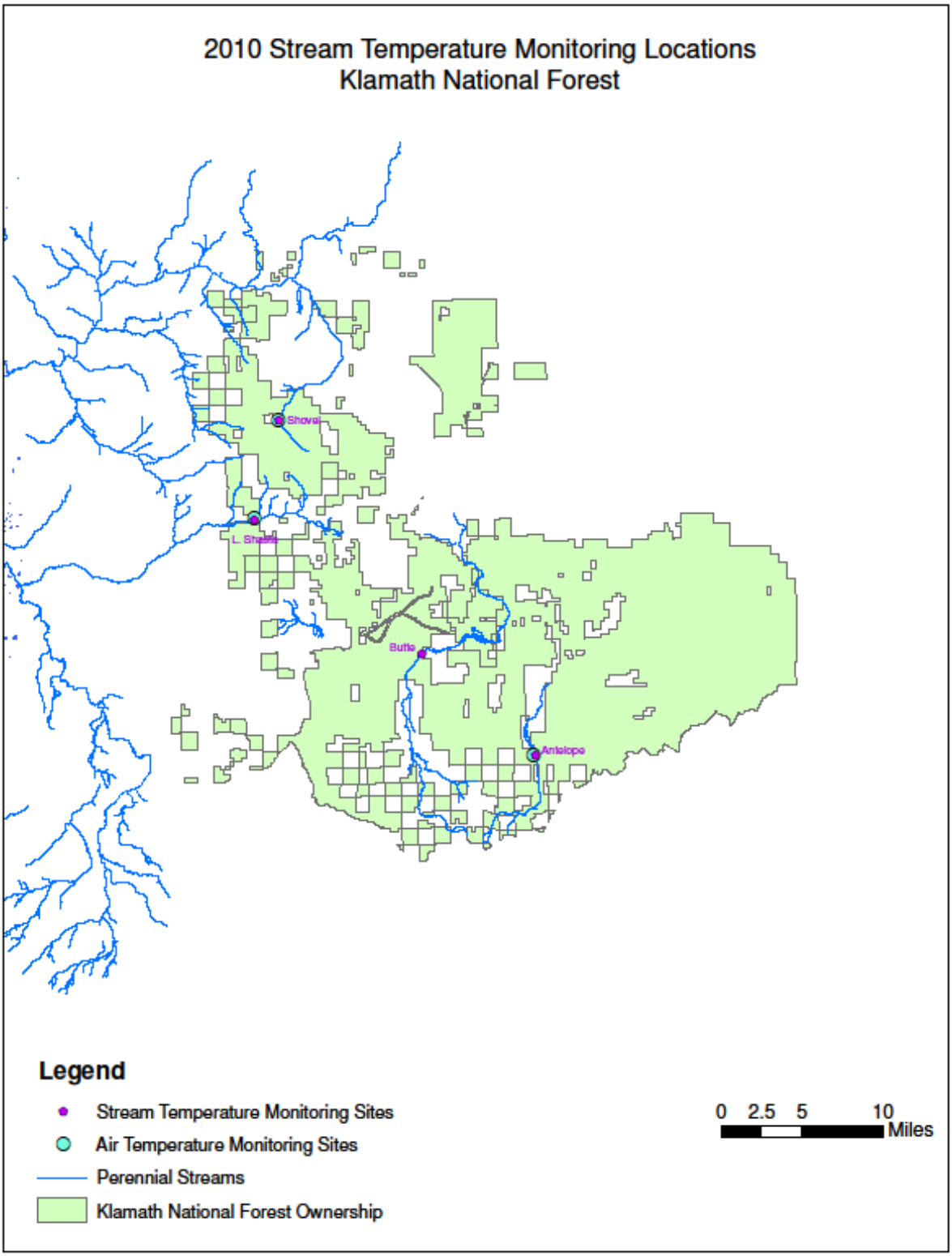

Figure 2. Temperature monitoring sites on the east side of the Klamath National Forest

RESULTS

Several stations did not record data due to theft of the dataloggers, malfunctioning equipment, or because the temperature sensors extended above the water surface during low flows. Useable data was obtained at 84 sites in 2010, and at 82 sites in 2011. All 87 sites were sampled at least once. In 2010 six dataloggers were not deployed until in late July but they appear to have sampled the annual maximum weekly temperature.

Air temperatures in 2011 were relatively cool when compared to the long-term record at Callahan (Figure 3). The effect of cooler air temperatures and higher stream flows (Figure 4) is reflected in a shift toward lower stream temperatures in 2011 (Figure 5). Between 2010 and 2011 a 1.7^{o}C decrease in the mean July air temperature at Callahan corresponds with a 1.0^{o}C decrease in the average stream temperature (average MWMT).

In 2010 and 2011 there were 71 and 59 streams respectively that had stream temperatures greater than the 16^{o}C threshold for core juvenile rearing (Tables 5 to 8). This represents 85% and 72% of the streams monitored each year. The highest MWMT on the Forest was 21.5^{o}C in the South Fork of Indian Creek in 2010. Most of the reference streams did not meet the temperature thresholds, with temperatures exceeding 16^{o}C in 15 out of the 20 reference streams.

To estimate the effect of human-caused shade loss on stream temperatures, we developed a multiple regression using stream shade data collected in a previous study (USFS 2011). A significant correlation was found using the watershed average stream shade, mean July air temperature at Callahan, drainage area, and elevation as predictor variables and maximum weekly maximum stream temperature as the response variable (Table 9, Figure 6). The mean July discharge in the Salmon River was also significant but was removed from the equation because it is correlated with other variables. Watershed aspect and precipitation were not significantly correlated with stream temperature. Although the correlation is weak we used equation 1 to estimate the temperature increase due to human-caused reductions in stream shade. Watersheds with a human-caused shade reduction of less than 0.1% have a predicted temperature increase of less than 0.01^{o}C, which is below the resolution of the dataloggers (Onset 2012). The largest temperature increase is 1.0^{o}C (1.8^{o}F) in Walker Creek (Figure 7). No streams had a temperature increase greater than 5^{o}F.

The effect of human-caused disturbance was also assessed by comparing stream temperatures in managed and reference streams. A comparison of the temperature distributions shows little difference between managed and reference streams at temperatures above 16^{o}C, but managed streams are warmer than reference streams at temperatures below 16^{o}C (Figure 8). This difference is most likely due to the influence of cold water springs, such as the karst springs at the headwaters of Canyon Creek. The median temperature in managed streams is not significantly different from reference streams in either year (Mann-Whitney at α=0.05).

To assess compliance with the Basin Plan objectives for temperature (Table 1), we combined the stream temperature and stream shade data as shown in Table 10. The Regional Water Board's outline for interpreting temperature standards (NCRWQCB 2010) is used to identify the number of watersheds that are impaired (Figure 9). There are 44 watersheds that have no human-caused shade loss. An additional

11 watersheds have a shade loss of less than 0.1% which has an undetectable effect on temperatures at the watershed scale. These 55 watersheds represent natural, unaltered shade conditions and are meeting the temperature objective. There are 35 watersheds where the human-caused shade loss is greater than 0.1%, which is interpreted as an alteration of the natural stream shade. In two of these streams the shade alteration has not had an adverse effect because stream temperatures are below the 16^{o}C threshold for support of beneficial uses, and temperatures have not been increased by more than 5^{o}F. The other 33 streams have temperatures >16^{o}C that adversely affect beneficial uses and are not meeting the temperature objective.

SUMMARY AND CONCLUSION

Stream temperature was monitored during the summer low flow period at a network of 87 watersheds representing most of the major tributaries on the Klamath National Forest. Reference conditions were monitored in 20 minimally disturbed watersheds that represent the natural background condition.

Stream temperatures were warmer than the 16^{o}C threshold for support of beneficial uses for core juvenile rearing in 85% of all streams on the Forest. There is ample evidence that most of the high temperatures are natural. Temperatures in 15 out of 20 reference streams exceed 16^{o}C. A comparison of the distributions of temperatures in managed and reference streams show no evidence of increased temperatures above 16^{o}C. Temperatures in managed streams did not differ significantly from reference streams when compared using the Mann-Whitney test ($\alpha = 0.05$). Stream shade data collected in a previous study showed that 41 out of 87 watersheds have no human-caused shade loss. Another 11 watersheds have a human-caused shade loss of less than 0.1%. A regression analysis between stream shade and steam temperature estimates that a watershed average shade loss of less than 0.1% would decrease temperatures by less than 0.01^{o}C. Our assessment is that the natural receiving temperatures of many streams on the Klamath National Forest are warmer than the thresholds used to assess adverse effects to beneficial uses. However, beneficial uses may still be supported in these streams if they contain thermal refuge areas. Our monitoring sampled areas with well-mixed stream temperatures because our goal is to monitor the cumulative effect of the overall watershed condition. We did not target thermal refuge areas at the reach scale.

To identify which streams are in compliance with the Basin Plan temperature standards, the stream shade and stream temperature data were evaluated using the Regional Water Board's three step process for interpreting the temperature standards. First, data for human-caused shade loss was used to assess if the natural receiving temperature has been altered. Second, the temperature data were used to determine if stream temperatures adversely affect beneficial uses. Third, the correlation between stream shade and temperature and the distributions for temperatures in managed and reference streams were used to determine if temperatures have increased by more than 5^{o}F. In 54 watersheds the natural shade condition has not been altered and the temperature objectives of the Basin Plan are attained. In two watersheds the natural shade has been altered, but stream temperatures are cold enough to support the beneficial uses. In no instance have temperatures been increased by more than the 5^{o}F. In 33 watersheds the natural shade conditions have been altered and water temperatures are warmer than the 16^{o}C required to support beneficial uses. In total there are 54 watersheds that meet the temperature objectives, and 33 watersheds that are not attaining the Basin

Plan standards for temperature. These totals would change If the North Coast Regional Water Board choses different compliance criteria than those proposed in Table 10.

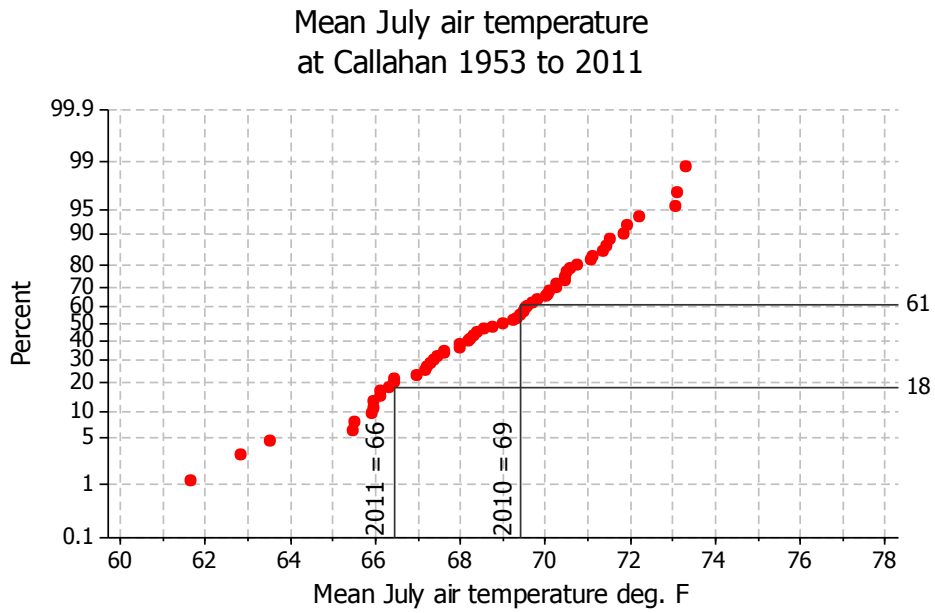

Figure 3. Mean July air temperatures at Callahan from 1953 to 2011 (source: WRCC). Temperatures in 2010 were slightly above normal while 2011 was a cool year.

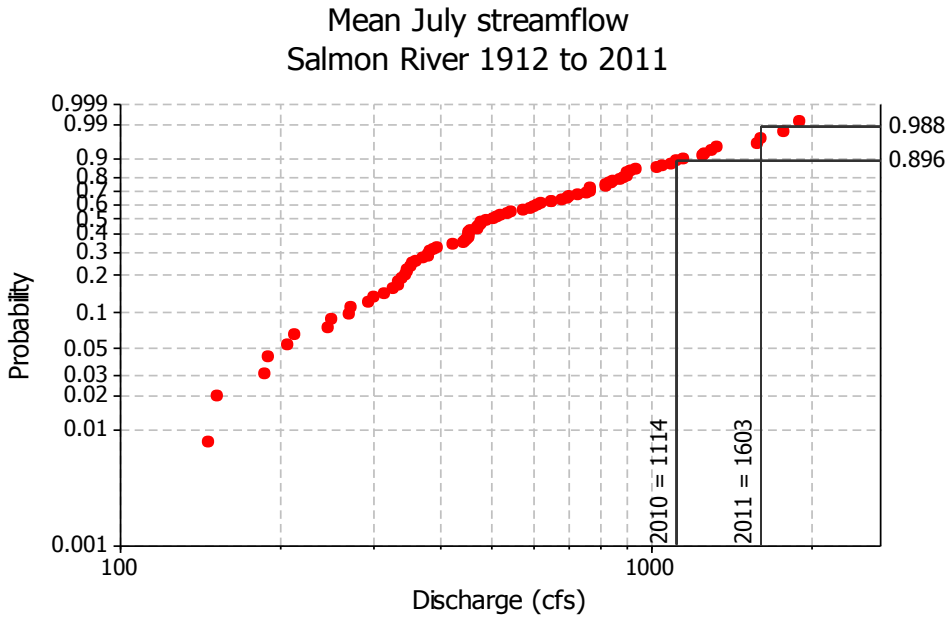

Figure 4. Mean July streamflow at Salmon River near Somes Bar, USGS gauge 11522500 1912 to 2011. Both 2010 and 2011 had high flows in the upper 90% of historic stream flows.

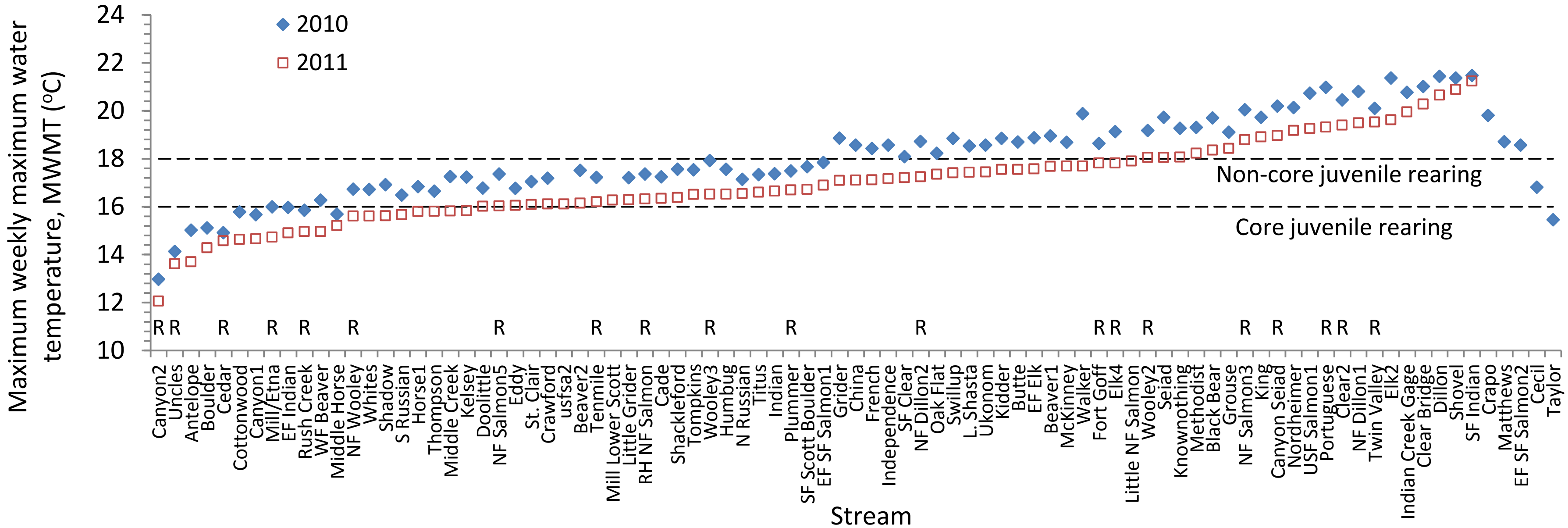

Figure 5. Maximum weekly maximum stream temperatures 2010 and 2011. R denotes reference streams.

Table 5. Salmon River stream temperatures. Watersheds in bold have >0.1% human-caused shade alteration, and have stream temperatures greater than the 16°C threshold for core juvenile rearing. Steam shade reduction is from USFS (2011).

Watershed Name	Reference or Managed	Water Temperature (MWMT, C°) 2010	2011	Shade Reduction: Human-caused (% of watershed)	Shade: Existing (% of watershed)	Drainage Area (km^2)	Elevation (m)	Aspect (degrees)	Precipitation (mean annual inches)
USF Salmon1	Managed	**20.7**	**19.3**	-1.5%	85%	204	738	0	50
Nordheimer	Managed	20.1	19.2	0.0%	87%	80	332	0	63
NF Salmon3	Reference	20.0	18.8	0.0%	90%	146	863	180	69
Crapo	Managed	19.8	-	0.0%	80%	45	346	225	58
Black Bear	Managed	19.7	18.4	0.0%	90%	37	513	225	40
Methodist	Managed	**19.3**	**18.2**	-1.1%	92%	33	459	0	50
Knownothing	Managed	19.3	18.1	-0.1%	92%	59	404	0	59
Wooley2	Reference	19.2	18.0	0.0%	91%	291	400	225	70
Matthews	Managed	18.7	-	0.0%	95%	19	574	315	35
EF SF Salmon2	Managed	18.6	-	-0.1%	90%	86	868	270	56
Wooley3	Reference	17.9	16.5	0.0%	92%	105	582	225	78
EF SF Salmon1	Managed	17.8	16.9	-0.1%	90%	175	731	225	51
Plummer	Reference	17.5	16.7	0.0%	89%	37	626	0	61
NF Salmon5	Reference	17.4	16.0	0.0%	91%	47	1045	225	76
RH NF Salmon	Reference	17.4	16.3	0.0%	90%	51	1044	90	66
Crawford	Managed	**17.2**	**16.1**	-0.4%	94%	34	741	180	40
N Russian	Managed	17.1	16.5	-0.1%	88%	47	797	225	53
St. Clair	Managed	17.0	16.1	0.0%	94%	27	676	0	55
Shadow	Managed	16.9	15.6	-0.1%	96%	23	903	180	48
Cecil	Managed	**16.8**	-	-0.2%	93%	15	711	0	47
Eddy	Managed	**16.8**	16.0	-2.5%	93%	18	673	0	49
NF Wooley	Reference	16.7	15.6	0.0%	91%	57	590	180	71
Whites	Managed	**16.7**	15.6	-0.4%	95%	35	727	315	55
S Russian	Managed	**16.5**	15.7	-0.5%	89%	48	801	315	54
Rush Creek	Reference	15.9	15.0	0.0%	90%	31	895	225	55
Taylor	Managed	15.5	-	0.0%	92%	47	792	270	49
Uncles	Reference	14.1	13.6	0.0%	95%	21	1004	180	73
usfsa2	Managed	-	**16.1**	-1.5%	86%	84	1431	180	67
Little NF Salmon	Managed	-	**17.9**	-1.5%	91%	156	1665	315	53

Table 6. Scott River stream temperatures. Watersheds in bold have >0.1% human-caused shade alteration, and have stream temperatures greater than the 16°C threshold for core juvenile rearing. Steam shade reduction is from USFS (2011).

Watershed Name	Reference or Managed	Water Temperature (MWMT, C°)		Shade reduction from human causes (% of watershed)	Existing shade (% of watershed)	Drainage Area (km^2)	Elevation (m)	Aspect (degrees)	Precipitation (mean annual inches)
		2010	2011						
Grouse	Managed	19.1	18.4	0.0%	90%	27	1119	45	47
Kidder	Managed	18.8	17.5	0.0%	88%	59	959	45	55
French	Managed	18.4	17.1	0.0%	91%	35	954	45	37
SF Scott Boulder	Managed	17.7	16.7	0.0%	89%	73	1023	0	49
Tompkins	Managed	**17.5**	**16.5**	-1.9%	90%	38	710	135	51
Shackleford	Managed	17.6	16.4	0.0%	75%	48	963	45	59
Mill Lower Scott	Managed	-	16.3	-0.1%	97%	29	1240	270	47
Kelsey	Managed	17.2	15.8	0.0%	89%	46	683	45	58
Middle Creek	Managed	**17.3**	15.8	-1.1%	90%	18	652	180	50
Mill/Etna	Reference	16.0	14.7	0.0%	93%	27	1193	45	57
Canyon1	Managed	15.7	14.7	-0.1%	84%	64	732	45	64
Boulder	Managed	15.1	14.3	0.0%	85%	33	1026	0	48
Canyon2	Reference	13.0	12.1	0.0%	87%	19	1300	0	74

Table 7. Lower Mid-Klamath River stream temperatures. Watersheds in bold have >0.1% human-caused shade alteration, and have stream temperatures greater than the 16°C threshold for core juvenile rearing. Steam shade reduction is from USFS (2011).

Watershed Name	Reference or Managed	Water Temperature (MWMT, C°) 2010	2011	Shade reduction from human causes (% of watershed)	Existing shade (% of watershed)	Drainage Area (km^2)	Elevation (m)	Aspect (degrees)	Precipitation (mean annual inches)
SF Indian	Managed	21.5	21.2	-0.1%	83%	129	459	45	83
Dillon	Managed	21.4	20.6	0.0%	84%	190	234	135	87
Clear Bridge	Managed	21.0	20.3	-0.1%	86%	289	284	135	83
Indian Creek Gage	Managed	**20.8**	**19.9**	-0.8%	88%	309	365	135	78
Elk2	Managed	**21.4**	**19.6**	-0.4%	80%	234	390	315	65
Twin Valley	Reference	20.1	19.5	0.0%	82%	36	649	90	92
NF Dillon1	Managed	20.8	19.5	0.0%	82%	86	447	135	86
Clear2	Reference	20.4	19.4	0.0%	87%	160	444	135	100
Portuguese	Reference	21.0	19.3	0.0%	91%	23	420	180	70
King	Managed	19.7	18.9	0.0%	93%	15	259	270	62
Elk4	Reference	19.1	17.8	0.0%	75%	83	719	315	74
Fort Goff	Reference	18.6	17.8	0.0%	90%	34	401	180	70
EF Elk	Managed	**18.9**	**17.6**	-0.3%	94%	42	408	270	56
Ukonom	Managed	**18.6**	**17.4**	-1.5%	86%	85	263	270	68
Swillup	Managed	**18.8**	**17.4**	-0.7%	88%	23	260	135	66
Oak Flat	Managed	**18.2**	**17.3**	-0.9%	96%	23	325	135	65
NF Dillon2	Reference	18.7	17.2	0.0%	78%	44	668	90	92
SF Clear	Managed	**18.1**	**17.2**	-0.5%	95%	32	312	45	65
Independence	Managed	18.6	17.2	-0.1%	87%	47	297	270	68
China	Managed	**18.6**	**17.1**	-0.5%	94%	25	404	90	54
Indian	Managed	**17.4**	**16.6**	-1.0%	91%	108	455	135	74
Titus	Managed	**17.3**	**16.6**	-0.2%	91%	22	279	270	55
Cade	Managed	**17.2**	**16.3**	-4.1%	93%	12	337	180	59
Little Grider	Managed	**17.2**	**16.3**	-0.2%	97%	21	349	90	68
Tenmile	Reference	17.2	16.2	0.0%	80%	41	446	180	78
Doolittle	Managed	**16.8**	16.0	-0.8%	95%	24	361	90	65
Thompson	Managed	**16.6**	15.8	-0.8%	95%	71	433	135	74
EF Indian	Managed	16.0	14.9	-0.5%	93%	48	456	180	73
Cedar	Reference	14.9	14.6	0.0%	97%	13	729	225	75

Table 8. Upper Mid-Klamath River stream temperatures. Watersheds in bold have >0.1% human-caused shade alteration, and have stream temperatures greater than the 16°C threshold for core juvenile rearing. Steam shade reduction is from USFS (2011).

Watershed Name	Reference or Managed	Water Temperature (MWMT, C°)		Shade reduction from human causes (% of watershed)	Existing shade (% of watershed)	Drainage Area (km^2)	Elevation (m)	Aspect (degrees)	Precipitation (mean annual inches)
		2010	2011						
Shovel	Managed	21.4	20.9	0.0%	54%	23	1801	315	35
Canyon Seiad	Reference	20.2	19.0	0.0%	85%	17	499	180	67
Seiad	Managed	**19.7**	**18.0**	-0.2%	85%	33	569	180	72
McKinney	Managed	**18.7**	**17.7**	-1.3%	91%	29	534	0	38
Walker	Managed	**19.9**	**17.7**	-8.2%	86%	31	495	0	53
Beaver1	Managed	**18.9**	**17.7**	-0.6%	85%	272	535	180	55
Butte	Managed	**18.7**	**17.5**	-	-	141	1456	0	29
L. Shasta	Managed	18.5	17.4	0.0%	63%	93	1247	225	33
Grider	Managed	**18.9**	**17.1**	-1.8%	90%	102	464	0	57
Humbug	Managed	17.6	16.5	0.0%	89%	74	707	45	40
Beaver2	Managed	**17.5**	**16.1**	-0.9%	86%	152	708	225	50
Horse1	Managed	**16.8**	15.8	-0.2%	94%	74	535	180	55
Middle Horse	Managed	15.7	15.2	0.0%	96%	24	643	180	51
WF Beaver	Managed	16.3	15.0	0.0%	86%	81	706	90	68
Cottonwood	Managed	15.8	14.6	-0.1%	95%	19	970	135	45
Antelope	Managed	15.0	13.7	-	-	66	1548	0	37

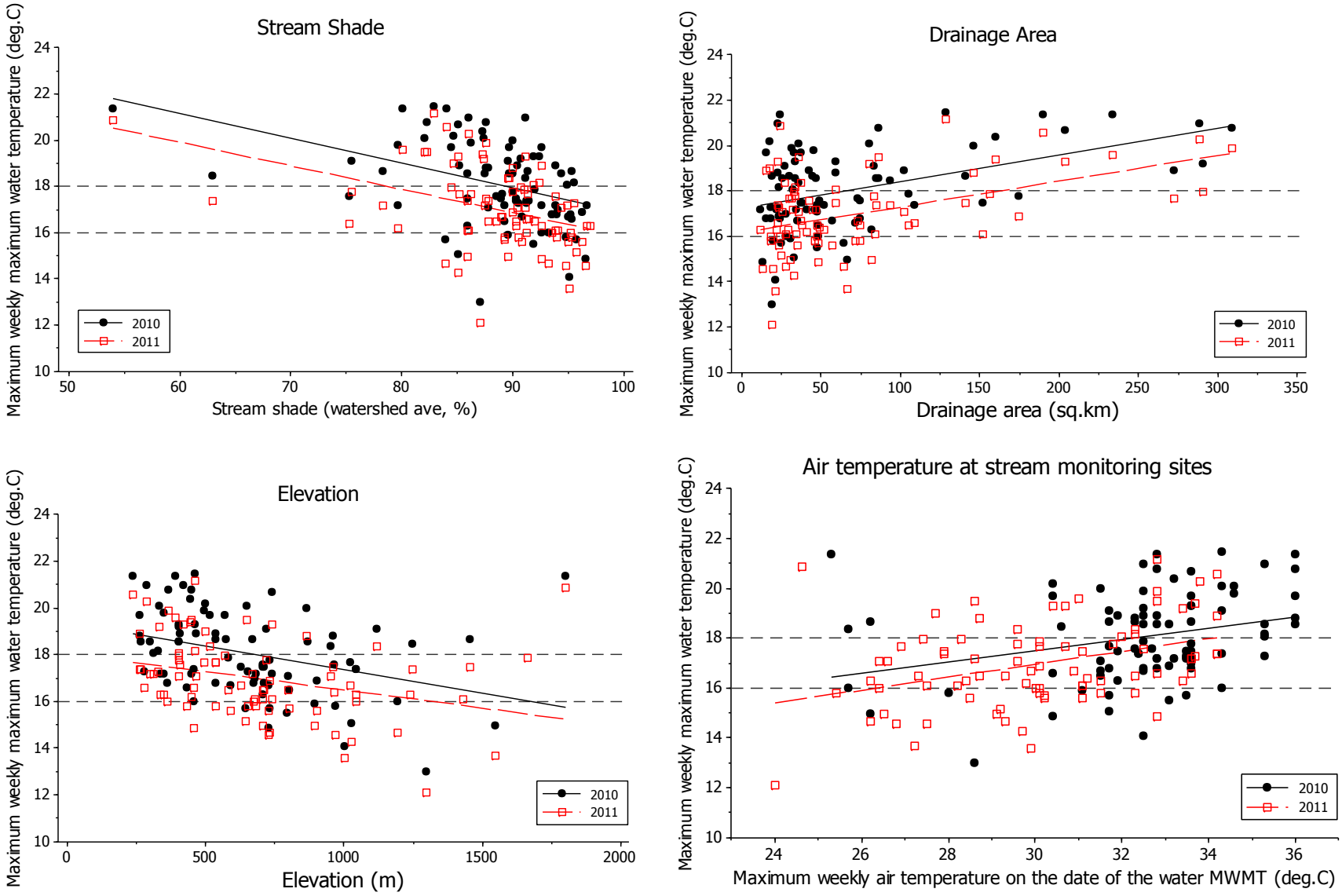

Figure 6. Stream temperature response to stream shade, drainage area, elevation, and air temperature. The high outlier for elevation and air temperature is Shovel Ck, which has a high water temperature due to 54% stream shade. The low outlier is Canyon Ck. which has cold water springs.

Table 9. Regression analysis for Maximum Weekly Maximum Stream Temperature (MWMT) for all data 2010 to 2011. Bold are significant at α = 0.05.

Equation:

Stream temperature = 17.7 + 0.60(Air) - 0.125(Stream Shade) + 0.00709(DA) - 0.00239(Elev) (1)

n = 162
R^2 = 0.51
RMSE = 1.31

	P
Constant	**0.000**
Air temperature (Mean July air temperature at Callahan, C^o)	**0.000**
Stream shade (watershed average, %)	**0.000**
Drainage area (km^2)	**0.000**
Elevation of sample site (m)	**0.000**
Watershed aspect (degrees)	0.523
Precipitation (mean annual, cm)	0.315

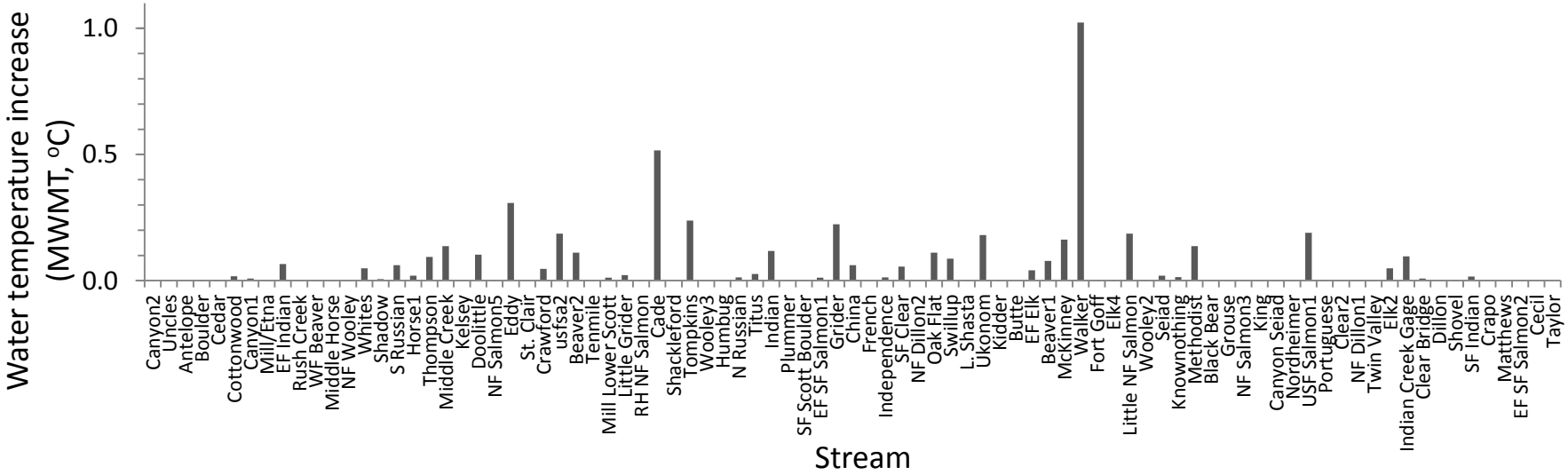

Figure 7. Increase in maximum weekly maximum stream temperature predicted by equation 1 (Table 10) from human-caused shade loss.

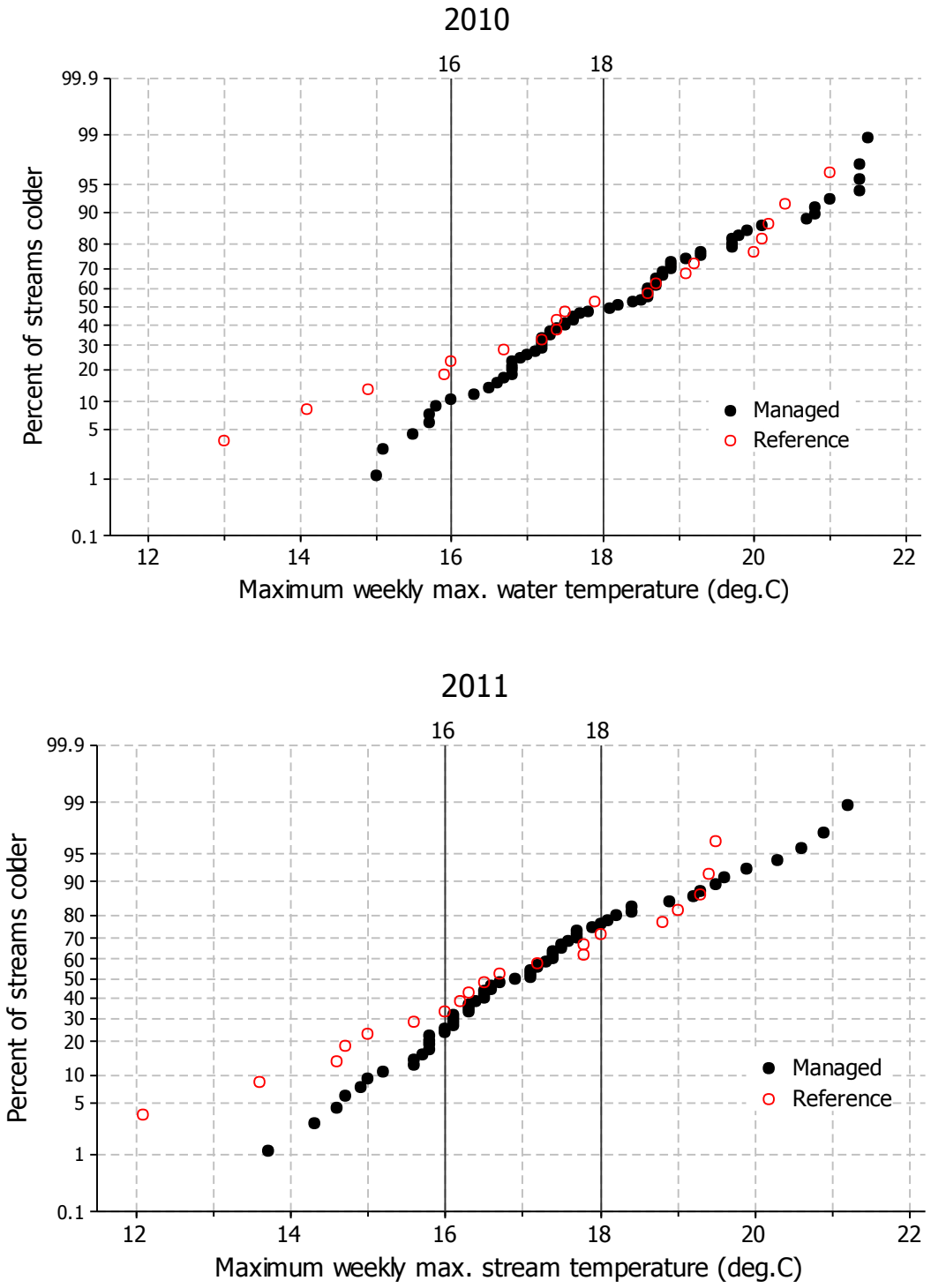

Figure 8. Distribution of stream temperatures in managed and reference watersheds 2010 to 2011. The 16°C threshold is for core juvenile rearing, and 18°C is for support of for adult migration plus non-core juvenile rearing beneficial uses (from Table 2).

Table 10. Proposed interpretation of stream shade and temperature data to determine compliance with the Basin Plan objectives for temperature from Table 1.

Stream shade loss from human activities (watershed average shade, %)	Stream Temperature (Maximum Weekly Maximum °C)	Temperature increase	Interpretation	Impairment
>0.1%	>16	>5°F	Alteration and adverse effect	Impaired
0 to 0.1%	>16		No detectable alteration	Not impaired
Any	<16	<5°F	No adverse effect	
0	Any		No alteration (natural conditions)	

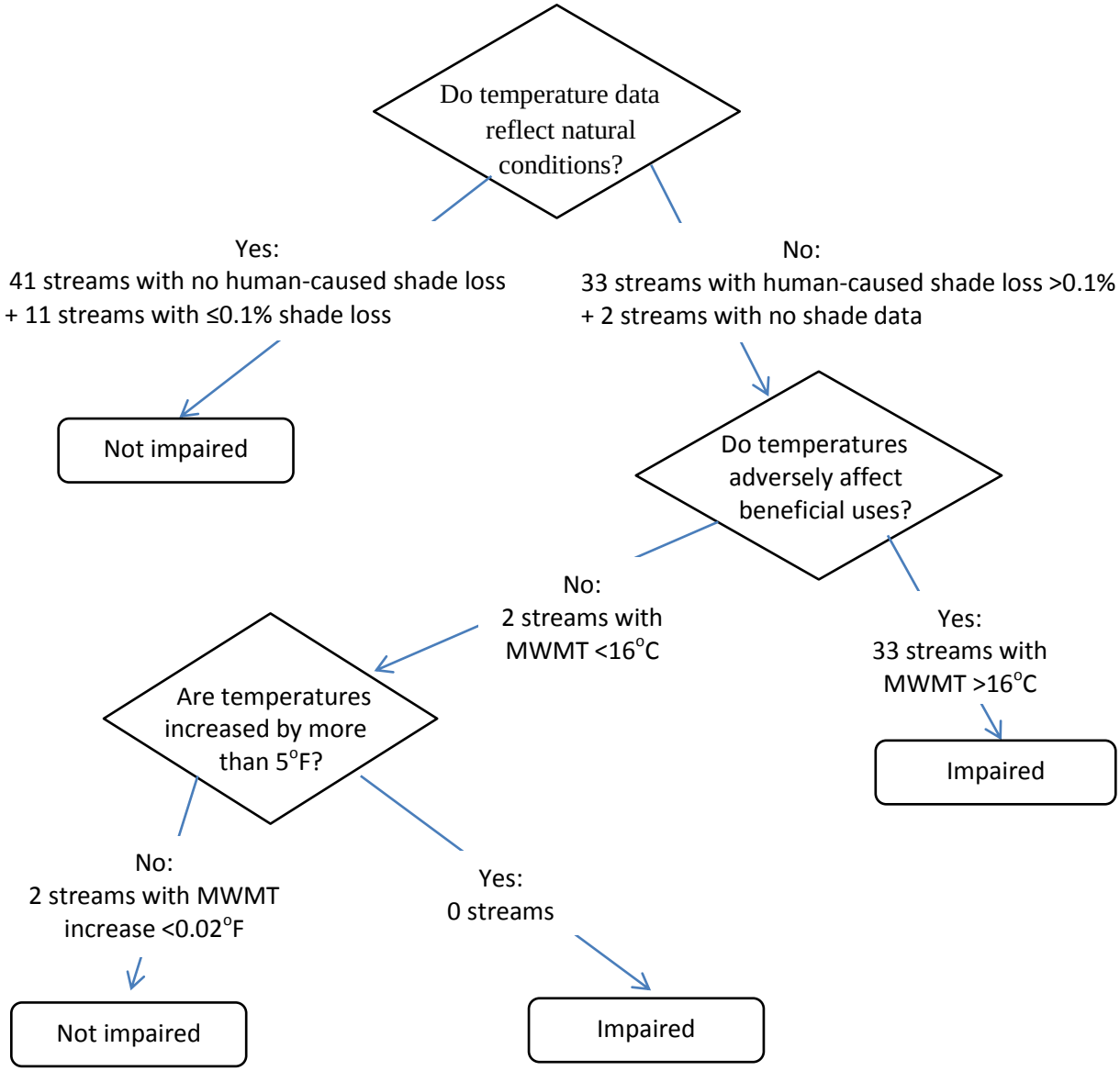

Figure 9. Evaluation of compliance with the Basin Plan objective for temperature using the Regional Water Board's outline for interpreting temperature standards (NCRWQCB 2010).

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APPENDIX

Further evidence that some streams on the Klamath National Forest cannot attain the TMDL temperature thresholds is demonstrated by the plots in Figure 6. Although the relationships in Figure 6 show a large amount of variability around the regression line, a lower bound to the scatter can be identified. The values in Table A1 are the approximate conditions at the lower bound for 16°C and 18°C. No reference or managed stream meets the TMDL thresholds under these conditions (Figure A1).

Figure A1 also shows that reference streams have a similar range of variability and the relationship with temperature has a similar slope as the managed streams. There is no evidence that stream temperatures in managed streams have been altered beyond the natural range of variability of the reference streams.

Table A1. Conditions under which no streams meet the TMDL temperature thresholds, based on Figure 6. Cool year and normal year air temperatures are defined as the 18th and 61st percentiles of mean July air temperatures at Callahan (from Figure 3).

	Cool year (2011) Thresholds		Normal year (2010) Thresholds	
	16°C	18°C	16°C	18°C
Stream shade (watershed ave %)	<73	<59	<80	<67
Drainage area (km^2)	>150	>290	>110	>215
Elevation (m)	<360	-	<450	-
Air temperature, weekly maximum on same date and location as the water MWMT	>34.3	-	>34.3	-

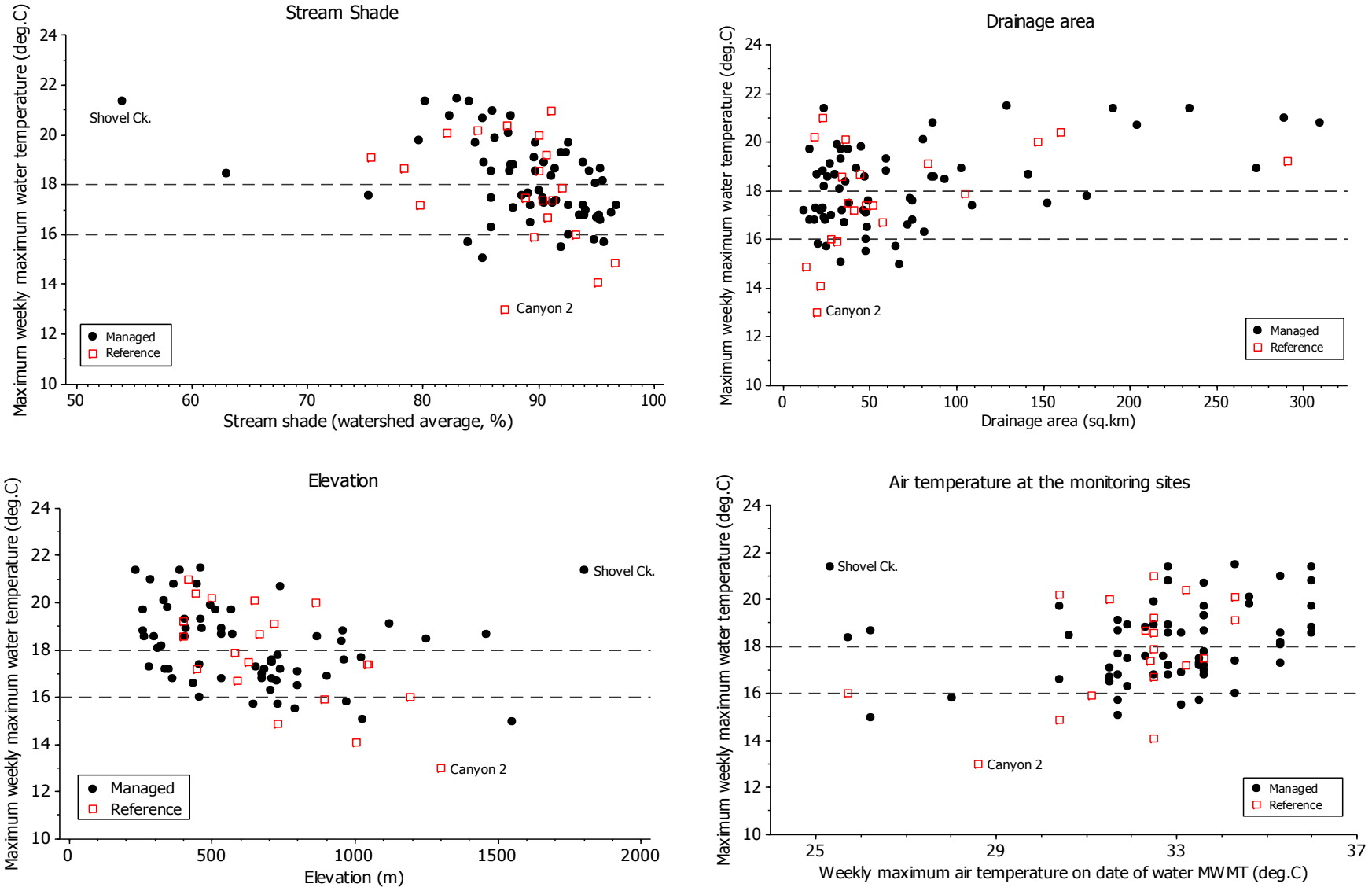
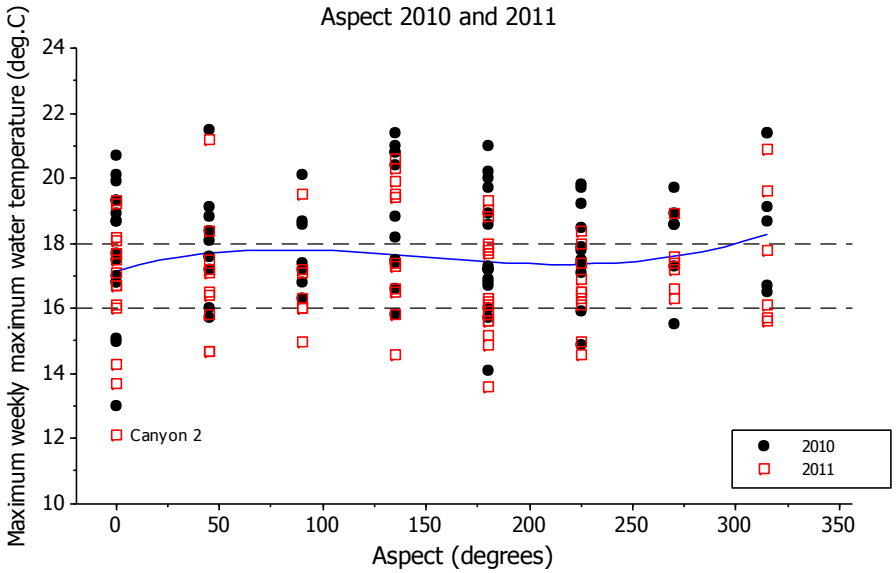


Figure A1. Comparison of stream temperature, stream shade, drainage area, elevation, and air temperature relationships in managed and reference streams, 2010.


Aspect 2010 and 2011
Maximum weekly maximum water temperature (deg.C)
Aspect (degrees)
Canyon 2
2010
2011