Stream temperatures on Jackson Demonstration State Forest, Mendocino County, California during summer of 1995.

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ABSTRACT

Stream temperature is an important factor defining the habitat quality of coldwater fish. Harvest of trees which shade a stream can impact water temperature both on-site and downstream, and may interact cumulatively with other stream warming activities. Knowledge of baseline, potential temperature regimes and existing regimes is needed to assess the effects because stream temperature is both spatially and temporally dynamic.

During the summer of 1995, continuous temperature monitors placed in watercourses in the South Fork Noyo Drainage documented the current temperature regimes and basin heat transport. Maximum water temperature recorded at two stations was 19.4 °C, well below lethal temperatures and slightly below those limiting populations. Stream temperatures were commonly above those published as "preferred" for coho salmon.

Monitors in shaded, near-stream, water-filled buckets approximated local shaded equilibria for comparison with in-stream monitors. The station at the upstream limit of the study was close to an equilibrium temperature that was near that of groundwater inflow. At the downstream limits of the study, the temperature of the bucket was consistently cooler than that of the stream, suggesting some thermal loading. However, the proximity of the ocean and of fog, as well as the naturally large stream course at this location complicates this determination.

INTRODUCTION

Biologists consider salmonids "cold-water" fishes because of their association with waters that are cool, and the fact that increases in water temperature may exclude them from a water body. The literature documents upper temperature limits for many salmonids, both in the laboratory (Brett 1952) and the field (Eaton et al. 1995). Salmonids are important as a recreation base, as an economic resource, and as a component of the aquatic and terrestrial ecosystem (Naiman et al. 1992). Their temperature sensitivity makes them susceptible to actions that warm waters. Although salmonids may be differentially sensitive to water temperature changes at several phases of their life cycle, shade removal will have its maximum influence on water temperature during summer (MacDonald et al. 1991).

The harvest of trees along a stream can remove shade and thus cause the waters too warm (Brown 1970a, 1970b, Brown and Krygier 1970, Moring 1975, Rishel et al. 1982, Beschta et al.

1987, Beschta and Taylor 1988). In response, forest practice regulations that came into effect in the 1970s in California and other western states provided buffer strips of vegetation along watercourses to cast shade. Stream temperature maintenance was a primary goal of the buffer strip regulations. Despite continued modifications and enhancement of the regulations, California regulations still permit limited timber harvest in buffers and a reduction of shade canopy. Thus, stream warming because of timber harvest remains an issue.

While measuring temperature is straightforward, assessing the results is not. The determinants of stream temperature are temporally and spatially dynamic, and the potential for on-site and downstream impacts varies accordingly. For instance, streams naturally tend to warm asymptotically as they flow from their headwaters downward through larger order streams (Theurer et al. 1984, Adams and Sullivan 1989, Sullivan et al. 1990). At the asymptote, regional climate controls stream temperature. At the headwaters, the temperature of the groundwater inflow dictates stream temperature. Factors such as discharge, channel characteristics, shade, and air temperature moderate the rate at which the asymptote is reached.

Fisheries experts (Moyle et al. 1989) have expressed concern about population trends of the coho salmon for sometime. Proposals to list the species under both the California and Federal Endangered Species Acts (Anon. 1993, Hope 1993) underscore the concerns. Coho salmon are sensitive to warm water -- their preferred temperature is 12-15°C (Brett 1952); their optimum temperature, as measured by swimming speed is ≈ 20 °C (Brett et al. 1958); limiting temperature is ≥ 20°C (Reeves et al 1989); and lethal temperature is about 25°C (Brett 1952).

The California Department of Forestry and Fire Protection manages Jackson Demonstration State Forest (JDSF) for timber production under California's Forest Practice Rules. This includes harvesting trees from stream side buffers, an action that can increase water temperature. Between coho salmon and steelhead, the two salmonid species inhabiting streams on JDSF, coho salmon are probably the more temperature sensitive (Bjornn and Reiser 1991). The intent of this report is to 1) document current stream temperatures on parts of JDSF, 2) assess some dynamics governing water temperature, 3) estimate the potential baseline temperature, and 4) relate this information to forest management and coho habitat needs.

STUDY AREA

JDSF, in western Mendocino County, is a publicly owned, timber producing redwood forest (Anon. 1991). The western boundary of the JDSF is about 2.4 km (1.5 miles) from the Pacific Ocean and its eastern boundary is about 32.2 km (20 miles) inland. Its elevation ranges from about 91 m (300 ft.) to 640 m (2100 ft). The South Fork of the Noyo River and several forks of Big River are the primary watersheds draining the Forest.

Smaller watersheds (Hare, Caspar, Jughandle, and Russian Gulch creeks) that are also at least partially managed by JDSF are directly tributary to the ocean.

The climate of JDSF follows an east-west gradient. Precipitation, almost entirely rainfall, totals about 100 cm (40 in.) near the coast to over 150 cm (60 in.) inland. More than 90% of the precipitation falls between November and April (Anon. 1991). In the summer, average air temperature for the western half of the forest ranges from near 10 to 21 °C. Summer fog often keeps the temperatures near 16°C within 10 miles of the coast. Summer high temperature near the eastern boundary of the forest may exceed 38°C.

This study focuses primarily on South Fork Noyo River (South Fork). It is centrally located between about five and 11 miles from the coast (Fig. 1). Based on USGS 7.5′ quads, the South Fork Noyo River is a 5th order watercourse that drains a 17,333 acre watershed. Stream temperature data is also presented from Bunker Gulch, a single site in the adjacent Hare Creek drainage.

METHODS & MATERIALS

Continuous water temperature monitors (Hobotemp and Stowaway ®) were activated in the office to record water temperature once every 96 minutes, or 15 readings per day. In early summer, I deployed monitors within JDSF along the South Fork from the upstream boundary near McQuire,s Pond to the downstream boundary near Kass Creek (Fig. 1, Table 1). I also placed monitors in several South Fork tributaries (Fig. 1, Table 1). A single temperature monitor recorded temperature in Hare Creek, an adjacent drainage.

Due to their position, the temperature monitors measured the "average" water temperature available to fish at that locale. Each monitor was in the thalweg of a riffle where shade canopy in the immediate upstream reach was homogeneous and continuous. A large rock on top of each monitor anchored it and shielded if from view and sun specks. I avoided placements in deep pools that might stratify and thus be cooler than average, or in shallow stream margins or backwaters that might be stagnant and thus warmer than average.

To attempt to isolate the effects of local climate and shade from those of groundwater influx and location along the river continuum, additional temperature monitors were placed in plastic 5-gal buckets in the streamside zone adjacent to the in-stream monitors at both the upstream and downstream boundary. I affixed the monitors to the bottom of the buckets, filled the buckets with water, placed them in a well-shaded location within 15 m of the watercourse. The lids of the buckets remained ajar to limit -- but not stop -- water surface phenomena such as evaporation and conduction of heat between the air and the water.

During autumn, monitors were retrieved to the office where their data were downloaded with software provided by the manufacturer. After importing the data into a spreadsheet (Lotus

123), I graphically displayed for indications of unrepresentative data. Examples of unrepresentative data include the time between launching at the computer and placement in the stream, and conversely that between retrieval and downloading. Dropping hydrographs partially exposed some of the monitors. I compared these graphs against those of monitors that maintained proper in-stream position. If either the daily fluctuation or the absolute value of data of the emerged monitors differed from the effectively-placed monitors, I considered the divergent data erroneous and eliminated them.

Because the monitors differed in dates of deployment and retrieval, and because of data gaps, comparing descriptive statistics between monitors or locations might be inappropriate. To make the data as comparable as possible, and to highlight the warmest period, I calculated a 4-week running average of temperatures over the entire time range for the stations with the longest records. The warmest 4-week period was centered on July 26 for one station and July 27 for the remainder. I then developed the descriptive statistics and cumulative temperature curves for all units based on a four-week period centered on mid-day t July 27.

To ease an assessment of the downstream temperature dynamics, I plotted the temperature data of the South Fork and Parlin Fork in two different ways. First, I graphed cumulative temperature curves for each station onto a single graph to enable comparisons among stations. Then, to add a geographic context to the data, I plotted the maximum and average temperature against a GIS-generated stream distance upstream from the downstream boundary.

Descriptive and regression statistics were calculated within the Lotus 123, Ver. 2.4 ® software of Microsoft.

RESULTS

Monitor placement was occasionally problematic. As flow receded across the summer season, several casings surfaced and were partially exposed to air. Temperature traces of these differed from those which maintained appropriate position primarily with uncharacteristic change in variability. Thus, some temperature traces include gaps.

The temporal relationships of peaks, valleys, and plateaus of the season-long temperature traces are consistent among the different units (Figs. 2a-f, 3a-c, 4a-c, 5). The stations differ in the absolute value of the water temperature and the amplitude of the daily cycle. For locations with season-long records, two or three warm periods are apparent -- a week-long peak near the end of June, a second in mid-July, and the strongest on July 28 (Figs 2a, 2d, 2e, 3c, 4a, 4c). The relative strength of these differed with the first peak being stronger than the second for the Upstream Boundary (Fig 2a), but being the weakest peak for the other stations (Fig. 2d,e,f).

Two locations on the South Fork -- above Road 320 (Fig. 2b) and the downstream boundary (Fig. 2f), shared the warmest water temperature of 19.4 °C. The Road 320 monitor is at the downstream end of a clearcut completed during 1986 in which the streamside buffer has suffered subsequent, moderate blowdown. As a result, it measures water temperature exposed to direct sunlight during the day. Its great daily amplitude also reflects its low canopy cover and warming during the day only to cool through cool-water inflow and re-radiation at night. The fact that the Road 320 monitor has an incomplete record complicates comparisons of its minimum and mean temperatures with those of others.

Despite the fact that the second station from the upstream boundary (Road 320) recorded the highest temperature, water along the South Fork tended to warm and vary more as it flowed downstream (Figs. 6a, 7a and 7b, Tables 2 and 3). When considered in a downstream direction, the cumulative temperature curves of the stations (Fig. 6a) tended to shift to the right. In addition, the curves tended to flatten in the downstream direction, portraying the greater amplitude of the die1 cycle. The two stations that are contrary to the warming and increasing variability (above Road 320 and upstream of Parlin Creek) have incomplete records, and thus their traces are not directly comparable. In addition, a plot of the mean temperature against distance (Fig. 7a) is more in line with the downstream warming expected than is a plot of the maximum temperature (Fig. 7b). This suggests that the canopy's openness exacerbated heating primarily during the peak temperature periods, and only slightly affected temperature during other periods.

For all stations on the South Fork, water temperatures during the warmest continuous four-week period of 1995 were below 18°C more than ≈85% of the time (Fig. 6a). Water temperatures were less than 15 °C only between 5 - 53% of the time (Fig. 6a).

Among the tributaries, the temperature regime of Parlin Creek is more similar to that of the South Fork than it is to those of the other streams (Figs. 6a , 6b). Water temperatures become warmer and more variable as Parlin Fork flows downstream. Peak temperature in Parlin Creek was 18.14 °C (Table 1) at the lower station. Of the warmest 4 weeks, water temperatures at the Parlin Creek stations were less than 18 °C more than 98% of the time and less than 15 °C between 33 and 75% of the time (Fig 6b). Most temperatures of the other three South Fork tributaries were between 12 and 15 °C (Fig. 6b, Table 2).

Absence of flow data, variable and excessive distances between stations, and incomplete temperature records complicates assessment of the influence of tributary inflow on temperatures in the South Fork. The downstream-most Parlin Fork station (Fig. 3c, Table 2) had slightly warmer maximum temperatures than the Noyo stations immediately up- and downstream of the confluence (Fig. 2c and 2d, respectively; Table 2). However, its mean temperatures were intermediate to the South Fork stations.

Parlin Fork appears to have had little influence downstream of the confluence. But the downstream-most Parlin Fork monitor measures water temperature over a km upstream from the confluence. The fact that temperature in the South Fork increases as the water flows past the (Tables 2, Figs. 7a and 7b) confluence suggests that Parlin Fork is warming the South Fork.

After the Road 320 station, inflow from 23 Gulch cooled the South Fork. Temperatures at the nearest downstream monitor (Upstream of Parlin) showed substantial declines after warming up at the Road 320 station (Table 2, Figs. 7a and 7b). The discharge of 23 Gulch was relatively minor to that of the South Fork, so its cooling effects should have accounted for only a small portion of the apparent cooling.

Like 23 Gulch, the temperatures of Bear Gulch and Peterson Gulch were substantially cooler than the downstream of Parlin station, the nearest upstream South Fork stations (Table 2, Figs. 7a and 7b). Assessing the magnitude of their cooling influence is difficult. Also like 23 Gulch, their discharge is also small compared to that of the South Fork. The next monitor downstream that might detect the cooling influence of Bear Gulch or Peterson Gulch is the Egg-taking Station. It is distant and the large, un-monitored North Fork of the South Fork is tributary between them.

At the upstream boundary, water temperature in the bucket was more variable than was the water in the stream. The temperature difference between the bucket and stream fluctuated around 0 °C (Fig. 8a).

At the downstream boundary, water temperatures in the bucket were consistently cooler than those in the stream, despite similar magnitudes and direction of fluctuations (Fig. 8b). The water temperature of the bucket tended to be about 3°C cooler than that of the South Fork. The difference exceeded 4 °C on occasion. Later during the season of monitoring, the temperature differences between the bucket and the stream declined (Fig. 8b).

Instream water temperature was always warmer at the downstream boundary than at the upstream boundary (Fig. 9a) by an average of 1.29 °C. Oppositely, water temperature in the bucket at the downstream boundary was cooler by an average of 0.7 ° C and less variable than that in the upstream bucket (Fig. 9b). During the warmest period, the buckets differed by an average of 1.29 °C, with a maximum difference of about 3.8 °C.

DISCUSSION

Exposure to air of some monitors' casings could elevate temperatures and increase variability. I reduced this concern by eliminating data that was obviously erroneous. The distinguishing feature of the data that lead to the decision to delete it was a sudden jump in daily amplitude. This was especially apparent when the temperature traces of fully submerged monitors did not display corresponding changes. The high specific heat of water makes it likely that substantial exposure would be necessary to significantly affect recorded temperature. However, the possibility remains that I did not delete all effect data from the units that became exposed.

Major peaks in temperature traces coincided between locations as expected in a study within a single, and small drainage. The relative height of major peaks differed. The likely causes for this are a combination of position within the drainage and the dynamics of fog influence, stream orientation, seasonal changes in solar angle as amplified by topography and stream-side shade, and the groundwater influx variations.

The three small tributaries, as well as the upstream stations on Parlin Fork are cooler and thermally more stable than the upstream station on the South Fork: The former tend to be in well-vegetated basins, in drainages with northerly aspects, and / or generally low-order watercourses. The latter is downstream of a large forest opening and artificial pond where the water may acquire some heat.

At their confluence, Parlin Creek and the South Fork are similar in drainage area and temperature dynamics. As such, the main influence of Parlin Fork upon the South Fork is largely a significant contribution to the flow. Comparing the monitor stations on Parlin with those bracketing the South Fork, it modified the temperature of the South Fork little, if at all. However, the jump in temperature between the bracketing stations suggests that there is substantial heating in Parlin downstream of the Lower Parlin station. The other tributaries were substantially cooler than was the South Fork at their inflow. Because of their limited discharge, their cooling influence upon the South Fork were probably localized. Their contribution to cooling would become overwhelmed by the greater flow of the South Fork as the accumulated water flowed moved downstream.

The trend of increased temperature in the downstream direction exhibited by the South Fork and Parlin Creek demonstrates the regular and predictable change of the factors that control water temperature (Theurer et al. 1984, Beschta et al. 1987, Adams and Sullivan 1989). Near headwater areas, the stream's water temperature reflects that of the ground water. It is the minimum possible summer temperature (Caldwell et al. 1991). After the cold groundwater's emergence, it begins to equalize with air temperature. The rate at which it equalizes is dependent on the magnitudes of the difference with the local air temperature and other heating influences, primarily shade canopy. During this adjustment time, because the water is flowing, achieving equilibrium requires some distance of stream. Stream temperatures at balance with local climate are at their equilibrium temperature. Local air temperature is a key predictor of equilibrium temperature. The factors that control the equilibrium temperature at the local scale are themselves subject to variation along geographic gradients. Thus, superimposed on local equilibrium characteristics is a basin scale equilibrium pattern (Caldwell et al. 1991).

Low temperature and little daily variability characterize groundwater-dominated headwater streams. Because they are substantially cooler than air temperature, they warm through exposure to the local climate and are very sensitive to solar heating. Along the watercourse, the mass of flowing water changes from one in which groundwater inflow dominates, through one in which the temperature results from a mixture of climatically-exposed water from upstream and local groundwater accretion, to finally one in which inflow from upstream dominates the water mass. At the downstream end of this continuum, the local climate regulates the water temperature regime. Little that is done including removal of stream side vegetation will alter its average temperature. Indeed, the stream would tend to return to the climatically regulated temperature below a heated water inflow. Thus, the potential for shade-canopy reductions to directly affect mean water temperature varies from greatly in more headwater areas (except at high elevations [Sullivan et al. 1990]) to very little in downstream areas. As a result, assessing anthropogenic changes to natural water temperature is difficult, and depends on the relative location in the drainage of question.

Monitors in a water-filled bucket stationed adjacent to a stream monitoring station should assist in differentiating different factors affecting water temperature. The water in a well-shaded bucket exposed to the local climate should approximate the local climatic conditions. This data, in conjunction with that of the instream monitors, should help isolate the influences of both groundwater cooling and upstream solar heating. The bucket's water temperature then should provide an approximation of stream water temperatures that are achievable through upstream and on-site shade management. That is, as long as the upstream shade canopy is comparable to that at the bucket, the temperatures should be similar. However, stream temperatures are unlikely to be identical to the buckets because the latter are less subjected to other factors that control heat exchange such as wind and evaporation. In addition, as stream size enlarges the ability of stream-side vegetation and topography to shade the stream diminishes naturally (Beschta et al. 1983, Theurer et al. 1984, Sullivan and Adams 1990). Temperatures in the stream and the bucket will naturally diverge. Still, the bucket's water temperature might provide a "best-case" picture of achievable low water temperature for the stream. The buckets in the present study are only approximations because their lids were not completely open, thus constraining heat exchange phenomena. In addition, the best size, construction, and-dimension of a stream-side storage chamber to approximate the local, climatically-controlled stream temperature is not known.

The similarity of the bucket's and the stream's water temperatures at the upstream boundary suggests that the stream is nearly at equilibrium. Paradoxically, the upstream bucket's greater temperature variability than that of the in-stream water suggests that groundwater inflow is important in determining the stream water temperature. Another explanation is that the temperatures of well-shaded water at equilibrium and groundwater inflow are similar. The stream temperature here is intermediate between the more headwater stations (upper Parlin Fork and the small tributaries). This suggest that the stream at the upper boundary is transitioning from cold groundwater to the local equilibrium temperature.

At the downstream boundary of JDSF, the bucket's water was cooler and less variable than was the stream's water. This difference reflects the station's proximity to the temperature moderating influence of the ocean. The greater variability and warmer temperature of the stream compared with the bucket suggests some combination factors, such as natural climatic and sun exposure due to stream size, as well as possibly anthropogenic influences are delivering warmed water to the location. The cool, stable temperatures within the bucket indicate that if the watercourse upstream had higher levels of shade than at present, then temperatures might be reduced. An alternate explanation is that the water delivered to the site from upstream is warming as expected but the station is within a zone strongly influenced by fog and ocean. In this scenario, stream water temperatures would be would be in the process of dropping to an equilibrium which has been reduced by fog and ocean-cooled air.

The fate of heat added to a stream varies along the watercourse. Where a stream is substantially below equilibrium, solar radiation dominates the factors that control water temperature (Adams and Sullivan 1989). Here, added heat does not readily dissipate from the stream (Brown 1970b, Beschta et al. 1987). In sub-equilibrium reaches, water temperatures downstream of a forest opening that are lower than those at the opening may not be interpretable as a downstream discharge of the acquired heat. As the heated water flows downstream, the stream channel disperses and dilutes it with water that passed the opening during non-heating periods. Groundwater influx downstream may further act to mask the added heat.

At the other extreme, where a stream is at the equilibrium temperature, heat added dissipates primarily through evaporation and re-radiation to the sky (Sullivan et al. 1990). Added heat is likely to elevate the maximum temperature and magnitude of variations with little modification of mean and perhaps even less change in minim temperatures. Transport downstream of the added heat in a reach at the equilibrium temperature would be minimal. Upon flowing into the shaded downstream channel it would begin dropping back to its cooler equilibrium temperature. Direct effects of stream heating might be most clearly depicted by changes in peak temperature. Both direct and cumulative impacts might best demonstrated by using the minimum or mean temperature.

As streams become wider, the inherent ability of stream-side vegetation to regulate the stream's temperature declines. When measured along the thalweg, large streams may be insensitive to changes in shade because climatic conditions and inflow from upstream so strongly dictate their temperature. However, stream side shade is still important. Shaded areas along the stream margin may have reduced heat maxima and thus reduced amplitude under shaded conditions relative to open conditions, providing a greater diversity of temperatures for organisms to choose among.

Using coho salmon as the assessment endpoint for this temperature study, the South Fork Noyo within JDSF did not exhibit conditions that are a serious cause for concern during the summer of 1995. Except in the very small tributaries of the South Fork, water temperature was often greater than the coho salmon's "preferred" temperature of 13-15 °C (Brett 1952). Brett et al. (1958) found the coho salmon's "optimal" temperature, as measured by cruising speed to be 20 °C. While maximum temperature exceeded 19 °C at two stations, they did so rarely. These stations never exceeded 20 °C, the temperature Reeves et al. (1989) suggest be considered as limiting. Bell (1973, in Reiser and Bjornn 1979) stated that above 20.3 °C, cold water fish cease growth because of increased metabolic activity. Bjornn and Reiser (1991) state that temperatures that exceed 23-25 °C places most salmonids in life threatening conditions. Sublethal temperatures may effect behavior and community dynamics, but this factors are poorly understood (Bjornn and Reiser 1991, MacDonald et al. 1991). Thus, while maximum water temperatures measured were generally warmer than coho salmon prefer, they were probably not limiting. Because monitors collected "average" water temperature available, both cooler and warmer water temperatures are spatially available. Coho salmon may select among a range of temperatures. In addition, daily and seasonal temperature fluctuations assured that suitable refuge temperatures were available and stressful conditions, if any, were short-lived.

Comparing the water temperature between in-stream and bucket monitors at the downstream boundary suggests some temperature loading along the South Fork. At the downstream limits of JDSF, the bucket monitor evidenced water temperature moderation, probably due to proximity to the ocean and fog. If fog and ocean influence are causing equilibrium temperatures to decline as the stream flows towards the coast, ‘increases in temperature observed along the South Fork during 1995 would likely subside in a short distance. Therefore, warming of the South Fork as it flows across JDSF would be unlikely to contribute to a significant water temperature impacts downstream. If the fog-cooling premise is true, then the heated water would continue to cool as it reaches equilibrium in an increasingly marine and fog-dominated climate.

Since the collection of this data, JDSF has several timber harvesting plans recently approved but not yet completed. Near-complete shade retention is planed in some. JDSF will prepare other timber harvest plans in the near future in the South Fork watershed; their level of shade retention can not be determined yet. Due to the probable thermal loading observed in this study -- along with the several recent, current, and future timber harvesting plans in the drainage -- maintaining a greater-than-standard (Forest Practice Rules) shade canopy along the streams is in order.

This temperature assessment should be repeated to both assess the annual variability in the temperature regime of coho salmon, to evaluate the protection measures of specific timber harvest plans, and to monitor the conditions and changes in the temperature-variable of coho salmon habitat.

MANAGEMENT IMPLICATIONS & RECOMMENDATIONS

Stream temperatures in the South Fork were only marginally of concern. Although monitors did not detect temperatures warm enough to be considered stressful, two monitors did detect instantaneous temperatures approaching that criteria. Water temperatures in the "preferred" range were scarce except in the small, fist and second order tributaries. Data from stream side, water-filled buckets evidenced possible thermal loading above background.

1. In future timber harvesting plans, shade tree removal in stream-side areas of the South Fork drainage should be minimized to maintain the summer temperature regime in a suitable condition.

This report covers only one summer period, and prior years data are sparse and marginally comparable. Timber harvest plans continue in the drainage, and JDSF is preparing other plans. CDF should continue to monitor water temperature to assess annual variability, as well as direct and cumulative project impacts. Future monitoring could document the recovery of shade as the stands regenerate.

2. Repeat the monitoring stations used in this study and expand into the North Fork of the South Fork, as well as adding additional buckets monitors.

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Table 1. Location, identification, and inter-station distance of continuous water temperature monitoring stations on the South Fork of the Noyo River, Jackson Demonstration State Forest, Mendocino County, during the summer of 1995.

Map Code[a]	Distance (m)[b]	Location, comments, and stations name (underlined) as used in the text.
1	0	Downstream boundary of JDSF, about 30 m upstream of large debris accumulation.
2	5230	Downstream of the egg-taking station, about 20 yards upstream of unnamed tributary from south.
3[c]	520	Confluence of North Fork of South Fork with the SF.
4[d]	240	Peterson Gulch, about 20 m upstream of confluence with the SF.
5[d]	960	Bear Gulch, about 15 m upstream of confluence with the SF.
6	2230	Downstream of Parlin Creek confluence, riffle upstream of water intake for Parlin Camp.
7[c]	90	Parlin Creek confluence with SF.
8.0[e]	30	South Fork between Parlin Fork and 23 Gulch.
8.1[d,e]	40	23 Gulch Creek, about 25 m upstream of confluence with the SF.
9	330	Upstream of Road 320 crossing about 30 m.
10	2380	20 yards downstream of the upstream boundary of JDSF.
7[c]		
11	1140	Lower Parlin Creek.
12	2050	Mid-Parlin Creek, upstream of Camp 7 Timber Harvesting Plan.
13	1280	Upper Parlin Creek, upstream of Frolic Timber Harvesting Plan.

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[a] Location codes as used in Fig. 1.

[b] Distance is as estimated to the nearest 10 m from the immediately downstream station. Data source is a GIS hydrology layer.

[c] These locations did not have a monitor and thus are not mapped in Fig. 1, but were included because they are major hydrological features.

[d] These stations were on the tributaries to the SF Noyo, but the tabular distances are to the confluence of the streams confluence.

[e] -Stations 8.0 and 8.1 are mapped in Fig. 1 as Station 8 due to resolution limitations.

Table 2. Descriptive statistics for water temperatures for a 4-week period centered on noon, July 27, 1995 in the South Fork Noyo River, Jackson Demonstration State Forest.

	Maximum	Minimum	Mean	Std	n
SOUTH FORE NOYO, MAIN STEM					
Upstream Boundary	17.02	13.56	15.10	0.63	412
Upstream of Road 320	19.43	14.02	16.12	1.08	180
Between 23 Gulch & Parlin	17.18	13.71	15.33	0.69	181
Downstream of Parlin	17.66	13.87	15.77	0.81	412
Downstream of Egg-taking Station	18.79	14.33	16.26	0.90	412
Downstream Boundary	19.43	14.18	16.67	1.09	412
SOUTH FORE NOYO, TRIBUTARIES					
PARLIN FORE					
Upper	16.54	13.09	14.63	0.65	270
Middle	17.66	13.25	15.30	0.94	412
Lower	18.14	13.56	15.60	0.97	412
SMALLER TRIBUTARIES					
23 Gulch	14.96	12.63	13.76	0.40	412
Peterson Gulch	15.12	12.63	13.86	0.45	412
Bear Creek	15.12	12.32	13.82	0.66	104

Table 3. Linear regression (y = ax + b) statistics of water temperature at downstream stations regressed against those at the upstream boundary for stations with complete records. Period of recording differed between two watercourses.

	a	b	SE of x	SE of y	r^2
SOUTH FORE NOYO, MAIN STEM STATIONS AGAINST THE UPSTREAM BOUNDARY 14 July - 10 August; df =410					
Downstream of Parlin	1.166	-1.826	0.03	0.35	0.82
Downstream of Egg-taking Station	1.243	-2.500	0.03	0.44	0.76
Downstream Boundary	1.531	-6.445	0.04	0.53	0.77
PARLIN FORE STATIONS AGAINST UPPER PARLIN 14 -31 July; df = 268					
Middle	1.219	-2.491	0.04	0.44	0.77
Lower	1.362	-4.336	0.02	0.26	0.92

Fig. 1. Summer 1995 continuous monitoring station in the South Fork Noyo River drainage, Jackson Demonstration State Forest, coastal Mendocino County, California.

Fig. 2. Time-temperature traces of stations on the South Fork of the Noyo River, summer 1995.
a Trace of Upstream Boundary
b Trace of Road 320
c Trace of between 23 gulch and parlin
d Trace of Downstream of Parlin
e Trace of Egg-taking station
f Trace of downstream boundary

Fig. 3. Time-temperature traces of stations on Parlin Fork, a major tributary to the South Fork of the Noyo River, summer 1995.
a Trace of Upper Parlin
b Trace of Mid-Parlin
c Trace of Lower Parlin

Fig. 4. Time-temperature traces of stations on small tributaries to the South Fork of the Noyo River, summer 1995.
a 23 Gulch
b Bear Creek
c Peterson Gulch

Fig. 5. Time-temperature trace for Hare Creek, summer 1995.

Fig. 6. Cumulative temperature curves for the four-week period centered on July 27, 1995. Stations identified with "**" included incomplete records. (a) Stations on the South Fork Noyo . (b) Stations on tributaries to the South Fork of the Noyo River.

Fig. 7. Longitudinal temperature profile of the monitoring stations on the South Fork Noyo River in Jackson Demonstration State Forest during the four week period centered on July 27, 1995. a) Mean temperature. b) Maximum temperature.

Fig. 8. Comparison of water temperature traces between in-stream water and a streamside 5-gallon bucket near a)the upstream and b) downstream boundaries of Jackson Demonstration State Forest on the South Fork Noyo River, 195.

Fig. 9. Comparison of water temperature traces between a) in-stream water monitors and b) bucket monitors near the upstream and downstream boundaries of Jackson Demonstration State Forest on the South Fork Noyo River, 1995.

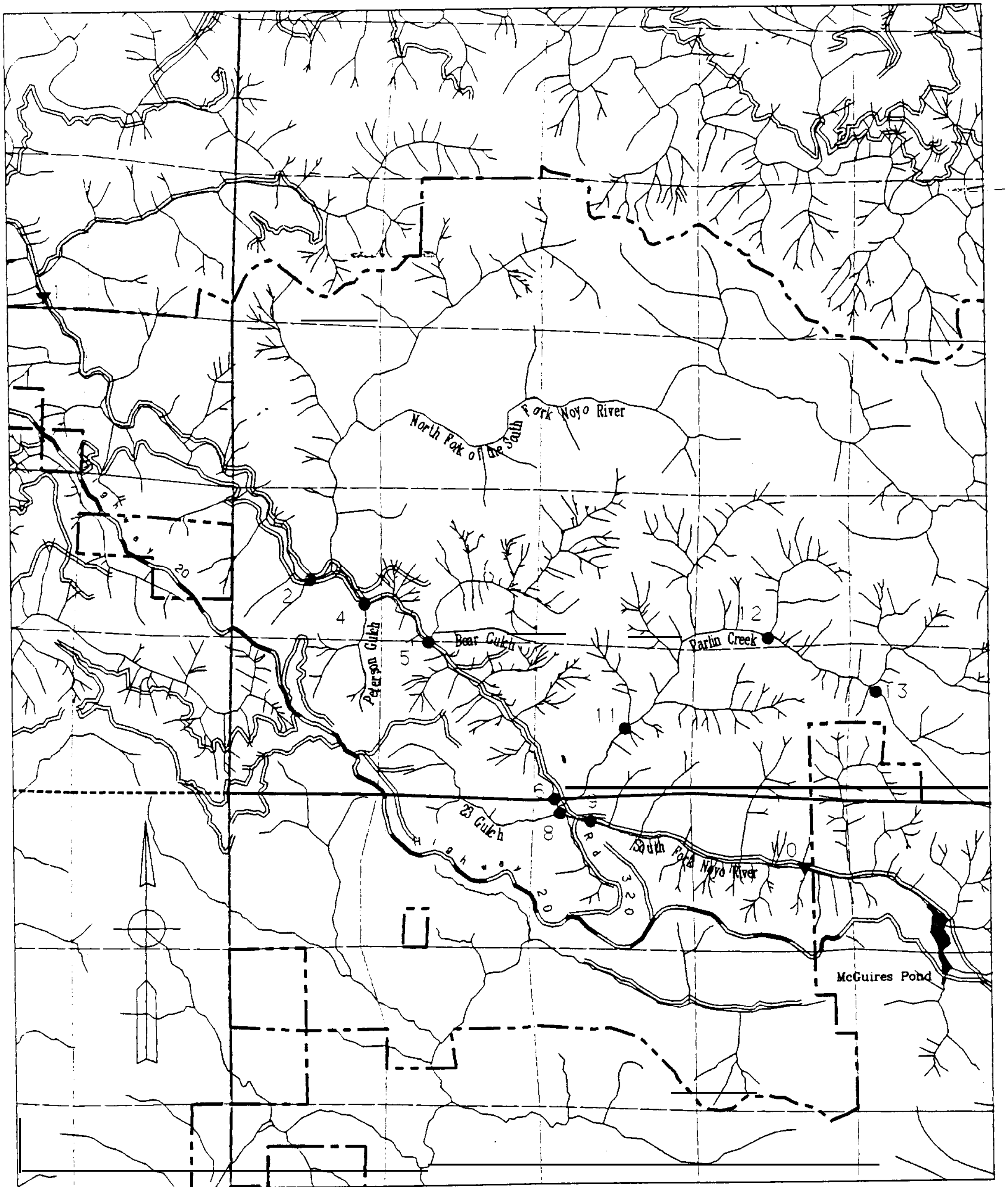
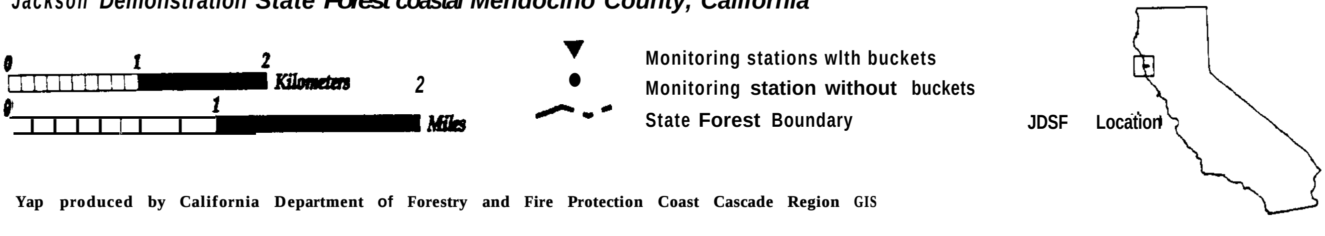


Fig. 1. *Summer 1996 continuous water tempemture monitoring station in the South Fork Noyo River drainage, Jackson Demonstration State Forest coastal Mendocino County, California*



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