Final Report

MORTALITY OF ANGLER CAUGHT AND RELEASED SUMMER STEELHEAD

by

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ABSTRACT

In California, summer steelhead (*Oncorhynchus mykiss*) inhabit waters reaching temperatures in excess of 23° C. Previous results suggests these high water temperatures may cause significant post-angling hooking mortality (Klein 1965; Dotson 1982; Titus and Vanicek 1988; Wilkie et al. 1996). We tested the null hypothesis that water temperature had no affect on post-angling hooking mortality in summer steelhead angled from the Mad and North Fork Trinity rivers, California. We also tested the effect of hook type and placement on mortality of adult summer steelhead.

Experimental angling was conducted by two-person teams using # three Blue Fox spinners with standard spinning and bait-casting gear. Steelhead were hooked, played, landed, marked (using a paper punch), and released back into the pool from which they were caught. Block nets were installed and pools were observed for mortalities for at least 36 hours. Mortalities were recovered and recorded.

A total of 126 lure caught summer steelhead were angled in water temperatures ranging from 8-25° C from the Mad and North Fork Trinity rivers from July-October 1995 and 1996. Of these, 12 mortalities were recovered with 10 mortalities occurring at water temperatures of 21° C or greater. Logistic regression analysis of hooking mortality versus water temperature was highly significant ($p = 0.002$) and stress time decreased significantly with increasing water temperature ($p < 0.005$). No significant relationship was found between hook type and mortality ($p > 0.05$)

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INTRODUCTION

Steelhead (*Oncorhynchus mykiss*) are generally classified into two separate races, summer and winter steelhead (Withler 1966; Smith 1960, 1969; Everest 1973). Summer steelhead enter streams in an immature state between May 1 and October 30. They hold for several months in deep pools, reach sexual maturity, and generally spawn in January or February. In California, summer steelhead numbers have declined steadily in the past 30 - 40 years (Moyle et al. 1993). Construction of dams, poor timber harvest practices, livestock grazing, over-fishing and road construction have all contributed to freshwater habitat loss and population declines. Summer steelhead runs in a large number of streams are less than 100 fish (Roelofs 1983). These small runs are increasingly vulnerable to impacts from poaching, predation, extreme environmental fluctuation, and angling.

To ameliorate declining runs of summer steelhead, catch and release fishing has been instituted on many California streams. Few studies, however, assess hooking mortality of adult steelhead. Hooten (1987) reported a 3.4 percent mortality rate for 3,715 adult steelhead caught using conventional tackle (bait, barbed hooks). An overall mortality rate of 5.1 percent was found for a two year steelhead study in the Keogh River, B.C. (Hooten 1987). No data have been collected on hooking mortality of adult summer steelhead.

In California, summer steelhead inhabit waters reaching temperatures in excess of 23° C. Titus and Vanicek (1988) found that mortality of lure-caught Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) rose to nearly 50 percent when water temperatures approached 21° C. Delayed post-angling mortality of 40 percent was observed in Atlantic salmon (*Salmo salar)* angled at 22° C (Wilke et al. 1996) . Hooking mortality has also been found to increase for lure-caught rainbow trout as water temperature increases (Klein 1965; Dotson 1982). These results suggested that steelhead angled during the summer months, when water temperatures often exceed 23° C, may be increasingly vulnerable to post-angling hooking mortality. To determine this, I tested the null hypothesis that water temperature had no effect on post-angling hooking mortality in summer steelhead angled from the North Fork Trinity and Mad River, California. In addition, the influence of hook type and hook placement in relation to hooking mortality was investigated.

STUDY SITE

The study was conducted on two streams during the summer and fall of 1995 and 1996. The Mad River, a fifth order coastal stream, located in Humboldt County, California was the predominant study stream (Figures 1, 2). The lower Mad (<20 rkm) is characterized by a braided channel and a wide unvegetated gravel floodplain. The study site, however, is complex and characterized predominantly by large boulders exceeding 1 m diameter (personal observation). Maximum water temperatures were recorded the last week of July 1996 at 25° C; Sept 1, 1996 maximum water temperatures decreased to 20 ° C. Angling teams fished the Mad River from the confluence of Humbug Creek to a point 1.6 km downstream (65 rkm) from September 22 - October 2, 1995. During the second field season we fished from the natural barrier at Deer Creek Ranch (70 rkm) to a point approximately 1.6 km downstream from July 15-September 14, 1996.

The North Fork Trinity (hereafter, NFT), the second study stream, is a large tributary of the Trinity River located in Trinity County, California (Figures 3, 4). The study site extended from Hobo Gulch Campground (24 km from the mouth) upstream approximately 8 km to Rattlesnake Creek (Figure 4). Average maximum depth of the pools used for angling was 2.3 m, average width 12.6 m, and pools had low complexity with little or no cover provided by instream wood or boulders. Angling teams fished the NFT from August 11 to October 27, 1995.

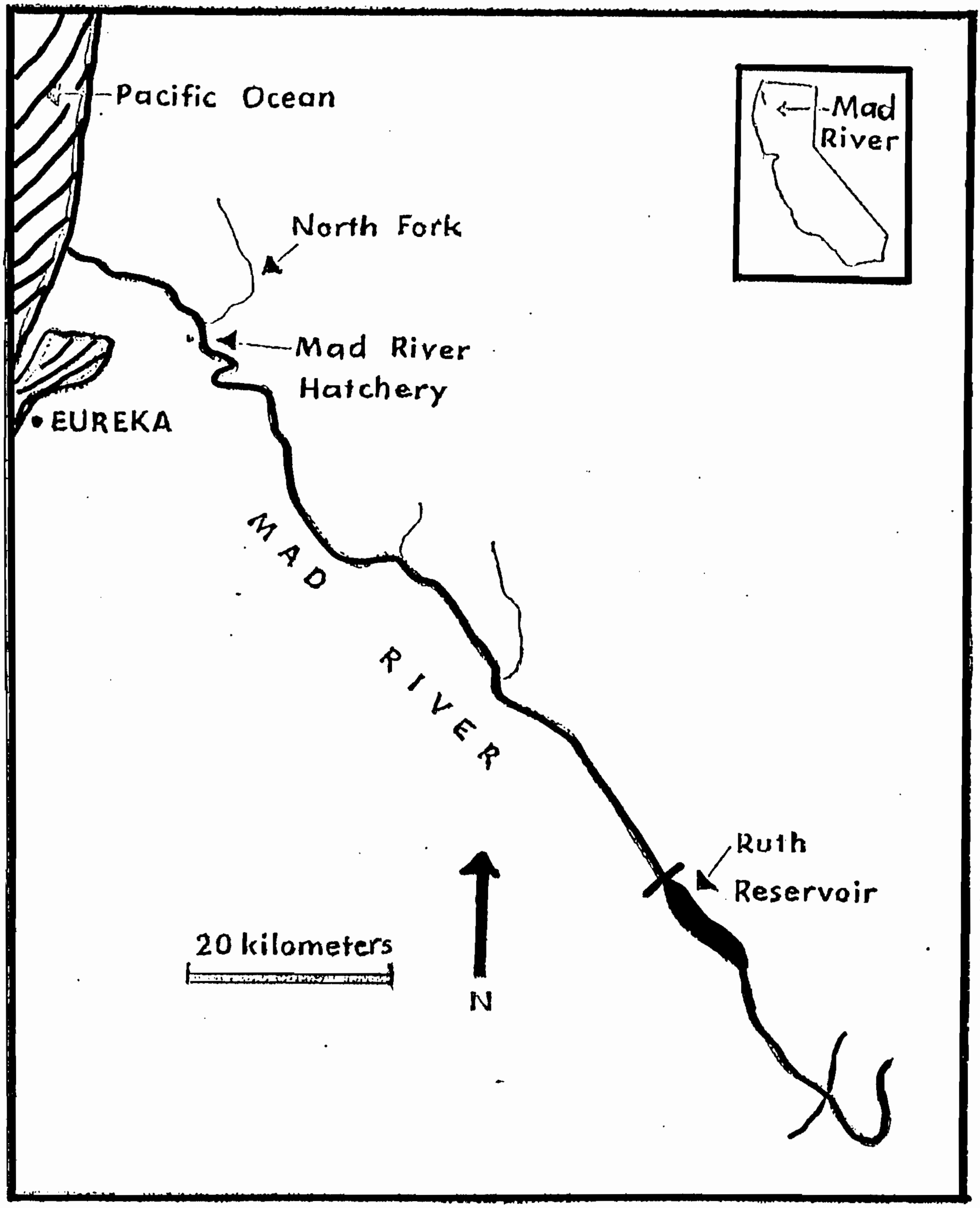


Figure 1. Mad River, California (from Knutson 1975).

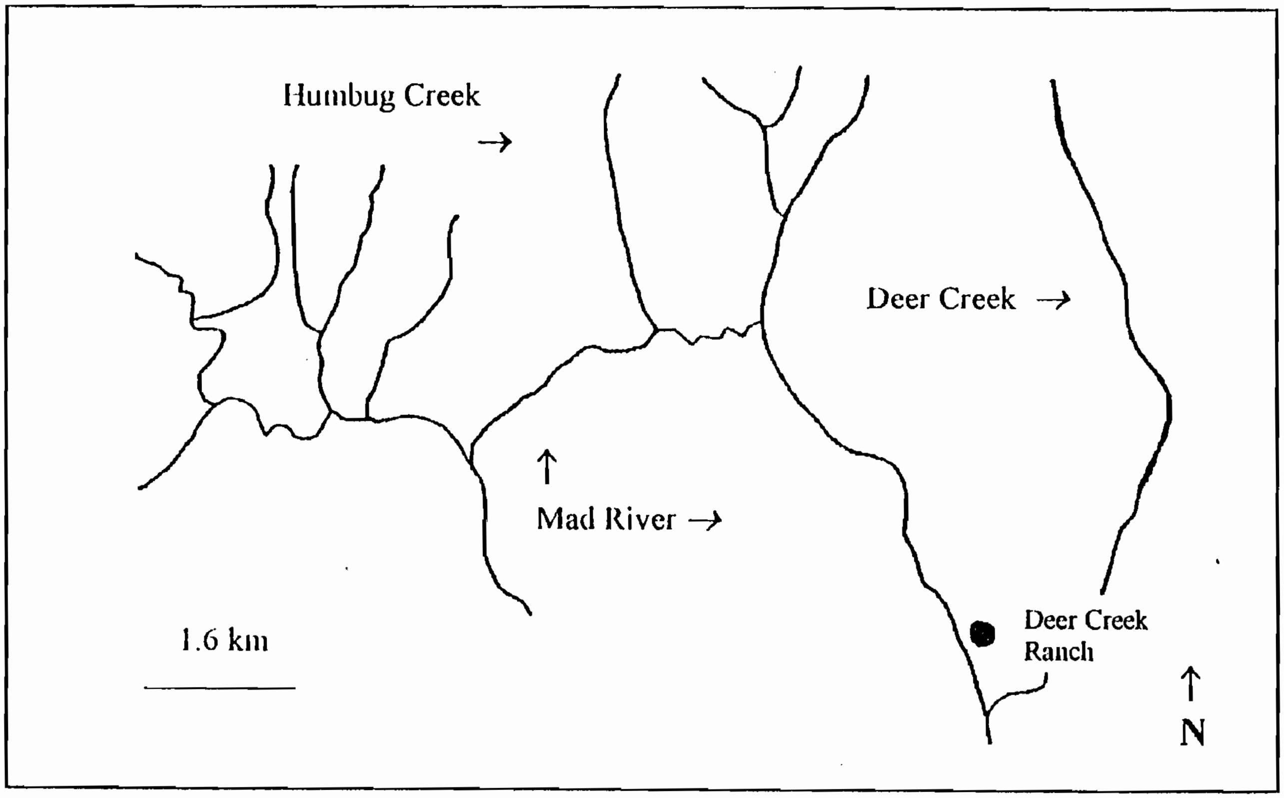


Figure 2. Location of the summer steelhead study sections on the upper Mad River, California 1995, 1996.

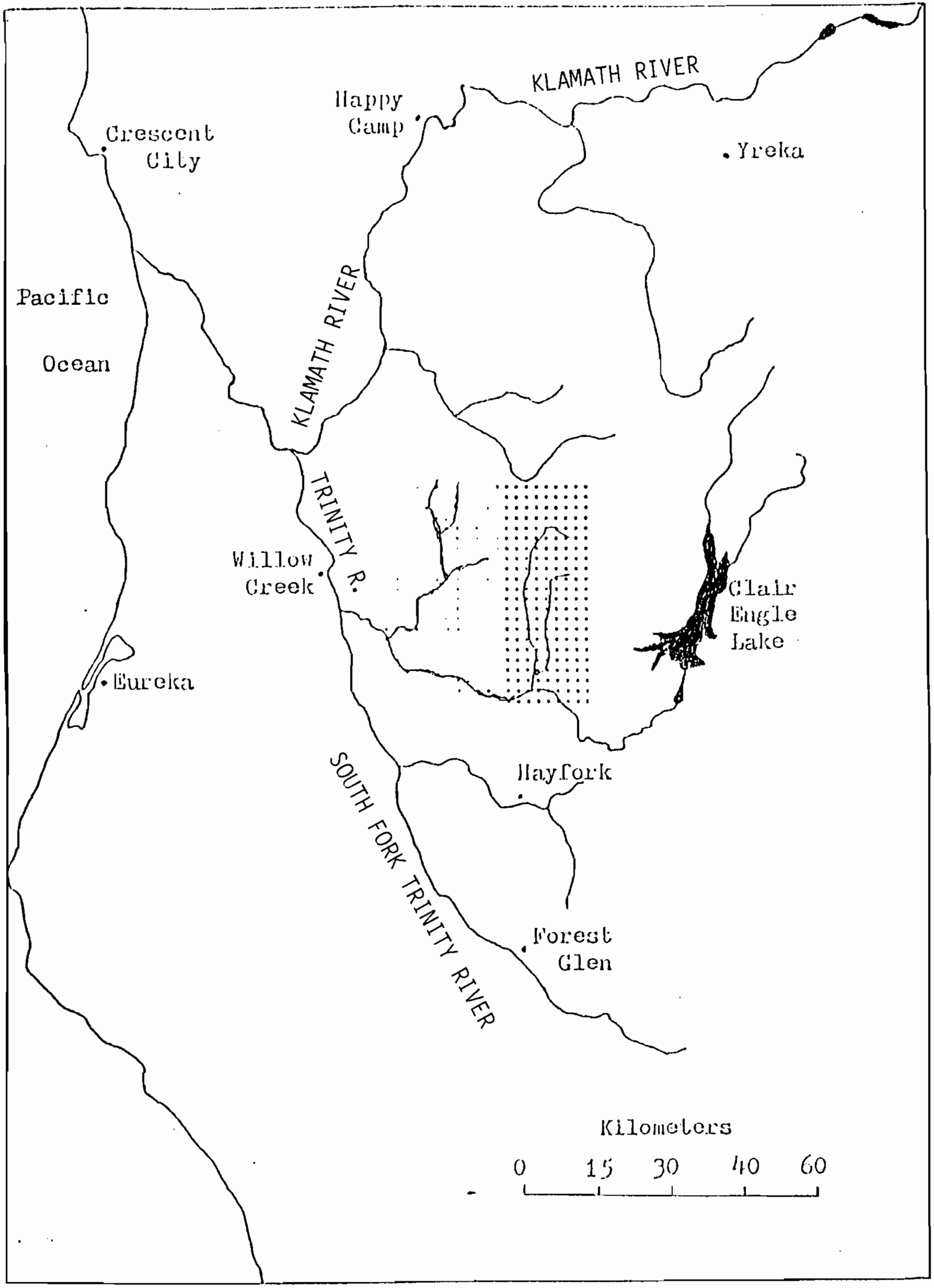


Figure 3. Klamath Trinity River system. Shading represents approximate location of study area (from Freese 1982).

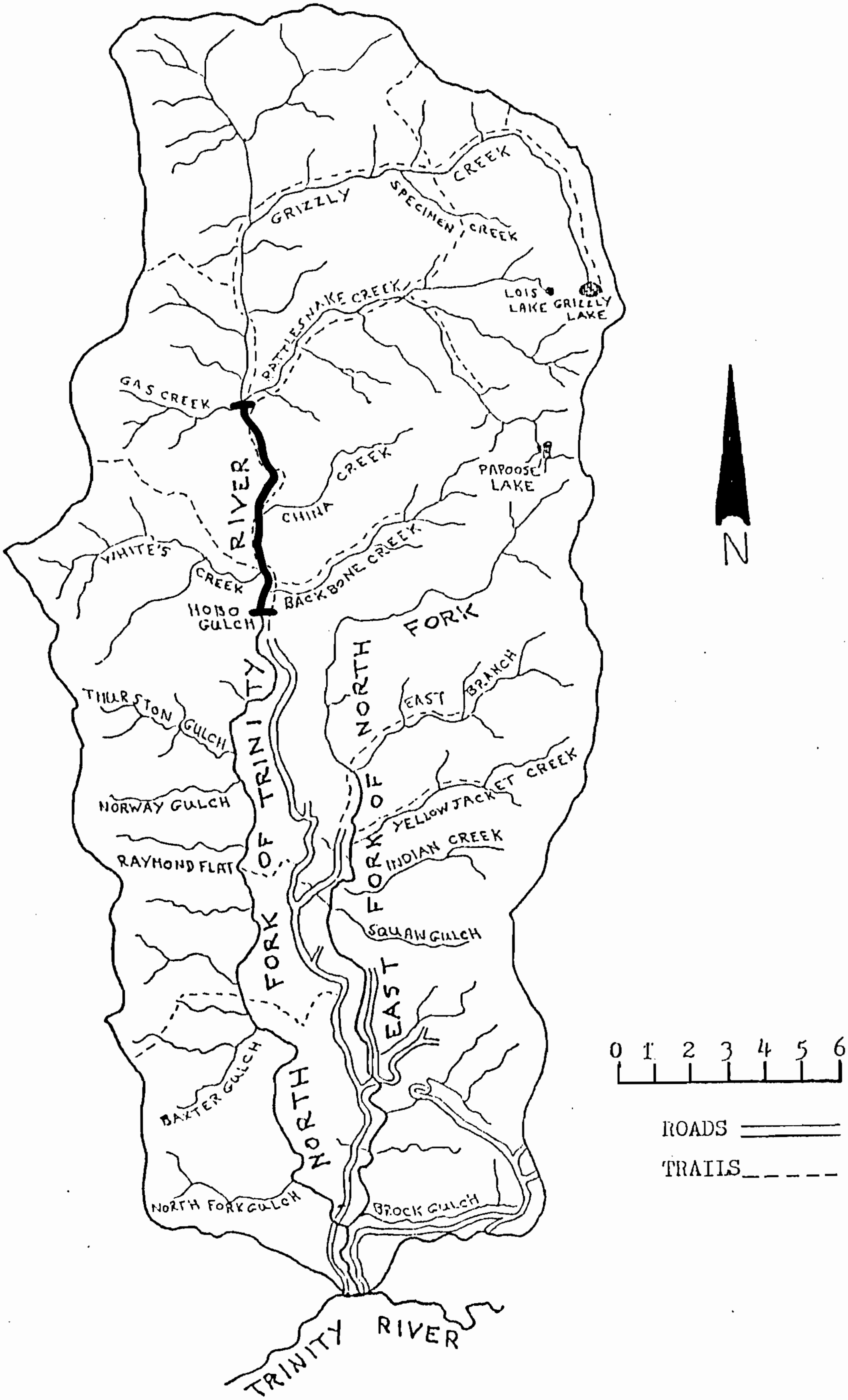


Figure 4. North Fork Trinity River watershed (from Freese 1982).

METHODS

The United States Forest Service and California Department of Fish and Game began surveying summer steelhead populations in northern California streams in the early 1980's to monitor population trends. The NFT and Mad River summer steelhead index survey data from previous years were analyzed to aid in locating pools that historically held large numbers of adult steelhead. These pools were then located in the field and examined for the presence of fish. Adult steelhead were identified by above surface observation and snorkel surveys. Pools holding 30 or more steelhead were selected for experimental study based on the following pool characteristics:

1. **Number of fish**: Pools that contained greater numbers of fish provided the best opportunity to obtain a large sample size.

2. **Pool accessibility**: The physical environment around the pool had to provide the angler with space to catch and release fish.

3. **Ability to isolate the pool**: Selected pools had to have morphological characteristics which allowed for placement and maintenance of block nets to retain the fish.

Standard spinning and bait casting gear was used for angling. All terminal gear used by anglers was artificial and limited to # three Blue Fox spinners. Hook size was standardized so that all lures contained size 6 single or treble barbless hooks (pinched barbs).

Experimental angling was conducted by two-person teams consisting of an angler and an assistant. The assistant measured the total time required to hook, play, land, mark, and release each fish landed, hereafter defined as stress time. Upon landing the fish, it was marked using a standard paper punch in the dorsal or anal fin and never removed from the water. Fish were marked so that identification of recovered mortalities could be attributed to experimental angling and allow knowledge of the hook type and hook location of each mortality recovered. The punched skin samples were then placed in plastic microcentrifuge tubes containing a buffer solution and saved for future genetic analysis.

After marking a fish, the angler released it back into the pool from where it was caught. The angler then recorded the date the fish was landed, pool location, gear type, stress time, water temperature, mark location and hook location (critical or non-critical area). In this study, critical areas were defined as hook placement occurring in the esophagus, eyes, gills, or tongue. Non-critical areas were hook placement in the mouth or jaw.

Upon completion of experimental angling, block nets were installed. A 10 cm mesh woven polyethylene netting 2 m deep by 41 m long was extended the entire width of the river at the head and tail of each pool. Rope was strung through the top of the netting and tied to rocks or trees on the opposing bank to secure the net. The bottom of the net was rocked and sealed to prevent fish from leaving the pools. In some cases block nets could not be placed safely at one end of a pool and were placed in the run above or below the study pool.

Upon completion of fishing within a given pool, observation for mortalities began. Pools were observed for no less than 36 hours following the release of the final fish back into the study pool. Observations were accomplished with the aid of snorkeling equipment. Mortalities within the pools were recovered and recorded.

Statistical Analysis

Logistic regression analysis was used to assess the relationship between water temperature and hooking mortality. To determine whether hook type was associated with differential hooking mortalities a chi-square test of homogeneity was employed . To determine the strength of the relationship between water temperature and stress time the Pearson product moment correlation coefficient was calculated. A two-sample t-test was used to determine if differences existed in the stress times of fish angled from the NFT and Mad Rivers. The mortality data were log transformed to meet normality assumptions. All analyses were conducted using the statistical package NCSS (Hintze 1996).

RESULTS

Water Temperature and Hooking Mortality

A total of 126 steelhead were hooked and released in water temperatures ranging from 8-25° C during the study (Table 1). Of the 126 steelhead caught and released, 12 mortalities were recovered and recorded. Ten of the 12 mortalities occurred at water temperatures in excess of 20° C (Table 2). Hooking mortality was positively related to water temperature (log-regr., $p = 0.002$) (Figure 5).

Hook Type and Mortality

Hook type was not significantly related to hooking mortality ($\chi_2 = 0.30$, 1, $P > 0.05$). A total of 64 steelhead were caught using treble hooks and 62 using single hooks (Table 1). Of these, seven mortalities occurred with the use of treble hooks and five with the use of single hooks. Hooking mortality associated with treble hooks was 10.9 percent compared with 8.1 percent for single hooks.

Table 1. Date, water temperature, hook type, hook placement, and the stress time for 126 summer steelhead angled from the Mad and North Fork Trinity rivers, California, 1995-1996.

	Temp.	Hook Type		Hook Placement		Stress		
Date	(C)	Single	Treble	Critical	Non-Crit.	(sec.)	Mortality	Loc.
7/27/96	25		x		x	183	0	Mad
7/27/96	25		x		x	195	1	Mad
7/27/96	25		x		x	139	0	Mad
7/27/96	25		x	x		270	1	Mad
7/27/96	25		x	x		110	1	Mad
7/30/96	25	x			x	291	0	Mad
7/30/96	25	x			x	196	0	Mad
7/30/96	25	x			x	269	1	Mad
7/30/96	25	x			x	257	1	Mad
7/15/96	24	x			x	171	0	Mad
7/27/96	24		x		x	165	0	Mad
7/30/96	24	x		x		128	1	Mad
7/30/96	24	x			x	155	0	Mad
7/15/96	23	x			x	123	0	Mad
7/15/96	23	x			x	147	0	Mad
7/15/96	23	x			x	320	0	Mad
7/15/96	23	x			x	212	0	Mad
7/15/96	23	x			x	131	0	Mad
7/26/96	23		x		x	180	0	Mad
7/26/96	23		x		x	128	0	Mad
7/30/96	23	x			x	224	0	Mad
7/21/96	23		x		x	248	1	Mad
7/21/96	23		x		x	219	0	Mad
7/21/96	23		x		x	107	0	Mad
7/26/96	23		x		x	147	0	Mad
8/9/96	22		x		x	118	0	Mad
8/9/96	22		x		x	194	0	Mad
8/9/96	22		x		x	152	0	Mad
8/13/96	22	x			x	143	0	Mad
8/13/96	22	x			x	171	*	Mad
8/13/96	22	x			x	165	*	Mad
8/12/96	21	x			x	199	0	Mad
8/12/96	21	x			x	152	0	Mad

Table 1. (Cont.)

	Temp.	Hook Type		Hook Placement		Stress		
Date	(C)	Single	Treble	Critical	Non-Crit.	(sec.)	Mortality	Loc.
8/12/96	21	x			x	147	0	Mad
8/12/96	21	x			x	190	0	Mad
8/12/96	21		x		x	170	1	Mad
8/13/96	21		x		x	150	0	Mad
8/13/96	21		x		x	175	0	Mad
8/13/96	21		x		x	218	0	Mad
8/13/96	21		x		x	177	0	Mad
8/16/96	21		x		x	115	0	Mad
8/16/96	21	x			x	150	0	Mad
8/16/96	21	x			x	210	0	Mad
8/16/96	21	x			x	164	0	Mad
8/31/96	21	x			x	270	1	Mad
8/31/96	20	x			x	210	0	Mad
8/31/96	20		x		x	163	0	Mad
8/31/96	20		x		x	228	0	Mad
8/31/96	20		x		x	105	0	Mad
8/31/96	20		x		x	103	0	Mad
9/1/96	20	x			x	210	0	Mad
9/1/96	20	x			x	188	0	Mad
9/1/96	20	x			x	231	0	Mad
9/1/96	20		x		x	170	0	Mad
9/1/96	20		x		x	103	0	Mad
9/1/96	20		x		x	143	1	Mad
9/1/96	20	x			x	212	0	Mad
8/18/96	19		x		x	230	0	Mad
8/18/96	19		x		x	165	0	Mad
8/18/96	19		x		x	118	0	Mad
8/18/96	19		x		x	132	0	Mad
8/18/96	19	x			x	161	0	Mad
8/18/96	19	x			x	146	0	Mad
8/18/96	19	x			x	270	0	Mad
8/18/96	19	x			x	190	0	Mad
8/18/96	19		x		x	168	0	Mad
8/18/96	19		x		x	250	0	Mad
8/18/96	19	x			x	215	0	Mad
9/24/95	19	x			x	152	0	Mad
9/22/95	18		x		x	146	0	Mad
9/23/95	18		x		x	157	0	Mad

Table 1. (Cont.)

	Temp.	Hook Type		Hook Placement		Stress		
Date	(C)	Single	Treble	Critical	Non-Crit.	(sec.)	Mortality	Loc.
9/24/95	18		x		x	127	0	Mad
9/24/95	18		x		x	135	0	Mad
9/24/95	18	x			x	139	0	Mad
9/24/95	18	x		x		157	0	Mad
9/22/95	18	x			x	243	0	Mad
9/28/95	18		x		x	215	0	Mad
9/28/95	18		x		x	140	0	Mad
9/28/95	18		x		x	130	0	Mad
9/28/95	18		x		x	217	0	Mad
9/29/95	18	x			x	250	0	Mad
9/29/95	18	x			x	289	0	Mad
10/2/95	18	x			x	189	0	Mad
10/2/95	18		x		x	190	0	Mad
9/28/95	17		x		x	229	0	Mad
9/28/95	17		x		x	222	0	Mad
9/29/95	17	x			x	343	0	Mad
9/29/95	17	x			x	316	0	Mad
9/29/95	17	x			x	222	0	Mad
9/13/96	16		x		x	190	0	Mad
9/13/96	16	x			x	317	0	Mad
9/13/96	16		x		x	250	**	Mad
9/13/96	16		x		x	196	**	Mad
9/13/96	16	x			x	172	0	Mad
9/13/96	16		x		x	168	**	Mad
9/13/96	16		x		x	160	**	Mad
9/14/96	16	x			x	250	0	Mad
9/14/96	16	x			x	210	0	Mad
8/12/95	13		x		x	150	0	NFT
8/12/95	13		x		x	420	0	NFT
9/16/95	13	x			x	325	0	NFT
9/16/95	13		x		x	114	0	NFT
9/16/95	13	x			x	248	0	NFT
9/16/95	13	x			x	238	0	NFT
8/12/95	12		x		x	270	0	NFT
8/12/95	12		x		x	223	0	NFT
8/12/95	12		x		x	110	0	NFT
8/12/95	12		x		x	230	0	NFT
9/16/95	12	x			x	335	0	NFT

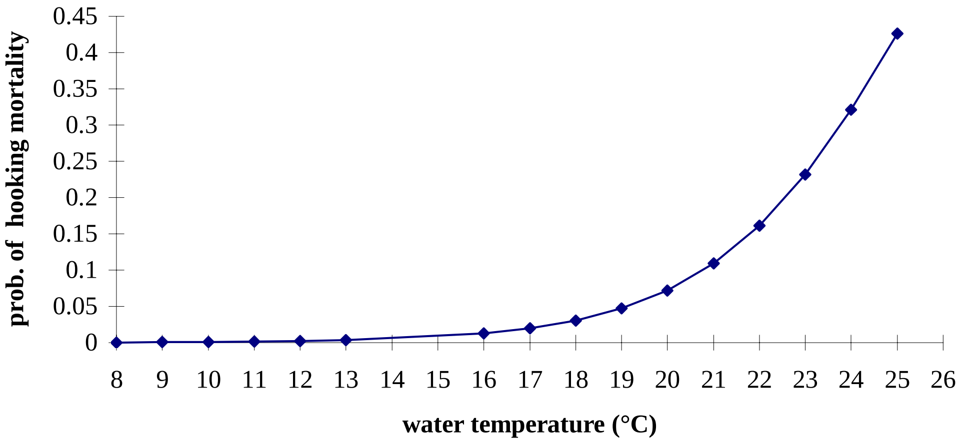
Table 1. (Cont.)

	Temp.	Hook Type		Hook Placement		Stress		
Date	(C)	Single	Treble	Critical	Non-Crit.	(sec.)	Mortality	Loc.
9/16/95	12	x			x	362	0	NFT
9/16/95	12	x			x	217	0	NFT
9/16/95	12		x		x	390	0	NFT
9/16/95	12		x		x	143	0	NFT
10/6/95	12	x			x	315	0	NFT
8/14/95	11	x			x	300	0	NFT
9/16/95	11	x			x	326	0	NFT
9/16/95	11	x			x	193	0	NFT
10/6/95	11		x		x	163	0	NFT
10/6/95	10		x		x	470	0	NFT
10/6/95	9	x			x	160	0	NFT
10/6/95	9	x			x	130	0	NFT
10/27/95	9		x		x	277	0	NFT
10/27/95	9		x		x	305	0	NFT
10/27/95	9		x		x	341	0	NFT
10/6/95	8	x			x	160	0	NFT
10/6/95	8	x			x	345	0	NFT
* Exact I.D. not possible. One of two fish caught 8/13/96.								
** Exact I.D. not possible. One of four fish caught 9/13/96.								
1 = mortality 0 = survival								

Table 2. The total number of summer steelhead caught and mortalities recovered for three water temperature strata during 1995 -1996 Mad and North Fork Trinity rivers, California.

	~~Water Temperature~~		
~~Stream~~	8-14° C	15-20° C	21-25° C
Mad	0/0	53/2	45/10
NF Trinity	28/0	0/0	0/0

Figure 5. Probability of hooking mortality of adult summer steelhead versus water temperature based on 126 summer steelhead angled from the Mad and North Fork Trinity rivers, California, 1995 and 1996.



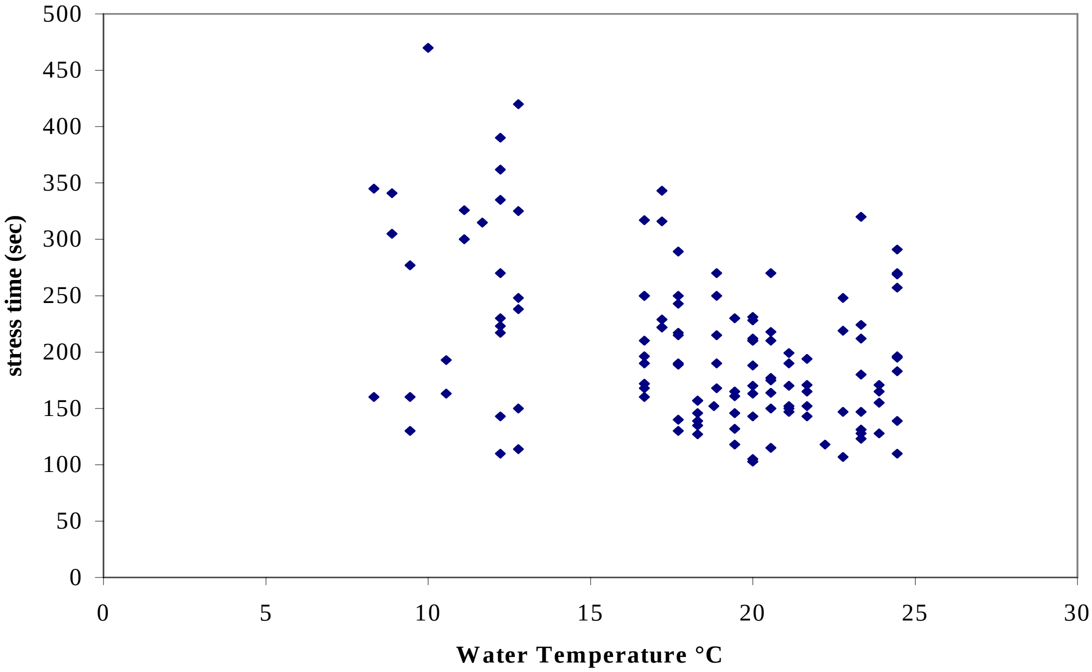
Water Temperature and Stress Time

Stress time decreased with increasing water temperature ($r = -0.41$, $p < 0.005$) (Figure 6). Mean stress time was significantly higher for steelhead from the NFT River when compared to steelhead from the Mad River ($p = 0.001$). Mean stress time also differed between hook types ($p < 0.05$). Fish caught using single hooks had a mean stress time of 218 seconds versus 189 seconds for treble hooks.

Hook Placement

Hook placement occurred almost exclusively in non-critical areas (96.8 percent) versus critical areas (3.2 percent). Fish hooked in non-critical regions had an associated mortality rate of 7.4 percent. In contrast, fish hooked in critical areas had a 75.0 percent mortality rate. Hook placement occurred more often in critical areas as water temperature increased. All four critically hooked fish were angled in the Mad River. The three critically hooked fish angled at water temperatures of 24-25° C died whereas the fourth fish angled at 18° C survived. Hook type did not influence hook placement.

Figure 6. Correlation of water temperature and stress time in seconds for 126 summer steelhead caught and released on the NFT and Mad rivers, California, 1995-1996.



Behavior Observations

Avoidance. Adult summer steelhead were counted and their behavior noted on weekly dives of the NFT from July 19-September 17, 1996. The most distinct behavior observed by these fish was "hiding". Fish approached by divers concealed their heads under rocks, logs, or other cover, but otherwise were exposed. Once in this position fish could be approached to a distance of 1 m. Steelhead in this position would be vulnerable to predation from people (spear gun) or natural predators (otters).

Other avoidance behaviors were dependent on pool depth, time of the year, and the number of fish present in the pool. In general, steelhead in the presence of a diver exhibited a "nervous behavior" which consisted of moving quickly around the pool in tight groups or moving to available cover. Steelhead seldom exited pools. Those that did were in shallow pools (< 3 m), early in the season (July-August), and in pools with few individuals (< 10 individuals). Fish exiting pools typically found cover in turbulent water upstream of the holding pool. Steelhead in deep pools (> 3 m), late in the season (August-September), and in large numbers (> 20 individuals) were never observed exiting pools. These fish typically moved away from divers towards cover under ledges, boulders, shade, and bubble curtains.

Fishing. Summer steelhead were most vulnerable to angling during the first 10 casts each day. Generally, one or two fish were caught, the fish would "spook", and the bite was off. Typically, if a pool was then left unfished for one or two hours one could return and catch more fish. The most productive time to fish was 30 minutes before sunset. Fish became active, aggressive, and did not spook during this time. During this study the same fish was never caught twice even though we caught 75 fish from one section of the Mad River estimated to hold 200-300 fish.

DISCUSSION

Water temperature was found to significantly influence hooking mortality (p =0.002) of summer steelhead. Based on the logistic regression model (Figure 5) estimated hooking mortality ranged from 17.0 – 43.0 percent respectively for fish angled in water temperatures from 22-25°C. Estimated hooking mortality was below five percent for steelhead angled in water temperatures below 18°C.

Other researchers have obtained similar results. Anglers using lures at Heenan Lake, California killed less than 1.5 percent of Lahontan Cutthroat trout at water temperatures between 5.5°C and 15.5°C, but nearly 50.0 percent when water temperatures were greater than 20°C (Titus and Vanicek 1988). Delayed post-angling mortality of 40.0 percent was observed in a small number of Atlantic salmon angled at 22°C (Wilkie et al. 1996). Several other studies have shown a relationship between water temperature and hooking mortality (Benson and Buckley 1963, Klein 1965, Dotson 1982, and Nuhfer and Alexander 1992).

Although it is clear that a relationship exists between water temperature and delayed post-angling hooking mortality, the direct cause of mortality is yet to be determined. In this study, three fish died directly from hooking injury occurring in a critical area, which resulted in significant blood loss and immediate death. The nine remaining mortalities were hooked in a non-critical region, but died six to 24 hours post-angling. Wilkie et al. (1996) showed that Atlantic salmon angled in water temperatures from 20°C ± 2°C had an increase in the magnitude of several physiological stressors including: slower lactate elimination, increases in white muscle lactate, changes in intramuscular glycogen stores, and no glycogen resynthesis during a four hour recovery period. They hypothesized that there was an increased susceptibility to delayed mortality due to an impairment of restorative processes.

Hook type did not affect mortality rate. Because of the large size of these fish in comparison with the artificial lure used, both single and treble hooks entered critical areas at nearly the same rate (3.2 percent versus 3.1 percent), thus producing no difference in hooking mortality directly related to hook type. The mean stress times between these groups were compared and it was found that steelhead caught using treble hooks had a significantly lower mean stress time ($p<0.05$). This may have occurred from deeper hook penetration of single hooks, which increased handling time. Although mean stress time was 29.0 seconds lower for steelhead caught on treble hooks, this did not produce a difference in the mortality rates between these groups. These findings indicate that hook type was not an important determinant of hooking mortality in this study.

There was a significant negative correlation between water temperature and stress time ($p < 0.005$). As water temperature increased, stress time decreased. Shorter stress times at higher water temperatures may indicate increased physiological stress. All of the fish caught at the lowest water temperatures however were from the North Fork Trinity. The mean stress times of steelhead caught on the NFT and Mad River were significantly different ($p = 0.001$). It is not clear whether this is a function of temperature or another variable (genetic differences between stocks, pool morphology etc.).

Anatomical hooking site is an important determinant of the overall rate of hooking mortality. Fish hooked critically are approximately four times more likely to die than those hooked non-critically (Mongillo 1984). Different gear types will contact critical areas at different rates thus producing differential rates of hooking mortality between gear types (e.g. bait vs. artificial lures) (Hooten 1987, Mongillo 1984). Wydowski (1977) reported that because bait is often taken deeply by fish, this terminal gear has caused the highest mortality in fish (mean 25.0 percent, range 3.3-61.5 percent, n=2839). In this study, only 3.2 percent of the fish were critically hooked. This is similar to other studies, and in general, artificial lures contact critical areas less than ten percent of the time (Schisler and Bergersen 1996, Nuhfer and Alexander 1992, Dotson 1982). Critically hooked fish, however, had a mortality rate of 75.0 percent, ten times the rate of non-critically hooked fish. This is a higher ratio than reported by (Mongillo 1984), but is based on a small sample (four). These limited data imply the importance of selecting gear types that penetrate critical areas less frequently (artificial lures).

Of the four fish critically hooked, three were hooked at the highest water temperatures. The fourth was caught at an intermediate water temperature and hooked in the jaw with the point of the hook penetrating the eye. Again, though the number of critical hookings was small, there is some indication that fish are more likely to be hooked critically as water temperature increases. This may occur because the fish become more active and aggressive as the water temperature increases.

Management Implications

Snorkel survey data of Northern California summer steelhead populations indicate only four populations consistently producing over 500 individuals. In the past, all of these populations were subject to catch and release fishing regulations. Currently, none of these populations receive any legal fishing pressure. This study has shown that during the summer months, when water temperatures are at their maximum, hooking mortality associated with catch and release fishing can be as high as 40.0 percent for lure caught summer steelhead. Based on the results of this study and the sensitive status of summer steelhead, I recommend the following regulations: No catch and release angling for Northern California summer steelhead from mid-June through mid-September or at water temperatures in excess of 18°C (65° F). If fishing is allowed, only artificial lures should be used to reduce the probability of critically hooking fish. The hook type could be either single or treble hooks no smaller than 1/0 in size. Anglers should not be allowed to remove fish from the water under any circumstances. Although the results of this study have application to other salmonid species in California (i.e. Klamath Basin Fall Run coho and chinook), further research would be advised before regulation changes are enacted.

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