POTENTIAL PHYSIOLOGICAL EFFECTS TO MIGRATING SALMONIDS FROM MOTORBOATS IN THE LOWER WILD AND SCENIC ROGUE RIVER, OREGON

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ABSTRACT

Experiments were performed during summer 2002, to indirectly evaluate physiological effects of motorboat activity on salmonids occupying thermal refugia in the Wild section of the Rogue River. There was a strong, negative linear correlation between boat wake height and distance from a refuge ($R^2 = 0.8679$, $p < 0.001$), but no correlation between wake height and mean refuge temperature change.

In three refugia, continuous data loggers were used to quantify temperature changes created by wake turbulence. Mean refugia temperatures during 70 % of boat wakes (7) were significantly higher than temperatures recorded immediately prior to boat activity (ANOVA, $p < 0.05$). Thermographs showed, however, that temperatures in some refugia were not constant and experienced natural, periodic fluctuations. The mean temperature increase in refugia during motorboat activity was 0.24 ° F ($s = 0.54$, $n = 10$).

Snorkeling observations revealed that the presence of motorboats and their wakes did not elicit startle responses in chinook salmon presmolts. Bioenergetic models predicted that temperature increases in thermal refugia caused by current levels of motorboat activity could cause less than a one-tenth of one percent (0.05 – 0.09 %) increase in adult spring chinook salmon (*Oncorhynchus tshawytscha*) daily standard metabolism. The calculated chance of lethality to juvenile chinook from motorboat wakes near one thermal refuge was negligible. These results suggest that current levels of motorboat activity have minor effects on the physiology of migrating salmonids in the lower Rogue River.

INTRODUCTION

Historical and Ecological Background

Historical

Oregon’s Rogue River is renowned for its prolific salmon and steelhead fisheries and its large expanses of undeveloped, rugged country. In 1968, Congress designated an 84-mile section of the Rogue River as one of the original eight Wild and Scenic Rivers. This portion included the 32-mile Wild Section, co-managed by the Bureau of Land Management’s Medford District and the U.S. Forest Service’s Siskiyou National Forest. The 35,818-acre Wild Rogue Wilderness was designated in 1978 and flanks the Wild Section from River Mile (RM) 31 to 48. Provisions in the Wild and Scenic River and Wilderness designations permitted continued motorboat usage by private and commercial parties in the 10-mile Wild Section below Blossom Bar rapids from RM 36 to RM 46 (hereafter the Motorized Wild Section).

Since 1976, a maximum of six 32-ft commercial tour boats, and six private motorboats have been allowed in the Motorized Wild Section (MWS) per day during the summer months. Additional motorboat use related to wilderness lodges and commercial fishing guides occurs during the summer, and is unlikely to exceed six trips per day (Blackwell pers. comm. 2002). Recent litigation issued against the U. S. Forest Service has alleged, among other points, that current levels of motorboat activity negatively affect Rogue River fisheries by altering salmonid thermal refugia in the MWS (Riverhawks et al. *Vs.* Zepeda et al. 2001). A prior study located upstream in the Hellgate section of the Rogue River (RM 95 to 122) thoroughly analyzed direct effects to salmonids from motorboats and concluded that motorboat activity in the river mainstem did not increase stress levels or risk of predation to juvenile salmonids (Satterthwaite 1995).

Ecological

The MWS has historically experienced high water temperatures that are outside salmonids' preferred ranges (Everest 1973; U.S. Geological Survey 2002). Even with the creation of Lost Creek Reservoir at RM 158 in 1977, and associated hypolimnetic releases, the river still warms considerably as it passes through the broad Rogue Valley (RM ~105-135) (Larson 1982). The period of warmest water temperatures in the Rogue River is normally in July or August, and coincides with large salmonid migrations of both out-migrating smolts and presmolts, and returning adults and sub-adults.

Many migrating salmonids use cool water thermal refugia during the warm summer months (e.g. Berman and Quinn 1991; Nielsen and Lisle 1994; Torgersen et al. 1999; Baigun et al. 2000), however the distribution, quantity, and quality of these areas in the Rogue River—especially in the MWS—have not been formally described. Salmonids use thermal refugia to ameliorate the physiological effects from warm water such as increased metabolic rate and decreased metabolic scope (Barton and Schreck 1987) and lowered resistance to disease (Berman and Quinn 1991). In laboratory experiments, salmonid pathogens such as *Aeromonas* spp., *Ceratomyxa shasta*, and *Flexibacter columnaris* were more virulent and lethal as water temperatures were increased (Holt et al. 1975; Udey et al. 1975; Groberg et al. 1978). Outbreaks of *F. columnaris* have caused substantial mortalities in migrating Rogue River spring chinook when water temperatures reached critically high levels. Warm water temperatures have also been shown to disrupt the smoltification process in juvenile salmonids (Zaugg et al. 1972).

During the summer months, migrating salmonids present in the MWS include adult spring chinook (*Oncorhynchus tshawytscha*) and summer steelhead (*O. mykiss*), sub-adult summer steelhead (half-pounders), and juvenile chinook and steelhead. Some coho salmon (*O. kisutch*) smolts may be in the MWS at this time, although many emigrate before the period of highest temperatures. The current status of steelhead and salmon populations in the Rogue basin ranges from highly productive in the case of fall chinook and winter steelhead, to federally threatened with extinction with regard to coho (62 Federal Register 42588).

The marginal status of wild Rogue River spring chinook and summer steelhead populations is likely strongly related to the loss of their historic spawning and rearing habitat in the upper portion of the basin, as these species use the lower watershed primarily for migration. However, Everest (1973) found most summer steelhead make prespawning upriver migrations as half-pounders, spending almost six months in the lower Rogue River (RM 0 - 50), after spending about only three months at sea. Summer steelhead peak entry into the Rogue River also corresponded with periods of maximum water temperature (Everest 1973). Spring chinook adults may also stage in the lower Rogue River for up to several months before migrating to spawning grounds in the upper part of the watershed. Subsequently, high water temperatures and the loss of thermal refugia can have adverse effects on the physiological and reproductive fitness of these species. Berman and Quinn (1991) suggested that land management agencies should identify and protect refugia used by migrating salmonids.

Objectives

The primary objective of this study was to identify thermal refugia within the 10-mile MWS and document the number and type of salmonids using these areas. Once these areas were identified, and salmonid use was documented, experiments were conducted to explore the potential effects of motorboat wakes on thermal stabilities within the refugia. This objective included measuring the duration and intensity of temperature change within the areas, and determining if these changes were related to wake height. I also wanted to determine if thermal stratification existed within these refugia, or if temperatures fluctuated. Finally, I was interested in describing how fishes responded to various types of motorboat activity (different boat types and sizes passing by at varying distances and producing wakes of different sizes).

METHODS

I used 1:24,000 U. S. Geological Survey topographic maps to identify potential thermal refugia within the study area (MWS). Based on prior observations in the Rogue and Illinois rivers (Reid 2001; personal observation 2002) and other studies (e.g. Berman and Quinn 1991; Torgersen et al. 1999), I predicted tributary junctions and the downstream portions of alluvial riffles might function as refugia. Both surface water from tributaries and mainstem hyporheic flow can create localized pockets of cooler water within the river channel.

Between July 8 and 16, 2002, I measured daytime water temperatures at 45 sites to determine if they were cooler than the mainstem Rogue River. A digital water- and shockproof thermometer with a 10-ft cable (VWR model 61161-283) was used to record spot temperatures. The thermometer was factory calibrated and had an accuracy of ± 0.7 ° F. To determine if the river mainstem or refugia showed thermal stratification or other discontinuities, I attached the thermometer probe to a sounding line marked in 1-ft increments.

I selected several sites near tributary junctions or alluvial riffles that were cooler than ambient river temperatures (Fig. 1), and used continuous data loggers (Onset Optic Stowaway WTA08) to record water temperatures every second for a 2-hour period. I assumed this level of resolution would be necessary to detect the potentially short duration temperature fluctuations created by motorboat turbulence. Data loggers were anchored with 5-lb lead weights and parachute cord, within two inches of the substrate, and exposed to full sunlight. I synchronized a digital timer with the data loggers' internal clocks, and recorded the time and duration of motorboat passes. Since the timer was only synchronized to the resolution of minutes, I did not know if boat turbulence started at the beginning or end of a given minute. To account for this variable, I graphed temperatures obtained during boat activity in 2-minute segments.

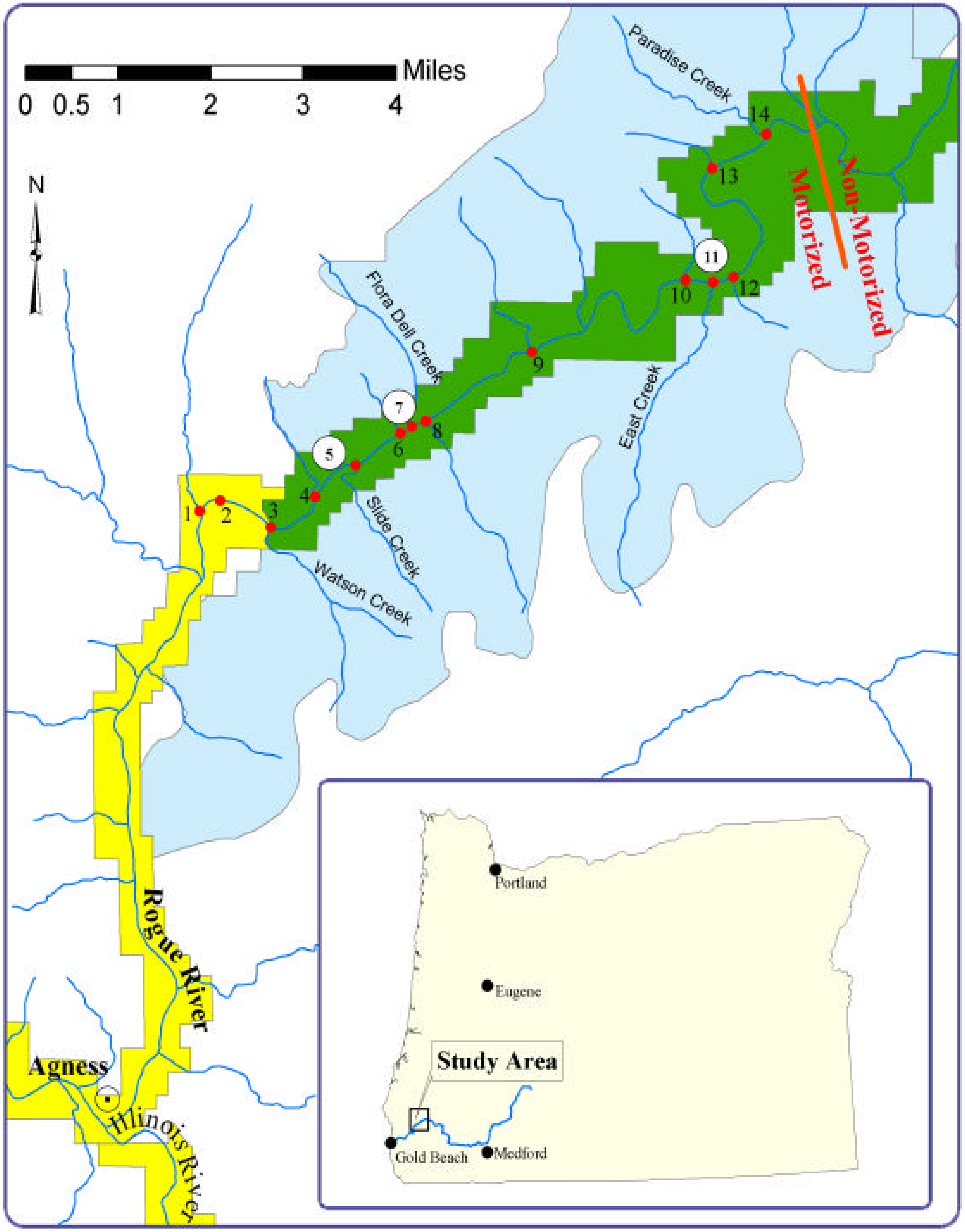

Figure 1. Map of the study area. Yellow = Recreational Section, Green = Wild Section, Blue = Wild Rogue Wilderness. Numbers correspond to study sites and potential thermal refugia; numbers inside circles represent sites where detailed temperature monitoring and behavioral observations occurred. Source: Siskiyou National Forest GIS, Gold Beach, Oregon.

I snorkeled selected areas near thermal refugia between 0930 and 1630 to determine fish usage and behavior in response to motorboats. I used single count snorkeling methods to enumerate and identify fishes. I counted the exact number of all salmonids observed, and estimated the number of non-salmonids (cyprinids and gasterosteids; which were usually at least 10 times more abundant). I classified salmonid behavior as either holding, feeding, or startled. Limited water clarity in the mainstem Rogue River, due to particulate organic matter, reduced visibility to less than three ft and complicated snorkeling. Visibility was improved slightly at tributary junctions due to the influence of clearer water. To measure the height of motorboat wakes, I inserted a vertical staff gauge marked in 0.1-ft increments near the physical centers of the refugia, or near the highest density of salmonids.

Boats used in the study were 32-ft aluminum tour boats equipped with two inboard 460-in^3 motors and jet pumps, from two commercial tour companies based in Gold Beach, Oregon (hereafter referred to as tour boats). Tour boat operators were not aware of this study, and I took precautions not to disrupt their normal operation patterns. The other boat type used was a 22-ft aluminum flat-bottomed sled with a 90-hp outboard jet pump, chartered from a local lodge owner (hereafter referred to as jet sled).

I downloaded temperature data using BoxCar Pro 3.51, organized and graphed this information in Microsoft Excel 2000, and used Statgraphics Plus 5.0 for statistical analysis. I used simple linear regression analysis to correlate boat distance from refugia, wake height and temperature change. Single factor analysis of variance (ANOVA) was used to compare differences in mean water temperatures before, during, and after motorboat passes. Fisher's Least Significant Difference (LSD) procedure was used to test for differences between individual groups. For all tests, $\alpha = 0.05$, except for ANOVA where it was adjusted by the Bonferoni method.

I recorded and compared temperature measurements using the Fahrenheit scale, and temperatures were converted to degrees Celsius when calculating bioenergetic costs. To preserve consistency, standard American units were also used when measuring and estimating distances.

RESULTS

Temperature

I combined over 80 spot temperature measurements with snorkeling observations to identify potential thermal refugia used by salmonids (Table 1). Three of these areas were channel margin pools located near tributary confluences, and varied in depth from 1.5 – 3.3 ft. Due to high discharge in the mainstem (> 1,700 ft^3 sec^{-1}), I was unable to snorkel riffles and accurately determine salmonid usage. Limited monitoring of a long (~300-ft) cobble-dominated riffle suggested thermal discontinuities existed, with the downstream portion being about 0.3 ° F cooler than the upstream portion (Fig. 2). However, most of the study focused on confluence pools where snorkeling was feasible.

Table 1. Spot temperatures of potential thermal refugia in relation to the mainstem Rogue River. All measurements were taken on 8 July 2002, except Site 5, where temperature was taken on 16 July 2002. U = unknown, Y = yes, N = no.

Site Number	Name	Time	Refuge Depth (ft)	Refuge Temp	River Temp	Salmonids Present
1	Billings	0905	2.0	67.6	68.6	U
2	Billing’s Ford	1045	2.0	70.4	70.4	U
3	Watson	0950	2.0	70.1	70.1	Y
4	Dan’s	1020	1.0	71.5	70.7	N
5	Slide	1105	1.5	73.5	77.7	Y
6	Flea	1125	2.0	70.2	70.6	N
7	Flora Dell	1140	2.0	69.6	70.8	Y
8	Fall	1520	0.5	72.0	72.5	N
9	Clay Hill	1225	0.2	70.8	71.4	U
10	Brushy Bar	1340	0.5	71.2	71.3	U
11	East	1400	2.5	62.6	71.6	Y
12	“Sly Fox”	1415	0.5	65.0	71.2	U
13	Jackson	1430	0.5	71.3	71.9	U
14	Paradise	1450	0.5	71.6	71.8	U

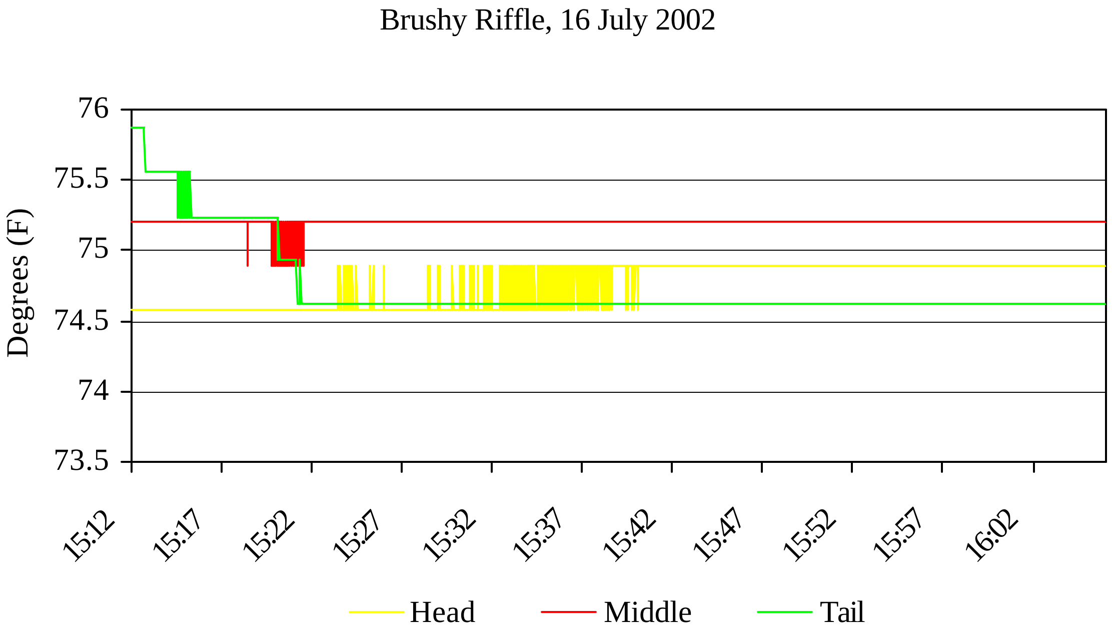

Figure 2. Continuous water temperature of three sites located in the ~300-ft long Brushy Riffle, Rogue River, Oregon. Head = beginning of riffle, Middle = approx. 150 ft downstream of Head, Tail = approx. 150 ft downstream from Middle.

Refugia water temperatures were up to 12 °F cooler than the mainstem Rogue River at the point of tributary inflow, however quickly warmed downstream of the tributary to ambient river temperature. East Creek had the greatest discharge of any tributary within the study area, and had a measurable effect on mainstem temperature at least 40 ft downstream of the confluence. During the study period, daily temperatures in the mainstem Rogue River near the study area always exceeded 55.9 °F, the upper thermal limit for adult spring chinook migration (Bjornn and Reiser 1991) (Fig. 3). Maximum daily temperatures also always exceeded 73.4 °F, an upper incipient lethal temperature for chinook smolts (Baker et al. 1995)

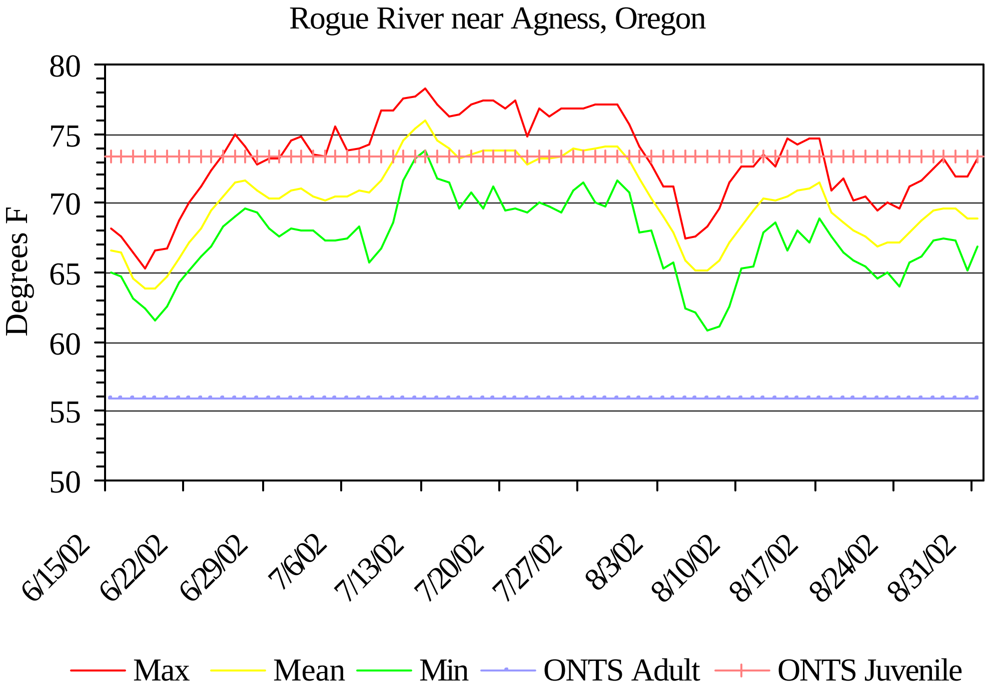

Figure 3. 2002 summer daily maximum, minimum, and mean water temperatures from gauging station 14372300 (U.S. Geological Survey 2002) on the mainstem Rogue River near Agness, Oregon (RM 30). The upper thermal tolerances for spring chinook (ONTS) adult migration and juvenile lethality are 55.9 and 73.4 °F respectively (Bjornn and Reiser 1991; Baker et al. 1995).

Boat Activity

Continuous data loggers showed that water temperatures in refugia fluctuated as much as 4 °F in one hour (Figs. 4 – 6). Temperatures taken during boat passes at Site 5 were within the range of temperatures measured when there was no boat activity (Fig. 4). However, temperatures recorded from Site 7 during boat activity exceeded baseline temperatures by almost 0.5 °F (Fig. 5). Conversely, water temperatures recorded from Site 11 during boat activity were within the range of temperatures measured without boat turbulence. Water temperatures from Site 11 also had more frequent and larger fluctuations than the other sites (Fig. 6). These fluctuations did not appear to be associated with boat activity.

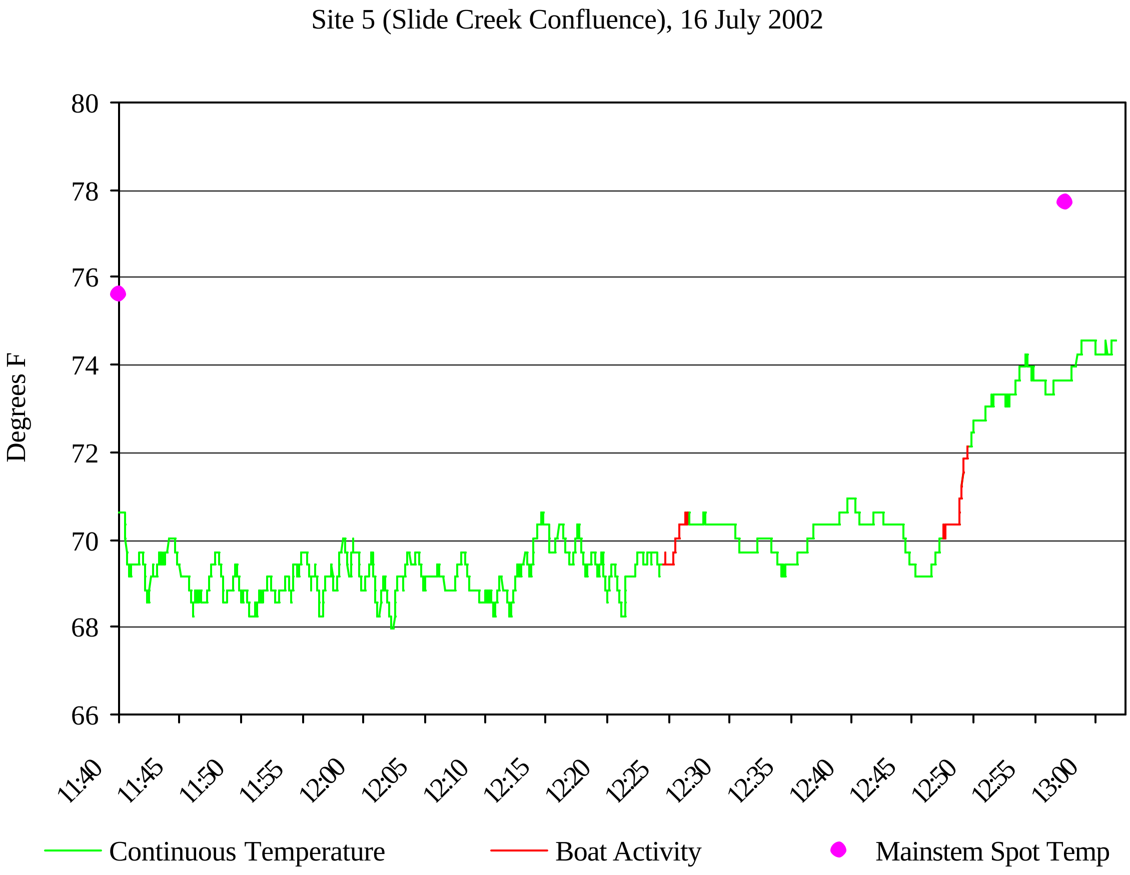

Figure 4. Continuous water temperature of thermal refuge near the confluence of Slide Creek and the Rogue River (Site 5) during boat activity on 16 July 2002.

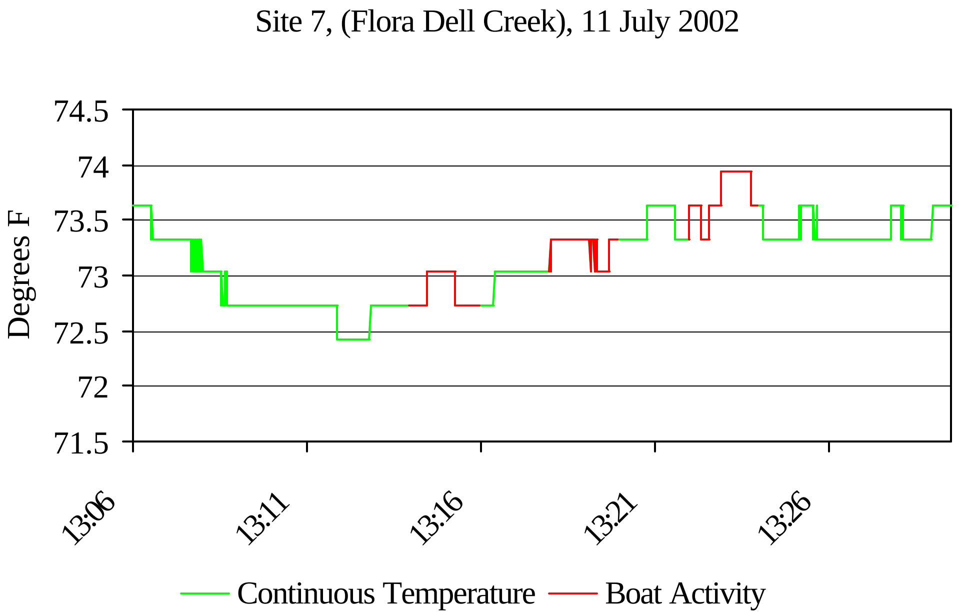

Figure 5. Continuous water temperature of thermal refuge near the confluence of Flora Dell Creek and the Rogue River (Site 7) during boat activity on 11 July 2002.

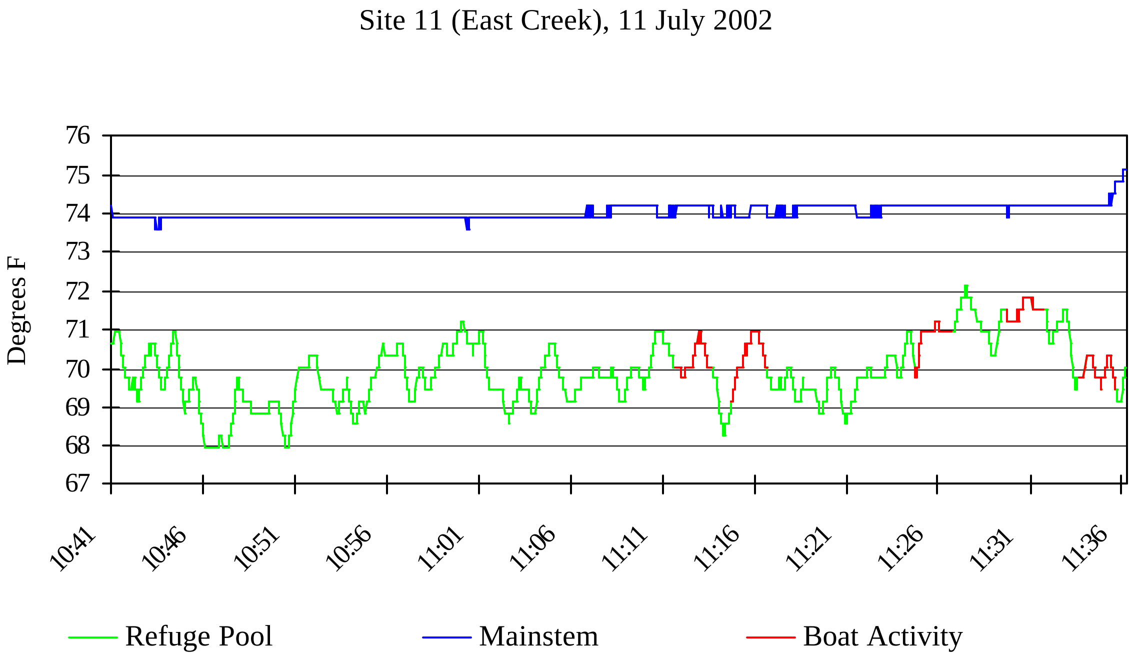

Figure 6. Continuous water temperature of thermal refuge near the confluence of East Creek and the Rogue River (Site 11) during boat activity on 11 July 2002.

Observed wake height and estimated distance from refuge were recorded from ten upstream boat passes (Table 2). Mean temperature change was calculated by subtracting the mean temperature from the two minutes prior to boat activity from the mean temperature of a two minute period of boat activity. The beginning of pass 3 at Site 7 was manually shifted one minute to the left during graphing, because of a probable error in recording the time of boat activity. The mean temperature increase of all tour boat passes was 0.45 °F (s = 0.57, n = 4), while the mean increase of all jet sled passes was 0.10 °F (s = 0.52, n = 6). Mean temperatures during 70 % of boat passes (7) were significantly warmer than temperatures recorded immediately prior to boat activity (Table 3). Likewise, 70 % of temperatures recorded immediately after boat activity were significantly higher than those recorded immediately before boat passes. Water temperatures decreased 40 % of the time and increased 60% of the time immediately following boat activity (Table 3).

Table 2. Boat activity and mean temperature change in refugia (mean temperature during boat activity minus mean temperature before boat activity). NS = not significant at $p < 0.05$ adjusted by Bonferoni methods.

Site	Pass #	Time	Boat Type	Approx. Distance Away (ft)	Wake Height (ft)	Mean Temperature Change (°F)
5	1	1225	Tour Boat	40	0.70	1.26
5	2	1248	Tour Boat	40	0.60	0.09
7	1	1314	Jet Sled	60	0.10	0.26
7	2	1318	Jet Sled	20	0.25	0.30
7	3	1323	Jet Sled	10	0.30	0.27
11	1	1112	Jet Sled	60	0.15	NS
11	2	1115	Tour Boat	60	0.70	NS
11	3	1125	Jet Sled	20	0.20	0.63
11	4	1130	Tour Boat	60	0.70	0.44
11	5	1134	Jet Sled	10	0.30	-0.88

Table 3. Summary of ANOVA comparisons of groups. A = mean water temperature two minutes prior to boat activity, B = two minutes during boat activity, C = mean temperature two minutes immediately following boat activity, % R. A. = percent relative abundance. When group means were unequal, results were significant using single factor ANOVA and Fisher's LSD, $p < 0.0001$, n = 10 boat passes.

Group	% R.A.	Group	% R.A.	Group	% R.A.
A > B	10	B > C	40	C > A	70
A = B	20	B = C	0	A = C	0
A < B	70	B < C	60	C < A	30
Total	100	Total	100	Total	100

Because of a small sample of commercial tour boat passes, and because the large boats produced substantially larger wakes than private jet sleds (Table 2), I did not pool data and used only jet sled data in regression analyses. There was a strong, negative linear correlation between jet sled distance from refugia and wake height (Fig. 7; $R^2 = 0.8679$, $p < 0.001$). However, there was no correlation between wake height or distance from refuge and mean refuge temperature change ($R^2 < 0.05$, $p = 0.4503$).

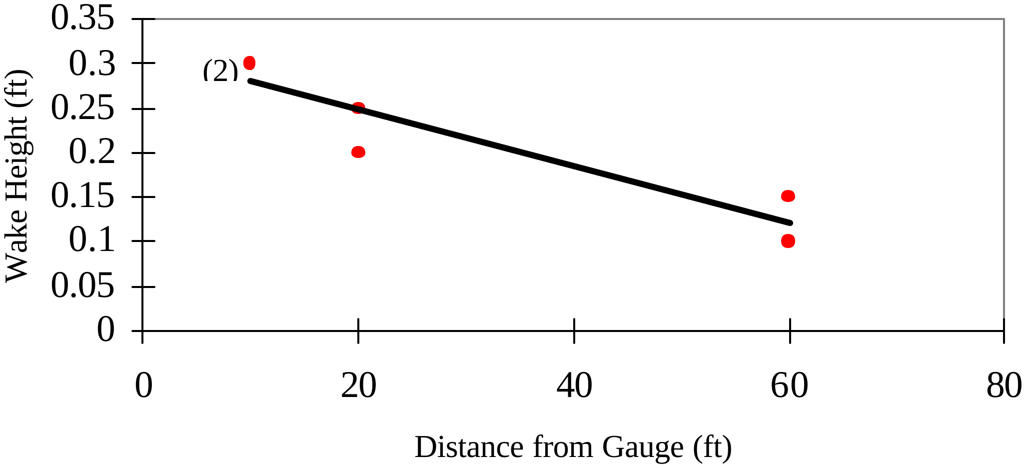

Figure 7. Relation between distances of jet sled from staff gauge and wake height. $y = -0.0032x + 0.3131$; $R^2 = 0.8679$; $p < 0.001$.

Fish

Adult salmonids were only observed at Site 11, while the highest number of juvenile salmonids (36) occurred at Site 7 (Table 3). On average, snorkeled refugia were 7.2 °F cooler than ambient river temperatures (s = 3.2, n = 4). Juvenile fishes, especially chinook presmolts, were oriented facing upstream into the tributary flow within one to two ft of tributary mouths. Although adult spring chinook were seen within two ft of the mouth of East Creek, they were also observed as far away as 20 ft downstream of the tributary junction. While the exotic cyprinids Umpqua pikeminnow (*Ptychocheilus umpquae*) and redside shiner (*Richardsonius balteatus*) were located in mainstem channel margins as well as refugia, salmonids were only observed in the immediate vicinity of refugia.

Table 4. Snorkeling observations of salmonids using potential thermal refugia.
-- = no data.

Site Number	Date	Time	Degrees (F) Below Mainstem	Species/Lifestage		
				Chinook Presmolts	Spring Chinook Adults	Steelhead Smolts
5	7/16	1130	9.1	7	0	0
7	7/11	1230	2.4	32	0	0
7	7/16	1420	--	36	0	2
11	7/11	1000	8.7	18	0	6
11	7/11	1130	--	20	0	4
11	7/16	0930	8.6	6	5	0
11	7/16	1600	--	12	2	3
Total				131	7	15

Snorkeling observations during seven boat passes (6 jet sled, 1 tour boat) suggested that chinook presmolts did not exhibit startle responses to boats or their associated turbulence, even when jet sleds passed within 10 ft of refugia. On one occasion, a 0.6-ft wake from a tour boat made it impossible to observe seven chinook presmolts for 2.75 minutes. However, it is unknown whether the fishes actually left the refugia or remained near their previous locations and were obscured by increased turbidity. Other boat wakes caused some minor changes (< 1 ft) in fish holding positions, but fishes returned to their previous locations within several seconds. Wakes at Site 11 appeared to increase feeding behavior in chinook presmolts, especially surface feeding activity. The number of fish counted in refugia did not change after boat activity had ended.

DISCUSSION

Temperature

While other refugia may occur in the 10-mile MWS, it is likely that the tributary junctions surveyed are some of the most important sources of cool water in this study reach. Nielsen and Lisle (1994) suggested that large inflows of cool water, such as those added by tributaries, are needed to prevent thermal mixing. This process might be especially true in relatively large rivers like the Rogue. Though alluvial riffles may be important to salmonids in the MWS for reasons involving cover, dissolved oxygen content, and feeding, tributary junctions are probably most important in respect to ameliorating the effects of warm temperatures. Furthermore, Bilby (1984) found that tributary contributions decreased mainstem water temperatures of a mid-order stream more than any other type of habitat feature, including riffles, and also suggested tributary mouths had the highest dissolved oxygen concentrations. Berman and Quinn (1991) speculated that tributary confluences are especially important to larger fishes, such as spring chinook, that have higher oxygen requirements than smaller fish.

Although all potential refugia were not snorkeled to determine salmonid usage, some that were snorkeled were not used by salmonids. Three potential reasons for this observation are: 1) Tributary inflow temperatures were warmer than ambient river temperatures (Site 4). 2) Areas had cooler temperatures, but lacked sufficient cover in the form of depth (Site 8). Several studies (e.g. Nakamoto 1994; Baigun et al. 2000) suggest that depth cover may be more important than temperature in determining holding areas for adult summer steelhead. 3). Sampling effort was too restricted. Some of these sites were only surveyed once, and may have been used by salmonids at different times throughout the summer. However, even though sampling effort was limited to three days, the study period coincided with the warmest water temperatures recorded this year (Fig. 3). This temporal overlap increases the validity of observations made during those dates.

Continuous temperature monitoring showed that water temperatures in some areas (e.g. Brushy Riffle, Site 7) were relatively stable over short time periods. Although there was a general warming trend of 1 °F over 15 min at Site 7, most of the sharp spikes in temperature were associated with boat activity. Conversely, Sites 5 and 11 showed large, often erratic, natural fluctuations in water temperature over the course of an hour. These periodic fluctuations in water temperatures were felt when snorkeling Site 11 as cool water from East Creek entered the confluence pool in distinct pulses.

Another variable in temperature monitoring is that thermographs may not represent the actual ambient water temperature where most fish were located. Since most fish were oriented within one ft of inflows, and since most data loggers were located slightly farther away from the inflow, it is possible that water temperatures where fish were located were actually cooler than those recorded.

Boat Activity

Observed values for boat wake heights in this study were very similar to those observed by Satterthwaite (1995). In the current study, tour boats always produced larger wakes than private jet sleds, even when jet sleds were six times closer to the gauge. Although the sample was too small to compare statistically, visual inspection of data did not suggest a linear relationship between wake height and distance from the gauge for commercial tour boats.

To answer the question of how much motorboat wakes affected the physiology of migrating salmonids, I visually estimated the maximum value of mean temperature change during tour boat activity (Site 5, Pass 1, 1.26 °F for 6.5 min) and the maximum value for jet sled activity (Site 11, Pass 3, 0.63 °F for 1.9 min). I also calculated effects separately using average values of mean temperature increase (0.45 °F for tour boats and 0.10 °F for jet sleds). For these latter two calculations, I used two minutes as the average time of temperature increase related to boat activity. I determined the total time period of temperature increase by multiplying the number of tour boat trips into the MWS per day (six) by two, to account for upstream and downstream travel past refugia. This assumed that the same wake intensity was produced from boats traveling downstream.

Using Q_{10} bioenergetic models calculated for Yakima River spring chinook by Berman and Quinn (1991) and extrapolated from sockeye salmon (*Oncorhynchus nerka*) (Brett and Glass 1973), I calculated that the current level of daily boat activity (six tour boats and 12 private sleds) could increase the daily standard metabolism of a Rogue River spring chinook by 0.05 (mean) to 0.09 (maximum) percent (Appendix A). This model makes several assumptions that need to be validated. The first is that the maximum amount of allowable boat use occurs on a given day. The second is that each boat passes a refuge twice each day (once upstream and once downstream, which may not be true in the case of lodge boats or overnight campers). Furthermore, the actual metabolic effects to Rogue River spring chinook may be less than calculated because of their relatively large body size and proportionately higher metabolic efficiency (Berman and Quinn 1991), and the high metabolism of sockeye (Brett and Glass 1973).

While this Q_{10} model may work relatively well for adult spring chinook and if adjusted, summer steelhead, it should not be applied to chinook presmolts, the most common salmonid observed in this study. Extrapolating bioenergetic models derived from one age class to another is not recommended due to weight-specific biases in metabolism vs. weight power functions (Ney 1993). Subsequently, one of the most precise *in situ* estimates of juvenile chinook upper incipient lethal temperatures is 73.4 °F (95% C.I. = ± 2.0 °F) (Baker et al. 1995). Figure 5 suggests that boat activity (Pass 3) may have pushed refuge temperature above this incipient threshold. However, water temperatures within the refuge before boat activity were within the lower 95% limit of this incipient estimate.

I also calculated estimates of lethality from this exposure time and temperature using the formula: $1 = \text{time} / 10^{[a + (b \cdot (\text{temp }^\circ\text{C} + 2\ ^\circ\text{C}))]}$, where “a” and “b” are regression equation coefficients from experimental studies (Armour 1991). Inspection of thermographs from all three sites showed that this observation (Site 7, Pass 3) was the only time boat activity directly increased refuge temperature to its maximum level. Using two different acclimation temperatures (68.0 and 75.2 °F), I found the chance of lethality to juvenile chinook from motorboat-related temperature increase at this site to be negligible (Appendix B). This site (Flora Dell) is also an area where chinook presmolts may be able to orient farther up the shallow inflow stream than larger fishes to compensate for wake turbulence.

Fish

Snorkel observations suggested that the presence of boats and their wakes did not elicit startle responses in salmonids using thermal refugia. These results were similar to Satterthwaite (1995) who almost always found boats to produce startle responses in juvenile salmonids only when they passed directly overhead. The current study did not pass boats directly over fish because the refugia were located close to the shore line where it was difficult or impossible to operate motorboats. Since startle responses were not observed in the current study it is unlikely that boat activity produced any other bioenergetic costs—such as those associated with increased swimming speed or physical stress (Barton and Schreck 1987)—than those directly related to elevated temperature.

Total numbers of fish observed in this study, especially adult spring chinook and summer steelhead, were relatively low. While sampling effort was limited, the low observed densities of salmonids suggested that they might spend less time in the MWS, relative to other sections of the lower Rogue River (unpublished data 2002). Although this theory needs to be validated, personal observations suggest that tributary junctions upstream of the MWS (e.g. Stair, Mule, Kelsey, Rum, and Whisky creeks) are more likely to be used for holding by migrating adult spring chinook than those in the MWS. Current research suggests that refugia important to salmonids may occur on larger scales, such as the reach or sub-basin level, than previously expected (Torgersen et al. 1999; Fausch et al. 2002). If this pattern exists in the lower Rogue River, spring chinook may migrate quickly through the MWS to documented holding and spawning habitat upstream. However, a greater sampling effort may have revealed diel or seasonal trends in salmonid distributions within these refugia not captured in this study.

While salmonid numbers observed in refugia were relatively low, tributary confluences were the only habitats where salmonids were observed in the MWS. Even if these areas may be less important to adult spring chinook, based on total numbers observed, they might still be important areas to juvenile and sub-adult chinook and steelhead. These refugia may function as areas where juvenile salmonids can out-compete exotic cyprinids that have an otherwise competitive advantage in warmer water temperatures (e.g. Reeves et al. 1987). In the current study I observed spatial segregation between chinook presmolts and exotic cyprinids, with chinook located closer to the cool inflows than cyprinids. Motorboat wakes did not produce agonistic behavior between species, nor did wakes disrupt spatial segregation.

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

While motorboat wakes did create statistically significant increases in water temperatures within refugia used by migrating salmonids, the mean increase in water temperature (0.24 °F) was small, and the biological significance of this increase seems slight. Bioenergetic modeling predicted that current levels of motorboat activity could increase the standard daily metabolism of an adult spring chinook by less than one percent. The chance of lethality to juvenile chinook from motorboat activity calculated from data at Site 7 was negligible. Startle behavior was not observed in juvenile salmonids in response to boat activity or wakes. Although wakes appeared to create a short-term physical disturbance within refugia, salmonids returned to their prior positions within a short time period. I conclude from this cursory research that the current level of motorboat activity and their wakes has minor effects on the physiology of migrating salmonids in the MWS.

On the other hand, salmonids can detect smaller changes in water temperature than those encountered in this study (Berman and Quinn 1991), suggesting some fishes may be affected by even minute changes in temperature. Boat activity occurring later in the day than measured by this study may have greater effects on salmonid physiology if ambient water temperatures are warmer. Also, the physiology of smaller adult and sub-adult summer steelhead may be affected differently than larger spring chinook. Furthermore, these fishes may also hold in riffles in the MWS, where motorboats could elicit startle responses by passing directly overhead. It has also been suggested that limited coho and fall chinook spawning may occur in the lower Rogue River mainstem during low water years (Rutledge pers. comm. 2002). Motorboat activity near redds could possibly disrupt spawning behavior or incubation. Consequently, it is possible that current motorboat levels in the MWS affect salmonids in other ways.

These above theories are speculative and could be explored with further studies. Future research should consider the use of FLIR (Forward Looking Infra-Red) to identify any thermal refugia in the MWS that may have been overlooked in this study. Radio telemetry studies would help answer the question of how long certain species hold within the MWS, as well as determine microhabitat preferences. Salmonids, especially summer steelhead and spring chinook, could be implanted with transmitters that measure body temperature; this would give a more accurate description of the degree that boat wakes affect fish physiology. More experiments could be conducted with *in situ* tour boat trials after refugia have been identified with FLIR and verified by snorkeling. Finally, a higher level of temporal resolution should be used with data loggers (i.e. timers and loggers should be synchronized to the level of seconds). It is likely that thermal disturbance from boat wakes within refugia does not last a full two minutes. Rather, this was a somewhat arbitrary interval selected because the exact times that thermal disturbance began and ended were unknown.

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APPENDIX A

Q_{10} Bioenergetic Calculations

		°F =	°C	% increase in R_s [a]	Mean time (min)	Max # of boats	# of passes	Total # of min	Total # of hr
Max	Tour Boat	1.26	0.7	7.0	6.5	6	2 [c]	78.0	1.30
	Jet Sled	0.63	0.35	3.5	1.9	12 [b]	2 [c]	45.6	0.76
Mean	Tour Boat	0.45	0.25	2.5	2.0	6	2 [c]	24.0	0.40
	Jet Sled	0.10	0.06	0.6	2.0	12 [b]	2 [c]	48.0	0.80

[a] = By applying Q_{10} formula where every increase of 10 °C leads to a doubling in R_s (standard or basal metabolism)

[b] = Assumes six private permits and six lodge or commercial fishing guides in a given day. On the average, less than this amount of boat traffic occurs (Blackwell pers. comm. 2002).

[c] = Assumes every boat that goes up the MWS comes back down the same day. Does not account for users who stay at lodges or camp overnight along the river.

Equation for

$[(R_{s1} \text{ x } T_1 \text{ h}) + (R_{s2} \text{ x } T_2 \text{ h})] / 24 \text{ h/day}$ = daily % increase in R_s

Maximum

$[(1.07 \text{ x } 1.3 \text{ h}) + (1.035 \text{ x } 0.76 \text{ h})] / 24\text{h/day} = .0907$ % increase in daily R_s

Mean

$[(1.025 \text{ x } 0.4 \text{ h}) + (1.006 \text{ x } 0.8 \text{ h})] / 24\text{h/day} = .0506$ % increase in daily R_s

APPENDIX B

Estimation of Lethality of an Exposure Time (Armour 1991)

Equation:

$1 = \text{time} / 10^{[a + (b \bullet (\text{temp } ^\circ\text{C} + 2\ ^\circ\text{C}))]}$, where “a” and “b” are regression equation coefficients from experimental studies

If the quotient is =1, the exposure time is lethal. The 2 °C constant is a safety margin to ensure 100% survival (Coutant 1972).

The following constants are for juvenile spring chinook salmon from Armour 1991:

Acclimation Temperature (°C)	a	B
20	22.9065	-0.7611
24	18.9940	-0.5992

Site 7, Pass 3 calculated at an acclimation temperature of 24 °C:
$1 = \text{time (min)} / 10^{[18.9940 + (-0.5992 \bullet (\ ^\circ 23.3 + 2\ ^\circ\text{C}))}$

Time = 81. 7 min (2.27 min of recorded Pass 3 temperature fluctuation x 18 boats/ day maximum (6 tour boats and 12 private) x 2 passes/ boat)

$1 = 81.7 / 10^{[18.9940 + (-0.5992 \bullet (\ ^\circ 23.3 + 2\ ^\circ\text{C}))}$
$= 81.7 / 7837 = 0.0104$
$0.0104 < 1$, so exposure time is not lethal

Site 7, Pass 3 calculated at the more conservative acclimation temperature of 20 °C:
$1 = 81.7 / 10^{[22.9065 + (-0.7611 \bullet (\ ^\circ 23.3 + 2\ ^\circ\text{C}))}$
$= 81.7 / 4474 = 0.0183$
$0.0183 < 1$, so exposure time is not lethal