North American Journal of Fisheries Management 16:314–323, 1996

Comparison of Day Snorkeling, Night Snorkeling, and Electrofishing to Estimate Bull Trout Abundance and Size Structure in a Second-Order Idaho Stream

RUSSELL F. THUROW

U.S. Forest Service, Intermountain Research Station
316 East Myrtle, Boise, Idaho 83702, USA

DANIEL J. SCHILL

Idaho Department of Fish and Game
3806 Powerline Road, Nampa, Idaho 83686, USA

Abstract.—Biologists lack sufficient information to develop protocols for sampling the abundance and size structure of bull trout *Salvelinus confluentus*. We compared summer estimates of the abundance and size structure of bull trout in a second-order central Idaho stream, derived by day snorkeling, night snorkeling, and electrofishing. We also examined the influence of water temperature and habitat type on day and night counts of bull trout. Electrofishing yielded the largest estimates of abundance of age-1 and older bull trout. Day snorkeling counts accounted for a mean of 75% and night snorkeling counts a mean of 77% of the fish estimated by electrofishing. Numbers of age-1 and older bull trout observed during day counts did not differ from numbers observed at night. Water temperatures during underwater surveys were 9–13.5°C. Counts were not influenced by temperatures in this range; however, statistical power of the tests was low. The three sampling techniques yielded similar estimates of the size structure of the bull trout population. When compared with electrofishing, underwater estimates recorded fewer small fish and overestimated the size of some fish. We detected no significant interaction between the type of snorkeling count (day or night) and fish densities observed in different habitat types. Densities of bull trout observed during both day and night were similar, regardless of the habitat type. Under the conditions of water temperature, conductivity, visibility, and habitat in which we sampled, day snorkeling surveys were suitable for estimating the relative abundance and size structure of the bull trout population. Our results conflict with those of other studies that suggest night snorkeling is more effective than day snorkeling for censusing bull trout. Explanations for this discrepancy may include differences in stream temperature and stream channel features.

Bull trout *Salvelinus confluentus* are native to the northwestern United States and southwestern Canada (Meehan and Bjornn 1991). Their range is discontinuous from about 41° to 60°N latitude (Bond 1992). A combination of factors including habitat degradation, expansion of exotic species, and exploitation have contributed to the decline and fragmentation of indigenous bull trout populations. Populations have declined throughout much of the range; some local populations are extinct, and many other stocks are isolated and may be at risk (Rieman and McIntyre 1995). Of 65 populations surveyed in Oregon, 12 were categorized as probably extinct and 31 had a moderate to high risk of extinction (Ratliff and Howell 1992). In Washington, 15 of 35 surveyed populations were categorized as having a moderate to high risk of extinction (Washington Department of Wildlife 1992). In recognition of declines in abundance and distribution, numerous federal, state, and provincial management agencies in the U.S. and Canada list bull trout as a species of special concern (Johnson 1987). Concern for the persistence of bull trout culminated in petitions for review of the species' status, and in June 1995, the U.S. Fish and Wildlife Service determined that listing under the Endangered Species Act was warranted but precluded.

Information on the distribution, abundance, and life history requirements of bull trout is lacking. Throughout much of the species' range, there is insufficient inventory even to determine presence or absence (Rieman and McIntyre 1993). Protocols for detecting bull trout presence and absence have been developed (Hillman and Platts 1993; Rieman and McIntyre 1995); however, biologists lack sufficient information to develop protocols for sampling bull trout abundance and size structure across the full range of potential habitat. Managers will require quantitative estimates of bull trout abundance and size structure to monitor the effectiveness of conservation strategies.

Behavior of bull trout and their habitat requirements may make the fish difficult to sample. They appear to have an affinity for stream reaches colder than 15°C (Pratt 1984; Goetz 1994). Many populations reside in streams with low water conductivities (<100 μS/cm) and high water clarity. Bull trout are cryptic and frequent areas with instream overhead cover and coarse substrate (Pratt 1984). Juvenile bull trout are closely associated with the streambed and may be found above, on, or within substrate (Pratt 1992). Common sampling techniques like electrofishing may fail to detect bull trout or underestimate their true abundance. Underwater counts of bull trout in stream reaches after successive removal by electrofishing showed unexpectedly large numbers of fish remaining in the reaches (Fraley et al. 1982).

Underwater surveys also may fail to detect bull trout or may underestimate their abundance. Their coloration and cryptic behavior make them difficult to see. Several biologists have reported that daytime counts underestimated the true abundance of juvenile bull trout (Shepard and Graham 1983; Fraley and Shepard 1989; Goetz 1994). Goetz (1994), Bonneau et al. (1995), and Jakober (1995) compared day and night snorkeling counts of bull trout and found that night counts exceeded day counts. Few biologists have compared day and night underwater counts with electrofishing estimates. Goetz (1994) and Jakober (1995) compared day snorkeling, night snorkeling, and electrofishing in various habitats and reported that day snorkeling underestimated bull trout abundance.

In this paper we compare day snorkeling, night snorkeling, and electrofishing for estimating the abundance and size structure of bull trout. We also examine the influence of water temperature and habitat type on the accuracy of day and night snorkeling counts.

Study Area

All observations of bull trout were made in Profile Creek, a second-order tributary to the East Fork of the South Fork Salmon River near Yellowpine, Idaho. Profile Creek flows through the central Idaho Batholith, an area of granitic bedrock characterized by steep slopes and highly erodible soils (Megahan et al. 1980). The creek originates near 1,800 m elevation and has an average gradient of 4%. Peak stream discharges are caused by snowmelt and typically occur in May or June with base flows from September through January. Most annual precipitation above 1,200 m falls as snow and can exceed 1.5 m.

Bull trout are the most abundant salmonid in Profile Creek; both fluvial and resident forms are present. Other native fish include steelhead *Oncorhynchus mykiss,* chinook salmon *O. tshawytscha,* westslope cutthroat trout *O. clarki lewisi,* mountain whitefish *Prosopium williamsoni,* dace *Rhinichthys* spp. and sculpins *Cottus* spp.

We selected six study reaches averaging 140 m long and 5.1 m wide in the lower 5 km of Profile Creek. We classified consecutive habitat types as pool, riffle, run, or pocket water (Bisson et al. 1982) in four reaches (1, 2, 5, and 6). Pocket water and run habitats were most common (58% of total); pools and riffles were equally common (21% each). Woody debris, large substrate, water depth, and surface turbulence provided instream cover. Woody debris was observed in 48% of the surveyed habitats and covered up to 85% of the surface area of some habitats. Boulder (>30 cm) and bedrock were the dominant substrates in 65% of the habitats and may be a surrogate for woody debris (Flebbe and Dolloff 1995). Maximum water depths were 0.4–1.1 m. On August 10, 1990, discharge was 0.71 m^3/s and conductivity was 102 μS/cm, corrected to 25°C.

Methods

Before sampling fish, we installed a continuously recording thermograph and measured water temperatures hourly. Block nets were installed at the upper and lower boundaries of each reach and inspected by a snorkeler.

All counts were completed from August 2 to 10, 1990. We conducted day counts first, between 1000 and 1600 hours when the sun was overhead. Night counts were conducted between 2300 and 0500 hours and within 24 h of the day counts. We used identical techniques during day and night except that night counts were completed with the aid of an underwater halogen light. All night counts were completed during full moon.

Counts were begun at the downstream end of each reach. During each count, a snorkeler equipped with a wetsuit, mask, snorkel, and recording sleeve proceeded slowly upstream searching for fish. We counted the total number of age-1 and older (age-1+) bull trout and other salmonids and estimated their total length (TL) by approaching fish, aligning their snout and tail with adjacent objects, and measuring that distance (Cunjak and Power 1986) or by aligning the fish with a known distance. We classified fish into 100-mm length groups (<100, 100–199, 200–299 mm), excluding age-0 fish less than 60 mm because of the difficulty in accurately counting salmonid fry (Griffith 1981). We made three replicate day counts and three replicate night counts in reaches 1, 2, 5, and 6. The second and third counts were begun about 1 h after the previous count was completed. The delay was to allow fish that may have been disturbed to return to their original locations. We completed one day and two night counts in reaches 3 and 4. During each count, an observer on shore walked behind the snorkeler, called out habitat boundaries, and recorded data.

Each reach was electrofished within 1 week of the underwater surveys. In reaches 1 and 2, block nets were held in place and electrofishing estimates were completed within 1 d of the underwater surveys. In reaches 3–6, we removed block nets after snorkeling and reinstalled them before electrofishing. We used two generator-powered backpack electrofishers with 30-cm ring anodes and wire cathodes and operated them simultaneously while proceeding upstream.

We conducted depletion-type population estimates (Seber and LeCren 1967). During each pass, all captured salmonids were counted and placed in live wells. We made two passes in reaches 2 and 3 where catches declined by 75% or more between successive catches. We made three passes in reach 1 and four passes in reaches 4–6. After the final pass, we anesthetized all bull trout and measured their total length before releasing them.

After electrofishing, we measured physical habitat characteristics of each reach. Within reaches 1, 2, 5, and 6, we measured the total length and average width of each delineated habitat. In reaches 3 and 4, we did not delineate individual habitats and simply measured the total length and mean width of the reaches.

We compared bull trout abundance estimates derived by the three techniques. We compiled the total number of trout observed during each day or night snorkeling count by reach. In reaches where counts were replicated, we averaged the replicated day and replicated night counts and calculated 95% confidence intervals about the means (Zar 1974). We used the one day count as the abundance estimate in the two reaches where counts were not replicated. We used the MicroFish software (Van Deventer and Platts 1989) to calculate electrofishing population estimates and 95% confidence intervals. The lower confidence interval for the electrofishing population estimate was truncated to equal the total number of fish captured. We used analysis of variance (ANOVA) with reach as a blocking variable to compare abundance estimates from the three techniques. Count data were logarithmically transformed. We performed multiple comparisons using Tukey–Kramer analysis (Sokal and Rohlf 1981).

The influence of replicating snorkel counts on abundance estimates was evaluated by two methods. We repeated the ANOVA described above and substituted the initial day or night snorkeling counts for the mean snorkeling counts and compared the two ANOVAs. Second, we used ANOVAs with reach as a blocking variable and compared replicated day or night counts (count 1 versus count 2 versus count 3).

Accuracy of underwater counts has been difficult to assess because the true population density is usually unknown (Hillman et al. 1992). Hankin and Reeves (1988) and Rodgers et al. (1992) suggested calibrating snorkeling counts with electrofishing and other methods of estimating population size. We assumed our electrofishing estimates represented the most accurate or "true" abundance estimates because we consistently captured more fish than we observed when snorkeling. We expressed individual day and night snorkeling counts as ratios of the electrofishing estimate by reach. To compare the precision of estimates, we calculated coefficients of variation (Zar 1974).

We evaluated the influence of water temperature on underwater abundance estimates by regressing underwater counts against water temperatures at the onset of each snorkeling count. We used *t*-tests to determine if the slopes of regression lines were significantly different from zero. When regressions were not significant, we calculated the statistical power of the test using tables in Cohen (1988) to approximate power.

We compared length-frequency distributions of bull trout estimated by the three techniques. We pooled all fish length estimates among reaches and derived cumulative length-frequency distributions by method. A Kolmogorov–Smirnov two-sample test was used to compare cumulative length-frequency distributions derived by the three techniques (Steele and Torrie 1980).

To evaluate the influence of habitat type on snorkeling counts, we compared densities observed during day and night snorkeling in different habitats. We calculated the surface area of each habitat snorkeled in reaches 1, 2, 5, and 6 and stratified the surface areas by habitat type (pool, riffle, run, pocket water). Using the initial day or night count, we calculated the density (fish/100 m^2) of trout observed in each habitat and stratified the data by habitat type. We used the initial counts to reduce the risk that fish were disturbed by the snorkeler and left their preferred habitats. We used a two-

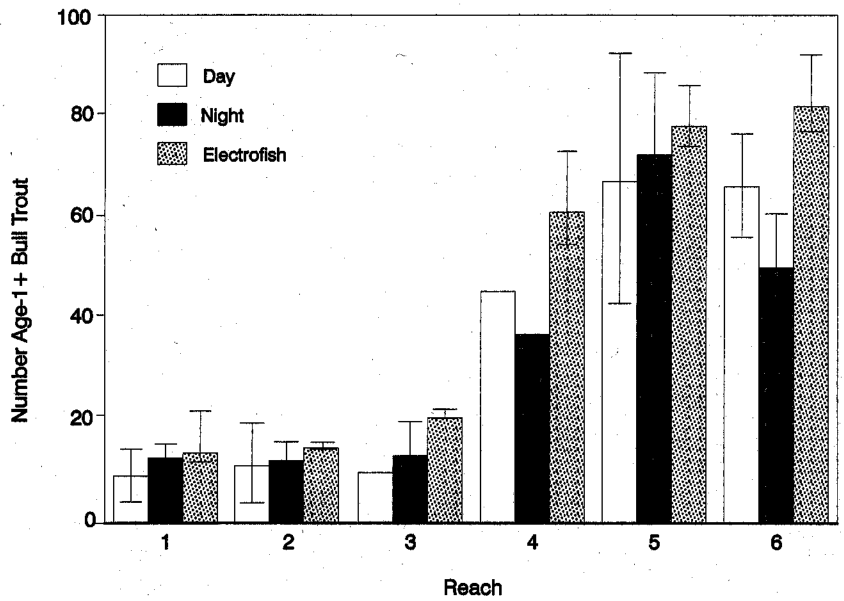

FIGURE 1.—Numbers of age-1 and older (age-1+) bull trout estimated by day snorkeling, night snorkeling, and electrofishing in six reaches of Profile Creek. Snorkeling estimates in reaches 1, 2, 5, and 6 are means of three counts; night counts in reaches 3 and 4 are means of two counts. Vertical lines depict 95% confidence intervals.

way ANOVA to test for interaction between fish densities in habitat types and the type of underwater count (day or night). Counts in some habitats equaled zero so we transformed the data (square root of density + square root of density plus 1) to normalize residuals (Kirby 1993).

Results

Abundance estimates differed between electrofishing and snorkeling techniques. Electrofishing yielded the largest estimates of age-1+ bull trout abundance (Figure 1). Electrofishing estimates were significantly larger than mean day underwater counts ($P < 0.01$) and mean night underwater counts ($P < 0.02$).

We found no consistent difference between day and night underwater counts. Multiple comparison tests suggested that mean numbers of age-1+ bull trout observed during day counts did not differ significantly ($P = 0.84$) from numbers observed at night. Mean day counts exceeded mean night counts in four reaches, whereas mean night counts exceeded mean day counts in two reaches. Day and night counts varied by observer; however, mean day and night counts did not differ significantly. Diver 1 observed more fish at night in six of eight day–night comparisons, whereas diver 2 observed more fish during the day in six of six comparisons.

Individually replicated underwater counts (count 1 versus count 2 versus count 3) were similar to each other and to mean counts by reach (Table 1). Neither replicated day counts ($P = 0.5$) nor replicated night counts ($P = 0.86$) were significantly different. Electrofishing estimates were significantly ($P < 0.02$) larger than individual replicate day or night underwater counts. Replicated day counts ($N = 14$) averaged 75% of the electrofishing estimate (SD, 0.153; range, 0.476–0.962) and replicated night counts ($N = 16$) averaged 77% of the electrofishing estimate (SD, 0.159; range, 0.50–1.0) (Table 1).

Precision of abundance estimates varied by method. Coefficients of variation were less than 10% in two of four day snorkeling estimates, five of six night snorkeling estimates, and five of six electrofishing estimates (Table 2). We replicated 126 counts in 42 habitats where at least one fish was observed. Mean counts ranged from 1 to 6 trout; 85% of the individual replicate counts were within one fish of the mean, and 98% were within two fish of the mean.

We completed day and night snorkeling surveys in water ranging from 9 to 13.5°C. Except for counts in reach 6, regressions of underwater counts against temperature were not significantly different from zero. Coefficients of determination ranged from 0.06 to 0.22 and all P values exceeded

TABLE 1.—Numbers of age-1+ bull trout estimated by day snorkeling, night snorkeling, and electrofishing in six reaches of Profile Creek. The proportion of the electrofishing population estimate observed by individual snorkeling counts appears in parentheses. Only one day and two night snorkeling counts were made in reaches 3 and 4.

Reach	Day snorkeling				Night snorkeling				Electro-fishing estimate
	Count 1	Count 2	Count 3	Mean	Count 1	Count 2	Count 3	Mean	
1	11 (0.786)	7 (0.500)	10 (0.714)	9.3	13 (0.929)	14 (1.000)	12 (0.857)	13.0	14
2	8 (0.533)	14 (0.933)	12 (0.800)	11.3	11 (0.733)	13 (0.867)	13 (0.867)	12.3	15
3	10 (0.476)				13 (0.619)	14 (0.667)		13.5	21
4	46 (0.742)				44 (0.710)	31 (0.500)		37.5	62
5	57 (0.722)	71 (0.899)	76 (0.962)	68.0	67 (0.848)	79 (1.000)	74 (0.937)	73.3	79
6	63 (0.759)	67 (0.807)	71 (0.855)	67.0	47 (0.566)	50 (0.602)	55 (0.663)	50.7	83

0.4. Sample sizes were small, however, and the statistical power of the regressions (the probability of correctly rejecting H_0) was less than 25%. Counts of bull trout in reach 6 increased significantly as water temperature increased from 11 to 13.2°C ($P < 0.02$, $r^2 = 0.81$).

We captured 257 age-1+ and 8 age-0 bull trout while electrofishing in all reaches combined. Age-0 bull trout averaged 45 mm TL and ranged from 41 to 48 mm. Age-1+ bull trout ranged from 70 to 630 mm TL (Figure 2). We did not capture any bull trout from 300 to 600 mm TL.

The three sampling techniques yielded similar pooled estimates of the size structure of the age-1+ bull trout population (Figure 3). Snorkelers recorded more bull trout from 200 to 299 mm and fewer from 100 to 199 mm than were captured by electrofishing (Figure 3). Snorkelers also recorded a small number of fish in the 300–399-mm size-class that were not captured by electrofishing (Figure 2). Size structure estimates did not differ significantly ($P = 0.19$) among the three techniques. Day snorkeling and night snorkeling yielded nearly identical estimates of the population size structure.

We did not detect any significant ($P = 0.69$) interaction between the type of snorkeling count

TABLE 2.—Coefficients of variation (SE/mean) for day snorkeling, night snorkeling, and electrofishing population estimates of bull trout in six reaches of Profile Creek.

Sampling method	Reaches					
	1	2	3	4	5	6
Day snorkeling	0.13	0.16			0.08	0.03
Night snorkeling	0.04	0.05	0.04	0.17	0.05	0.05
Electrofishing	0.27	0.04	0.05	0.09	0.05	0.05

(day or night) and fish densities observed in different habitat types. Densities of bull trout observed during both day and night were similar, regardless of the habitat type (Figure 4). Bull trout densities were highest in pools and runs and lowest in riffles.

Discussion

Electrofishing consistently yielded larger estimates of bull trout abundance than did snorkeling. Both day and night snorkeling counts had similar sampling efficiencies. Daytime counts accounted for an average of 75% and night counts an average of 77% of the bull trout estimated with electrofishing. Goetz (1994) also compared day and night snorkeling counts with electrofishing in two streams. Day counts of age-1+ bull trout averaged 71% of electrofishing estimates, but in contrast to our results, electrofishing estimates were less than night counts in six of seven habitats and averaged 53% of night counts. Jakober (1995) reported that night counts averaged 80% and day counts 10% of bull trout electrofishing efforts. Shepard and Graham (1983) compared daytime snorkeling counts with electrofishing estimates in three reaches of a Montana stream. Their daytime underwater surveys accounted for an average of 78% of the bull trout estimated with electrofishing. Bonneau et al. (1995) reported that electrofishing was ineffective for capturing bull trout in small streams with conductivities less than 50 μS/cm.

We observed no differences in day and night snorkeling counts of bull trout, in contrast to results reported by several other researchers (Bonneau 1994; Goetz 1994; Bonneau et al. 1995; Jakober 1995). The other researchers reported that average night counts of bull trout exceeded day

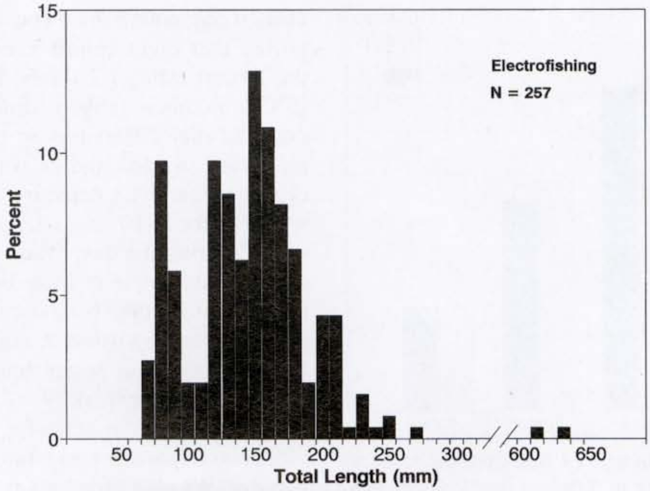

FIGURE 2.—Length frequency of age-1+ bull trout captured by electrofishing in six reaches of Profile Creek.

counts by 3.8–8.4 times (Bonneau 1994), 3.6–3.9 times (Goetz 1994), and 5–10 times (Jakober 1995).

Comparisons of day and night underwater counts may change in response to water temperature, so differences in water temperature among studies may explain discrepancies in results. As water temperatures decline, stream-dwelling salmonids typically seek cover or migrate (Edmundson et al. 1968; Everest and Chapman 1972; Hillman et al. 1987; Griffith and Smith 1993). As salmonids seek cover at colder temperatures, the

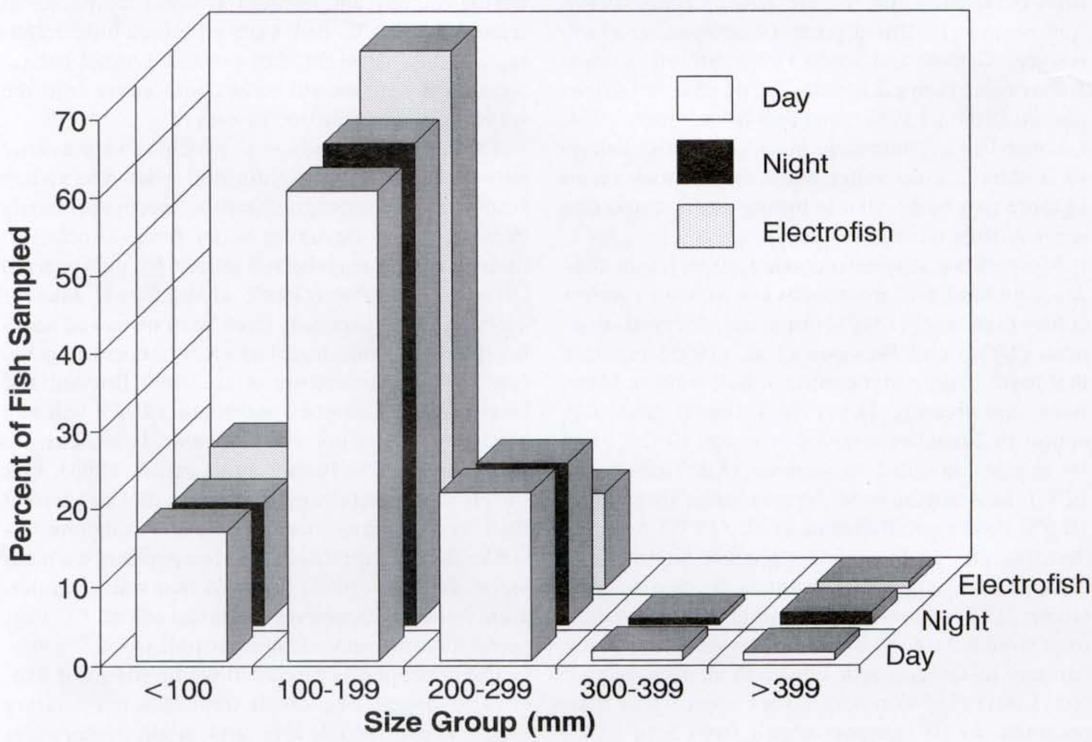

FIGURE 3.—Length-frequency distributions of age-1+ bull trout estimated by day snorkeling, night snorkeling, and electrofishing in Profile Creek.

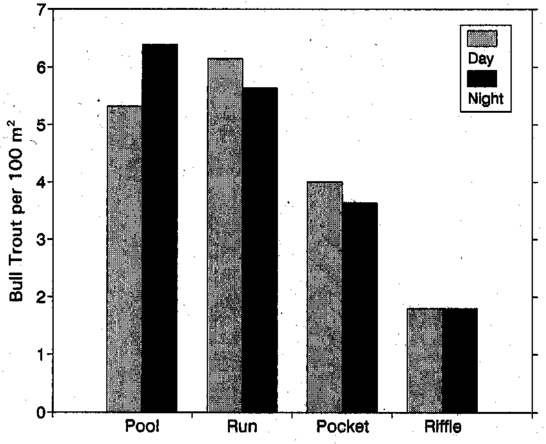

FIGURE 4.—Density of age-1+ bull trout observed by day and night snorkeling in different Profile Creek habitat types.

accuracy of daytime underwater counts may decline (Hillman et al. 1992; Riehle and Griffith 1993). Juvenile salmonids that remain concealed during the day may exhibit a diel behavioral shift and move into the water column at night. Diel behavioral shifts have been observed in rainbow trout (Campbell and Neuner 1985; Contor 1989), Yellowstone cutthroat trout *Oncorhynchus clarki bouveri* (Griffith and Smith 1993), Atlantic salmon *Salmo salar* (Cunjak 1988), Arctic char *Salvelinus alpinus* (Stenzel 1987), and bull trout (Goetz 1994; Jakober 1995; Thurow, in press). This diel behavioral shift at cold water temperatures may result in more fish being visible during night snorkeling surveys than during day surveys.

Most of the studies reporting larger night than day counts of bull trout were conducted in waters colder than the 9–13.5°C range we surveyed. Bonneau (1994) and Bonneau et al. (1995) reported that night underwater counts of bull trout in Idaho were significantly larger (8.4 times) than day counts in 2 reaches sampled in winter (0–2°C) and 10 reaches sampled in summer (3.8 times at 7–12°C). In a test at water temperatures from 11 to 12.5°C, however, Bonneau et al. (1995) reported that day and night counts were not significantly different. At water temperatures from 6 to 9°C, Goetz (1994) reported that night counts of bull trout were 3.9 times larger than day counts in seven habitats in Oregon and Washington. In a second test, Goetz (1994) reported maximum water temperatures in 10 streams ranged from 5 to 11°C, with maximum water temperatures in two streams exceeding 9°C. Night counts in the 10 streams exceeded day counts by 3.6 times. Goetz (1994) reported that night counts exceeded day counts by the largest ratio (7.2 times) in the coldest stream (5°C). Jakober (1995) similarly reported pronounced diel differences in observed densities of bull trout in Montana as water temperatures declined below 7°C; densities observed at night in winter were 5–10 times larger than densities observed during the day. Water temperatures in each of these studies may have been sufficiently cold to stimulate a diel behavioral shift causing more bull trout to be visible at night.

At the summer water temperatures in Profile Creek during our work (9–13.5°C), we did not observe a diel shift in behavior, and counts were not influenced by water temperatures at the time of the surveys. We also found no evidence that bull trout used different habitat types during the day than at night. As water temperatures declined during a later survey of Profile Creek in fall, we did observe a diel shift in behavior. In October 1990, we snorkeled reaches 3 and 5 during the day at a water temperature of 2°C. No bull trout were observed in the water column, and fish were concealed beneath cobble and small boulder substrate in pools. In November 1991, we snorkeled reaches 3 and 5 during the day and at night at water temperatures from 0.7 to 1.6°C. Bull trout remained hidden during the day. At night, fish exhibited a diel behavioral shift and moved away from cover into the water column (Thurow, in press).

The temperature range at which diel behavioral shifts occur is undefined for bull trout. The switch from diurnal to nocturnal activity occurs primarily in response to declining water temperatures, although it also may be influenced by photoperiod (Rimmer and Paim 1990; Goetz 1994; Jakober 1995). Other salmonids have been observed seeking daytime concealment at water temperatures below 8–9°C (Edmundson et al. 1968; Bustard and Narver 1975; Campbell and Neuner 1985; Hillman et al. 1987; Cunjak 1988; Contor 1989; Griffith and Smith 1993; Riehle and Griffith 1993). Our Profile Creek data suggest that the diel behavioral shift in bull trout occurs at water temperatures colder than the minimum 9°C temperature we measured. Jakober (1995) reported that water temperature below an approximate threshold of 7°C triggered daytime concealment in bull trout.

The concept of a threshold is important for fisheries managers because it implies a temperature exists above which day and night underwater counts would be similar. Day snorkeling is safer and accessing remote sites during the day is logistically easier. Night snorkeling can be hazardous in streams with steep gradients, large substrate, dense woody debris, and cold temperatures. Further research is needed to evaluate the influence of temperature on diel behavior and to determine if temperature guidelines can be developed for day and night snorkeling surveys.

The three sampling techniques we tested yielded similar estimates of the size structure of the age-1+ bull trout population. Although snorkelers recorded fewer fish in the two smaller size-groups (<100 and 100–199 mm) than were captured by electrofishing (Figure 3), differences were not significant. Differences in abundance estimates may have been influenced by snorkelers missing some small fish less than 200 mm. Small fish, particularly those that remain near cover, may be more difficult for snorkelers to observe than larger fish (Griffith 1981; Helfman 1983; Hillman et al. 1992). Discrepancies in size-class estimates also may have been influenced by inaccurate estimates of fish size. We believe snorkelers in Profile Creek overestimated the size of some fish and incorrectly recorded them in a larger size-category. For example, although no fish 300–399 mm were captured by electrofishing, both day and night snorkelers observed fish in that size-group (Figure 3). As Griffith (1981) suggested, snorkelers can increase the accuracy of their size estimates by having prior knowledge of the sizes of fish residing in the study streams.

Our comparisons of snorkeling and electrofishing have some limitations. In four of six reaches, block nets were removed after snorkelers made their estimates and were reinstalled within 1 week. We assumed no fish moved into or out of the reaches while the block nets were absent. Migratory adults are known to move upstream to spawning locations in summer (Goetz 1989); however, the two large (>400 mm) adults we observed by snorkeling did not move and were captured by electrofishing a week later. Juvenile bull trout also move, although migrations typically peak in the spring and fall (Goetz 1989). If substantial numbers of fish moved into or out of those reaches after block nets were removed, the ratio of fish estimated by electrofishing might differ from that estimated in reaches where block nets were held in place. Except in reach 3, the ratio of fish observed by snorkeling was equal to or larger than it was in those reaches where block nets were held (Table 1). For safety reasons, we completed day counts first and then night counts. We possibly biased counts by not varying the sequence of day and night counts, although the consistency in counts suggests this bias was not important.

Our sampling comparisons also were limited by our inability to measure the actual population abundance and size structure. Although we assumed the electrofishing estimates were the least biased, they may not represent the true population. Fraley and Shepard (1989) suggested that the benthic orientation and cover-seeking behavior of bull trout resulted in underestimates with electrofishing. Reynolds (1983) reviewed factors influencing electrofishing efficiency and reported that cold water temperatures decreased flotation of stunned fish, making capture less likely. The combination of cold water, high water clarity, and abundant cover may have enabled some bull trout to avoid electrical fields during our surveys. Bonneau et al. (1995) reported that backpack electrofishing was ineffective for capturing bull trout in the small, low-conductivity and high-gradient streams they surveyed. As Hillman et al. (1992) observed, the accuracy of underwater counts has been difficult to assess because the true population is usually unknown. In the absence of a true population estimate, we applied the recommendations of Rodgers et al. (1992) and compared snorkeling counts with electrofishing estimates.

Our results suggest that under the conditions of water temperature, conductivity, visibility, and habitat in which we sampled, day snorkeling surveys are suitable for estimating the relative abundance and size structure of age-1+ bull trout. The application of these results should be limited to the conditions under which the data were collected, and caution must be used in applying them to other watersheds. As previously discussed, accuracy of day and night snorkeling and electrofishing estimates may change in response to water temperature. Other factors including type and abundance of cover and lunar cycle may also influence the accuracy of snorkeling counts. Counts in habitat lacking cover may be more accurate than counts in complex habitat with abundant cover (Rodgers et al. 1992). The presence of a full moon during our surveys may have reduced differences between day and night counts. During night winter surveys, Angradi and Contor (1989) observed fewer rainbow trout during full moon phases or in the presence of large amounts of artificial light. Wyman (1975 as cited in Goetz 1994) reported bull trout avoiding shallow water during moonlit nights.

Efforts to effectively manage bull trout will depend on accurate techniques to estimate abundance by life stage and population size structure. Increasing numbers of biologists may be rejecting day snorkeling in favor of night snorkeling or electrofishing to census bull trout (Goetz 1994). Our results suggest that under some conditions, night snorkeling may not have an advantage over day snorkeling. However, we do not know how applicable our results are to other areas. Additional research is needed to evaluate the accuracy of snorkeling and electrofishing techniques to survey bull trout across the species' range.

Acknowledgments

S. Adams and P. Saffel assisted with field data collection and compilation. F. Goetz, P. James, J. McIntyre, T. McMahon, B. Rieman, and G. Watson provided constructive reviews of the manuscript. This research was a cooperative venture supported by funds provided by the U.S. Forest Service, Intermountain Research Station, and by the Federal Aid in Sport Fish Restoration Act to the Idaho Department of Fish and Game.

References

Angradi, T., and C. Contor. 1989. Henrys Fork fisheries investigations. Idaho Department of Fish and Game, Job Completion Report, Project F-71-R-12, Boise.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62–73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Bond, C. E. 1992. Notes on the nomenclature and distribution of the bull trout and the effects of human activity on the species. Pages 1–4 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. American Fisheries Society, Oregon Chapter, Corvallis.

Bonneau, J. L. 1994. Seasonal habitat use and changes in distribution of juvenile bull trout and cutthroat trout in small, high gradient streams. Master's thesis. University of Idaho, Moscow.

Bonneau, J. L., R. F. Thurow, and D. L. Scarnecchia. 1995. Capture, marking, and enumeration of juvenile bull trout and cutthroat trout in small, low-conductivity streams. North American Journal of Fisheries Management 15:563–568.

Bustard, D. R., and D. W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). Journal of the Fisheries Research Board of Canada 32:667–680.

Campbell, R. F., and J. H. Neuner. 1985. Seasonal and diurnal shifts in habitat utilization by resident rainbow trout in western Washington Cascade Mountain streams. Pages 39–48 *in* F. W. Olson, R. G. White, and R. H. Hamre, editors. Symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Engineering Section, Bethesda, Maryland.

Cohen, J. 1988. Statistical power analysis for the behavioral sciences, 2nd edition. L. Erlbaum Associates, Hillsdale, New Jersey.

Contor, C. R. 1989. Diurnal and nocturnal winter habitat utilization by juvenile rainbow trout in the Henry's Fork of the Snake River, Idaho. Master's thesis. Idaho State University, Pocatello.

Cunjak, R. A. 1988. Behavior and microhabitat of young Atlantic salmon (*Salmo salar*) during winter. Canadian Journal of Fisheries and Aquatic Sciences 45:2156–2160.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43:1970–1981.

Edmundson, E., F. H. Everest, and D. W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. Canadian Journal of Fisheries and Aquatic Sciences 25:1453–1464.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spacial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29:91–100.

Flebbe, P. A., and C. A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian wilderness streams of North Carolina. North American Journal of Fisheries Management 15:579–590.

Fraley, J., D. Read, and P. Graham. 1982. Flathead River fisheries study. Montana Department of Fish, Wildlife, and Parks, Kalispell.

Fraley, J. J., and B. B. Shepard. 1989. Life history, ecology and population status of migratory bull trout (*Salvelinus confluentus*) in the Flathead Lake and River system, Montana. Northwest Science 63:133–143.

Goetz, F. 1989. Biology of the bull trout, *Salvelinus confluentus*, a literature review. U.S. Forest Service, Willamette National Forest, Eugene, Oregon.

Goetz, F. A. 1994. Distribution and juvenile ecology of bull trout (*Salvelinus confluentus*) in the Cascade Mountains. Master's thesis. Oregon State University, Corvallis.

Griffith, J. S. 1981. Estimation of the age-frequency distribution of stream dwelling trout by underwater observation. Progressive Fish-Culturist 43:51–53.

Griffith, J. S., and R. W. Smith. 1993. Use of winter concealment cover by juvenile cutthroat and brown trout in the South Fork of the Snake River, Idaho. North American Journal of Fisheries Management 13:823–830.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Helfman, G. S. 1983. Underwater methods. Pages 349–370 *in* L. A. Nielsen and D. L. Johnson, editors.

Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Hillman, T. W., J. S. Griffith, and W. S. Platts. 1987. Summer and winter habitat selection by juvenile chinook salmon in a highly sedimented Idaho stream. Transactions of the American Fisheries Society 116:185–195.

Hillman, T. C., J. W. Mullan, and J. S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. North American Journal of Fisheries Management 12:598–603.

Hillman, T. W., and W. S. Platts. 1993. Survey plan to detect the presence of bull trout. Don Chapman Consultants, Boise, Idaho.

Jakober, M. J. 1995. Influence of stream size and morphology on the seasonal distribution and habitat use of resident bull trout and westslope cutthroat trout in Montana. Master's thesis. Montana State University, Bozeman.

Johnson, J. E. 1987. Protected fishes of the United States and Canada. American Fisheries Society, Bethesda, Maryland.

Kirby, K. N. 1993. Advanced data analysis with Systat. Van Nostrand Reinhold, New York.

Meehan, W. R., and T. C. Bjornn. 1991. Salmonid distributions and life histories. Pages 47–82 *in* W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda, Maryland.

Megahan, W. F., W. S. Platts, and B. Kulesza. 1980. Riverbed improves over time. Pages 380–394 *in* Symposium on watershed management, volume 1. American Society of Civil Engineers. New York.

Pratt, K. L. 1984. Habitat selection and species interactions of juvenile westslope cutthroat trout (*Salmo clarki lewisi*) and bull trout (*Salvelinus confluentus*) in the upper Flathead River basin. Master's thesis. University of Idaho, Moscow.

Pratt, K. L. 1992. A review of bull trout life history. Pages 5–9 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. American Fisheries Society, Oregon Chapter, Corvallis.

Ratliff, D. E., and P. J. Howell. 1992. The status of bull trout populations in Oregon. Pages 10–17 *in* P. J. Howell and D. V. Buchanan, editors. Proceedings of the Gearhart Mountain bull trout workshop. American Fisheries Society, Oregon Chapter, Corvallis.

Reynolds, J. B. 1983. Underwater methods. Pages 147–164 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Riehle, M. D., and J. S. Griffith. 1993. Changes in habitat use and feeding chronology of juvenile rainbow trout (*Oncorhynchus mykiss*) in fall and the onset of winter in Silver Creek, Idaho. Canadian Journal of Fisheries and Aquatic Sciences 50:2119–2128.

Rieman, B. E., and J. D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Forest Service General Technical Report INT-302.

Rieman, B. E., and J. D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of varied size. Transactions of the American Fisheries Society 124:285–296.

Rimmer, D. M., and U. Paim. 1990. Effects of temperature, photoperiod, and season on the photobehavior of juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Zoology 68:1098–1103.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson, and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. North American Journal of Fisheries Management 12:79–86.

Seber, G. A. F., and E. D. LeCren. 1967. Estimating population parameters from catches large relative to the population. Journal of Animal Ecology 36: 631–643.

Shepard, B. B., and P. J. Graham. 1983. Fish resource monitoring program for the upper Flathead basin. Montana Department of Fish, Wildlife and Parks, EPA Contract R008224-01-4, Kalispell.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry, 2nd edition. Freeman, San Francisco.

Steele, R. G., and J. H. Torrie. 1980. Principles and procedures of statistics: a biometrical approach, 2nd edition. McGraw-Hill, New York.

Stenzel, A. 1987. Ecological aspects of juvenile Arctic char (*Salvelinus alpinus*) in the Koroc River, Ungava Bay, Quebec. Master's thesis. University of Waterloo, Waterloo, Ontario.

Thurow, R. F. In press. Habitat utilization and diel behavior of juvenile bull trout (*Salvelinus confluentus*) at the onset of winter. Ecology of Freshwater Fish.

Van Deventer, J. S., and W. S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data—user's guide for MicroFish 3.0. U.S. Forest Service General Technical Report INT-254.

Washington Department of Wildlife. 1992. Bull trout/Dolly Varden management and recovery plan. Washington Department of Wildlife, Fisheries Management Division, Report 92-22, Olympia.

Wyman, K. H. 1975. Two unfished salmonid populations in Lake Chester Morse. Master's thesis. University of Washington, Seattle. (Not seen; cited *in* Goetz 1994.)

Zar, J. E. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, New Jersey.