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Estimating Fish Populations by Removal Methods with Minnow Traps in Southeast Alaska Streams

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Abstract.-Passive capture methods, such as minnow traps, are commonly used to capture fish for mark-recapture population estimates; however, they have not been used for removal methods. Minnow traps set for 90-min periods during three or four sequential capture occasions during the summer of 1996 were used to capture coho salmon *Oncorhynchus kisutch* fry and parr, Dolly Varden *Salvelinus malma*, cutthroat trout *O. clarki*, and juvenile steelhead *O. mykiss* to estimate population size with the Zippin or generalized removal method. More than 45% of the total catch was obtained during the first capture occasion, and in most cases, the catch during the fourth occasion was less than 15% of the total catch. In most pools, the probability of capture was greater than 0.4 but was lower for coho salmon fry than for coho salmon parr and other species. Mean population estimates for coho salmon parr made with concurrent mark-recapture and removal methods differed significantly in small streams. Estimates from mark-recapture and removal methods were not significantly different for coho salmon fry and Dolly Varden, but mark-recapture estimates were higher than removal estimates in most cases. My results show that removal estimates can be obtained with minnow traps if sampling procedures conform to the assumptions required for the method.

Obtaining precise and accurate estimates of fish abundance in streams continues to challenge fishery biologists, despite the development of sophisticated mathematical models. Commonly used methods include mark-recapture experiments (Ricker 1975; Zubik and Fraley 1988) and removal estimates (Moran 1951; Zippin 1958; White et al. 1982). Though snorkel surveys are also used to estimate fish abundance (Northcote and Wilke 1963; Schill and Griffith 1984; Thurow 1994), they require a separate estimate of the population to calibrate the counts (Hankin 1986). Mathematical models for both mark-recapture and removal estimates are well-tested, but present substantial logistical challenges to meet the assumptions.

Mark-recapture estimates are commonly used in southeast Alaska and elsewhere to estimate Populations of juvenile salmonids, most commonly coho salmon *Oncoryhnchus kisutch* and Dolly Varden *Salvelinus malma*, in small (<4-m-wide) second- to third-order streams (Elliott and Hubartt 1978; Dolloff 1983; Bryant 1984; Young et al. 1999). Sample reaches in streams wider than 4 m and with higher water flows are difficult to isolate, and mark-recapture methods are not reliable because of movement between sample periods. High flows, common in southeast Alaska, also affect movement and catchability between sample periods. Removal methods or snorkel surveys are often used in these streams, yet even these methods are limited. Low conductivity and patches of complex habitat with large woody debris make the removal method of electrofishing impractical. Snorkel surveys also are impractical because of complex habitat and poor visibility in the dark waters of many southeast Alaska streams.

Removal methods have several advantages over mark-recapture methods to estimate fish numbers. Fish are captured only once, which eliminates bias due to behavioral responses to a trap. Fish do not need to be marked, which removes assumptions that all marks are identified and that negligible mortality occurs due to marking. The stream section can be sampled in 1 d, which substantially reduces the probability of movement by fish into and out of the sample area in cases in which the stream section cannot be isolated for the duration of the mark-recapture sequence. In addition, a 1 d sampling effort simplifies logistics for those locations that are difficult to reach and eliminates any differences in sampling efficiency due to changes in flow regimes (i.e., high-water events that occur after marking and before or during recapture).

Passive capture methods are commonly used for mark-recapture experiments but are seldom used for removal estimates. Minnow traps baited with salmon eggs are an effective method for capturing juvenile salmonids and have been used in numer-

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ous studies throughout southeast Alaska (Bloom 1976; Elliott and Hubartt 1978; Dolloff 1983; Bryant 1985). Minnow traps have not been used for removal population estimates but have several advantages over electrofishing: they are less harmful to the fish, disturb the stream less, can be used efficiently in complex habitats, and are not dependent on the water chemistry of the stream (Mesa and Schreck 1989; Riley and Fausch 1992; Hollender and Carline 1994; Habera et al. 1996; Reynolds 1996). Although minnow traps are not effective in riffle or fast-water habitats, they offer a less-intrusive alternative to electrofishing in streams with pools or slow-moving water. However, their use as a removal method for population estimates has not been studied.

My purpose is to determine if minnow traps can be used as a removal method to estimate population sizes of fish in streams. My first objective is to determine if minnow traps capture a sufficient part of the population on each capture occasion to estimate population size of juvenile salmonids using a removal method and to examine probabilities of capture in natural streams. My second objective is to determine if concurrent mark-recapture estimates and removal estimates through the use of minnow traps differ significantly.

Methods

The study was conducted on five small secondto third-order streams, Convenience, Picnic, Switzer, Twiw, and Tye creeks, and three medium-size fourth- to fifth-order streams, Painted, Sal, and Trap creeks, in southeast Alaska during the summer of 1996. The small streams were all less than 4 m in bank-full width and had summer mean flows of less than 0.5 m^3/s. The medium-size streams were greater than 4 m but less than 30 m in bankfull width and drained into salt water. All streams supported populations of coho salmon and Dolly Varden. Steelhead *Onchorhynchus mykiss* and cutthroat trout *O. clarki* were found in some streams and were not sympatric in any stream that was sampled. Coastrange sculpins C*ottus aleuticus* were occasionally captured but not included in the estimates. The three medium-size streams were sampled with the removal estimate only. Concurrent mark-recapture and removal experiments were completed on all five small streams.

Mark-recapture and removal methods require closed populations; therefore, sample reaches were selected to minimize emigration or immigration during the sample period. In the five small streams, the sample reaches ranged from 100 to 350 m and were blocked by nets, weirs, or barriers at both ends for the duration of the experiment, usually 3-4 d. In the three medium-size streams, nets could not be used; natural barriers were used to isolate the reach and pools within the reach. These included long, shallow riffles (<5 cm depth) or submerged logs that fully spanned the stream, forming a dam. While complete isolation was not achieved, fish movement across these barriers was not observed during sampling, which usually lasted no longer than 8 h at each site.

The removal experiment was completed in 1 d on each medium-size stream. Three capture occasions were used in Painted Creek, the first stream sampled with the removal method. Four capture occasions were used on Trap and Sal creeks. Reaches ranged in length from about 200 to 300 m. Individual pools were identified and counted in each reach. At least 50% of the pools were randomly selected and population estimates were computed for fish in each pool. The size of the pools ranged from 9.7 to 1,480 m^2, the average size being 288 m^2. One to three pools were sampled concurrently, depending upon their size and complexity. Once a pool was selected, sample locations for the minnow traps (3.2-mm mesh size; 19 cm diameter and 35.5 cm long) were selected. Distances between traps depended upon habitat complexity, but generally traps were separated by about 2 m. Traps were set more densely in complex habitats (i.e., pools with large amounts of woody debris) than in more open pools. Between 40 and 50 traps were set for each removal experiment.

Traps were baited with salmon eggs (disinfected for 10 min with 1:100 betadyne to water solution) held in perforated "whirlpaks." Traps were set on the stream bottom next to suspected habitat of juvenile salmonids, such as woody debris, rootwads, or undercut banks, but were distributed to completely sample the pool. Traps were left undisturbed for 90 ± 10 min and then were picked up in the same order in which they were set. Fish were removed, and fresh bait was placed in each trap. Traps were set again in the same locations. Fish from each pool and capture occasion were processed separately. While the second set was fishing, the fish from the first set were identified, counted, measured (mm), and weighed (nearest 0.1 g). Data from each capture occasion were identified by number (1, 2, 3, or 4), each of which identified the capture occasion. The procedure was repeated three to four times, depending upon the desired number of capture occasions. Fish from each capture occasion were placed in a holding net (or blocked minnow traps) until the last capture occasion was completed, at which time all fish were returned to the same area from which they were captured. Population size was estimated for each species in each pool. Coho salmon were classified as fry (age 0) or parr (age 1+) based on analysis of length-frequency data. Coho salmon were considered to be fry if they were less than 50 mm in June, less than 55 mm in July, or less than 60 mm in August.

The same procedures for the removal estimate in the medium-size streams were used in the small streams during the concurrent mark-recapture and removal experiments. Sample reaches, which were 100 to 300 m long and ranged in area from 68 to 274 m^2, could be easily sampled with 40-50 traps. The entire reach was sampled during one experiment, and population size was estimated for the entire reach. All fish were marked during four capture occasions in the removal estimate, which served as the mark sample in a single-census Peterson mark-recapture estimate determined by the Chapman modification (Ricker 1975). The recapture sample was completed during one capture occasion 3-4 d after the fish were released. All fish were identified by species and measured. Recaptured marked fish were recorded.

Removal estimates and probabilities of capture (P_c) were computed by the capture program (White et al. 1982). If four capture occasions were used, population size was estimated by the generalized removal estimate in the capture program: both equal P_c among occasions and unequal P_c between the first and subsequent occasions. The program also tested whether P_c was constant, based on a chi-square test (α = 0.05). The Zippin method, which assumes equal probabilities of capture, was used for Painted Creek where three capture occasions were completed.

A paired t-test (α = 0.05) was used to compare the probability of capture from the first capture occasion to subsequent capture occasions in pools where a variable probability of capture was used to estimate populations. A paired t-test (α = 0.05) was also used to examine differences in population estimates and probabilities of capture between three or four capture occasions for coho salmon fry, coho salmon part, Dolly Varden, and steelhead. Estimates from individual pools that had valid estimates for four capture occasions were used as the sample unit. Estimates for three capture occasions were made by recomputing the first three capture occasions from estimates with four capture occasions.

Depletion and mark-recapture estimates from reaches in the five small streams were compared by a paired t-test (α = 0.05). The test was completed separately for coho salmon fry, coho salmon parr, and Dolly Varden. Cutthroat trout and steelhead were not captured in all streams and were not included in the analysis. Normality and homogeneity of variance was tested before use of the t-tests (SAS Institute 1988).

Results

Removal Estimates

Abundance of coho salmon parr was estimated for 47 pools in Painted, Sal, and Trap creeks. Estimates were not computed (defined as "failures" by the computer program) in three pools for coho salmon fry and Dolly Varden when less than 10 fish were caught during all capture occasions. For two of the pools, failures occurred when more coho salmon fry were caught during either the second or third capture occasion than during the first capture occasion. For the third pool, no Dolly Varden were captured during the first two capture occasions, 16 were captured during the third capture occasion, and 3 were captured during the fourth capture occasion. Steelhead were captured only in Sal Creek, and 3 failures occurred out of the 10 pools sampled.

For all species, more than 45% of the total catch in all reaches of Painted, Sal, and Trap creeks were taken during the first capture occasion (Figure 1). In most cases, the number of fish captured during the fourth capture occasion was less than 15% of the total catch. For all species except coho salmon fry, the probability of capture was greater than 0.3 for at least 80% of the pools sampled when it was assumed constant for all capture occasions (Figure 2). Probability of capture was greater than 0.4 in more than 90% of the pools for cutthroat trout and steelhead. Coho salmon fry and parr had the lowest probability of capture, but more than 50% of the pools exceeded 0.4. In most cases, however, substantially fewer coho salmon fry and parr were caught upon each successive sampling occasion, even with lower probabilities of capture. For example, in one pool, 123, 95, and 51 coho salmon fry were captured during successive capture occasions. The probability of capture calculated to 0.344. The 95% confidence interval ranged from 324 to 472 fish around the population estimate of 374 fish. While the lower probability of capture resulted in less precision, the lower confidence interval was within 13% and the upper confidence interval within 26% of the estimate.

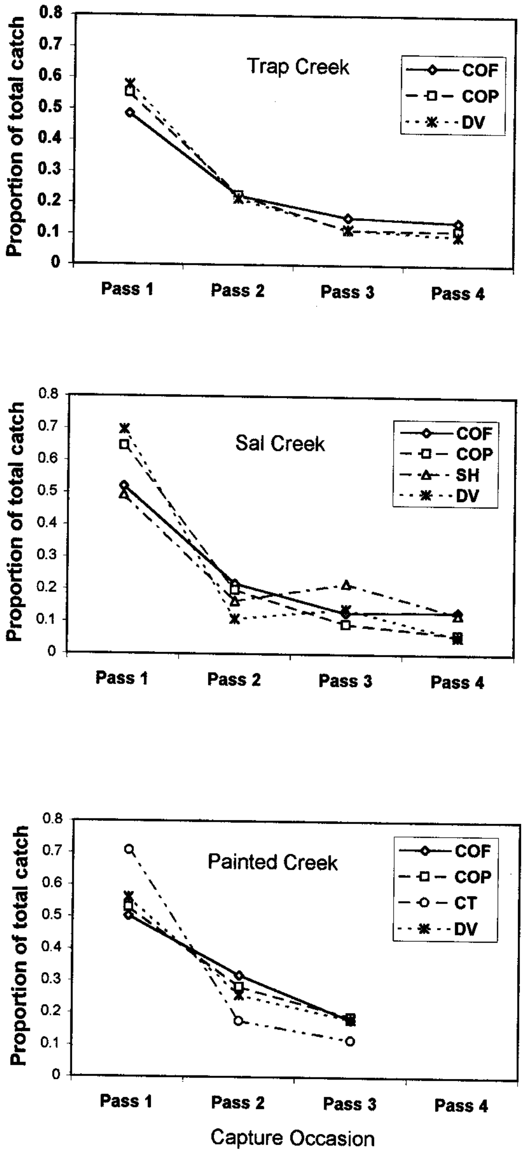

FIGURE 1.—The proportion of coho salmon fry (COF), coho salmon parr (COP), Dolly Varden (DV), cutthroat trout (CT), and steelhead (SH) captured during each capture occasion in Trap, Sal, and Painted creeks for the removal experiment in southeast Alaska, 1996.

In Sal and Trap creeks, both of which had four capture occasions, the capture program compared constant-capture probability and variable-capture probability. In most pools, the probabilities of capture were constant. The constant-probability-of-capture model was selected for all species in 88% of the pools in Sal Creek and in 93% of the pools in Trap Creek (chi-square, $\alpha = 0.05$; White et al. 1982). The constant-probability-of-capture model was selected for Dolly Varden and steelhead in all pools of Sal Creek (Table 1). In Trap Creek, the constant-probability-of-capture model was selected for Dolly Varden in 81% of the pools. A variable-probability-of-capture model was used to estimate population size for coho salmon fry in five pools, for coho salmon parr in eight pools, and for Dolly Varden in four pools. Only for coho salmon fry was the probability of capture significantly greater for the first capture occasion than for subsequent capture occasions (Table 2).

Population estimates and probabilities of capture for three sample occasions were generally lower than those computed for four sample occasions (Table 3). Population estimates for three and four capture occasions were significantly different for coho salmon parr ($P = 0.013$), but differences were not observed for population estimates of coho salmon fry and Dolly Varden. Differences between the probabilities of capture for three and four capture occasions were observed for coho salmon fry, coho salmon parr, and Dolly Varden. The probabilities of capture for three capture occasions were greater than that estimated for four capture occasions (Table 3). The population estimates or probabilities of capture for steelhead were not significantly different between three and four capture occasions (Table 3).

Mark-Recapture and Removal Estimates

Comparisons of population estimates for the two methods showed mixed results among species, but generally estimates from the mark-recapture method were higher than those from the removal method. Mark-recapture and removal estimates were significantly different for coho salmon parr ($P = 0.049$) but were not significantly different for Dolly Varden and coho salmon fry (Figure 3). Mark-recapture estimates were higher in all streams and for all species except coho salmon fry in Twiw Creek and Dolly Varden in Picnic Creek. In both cases, removal estimates had wider confidence intervals than the mark-recapture estimates. Removal estimates for both streams had low probabilities of capture and a high number of fish captured during the final capture occasion.

Discussion

Probabilities of capture were generally high, and in most cases, 50-65% of the population was captured during the first sample occasion. However, even with high probabilities of capture, underestimation of the population may be a problem be-

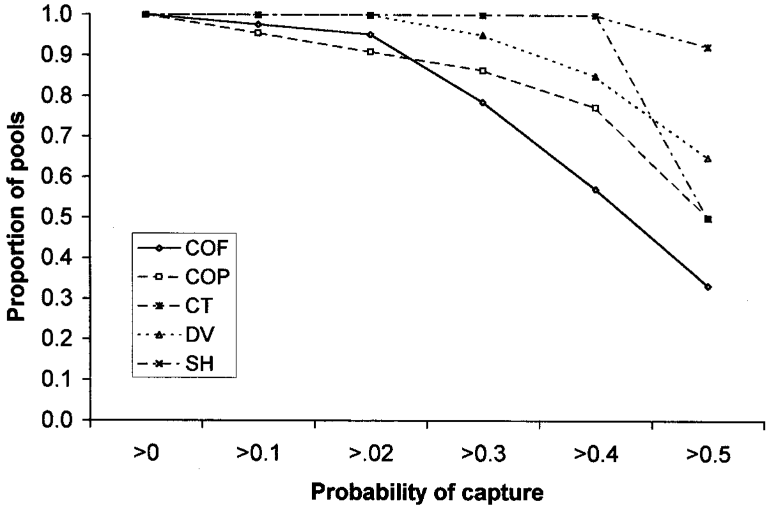

FIGURE 2.—The relationship between probability of capture of all five species and the number of pools expressed as a proportion of total pools sampled in Trap, Sal, and Painted creeks for the removal experiment in southeast Alaska, 1996.

cause of differences in probabilities of capture between sample occasions (Riley and Fausch 1992). Underestimation would occur if the probability of capture was higher during the first sample occasion and lower during subsequent sampling occasions (Riley and Fausch 1992). The bias can be accounted for if the differences between probability of capture can be detected during the estimation through the use of four capture occasions and the generalized removal method (White et al. 1982). Results from this study agree with the recommendation of Riley and Fausch (1992) that four capture occasions be used for removal estimates whenever possible.

Riley and Fausch (1992) and the numerous studies they cite report decreasing catchability after the first capture occasion during electrofishing and suggest that it is important to maintain equal effort among all samples. However, not only does the process of electrofishing impose a considerable disturbance upon the stream and influence fish behavior during subsequent samples, but it also imposes a physiological response in fish that influences behavior on those that were shocked but not captured during the first attempt (Mesa and Schreck 1989). Minnow traps are a passive capture method and impose a much lower degree of disturbance than electrofishing. This eliminates the effects of disturbances if care is used when the traps are set and retrieved.

Regardless of the method used to capture fish, assumptions of removal estimates must be met that include isolation of the sample area during the sample period. Recruitment into the sample area during the estimate will result in an upward bias in the estimate; however, recruitment was not observed in study sections of the larger streams during 6-7 h sample periods. If the pool within the

TABLE 1.—Percent of pools with constant and variable probabilities of capture for coho salmon fry, coho salmon parr, Dolly Varden, and steelhead captured in two streams in southeast Alaska, 1996.

Stream	Type of probability	Coho salmon Parr	Coho salmon Fry	Dolly Varden	Steelhead	All
Sal Creek	Constant	78	80	100	100	88
	Variable	22	20			12
Trap Creek	Constant	89	73	81		93
	Variable	11	27	19		19

TABLE 2.—Comparison (paired t-test) between probabilities of capture (P_c) on first and subsequent capture occasions in pools where a variable probability of capture was used to estimate populations for coho salmon fry and parr and Dolly Varden in two streams in southeast Alaska, 1996.

Species	Mean P_c First capture	Mean P_c Subsequent captures	df	P
Coho salmon				
Fry	0.523	0.302	4	0.01
Parr	0.574	0.546	7	0.85
Dolly Varden	0.435	0.232	3	0.06

TABLE 3.—Comparison (paired *t*-test) between 3-sample and 4-sample removal estimates of population and probabilities of capture for coho salmon fry and parr, Dolly Varden, and steelhead in Trap and Sal creeks, southeast Alaska, 1996.

		Mean population estimate (number of fish)			Mean probability of capture		
Species	Number of pools	Three-sample	Four-sample	*P*	Three-sample	Four-sample	*P*
Coho salmon							
Fry	24	54	61	0.087	0.559	0.445	0.0017
Parr	24	22	25	0.013	0.655	0.573	0.0085
Dolly Varden	22	53	56	0.101	0.654	0.571	0.0064
Steelhead	5	8	9	0.393	0.687	0.661	0.804

reach is not saturated with traps, fish from within the pool may be recruited into nearby traps during subsequent sampling occasions. Evidence of recruitment during the sample period may be observed when more fish are captured in later sample occasions than during the first or second sample occasions. Effort should be made to capture the greatest number of fish from the pool while completely sampling the pool and maintaining equal sampling effort among capture occasions.

Minnow traps have physical limitations that limit their use as a capture method. They do not adequately sample riffle habitat; therefore, the method is limited to pool habitats. Stream depth must be sufficient to submerge the opening of the trap. The effective range or orientation of baited minnow traps has not been systematically tested, but traps are usually set parallel to the flow or in pools with minimal flow. Extensive field experience in southeast Alaska suggests that minnow traps are effective at a radius of at least 2 m; a downstream bias may extend the range depending on flow. Complex habitats, such as large, dense debris jams, may require a higher density of traps than open pools. Fish behavior and habitat preferences will determine the distribution of traps. Large scour pools with little cover and high flows generally did not yield large numbers of juvenile salmonids. They also did not require as many traps as pools with large rootwads and several smaller connected pools.

Although removal and mark-recapture esti-

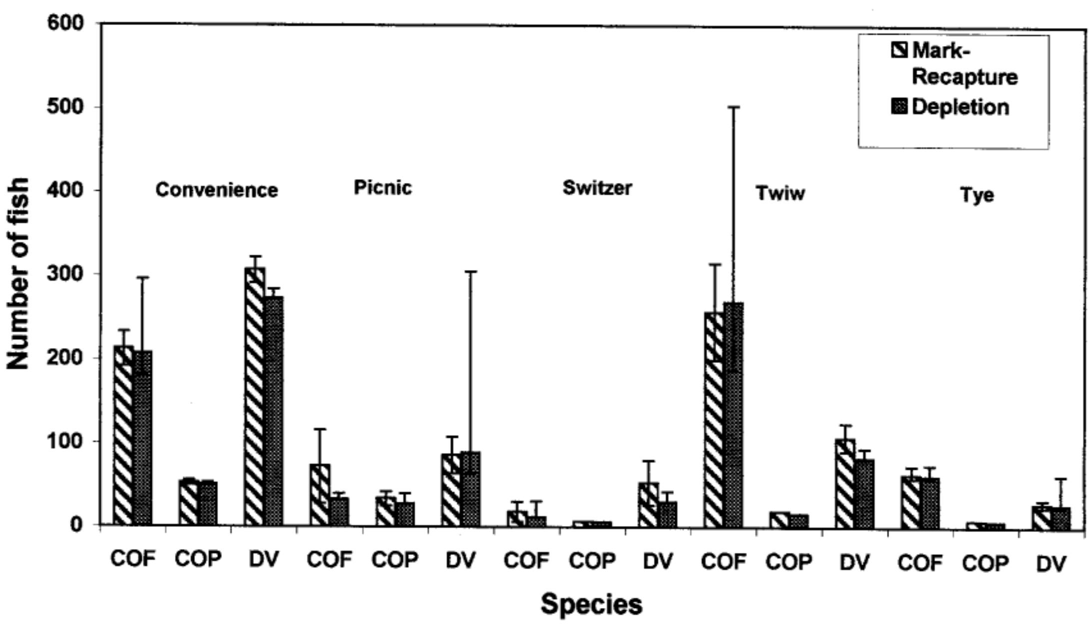

FIGURE 3.—The comparison of population estimates from mark–recapture and removal methods by species for five small streams in southeast Alaska, 1996.

mates in small streams were not significantly different for coho salmon fry and Dolly Varden, mark-recapture mean estimates were 13-17% greater than removal mean estimates. Violations of at least two assumptions, equal vulnerability of marked-to-unmarked fish (trap-shy) and greater mortality of marked fish, could account for higher mark-recapture estimates. Removal estimates were often lower than mark-recapture estimates. Mahon (1980) and Peterson and Cederholm (1984) generally attributed this to decreasing probability of capture upon successive capture occasions. Their estimates, however, were derived from electrofishing and not by less-obtrusive methods, such as minnow traps. The generalized removal program used a constant probability of capture for all five of the streams rather than a variable probability of capture, which suggests the minnow traps did not affect fish behavior.

Removal methods have several advantages over mark-recapture methods, including the ability to complete sampling in a single day and requiring fewer assumptions. Minnow traps impose less stress on fish than electrofishing, though care must be taken when fish are held for several hours. In streams that cannot be completely blocked, the shorter time interval needed for the removal estimate reduces the probability of movement and more closely satisfies the closure assumption than is possible for mark-recapture experiments that require several days between the mark and recapture. The assumption of closure can seldomly be accomplished in large streams with greater flow volumes, but short-term movement can be reduced during a removal estimate through the use of sample reaches that are separated by naturally occurring obstructions. Minnow traps, carefully placed in a stream and left undisturbed, are also less likely to disturb fish than during electrofishing or seining when several people move through the stream during each sample occasion. Minnow traps offer an attractive alternative for conducting removal estimates for juvenile salmonids. Similar methods may be applicable to other species that are susceptible to passive capture methods.

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