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Abstract

The annual juvenile (smolt) migration to the lake by Great Lakes salmonids provides an opportunity for fishery managers to estimate the abundance of the smolting cohort. This information is valuable for modeling recruitment potential to the fishery and for estimates of the returning broodstock. The purpose of this study was to compare several techniques for estimating the number of steelhead *Oncorhynchus mykiss* smolts emigrating from the Betsie River in northwestern Michigan. We also compared the production of steelhead smolts from this river with other rivers in the state. In May and June, 1993-1996, we monitored emigrating smolts by use of visual observations, time-lapse videography and mark-recapture to estimate the number of steelhead smolts migrating past a lamprey weir located 18 km upstream of the river mouth. In 1993 and 1994, two observers counted smolts passing over the weir for 20 minutes out of each hour from 21:00 to 05:00 hours. In 1995 and 1996, black and white video cameras and time lapse videocassette recorders continuously monitored the passing smolts through the night. We reviewed each videotape and counts of the number of smolts passing over the weir from 21:00 to 05:00 for each night. We also collected 20 minute samples from the videotapes following the same schedules as was used for visual observations. A subsample of videotapes were reviewed a second time to measure variation of the counts. In all four years, a constriction weir was constructed every 5th night during the smolt run to capture emigrating fish and to quantify species composition and the origin of steelhead (hatchery or wild). Steelhead smolts comprised 30-61% of all the salmonid juveniles sampled. Other species present were brown trout *Salmo trutta*, coho salmon *Oncorhynchus kisutch*, and chinook salmon *Oncorhynchus tshawytscha*. Wild steelhead comprised 12-52% of the steelhead smolts. Mark-recapture estimates and 95% confidence intervals for hatchery and wild steelhead smolts ranged from 13,837 (12,583-15,215) in 1985 to 56,661 (46,036-69,703) in 1993 and were 2-9 times greater than the estimates from direct observation and videography. The results from time-lapse videography and visual observation were similar and gave the most reliable estimates for steelhead smolts produced from the watershed. Estimates of steelhead smolt numbers from observation methods ranged from 2,198 (± 512) in 1996 to 9,645 (± 1,111) in 1994. The Betsie River produces fewer wild steelhead smolts (12-22/ha) than other streams studied in Michigan.

Introduction

Steelhead were introduced to Michigan streams in 1876 and since then, have established naturalized populations (Latta 1974, Biette et al. 1981). Great Lakes steelhead retain the life history characteristics of their Pacific counterparts and spend 2-3 years growing to sexual maturation in one of the Great Lakes. Either in late fall or early spring, adult steelhead return to their natal stream and spawn in the spring. Juveniles reside in the stream for 1-3 years before smolting and emigrating back to the lake (Biette et al. 1981, Seelbach 1993).

The smolting period is a sensitive and critical phase in steelhead life history. Wild smolts reach a size of 160-200 mm before the necessary changes for smoltification, including the ability to hypoosmoregulate and migratory behavior, occur (Wagner 1974, Seelbach 1987). Although Great Lakes steelhead do not encounter saltwater, they follow the same smoltification process as steelhead in Pacific streams: juvenile steelhead smolts lose their parr marks, become silvery, and emigrate in water temperatures of 10-15°C during the months of April-June (Biette et al. 1981).

Estimation of steelhead smolt numbers is an important component in the management of steelhead fisheries. The abundance of the smolting cohort, coupled with expected survival rates, can aid in forecasting recruitment to the fishery and give indices of expected returns for escapement and stock sustainment (Raymond 1988). Furthermore, because steelhead parr are resident in the stream for more than one year and require good water quality (high levels of dissolved oxygen, suitable water temperatures for survival and growth, low sedimentation rates, an adequate forage base, and instream habitat for refuge and cover), the number of smolts produced annually may provide a relative index of the overall health of a watershed for cold water species.

Many methods have been used to monitor emigrating smolts, and each method has produced various levels of success in providing accurate measures of emigrants. Smolts are difficult to monitor because they migrate at night. In addition, spring high flows from snowmelt and rain can be problematic for some methods, especially in larger rivers. Methods to monitor and estimate smolt abundance include mark-recapture for trapping efficiency (Seelbach 1987, Dempson and Stansbury 1991) or for total run estimates (Macdonald and Smith 1980), trapping a portion or all of the smolt run with fyke nets and box traps (Davis et al. 1980, Seelbach and Miller 1993) or inclined screen smolt traps (Wagner et al. 1963, Lister et al. 1969, Seelbach et al. 1984, DuBois et al. 1991, Seelbach and Miller 1993), electronic fish counters (Appleby and Tipping 1991), and camera monitoring (Cousens et al. 1982). When a dam is present, collection methods at turbine intake gatewells or bypass collection methods are often used (Raymond 1979, Giorgi and Sims 1987, Peven and Hays 1989, Peven et al. 1994).

Problems inherent with various sampling methods for smolts include gear function at varying flows, debris loading of nets and screens, trap avoidance by smolts, and mortality associated with handling stress and gear design. Modifications to the inclined-screen smolt trap make this a promising method for a variety of applications. However, these have problems with low capture efficiencies and a low head dam must be in place to use this gear (Dubois et al. 1991, Seelbach 1993). Fyke nets become clogged with debris (Davis et al. 1980). In many cases, trapping efficiency can be highly variable or very low (DuBois et al. 1991, Seelbach 1993), both of which introduce large amounts of error to the estimates. Electronic counters often require that fish pass through a very constricted area, and are most accurate when fish are of a uniform length (Appleby and Tipping 1991). Although this is applicable to hatchery settings, both of these conditions are not usually attainable for monitoring smolts in a field setting.

Time-lapse videography has been used successfully to record escapement of adult salmonids (Dexter and Ledet 1994, Hatch et al. 1994). The advantages of this non-intrusive methodology include establishment of a permanent record, low labor requirements, ability to review and automate counts, and fairly low cost of equipment as videographic technology advances (Collins et al. 1991). In the Dexter and Ledet (1994) study, fish were viewed through windows in a fish ladder which allowed for identification of species, but also involved an additional construction cost. Irvine et al. (1991) developed a computerized video-camera system to monitor coho smolts by use of cameras trained on tunnels through which smolts passed. Although this early prototype of the method was promising and provided the additional benefit of smolt length measurements, it was a highly controlled situation and not generally applicable to typical field settings.

Although steelhead have been naturalized in the Great Lakes Region for over 125 years, emigrating smolts have been counted in only in a few cases. Yearly production of smolts is known to vary widely in high quality trout streams in Michigan (Seelbach 1987, Seelbach and Miller 1993), but little is known about their production from watersheds with marginal trout habitat. In southern Michigan, for example, rivers tributary to Lake Michigan which are stocked with steelhead receive large returns of adults, a fraction of which are wild. Although some natural reproduction is known to occur, it has yet to be quantified (Seelbach 1987). The tendency of rivers in this region to warm significantly during the summer makes them marginal for salmonid production (Seelbach et al 1994).

The objectives of this study were to 1) monitor smolts emigrating from the Betsie River in northern Michigan, by use of direct observation, time lapse videography, and mark-recapture, 2) estimate the number of steelhead smolts emigrating from the Betsie River and compare results among the three methods, and 3) compare the number of emigrating smolts in the Betsie River watershed with other rivers in Michigan.

Study Site

The Betsie River watershed is tributary to northern Lake Michigan. The main branch of the Betsie River is 79 kilometers long and the watershed drains an area of 67,100 hectares (Figure 1). Land use in the watershed consists primarily of tree farming and some fruit farms. A large portion of the watershed is owned by the state of Michigan is managed as a State Forest. The river also flows through two small municipalities, with little development or industry along the river. Glacial moraines are dominant landscape features throughout the watershed and permanent flowing springs supply groundwater directly into the river. The two largest tributaries that empty into the Betsie River are Dair Creek and Little Betsie River and both of these are spring-fed.

Although the river has no gaging stations, we measured river stage weekly by use of temporary staff gages from 1993-1996. The mean May-June measured discharge ranged from 4.3 to 11.3 cubic meters per second (cms) during this period (Newcomb and Coon 1997). Gradient is low, and averages 0.002%. Historical water temperature data showed that the Betsie River warms significantly in the summer months (Wicklund and Dean 1958) and for this reason, the river is considered a marginal trout stream. The fish community of the Betsie River includes rockbass *Ambloplites rupestris*, creek chub *Semotilus atromaculatus*, common shiner *Notropis cornutus*, hornyhead chub *Nocomis biguttatus*, blacknose dace *Rhinichthys atratulus*, mottled sculpin *Cottus bairdi*, brown trout *Salmo trutta*, and juvenile steelhead. Dair Creek and Little Betsie River fish communities consist of cold water species, including brown trout, slimy sculpin *Cottus cognatus*, mottled sculpin, steelhead, and coho salmon parr. Although the mainstem Betsie River is classified as marginal for trout, it still supports a popular fishery for returning salmon and steelhead (Rakoczy and Rogers 1987, 1988, 1990).

Since 1991, juvenile steelhead have been raised in a hatchery adjacent to the Betsie River and linked to the river by a small flowing spring. Yearling steelhead were released volitionally, beginning in April. Most of the smolts from this hatchery were clipped with either a right ventral (1993-1995) or right pectoral clip (1996). The number of steelhead released from this facility has ranged from 20,000 (1991) - 55,000 (1996).

We monitored emigrating smolts at a lamprey weir located in the lower river reach, 17.7 km upstream from Lake Michigan. Formerly the site of Homestead Dam, a low-head hydroelectric dam, the site now consists of a lamprey weir which is divided into two sills (10 m wide each) that are staggered, with one sill approximately 5 m further downstream than the other (Figure 2). The weir has a head of approximately 2 m which is stepped into 1 m jumps on the most upstream sill and there are no steps on the downstream sill.

Methods

Beginning the first week in May and ending in late June, 1993-1996, we monitored outmigrating smolts by use of three methods: visual observation, time-lapse videography, and mark-recapture. In 1993 and 1994, two observers counted smolts passing over the downstream sill of the weir for 20 minutes out of every hour from 21:00 to 05:00 hours, approximately dusk to dawn . To check for daytime emigration, we randomly sampled during daytime hours approximately every other day during the smolt run. Visual observations in 1993 and 1994 indicated that the majority (80%) of the smolt movement occurred over the most downstream sill. Therefore, the visual and video observations were concentrated on this sill and estimates were adjusted accordingly. During night sampling each viewer monitored half of the 10 m wide sill while hand held lights illuminated the sill. After turning on the lights, the viewers waited 5 minutes before beginning to count. In 1995 and 1996, visual observations were corroborated with camera observations and similar 20 minute observations were obtained from the videotapes. For each night of observation, a mean 20-minute sample was calculated and multiplied by 24 to calculate a nightly estimate for 8 hours of smolt movement. Because a few nights were not sampled due to equipment malfunction, weather interference, and flooding, a weekly estimate for the smolt run was determined from:

$$C_\tau = (N/n) * (\sum C_i + EF) \qquad \text{(Equation 1)}$$

and,

$$Var (C_\tau) = N(N-n)1/(N-1)* \sum (C_i - C_{avg}) \qquad \text{(Equation 2)}$$

where,

C_τ = total number of smolts for the week,

N = total number of nights of smolt movement,

n = number of nights sampled by electrofishing or observation,

C_i = the total estimate for a single night,

EF = the number of smolts captured by electrofishing, and

C_{avg} = the average of all night estimates for the week.

This estimate of total smolts was adjusted by the proportion of steelhead captured by trapping in that week to obtain an estimate of steelhead smolts. All C_t and $Var(C_t)$ estimates were summed for an annual estimate of smolt numbers and variance of annual smolt numbers, respectively.

In addition to estimating smolt numbers with 20 minute observations, we evaluated estimates and the error rates associated with different frequencies of this type of sampling. We used the original estimate, derived from all days of sampling, was the estimate for 100% of observations through the duration of the smolt migration. Estimates and standard errors were then derived for each of the four years by using the values obtained from periodic sampling schedules including: every-other day (50%), every 3rd day (30%), and by obtaining a random sample of 80% and 20% of the nights during the smolt run in 1993-1996. Estimates and variances were calculated according to equations 1 and 2.

In 1995 and 1996, we used surface-view, time-lapse videography to continuously monitor and record a visual record of emigrating smolts. Two video cassette recorders (Sony SVT-100) stationed in housing next to the river and connected to two solid state black and white cameras (Vicon 12.5 mm F1.3 (A) and 25 mm F1.3 (B), housed in Environmental Enclosures (Pelco EH4500)) each monitored and recorded smolts passing over half of the sill (Figure 2). Five frames per second were recorded, resulting in 12 hours of actual smolt movement condensed to 1 hour of videotape. The sill of the dam was illuminated with a 250 watt halogen light. Due to the remote location of the monitoring site, gasoline powered generators were used to provide electricity. Twice each night, recording was interrupted for less than 2 minutes to refuel the generators. Cameras were set up each night before dark and removed in the morning to prevent vandalism and theft. A small monitor was also located in the housing next to the stream to aid in camera placement and focus. A fishing bobber, positioned in the middle of the sill aided in positioning each camera's view over half the sill and avoided overlap and duplicate recording of smolts.

Tapes were reviewed by 3 observers using a professional editing videocassette recorder (Panasonic AG1980P) which allowed frame by frame and reverse playback of the videotapes. All reviewers worked together initially to develop a consensus on smolt images and counting methods. Fish were identified on the videotapes of the water passing over the sill by their fusiform shape and thickness, and subsurface presentation. In addition, smolt behavior while passing over the weir typically consisted of smolts backing downstream tail first and approaching the sill. Smolts also exhibited a slight bending to form a C- shape, movement that was slower and often lateral to the water current. Smolts usually were present in two or more frames. All tapes were reviewed from the beginning of the evening, 21:00 hours, to the end of the smolt movement at 05:00 hours.

Camera A and camera B counts were summed to obtain an estimate of smolts for the night. Similar to the 20 minute estimates, a weekly estimate of smolts from the videotape counts was calculated by the equation:

$$C_{\tau(AB)} = N_{(A)} / n_{(A)} * \sum C_{i(A)} + N_{(B)} / n_{(B)} * \sum C_{i(B)} + EF \qquad \text{(Equation 3)}$$

where A and B designate the cameras of observation. Each weekly estimate was then adjusted by the proportion of steelhead in the captured smolts and weeks were summed to obtain an annual estimate for 1995 and 1996.

In consideration of the viewer subjective interpretation that was required to review tapes and enumerate smolts, an error analysis from a stratified, random sampling of the tapes was conducted on the observations. Because rates of smolt movement varied hourly, daily, and weekly through May and June, we randomly selected on night from each week during the smolt run for recounting. The selected night was divided into three equal time blocks, and we randomly selected one 30 minute period per time block to recount by a second reviewer. A paired t-test was used to test for differences between 2 viewers and variances of the daily estimates based on viewer interpretation were calculated according to the following equation:

$$\mathrm{Var}\,(C_i) = (K\,C_i)^2 \qquad \text{(Equation 4)}$$

where C_i = total number of smolts observed for night i, and K = the coefficient of variation (CV) among viewers. The CV was calculated by:

$$CV_i = (\mathrm{sqrt}(\sum ((X_i - X_{i(mean)})^2)/ n_i - 1)/ X_{i(mean)}) \qquad \text{(Equation 5)}$$

where,

X_i = the sum of the 2 reviewers counts for a night,

$X_{i(mean)}$ = the nightly average from the two reviews, and

n_i = number of reviews of night (I) = 2.

A mean CV was calculated for each camera from the nightly variance among viewers. The CV was assumed to be constant over time and a variance of the estimate of the numbers of smolts based on viewer interpretation was calculated by:

$$\mathrm{Var}\ (C_\tau) = N(N-n)(1/N-1) * \sum (C_i - C_{(mean)})^2 + N/n * \sum \mathrm{Var}\ (C_i) \qquad \text{(Equation 6)}$$

Separate estimates of smolt numbers and variances were determined for each camera and summed to determine a yearly smolt estimate and variance.

To determine species composition of the outmigrants and also to identify the origin of the steelhead smolts, we constructed a temporary constriction weir upstream of the lamprey weir approximately every 5th night during the outmigration period. The weir consisted of construction netting angled from both streambanks to a 3 m downstream opening (Figure 3). A large block net was placed in the opening to collect the smolts. Beginning at 21:00 hours, we used a 250 volt DC barge electrofishing unit within the block net every two hours until 05:00 hours to capture smolts. All fish were identified to species, measured for total length, weighed, and released below Homestead Dam. In addition, we checked all steelhead for either a right pelvic (1993-1996) or right pectoral (1996) fin clip and removed scale samples from a subsample of hatchery (fin-clipped) steelhead and all steelhead without a fin clip. Scales were analyzed by inspection of circuli surrounding the first annulus (Seelbach and Whelan 1988) to determine if the smolt was hatchery or wild.

We calculated a Peterson mark-recapture estimate of the steelhead smolts leaving the Betsie River watershed by assuming that the number of stocked hatchery fish each year comprised the marked population, and that clipped fish were equally likely to be recaptured in the constriction weir as the unmarked wild portion of the population (Ricker 1975).

Our summer electrofishing surveys revealed that a large number of hatchery steelhead did not leave the watershed (Figure 4). We estimated the number of stocked steelhead that remained in the river (residualized fish) in July to determine the actual number of marked migratory steelhead that migrated downstream for the mark-recapture estimates. We stratified the watershed into reaches based on hydrology, gradient, and thermal regime and randomly sampled equally in the reaches for a total of 21 sites. We used electrofishing and multiple-pass depletion methods to determine the number of residual steelhead (Zippen 1958). An estimate of residual steelhead abundance was calculated by determining the mean density of hatchery fish for the sample reach and multiplying by channel area in the reach. Because residual hatchery fish are known to remain within the area where they were stocked (Seelbach 1987) we estimated the density of residual fish from a site sampled near the hatchery to determine the abundance of hatchery fish within 2 miles upstream and downstream of the stocking location. Reach estimates were then summed to obtain a total watershed estimate for residual hatchery steelhead. The estimate of residual steelhead was subtracted from the number of fish stocked from the hatchery to determine the number of marked, migratory fish that was assumed to be randomly mixed with the wild migrating smolts (Figure 4). Standard methods were used to calculate the Peterson estimate and variance (Ricker 1975).

Results

Observations of smolt movement commenced at the beginning of May each year and continued until mid- to late June, with the exception of 1993 when sampling was discontinued early due to logistical complications. Steelhead smolts ceased migratory activity in the last two weeks of June and the duration of the smolt run ranged from 39 to 51 days (Table 1). From 1993-1996, we captured 1,755 steelhead smolts of which 365 were determined to be wild on the basis of scale analysis. Annual mean length of wild steelhead smolts in 1993-1996 ranged from 193.6 to 195.0 mm. Over half of the wild emigrating smolts were age-1 (55-72%) each year, less than half were age-2 (26-45%), and fewer than 3% of the emigrating steelhead smolts were age-3.

Smolts migrated past the monitoring site in a consistent nightly pattern. The greatest number of smolts passed over the Homestead Weir between dusk and midnight. Over 80% of the smolt passage occurred before 02:00 hours (Figure 5) on most nights.

Four species of fish were captured in the constriction weir above Homestead Dam during the hours of 1800 through 0500. Recently released hatchery brown trout (fin erosion indicated hatchery origin), wild coho salmon, wild and hatchery steelhead, and wild chinook salmon smolts were present in the catch. The proportions of each species captured varied between years; steelhead made up 30% to 61% of the spring smolt run (Figure 6).

Each year the number of marked fish stocked into the Betsie River increased. The number of residual fish also was very large in some years, which accounted for between-year variance in the number of marked migratory steelhead (Figure 4). Peterson mark-recapture estimates that were not adjusted for residual fish resulted in estimates 2-5 times greater than those adjusted for residual fish (Figure 7). Total estimates for hatchery and wild steelhead passing the weir ranged from 13,837 (12,583-15,215) in 1995 to 56,661 (46,036-69,703) in 1993 (Table 2). Wild steelhead smolts comprised 30%, 12%, 24%, and 52% of the captured steelhead smolts in 1993-1996, respectively.

The mean number of steelhead outmigrants was lower based on the 20 minute visual sampling and videographic methods. The number of wild and hatchery steelhead passing the weir ranged from 2,328 (± 1,249) in 1996 to 9,645 (± 1,111) in 1994. The number of wild steelhead smolts was determined from the overall estimate of steelhead smolts and varied only slightly among years from 1,211 (± 649) in 1996 to 2,151 (± 286) in 1993 (Table 3). We used videographic methods in the last two years of the study, and smolt numbers were similar to the estimates derived from direct observation, 20 minute sampling (Table 3).

With a few exceptions, estimates of smolt numbers from subsamples of the nights of observation were similar to those from sampling the entire smolt run (Figure 8).

Large differences occurred however, in the 95% confidence intervals and standard error (Figures 8 and 9). Standard error increased with decreasing levels of effort. Effort involving every other day (50%) and an 80% random sample had similar error rates , and sampling efforts of every 3rd day (30%) and a random 20% were much larger in error (Figure 9).

Discussion

Steelhead smolts in the Betsie River followed similar migratory patterns to those described from other Michigan streams and elsewhere in their timing, and nocturnal movement (Stauffer 1968, Seelbach 1993). Because we observed no significant smolt movement during the hours between 05:00 and 21:00, our efforts were concentrated on nocturnal movement. Brege et al. (1996) monitored salmonid smolt movement on the Columbia River over 6 years and nocturnal movement of steelhead smolts accounted for 66.2% to 87.4% of the daily observations, with a mean of 77.9% (Brege et al. 1996). Using this information, our estimates could be increased by 22% to account for any daytime passage that may have occurred. However, from periodic checks of smolt activity during the day, only once, in 1995 was any movement observed between the hours of 07:00 and 21:00.

The mark-recapture estimates of outmigrating smolt numbers were 2-9 times greater than those determined from the videography and direct observation methods (Figure 10). Assumptions of mark-recapture methodology include: 1) animals do not lose marks, 2) sampled fish are classified correctly, 3) either the population is closed, or there is neither recruitment or immigration, and 4) sampling is random with regard to marks, so that every fish has an equal chance of capture (Cormack 1968, Pollock 1981). Because fin clips were used to identify hatchery fish, marks were not lost. However, fish marking was not consistent (up to 35% of the smolts were not clipped in one year). To avoid an error in the assumption of correct classification, we used scale analysis to verify classification of smolts as either hatchery or wild. We also assumed that the migratory population of smolts was closed. This is a reasonable assumption as this was a watershed assessment and smolts were not able to move upstream past the Homestead lamprey weir.

Significant numbers of marked fish did residualize and we made adjustments to determine an estimate of the marked migratory population. It is possible that we underestimated the number of residual smolts: e.g., they may have concentrated in large pools below the hatchery which were not amenable to sampling with our electrofishing procedures. In a different approach to determining residual steelhead, we calculated the number of fish that were likely to residualize based on lengths observed in the hatchery in April. From measures of individual fish in the hatchery in 1994-1996, we determined that 97%, 81%, and 88% (respectively) of the steelhead in the hatchery were less than 180 mm, the length at or above which steelhead smoltification is likely to occur (Seelbach 1987). Using this method, the estimates of residual steelhead were 47142, 40500, and 48400 in 1994-1996. In this approach, the estimates for 1995 and 1996 are similar to the estimates of residual fish determined from electrofishing throughout the watershed in July (Figure 4). However, the 1994 estimate from the hatchery approach was nearly twice as large as that determined from the watershed estimates. This may indicate that we underestimated the number of residual fish for that year with electrofishing, or that other factors, such as release dates or hatchery crowding may have influenced the emigration of these fish (Wedemeyer et al. 1980).

A failure to recapture a sufficient number of marked fish for a precise estimate would have been indicated by large confidence intervals (Dempson and Stansbury 1991). The confidence intervals determined in this study ranged from 10-24% of the estimates, which may be considered as fairly reliable estimates (Roff 1973, Cousens et al. 1982)

The most likely reason for the seemingly disproportionate mark-recapture estimates were due to violations of the assumption of equal chance of capture (Pollock 1981). Inherent in this assumption is that marked and unmarked fish mix randomly and that the probability of capture is equal for either classification. Juvenile steelhead were released volitionally from the hatchery, which was located approximately 29 km upstream of the Homestead lamprey weir. Volitional releases resulted in the hatchery fish being released at different rates between years. In some years, smolts left the hatchery one to two weeks after a peak in the number of outmigrating wild smolts and as the river was warming above the upper limit (13°C; Zaugg and McClain 1976) for steelhead smolting behavior.

In a similar mark-recapture application to estimate the number of outmigrating smolts (Peven and Hays 1989), the estimates of smolt numbers were corroborated with a life-history method (estimating smolt production based on spawner escapement values, fecundity rates, and survival to age information) to determine the number of smolts. Peven and Hays (1989) found similar results between the two methods, with mark-recapture of smolts giving a likely and reasonable estimate. The difference in this application from the Betsie River is that Peven and Hays (1989) verified that marked smolts were migrating when they were marked, but I cannot verify that the marked fish were migrating when they entered the Betsie River.

Other estimates, using mark-recapture and maximum-likelihood methods, may have yielded better estimates than the single census mark-recapture (Cormack 1968, Dempson and Stansbury 1991, Schwarz and Dempson 1994, Pollock 1981, Macdonald and Smith 1980). However, we could not obtain estimates of the number of smolts released on any given day and smolts were released at varying times (e.g. weekdays only and not on holidays), which precluded the use of any method other than the single census Lincoln-Peterson index.

Mark-recapture estimates are used often to estimate trap efficiency for smolt collection methods (Raymond 1979, Seelbach 1987). Raymond (1979) concluded that the marked steelhead smolts were equally mixed with the nonmarked smolts because of an equal capture rate at a downstream location. When used to estimate escapement by adult salmonids, the accuracy of mark recapture ranged from ± 25% to ± 30% of the estimated value (Cousens et al. 1982). Based on our experience in the Betsie River, mark-recapture methods overestimated the number of emigrating smolts and we caution against the use of single-census Peterson estimates alone to estimate smolts with stocked, marked hatchery fish. At the very least, an estimate of residual marked fish should be determined to make adjustments in the number of marked migrants.

The time-lapse videography used in this study has many advantages that make it feasible in many different field applications. Use of such monitoring systems is labor efficient in that many stations can be operated by a single individual, allowing a large amount of information to be recorded during this time-specific life history phase for later analysis. The system can be used in remote locations, as demonstrated by our use of gasoline generators which provided sufficient power and did not cause interference with the cameras or recorders. A surface view approach provided an effective and inexpensive viewing of emigrating smolts. Although this application involved a lamprey weir, we could have easily established a viewing station on a hydraulic control or riffle; the system should work at any location where fish could be guided over a narrow backdrop presented at a depth where smolts could still be viewed. Drawbacks to the surface view approach are that it requires an additional trapping effort when multiple species are migrating and that turbidity of the water can impede observations. However, turbidity prevented visual observations on only 3 days in four years (185 days) of viewing. A ruled backdrop and slightly higher resolution of the images (which would require at least one additional camera in this application) could have allowed us to use inference from lengths to determine species composition among coho salmon, chinook salmon and steelhead based on the differences in mean length of smolts of each species.

Although the video monitoring was relatively labor efficient, manual review of the videotapes was tedious, but produced accurate results. A single taping event for one camera included 8 hours of recording and required 3-4 hours to carefully review and count smolts. The efficiency of this effort could be enhanced by automated viewing techniques (Irvine et al. 1991). Similar to Hatch et al. (1994), comparisons between direct observation estimates and videotape results were similar. In addition, no significant differences were found between the 3 trained reviewers in counting smolts from the videotapes.

Because of the nocturnal movement of smolts, lighting was required to illuminate the area enough to provide a view through the water to the sill. We used 250 watt diffuse halogen lighting to illuminate the area for monitoring. Because the lighting was constant, it is not likely to have affected the passage of smolts. The change in environment for the emigrating smolts from the dark upstream areas to the lighted sill area may have caused hesitation in passage over the weir. A typical pattern observed by the smolts was for them to back down to the front of the sill and school together. The school would swim back and forth across the front of the sill and continually increase in numbers until a time when the large numbers of smolts would pass over the sill either together or sequentially. Artificial lighting was not likely to have caused this behavior, because the same behavior was observed during dusk when lighting was not required and during the few daylight observations of smolt passage. One problem with the use of halogen lighting was that it attracted clouds of emerging insects. At times, this caused the cameras to focus on the insects rather than the sill and sometimes the insects were so thick that they prevented counting of the smolts. This was usually an early evening phenomenon, and occurred when air temperatures were higher. However, it could be avoided by the use of infra-red lighting, without an effect on fish behavior (Beach 1978).

The abundance of smolts passing through any given night was variable. In a telemetry study of coho smolts, Moser et al. (1991) found that movement was in a saltatory fashion with movement in the direction of the current and then extended periods of holding in areas of low current velocity. This behavior could explain some of the variability in the abundance of smolts observed between nights, especially when considering the small number of smolts that emigrated from the watershed. Subsamples of the number of nights required to establish an estimate of smolts indicated that sampling between 60-100% of the nights during smolt outmigration would give similar estimates for the effort incurred. An effort of observation that included less than 60% of the nights of smolt movement would likely result in an estimate with an extremely large error. Of course, in any smolt monitoring application, determination of the beginning and end of smolt movement is required to determine the extent of sampling required. In some cases, the onset and cessation of smolt movement may be approximated with water temperature trends (Wedemeyer et al. 1980, Hoar 1984).

The Betsie River watershed produced few smolts per hectare when compared to other streams in Michigan. The Huron River, a tributary of Lake Superior and a smaller river than the Betsie River, produced 9,141 and 1,031 wild steelhead smolts in 1987 and 1988 or 46-262 steelhead smolts/ha (Seelbach and Miller 1993). The Little Manistee River is a high quality trout stream tributary to Lake Michigan, south of the Betsie River, with a drainage of 59,000 ha and a mean annual flow of 5-6 m^3/s (Seelbach et al. 1984). This river produces a greater number of wild smolts annually, ranging from 11,845 to 86,425 smolts/year with a density of 425/ha (97-713/ha).

Conclusions and Management Implications

Currently, the Betsie River watershed produces fewer than 3,000 wild steelhead smolts, far less than a high quality trout stream such as the Little Manistee River. However, this level of production may reflect the type of production that could be expected in the marginal trout streams that experience high summer temperatures and moderate to severe winter temperatures.

Mark-recapture methods largely overestimated the numbers of smolts leaving this watershed. A single census, Peterson estimate should be used with great caution and the assumptions of equal mixing and equal probability of capture should be addressed for conclusive results.

The surface-view time-lapse videography and 20 minute observational sampling provided estimates similar to one another. Both are inexpensive and could be conducted on weirs and natural hydraulic controls in smaller rivers. The videography has additional advantages of providing a permanent record and requiring less labor. Improvements to the video system we used could include electricity at the site, infra-red lighting to decrease interference with the view frame by flying insects, and a contrasting backdrop to help clearly illuminate the fish. Further efficiency could be accomplished by increasing the resolution of the cameras and adding a ruled backdrop to measure emigrating smolts.

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Table 1. Duration of observations and smolt movement at Homestead Dam, Betsie River, Michigan, 1993-1996.

Date of First Observation	First Smolt Observed	Last Smolt Observed	Date of Last Observation	Duration of Smolt Movement
5-8-93	5-10-93	6-16-93	6-17-93	39 days
5-5-94	5- 7-94	6-22-94	6-23-94	47 days
5-1-95	5- 2-95	6-19-95	6-22-95	48 days
5-1-96	5- 7-96	6-27-96	6-28-96	51 days

Table 2. Peterson mark-recapture estimates of the number of steelhead in the Betsie River smolt run.

Year	# Marked Migratory Steelhead	Total # of Steelhead Captured	# of Hatchery Smolts Recaptured	Estimate and 95% C. I. Of All Steelhead	Estimate and 95% C. I. of Wild Steelhead
1993	39,888	124	87	56,661 46,036-69,703	16,998 15,057-18,939
1994	23,335	977	860	26,507 27,795 - 28,337	3,181 3,107 - 3,255
1995	10,463	561	424	13,837 12,583 - 15,215	3,321 3,164 - 3,478
1996	9,832	13	54	20,381 15,687 - 26,448	10,598 8,581- 12,615

Table 3. Estimate of the number of smolts from 20 minute direct observation sampling and continuous time-lapse videography at the Homestead Lamprey Weir, Betsie River, Michigan.

Year	Estimate and 95% Confidence Limit for all Steelhead Smolts	Estimate and 95% Confidence Limit for Wild Steelhead Smolts
20 Minute Observations		
1993	7,169 ± 954	2,151 ± 286
1994	9,645 ± 1,111	1,157 ± 133
1995	7,120 ± 1,282	1,709 ± 308
1996	2,198 ± 512	1,143 ± 266
Time Lapse Videography		
1995	5,259 ± 3,328	1,262 ± 799
1996	2,328 ± 1,249	1,211 ± 649

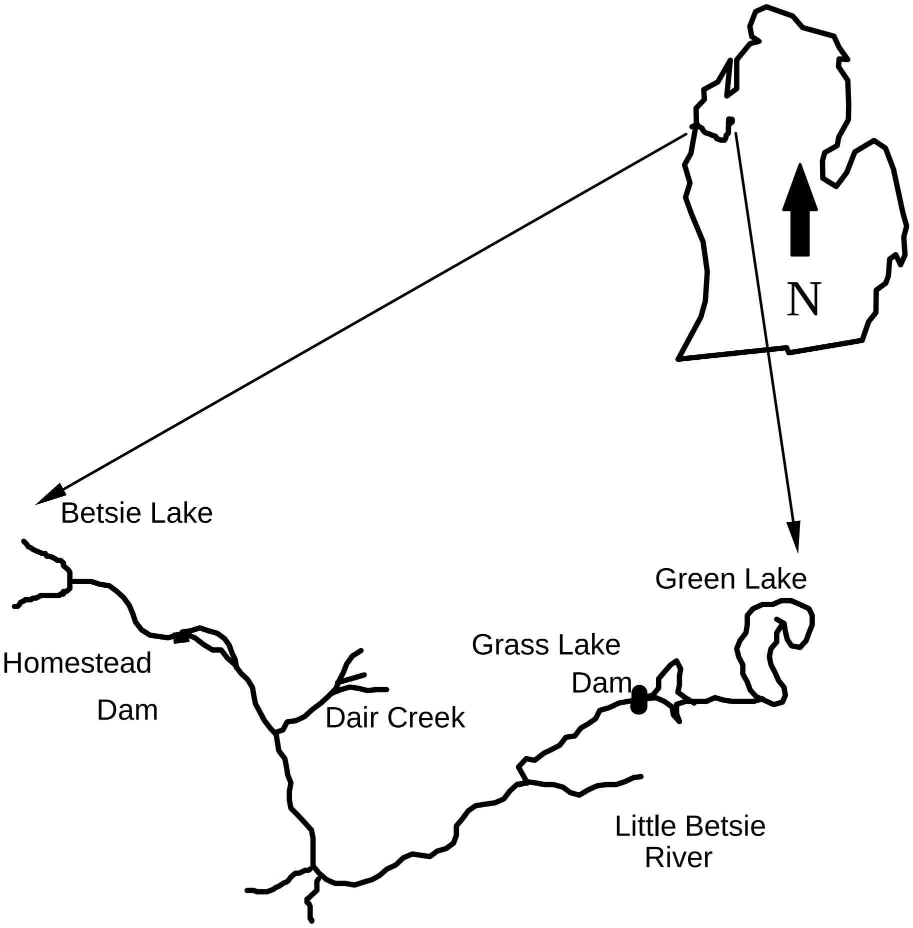

Figure 1. Location and map of the Betsie River watershed in northwestern Michigan.

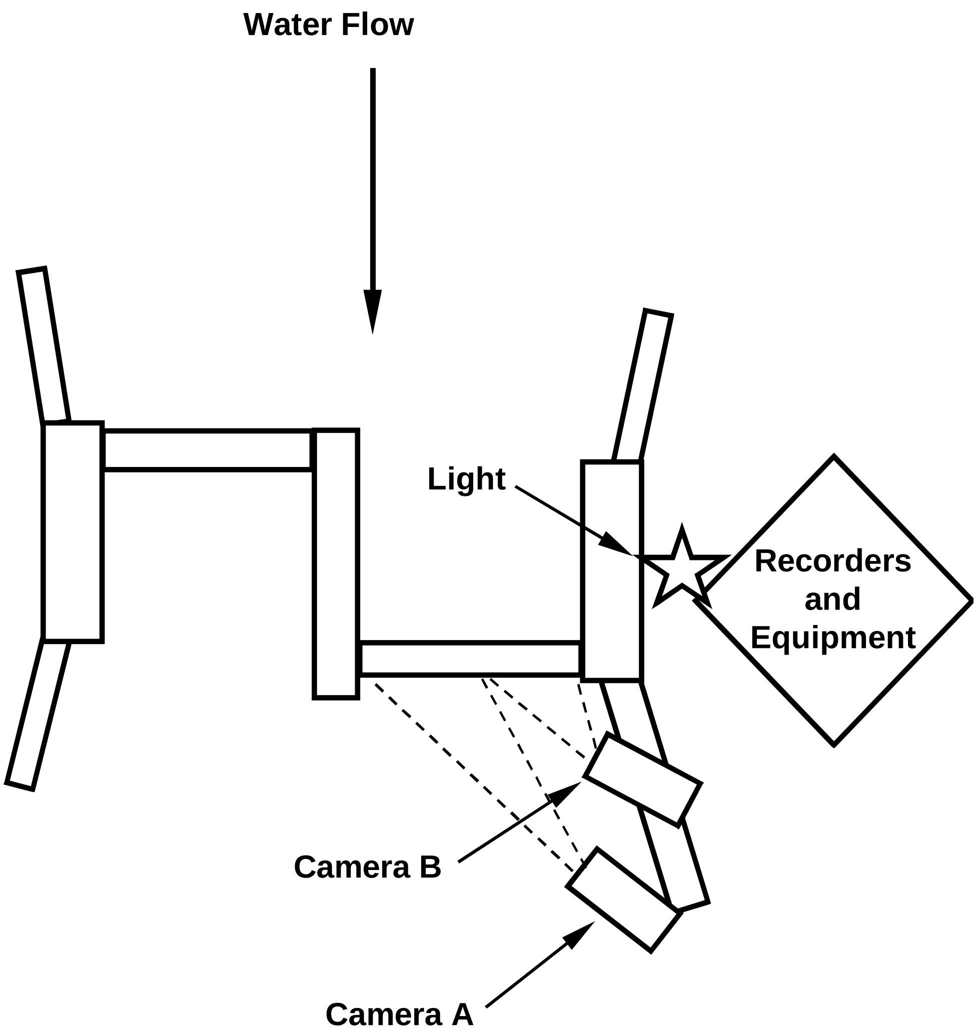

Figure 2. Diagram of equipment used at the Homestead Lamprey Weir to monitor emigrating smolts in the Betsie River, Michigan.

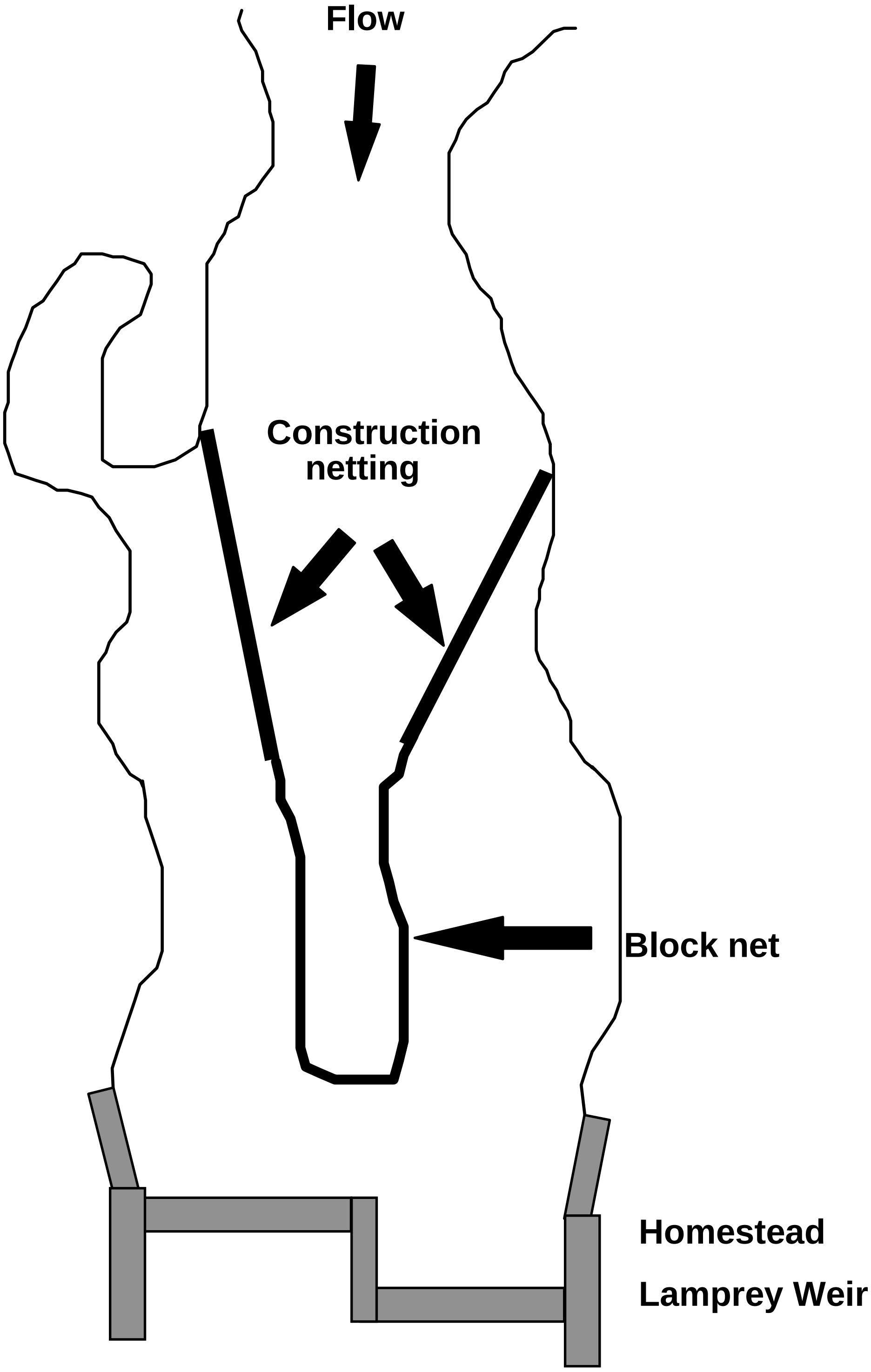

Figure 3. Constriction weir and block net design for capture of emigrating in the Betsie River, Michigan.

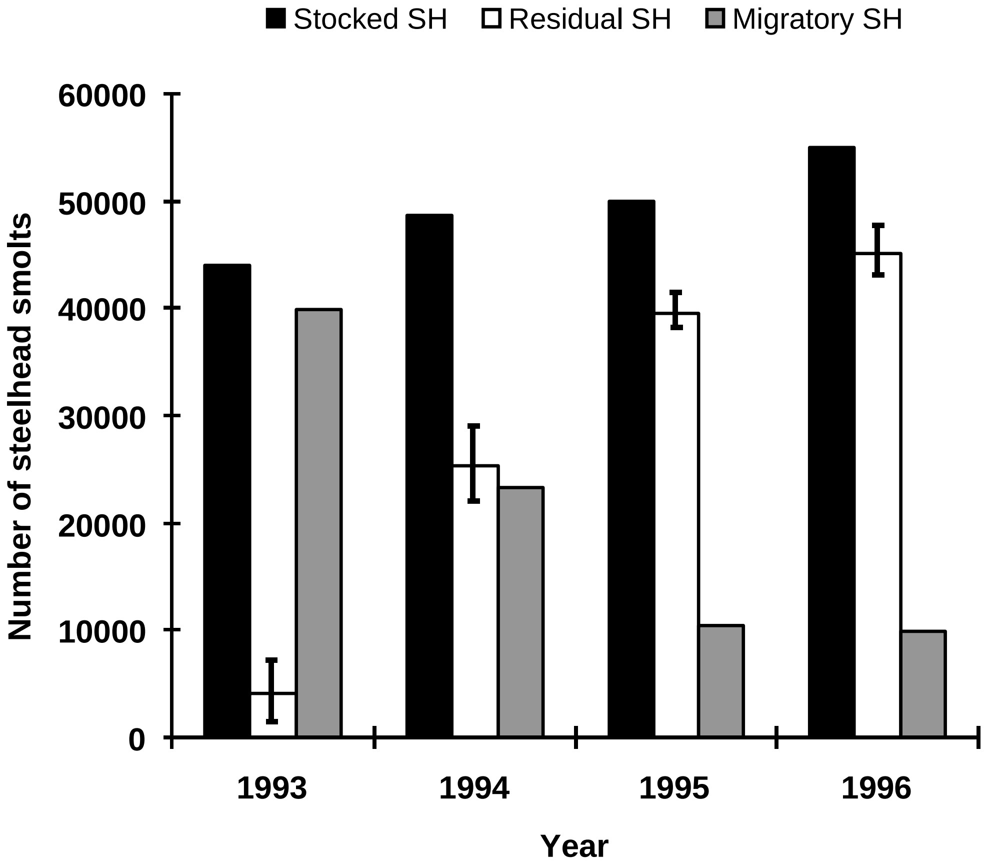

Figure 4. Number of steelhead smolts stocked, estimated number of residual hatchery steelhead, and estimated number of migratory steelhead smolts in the Betsie River, Michigan, 1993-1996.

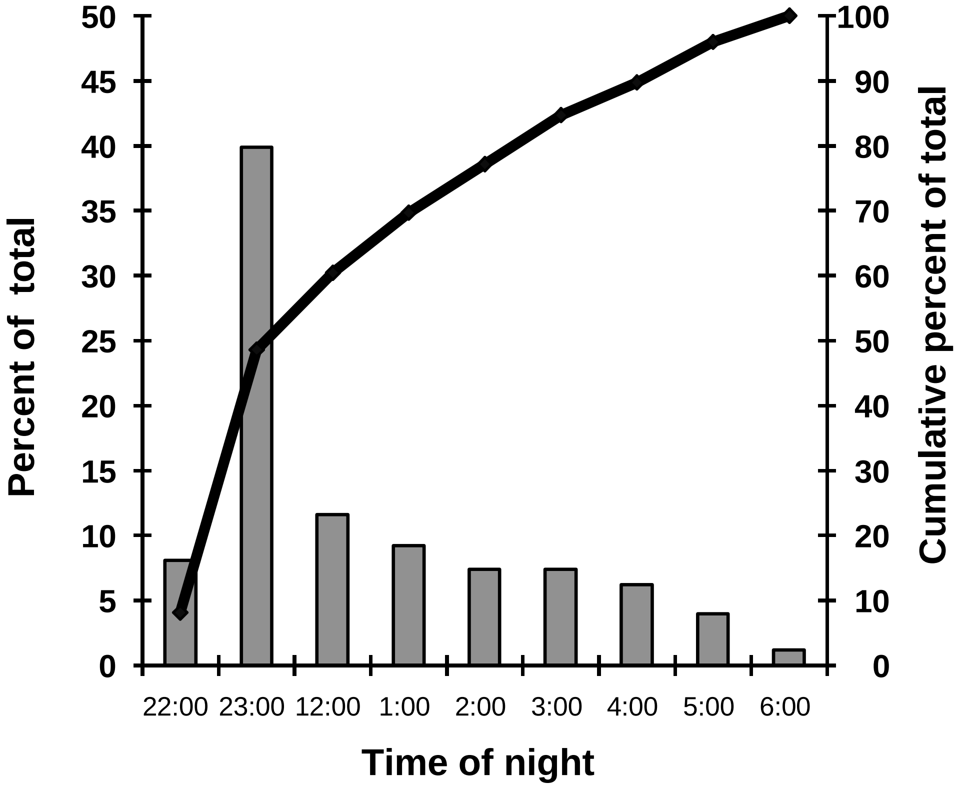

Figure 5. Temporal distribution of outmigrating steelhead smolts in the Betsie River, Michigan. Hourly values represent the mean for observations during that time period.

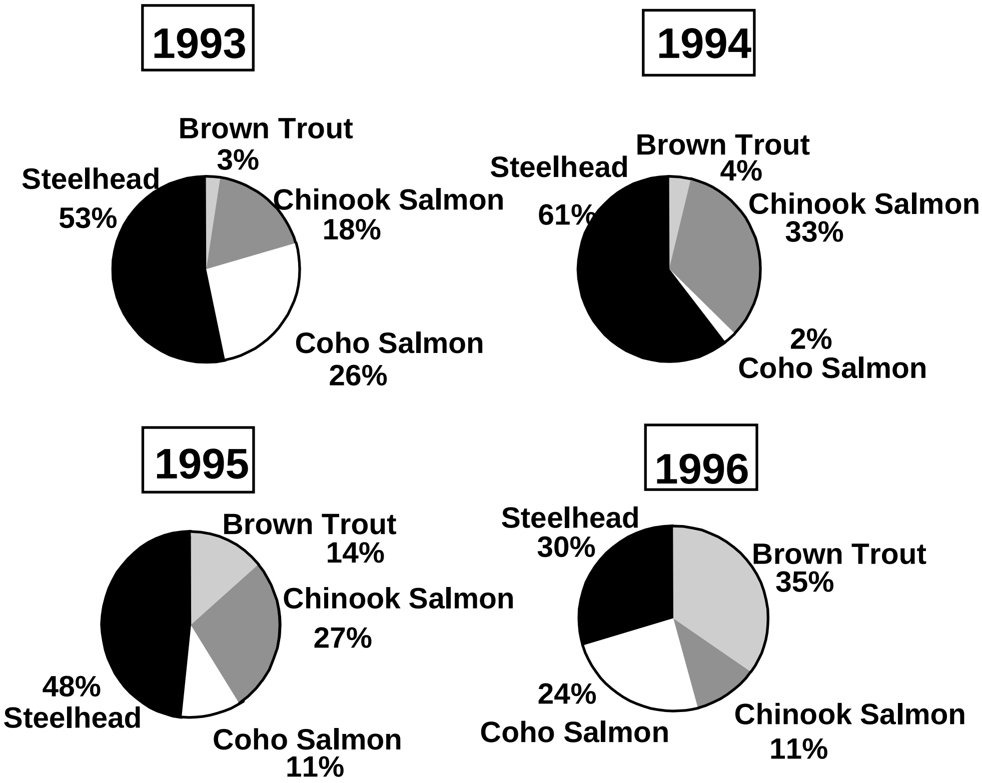

Figure 6. Species composition of the juvenile salmonids captured at Homestead Dam, Betsie River, Michigan, 1993-1996.

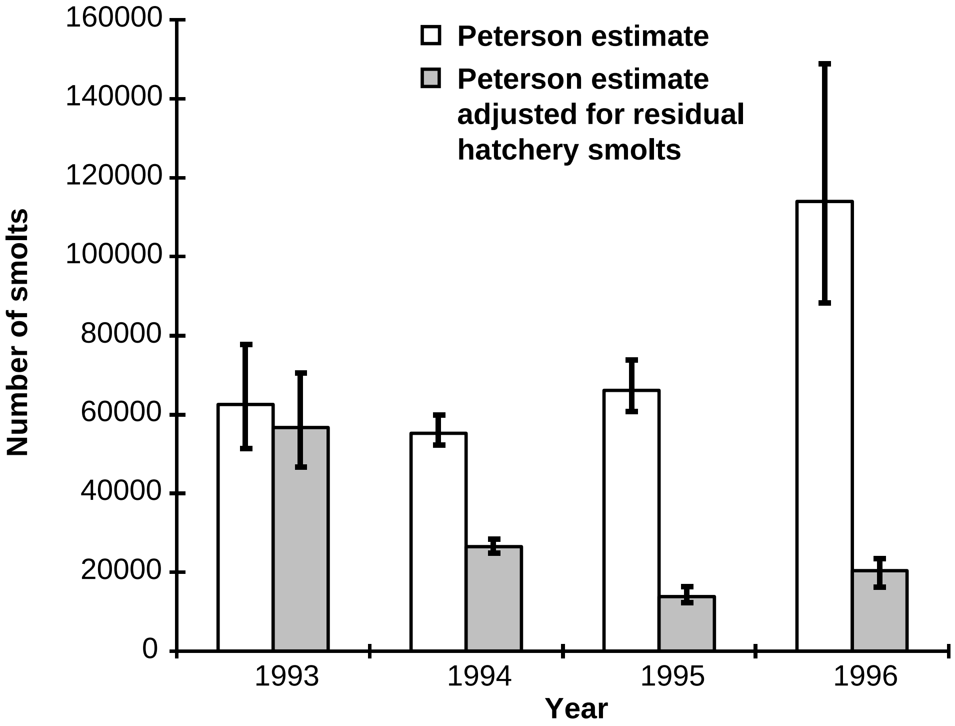

Figure 7. Comparison of mark-recapture estimates and 95% confidence intervals of steelhead smolt numbers with and without adjustment for residual steelhead in the Betsie River, Michigan, 1993-1996.

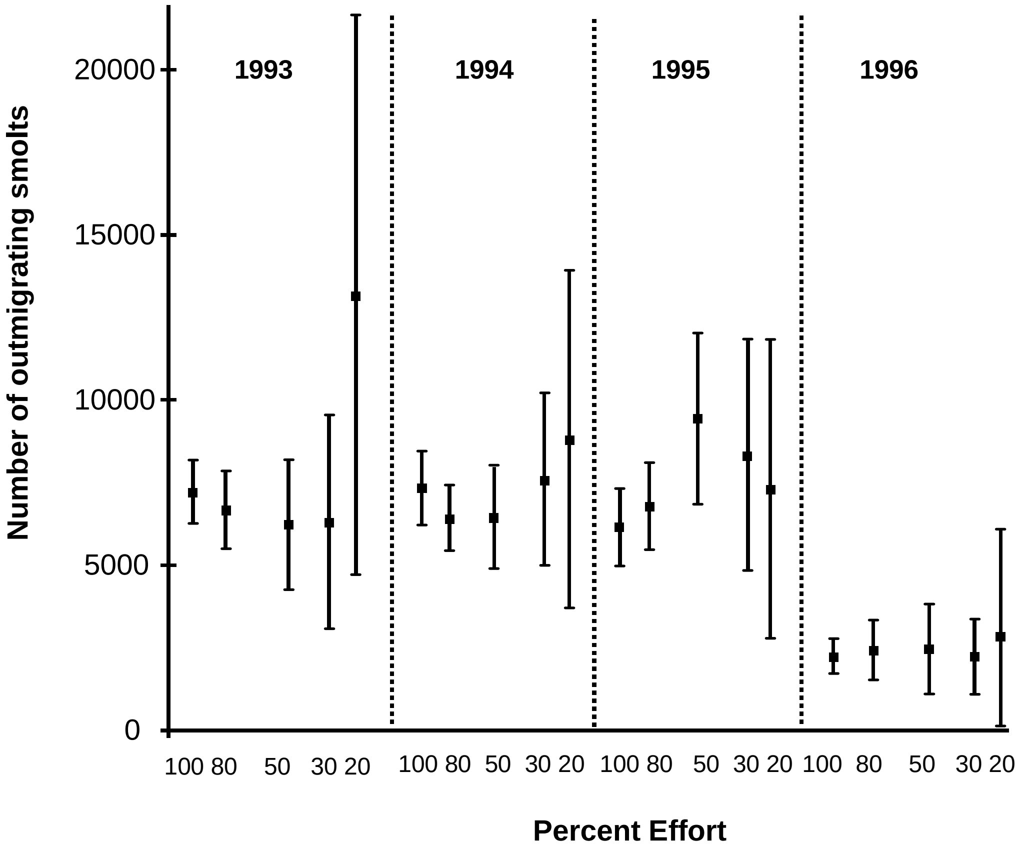

Figure 8. Comparison of the number of outmigrating smolts and 95% confidence intervals calculated from variable sampling efforts ranging from 100% to 20% of the days during the smolt run.

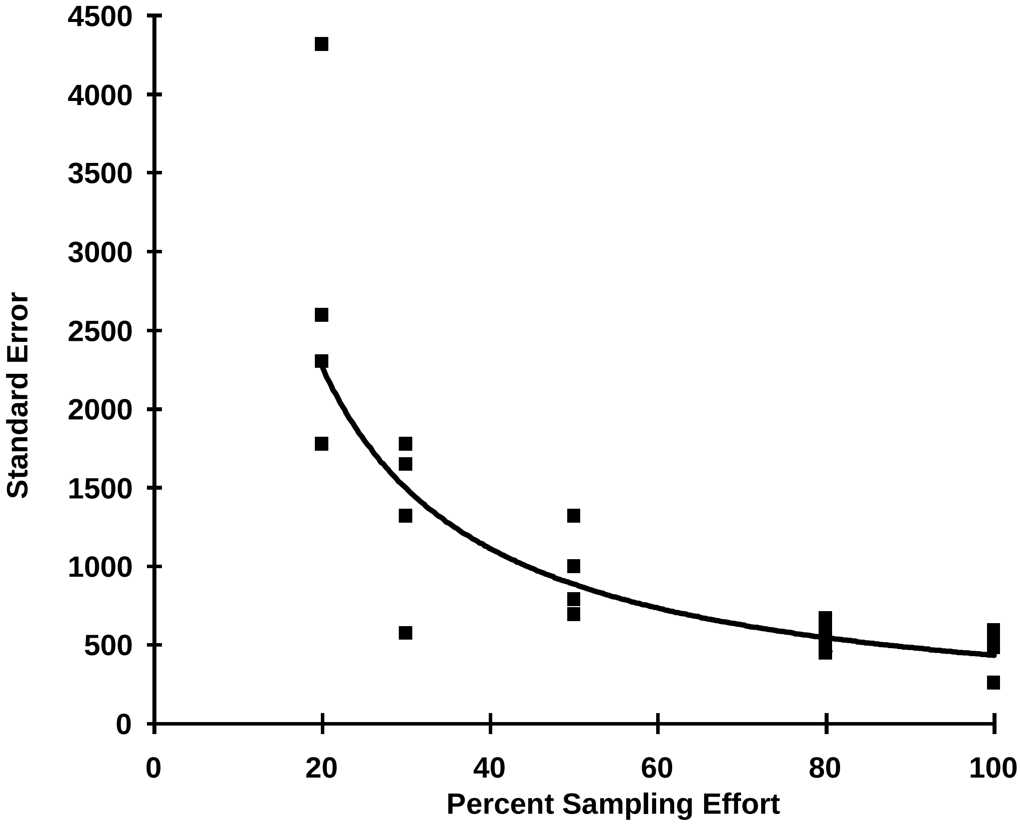

Figure 9. A comparison of the standard error of number of outmigrating steelhead smolts as affected by sampling effort. Fitted line is a logarithmic relationship with $r^2 = 0.7697$.

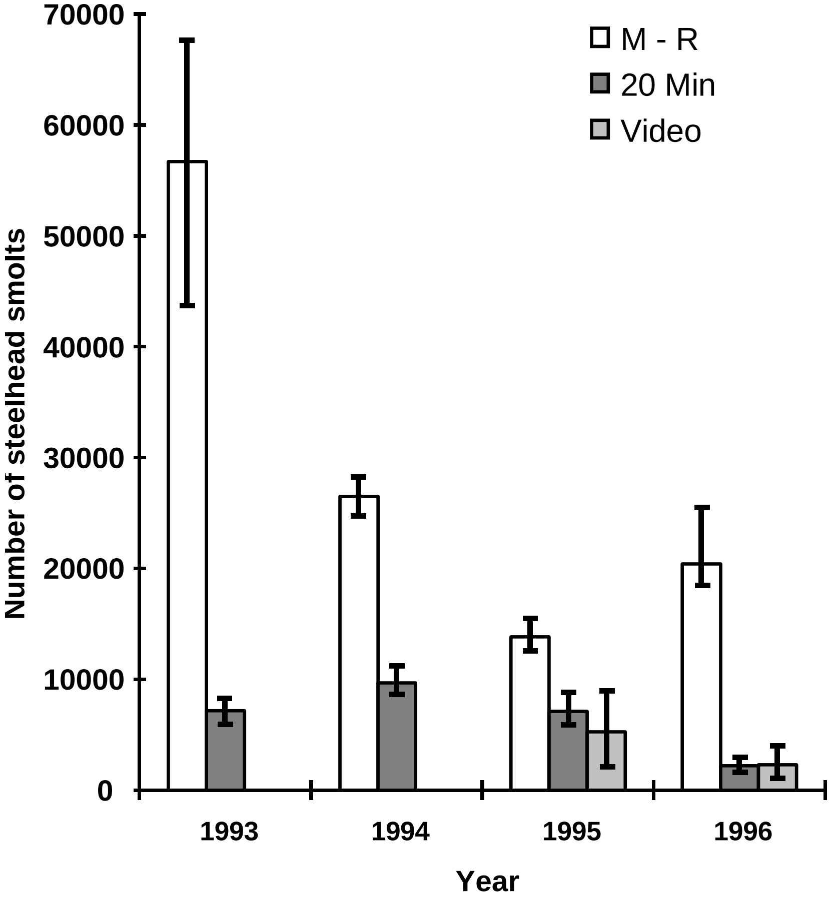

Figure 10. Comparison of the steelhead smolt numbers determined from mark-recapture (M-R), 20 minute observations (20 Min) and continuous recording (Video) in the Betsie River, Michigan, 1993-1996. Error bars represent 95% confidence intervals.

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