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Basinwide Estimation of Habitat and Fish Populations in Streams

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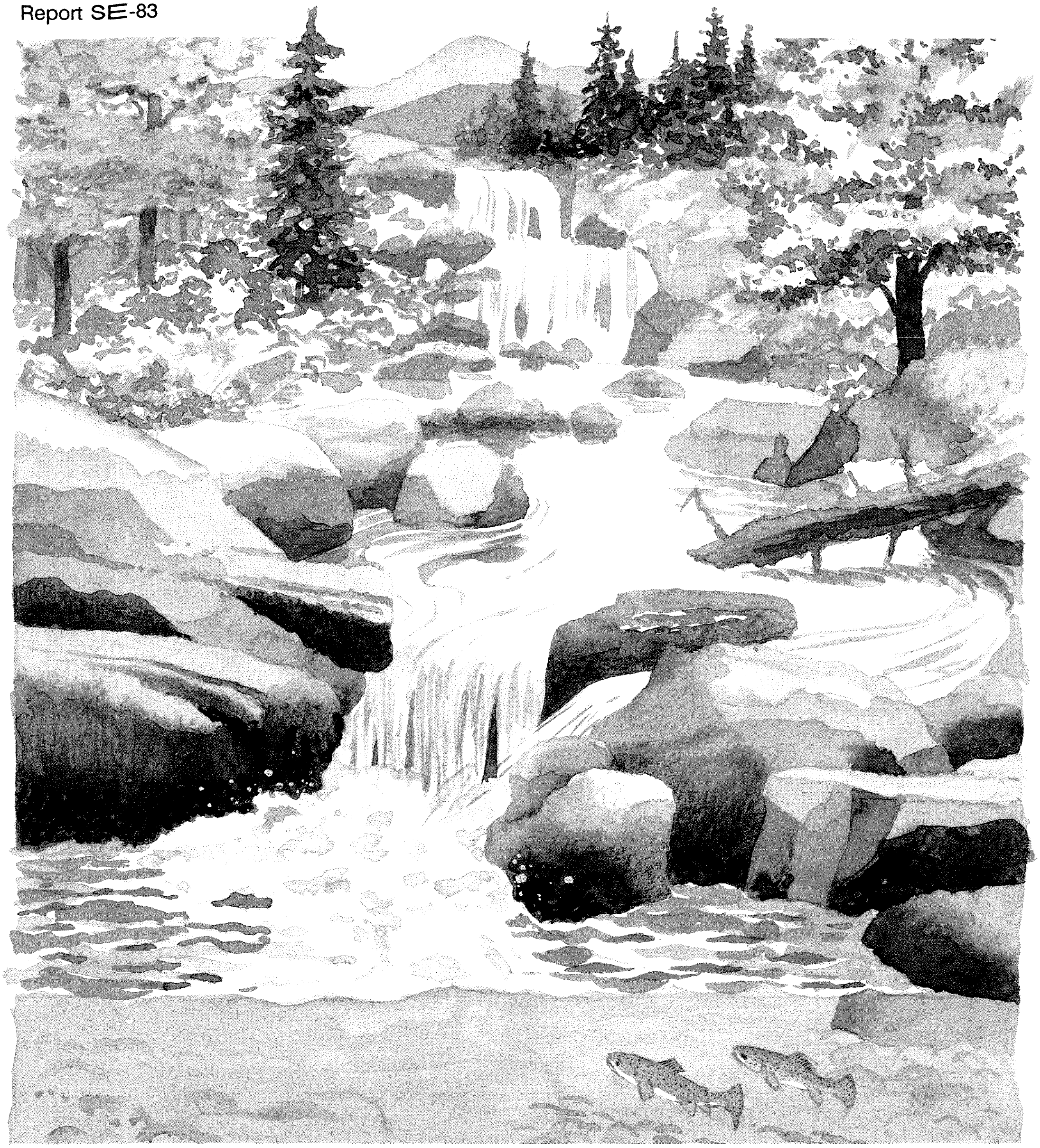

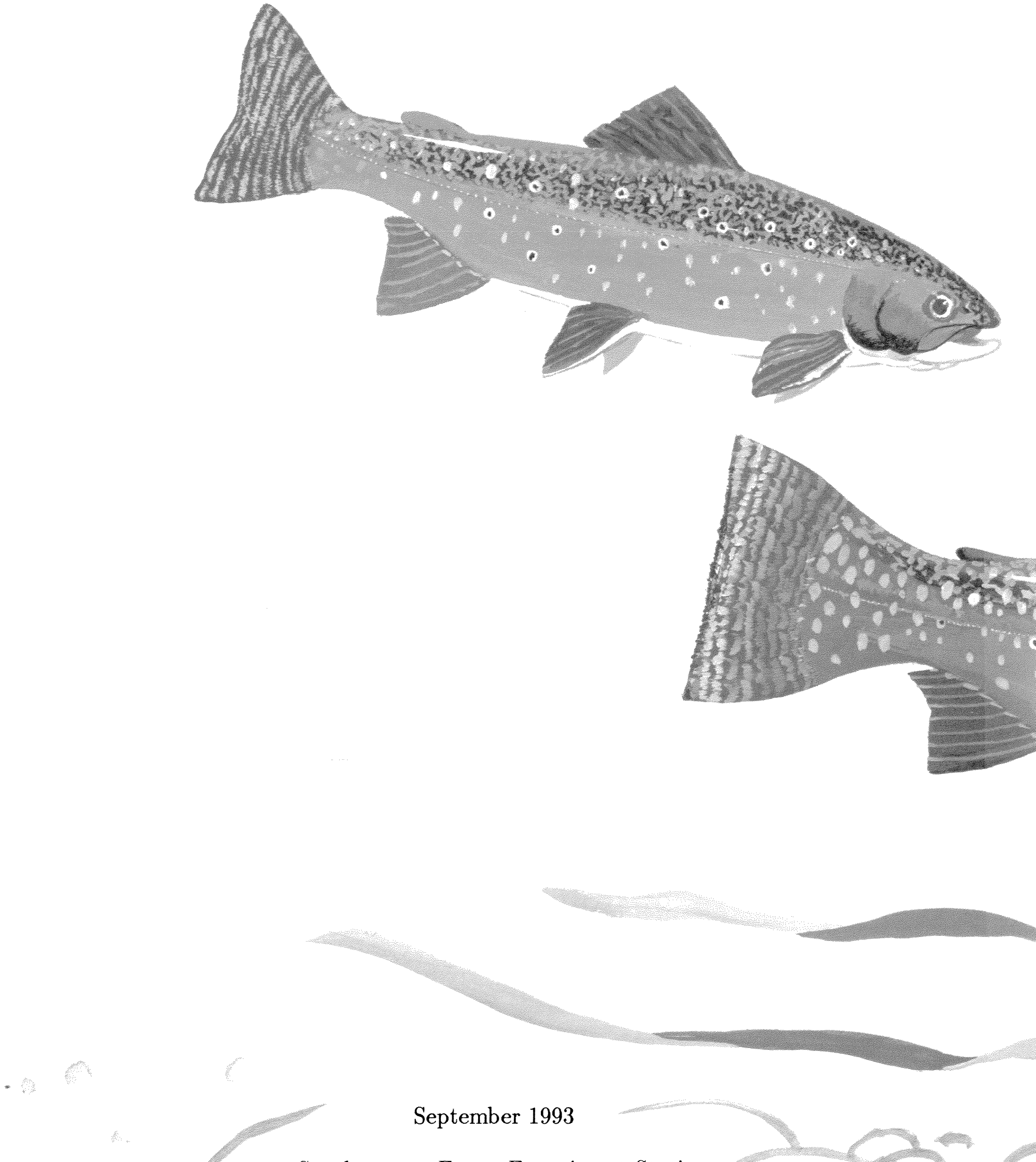

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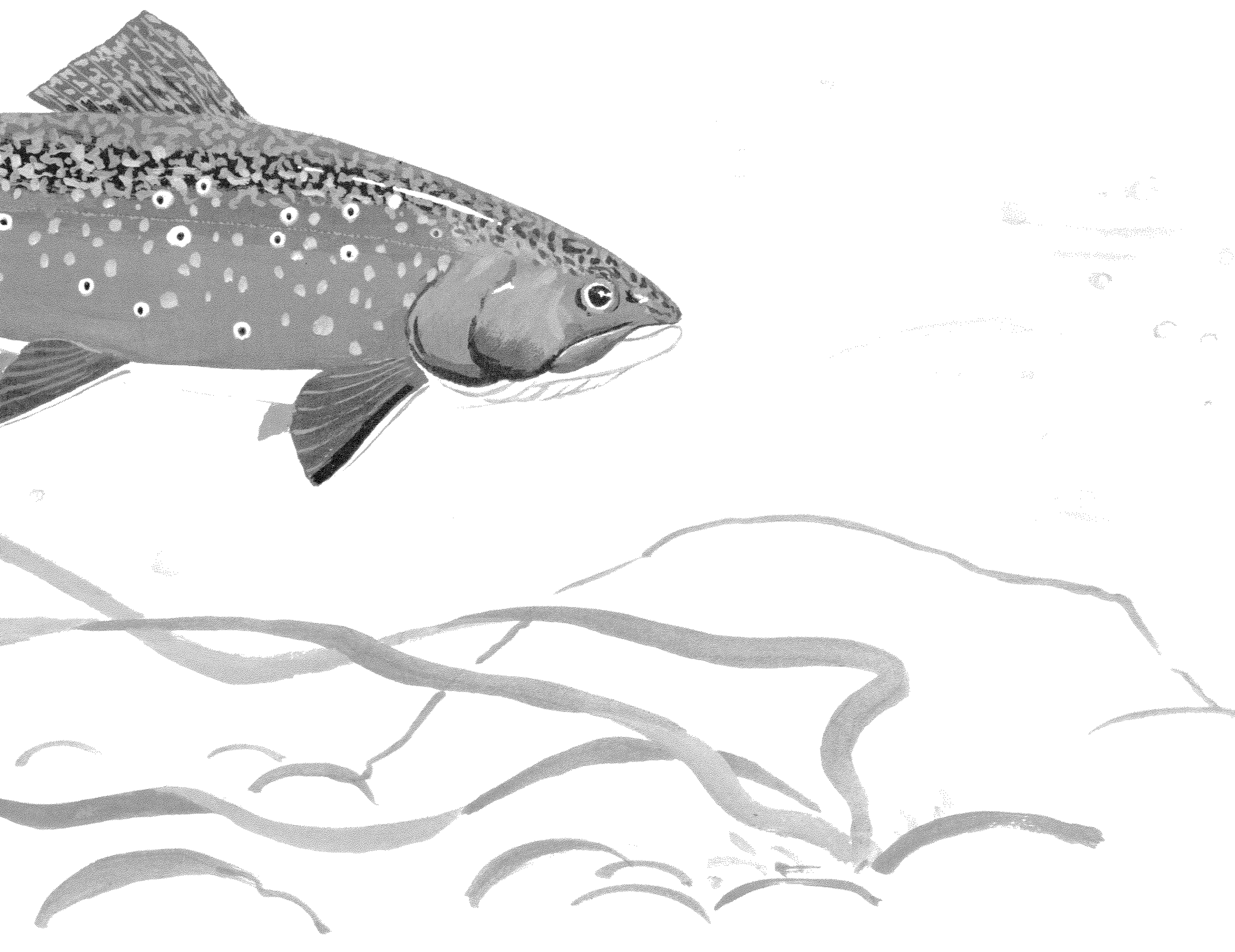

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Introduction

Inventories of habitat and fish populations are the primary source of information for the evaluation of watershed conditions and the management of aquatic resources. Data collected in comprehensive, statistically valid surveys can be the basis for habitat restoration and improvement programs and can be used to monitor changes in the quality and quantity of resources. The selection of an appropriate survey methodology is therefore a critical step in the design of an inventory. The following three approaches are available for determining the amount, type, distribution, and quality of habitat; and for developing habitat-specific calculations of fish species composition, distribution, and numbers:

Comprehensive Census – The most accurate way to inventory habitat and fish populations is to visit and measure all habitats and to count every fish in the watershed. For all but very small experimental streams, this approach is clearly impractical.

Representative Reaches – Until recently, the most-widely-used alternative to a complete inventory of an entire study area has been the Representative Reach Extrapolation Technique (RRET). Using the RRET, biologists measure habitat and fish populations in a particular section or sections of a stream (typically 30 to 300 meters long) and extrapolate their findings to the watershed scale. When selecting representative reaches and identifying upper and lower boundaries, biologists must rely heavily on their professional experience and intuition. Estimates from the RRET are usually accurate for the particular reach that has been surveyed, and it is common practice to extrapolate from a representative reach to an entire watershed. Because a representative reach is selected purposively, however, it is impossible to establish the accuracy of such extrapolated estimates (Hankin 1984, 1986; Jessen 1978). Further, the selected representative reach may not include all habitat types present in the watershed.

Basinwide Estimates – To provide a statistically valid, accurate, and cost-effective alternative for developing habitat and fish-population inventories, Hankin and Reeves (1988) developed the Basinwide Visual Estimation Technique (BVET). Unlike the RRET approach, the BVET will always include data from all the habitat types and locations within a watershed. The technique entails a visit to every reach within the study area to record visual observations of habitat characteristics and fish populations. At preselected intervals, actual measurements are also recorded. Visual observations and actual measurements are used in computing calibration ratios to correct for observer biases and to allow estimation of sampling variances.

Since 1988, the BVET has been extremely useful to both research and management biologists, especially those working on western streams and rivers. The purpose of this handbook is to introduce the BVET to a wider audience and to provide practical instructions for its use by a variety of resource professionals. See the appendix for a checklist of recommended equipment.

Habitat Survey

The purpose of sampling by the BVET is to inventory a preselected set of habitat characteristics in an entire watershed. Habitat sampling occurs in two steps (Hankin and Reeves 1988). During the first step, the sampling team classifies individual habitat units by habitat type and records visual observations of habitat characteristics, such as water surface area and substrate composition. In the second step, the sampling team pairs visual observations of surface area with actual measurements taken at a predetermined number of units (at least 10 for each habitat type) to develop calibration ratios. Sampling teams consist of two people, one who estimates habitat characteristics and another who records information and challenges any apparent errors.

Although data entry and analysis are a part of BVET total costs, the biggest factors are the team's experience, the size of the basin, and the number of habitat types and characteristics. On most streams, an experienced team can cover at least 1 to 1.5 kilometers a day. Interestingly, surveys of large stream systems often take less time than smaller ones, because they consist of fewer but larger habitat units for any given length. Because actual measurements should be taken on a minimum of 10 units for each habitat type, costs are lower if the sampling team identifies only a few habitat types.

Getting Started

Before beginning the stream survey, the team should take time to do some preliminary planning. At a minimum, they should:

- Select the classification system they will use to identify habitat types
- Determine the habitat characteristics they will survey
- Stratify the study area into survey units (reaches) based on gradient, confluence of same-order channels, or other distinctive features

The most basic classification system recognizes two habitat types–pool and riffle (see the appendix for definitions). In mountain streams, a third type called cascade accounts for areas of exceptionally steep slope. When using this basic system, a team should make every effort to fit each sampling unit into one of these classifications. Where pools and riffles exist side by side, the team should assign the name of the habitat type that predominates. Once on the stream, however, it may be impossible to assign one classification to a unit–for example, a unit with 50-percent pool and 50-percent riffle characteristics. In these situations, the team may use a fourth classification, called complex; if the survey reveals a significant number of these units, the team should be prepared to provide a detailed description of each.

Although other classifications (Platts and others 1983) and subcategories (Bisson and others 1981) are available, their widespread use is limited because they rely on personal interpretations of subtle differences. Using the system described above assures that classifications are unambiguous and mutually exclusive, allowing comparisons of data collected by different observers on the same stream and comparisons of characteristics from one stream to the next. Strict adherence to the four types–pool, riffle, cascade, or complex–leaves little opportunity for misclassification; additional categories become subcategories that ultimately can be assigned to one of the four primary types.

The team next decides how many of the units in each habitat type they will measure for surface area as a check for their visual observations. The number of units undergoing actual measurement is based on the expected number of units in a habitat type and on the expected degree of consistency between visual observations and actual measurements from one unit to the next. The number of units that should be measured depends on the linear correlation between visual observations and actual measurements–as the correlation gets higher, the number of units that must be measured gets smaller. If the habitat type is likely to be rare, the team may need to measure most or even all of the units of that type to assure that the number of paired observations meets the recommended minimum of 10. For teams that are just getting started with the BVET, measurements should occur on one out of every five units, for a sampling fraction of 20 percent.

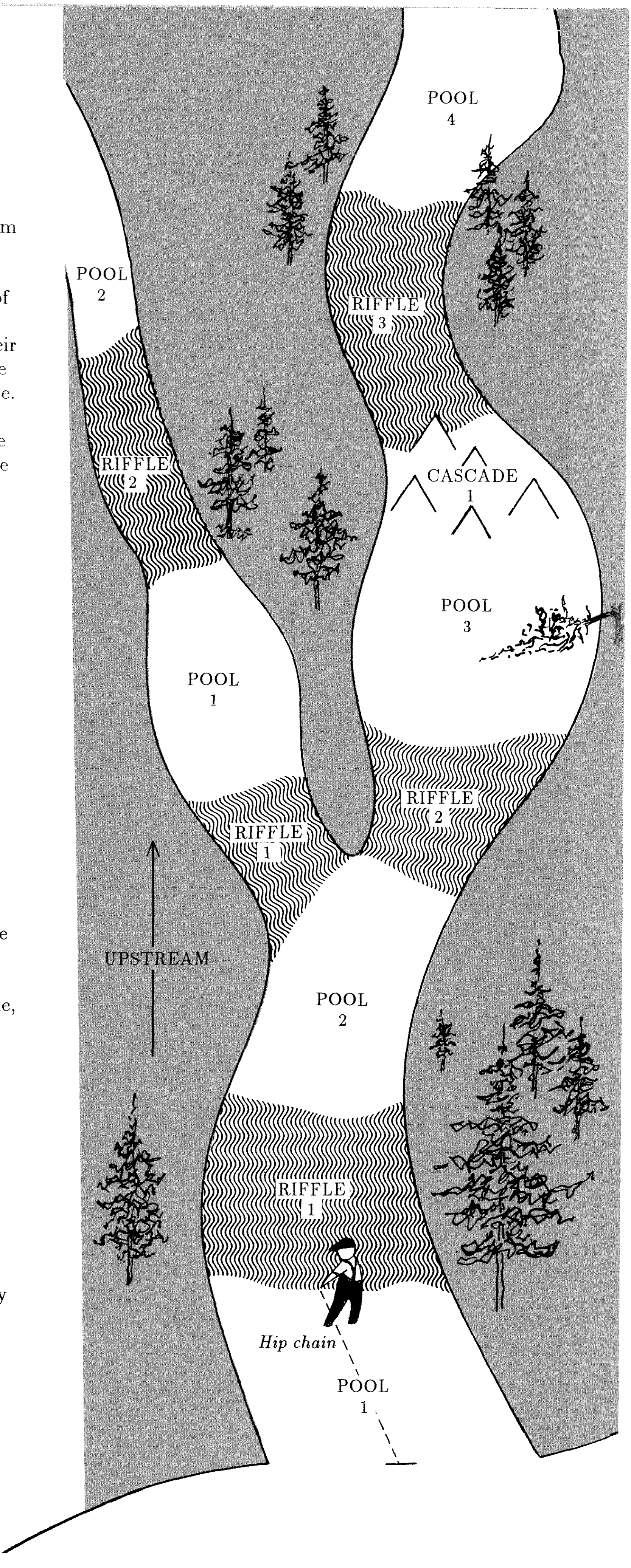
For each habitat type, the team then selects a random number to use as the starting point for intervals between habitat units they will measure. For a 20-percent sample, the starting point would be one of the first five units. If the team drew lots and settled on the 4th unit for the first set of measurements, their next set would occur on the 9th unit, followed by the 14th, the 19th, and so on until the survey is complete. Teams that are unfamiliar with BVET should also consider measuring the first unit of each habitat type to see how closely their visual observations match the true size.

Field Work

The procedures for conducting a specific habitat survey vary according to the objectives of the study and the stream habitat characteristics of particular interest. The following procedure is useful for collecting data on basic habitat characteristics of importance to fish. Because other surveys will have different objectives, users are encouraged to modify the basic procedures to suit their individual needs.

A hip chain, though not a necessary piece of equipment, is helpful in estimating the length of habitat units when following the thalweg of the stream and in maintaining consistent visual observations. The surveyor attaches the thread of the hip chain to a rock or branch at the beginning of the habitat unit, moves to the end of the unit, and classifies the unit by habitat type (pool, riffle, cascade, or complex).

The recorder assigns a unique number to the unit (examples: POOL-1, RIFFLE-1, POOL-2, CASCADE-1, POOL-3) and writes this number on two labels–one for the upstream boundary and the other for the downstream boundary–if the unit is scheduled for a fish survey. The team moves upstream, with the recorder logging observations of habitat characteristics such as surface area, average and maximum depth, dominant substrate, degree of embeddedness, and number of woody debris pieces by size category (see table 1 for an example of a size classification scheme). They also record any other features that are likely to influence fish populations, such as landslides, tributary junctions, bridges, trail crossings, debris dams, and significant changes in riparian vegetation.



When the habitat type changes, the surveyor notes the distance on the hip-chain meter and identifies the new habitat unit. When in doubt about defining the boundaries of a habitat unit, surveyors are advised to "think like a fish"; in other words, they should look at the physical conditions at the margins of the unit and try to predict how a fish would react to those conditions.

The team continues making and recording visual observations until they arrive at a habitat unit that they have designated for measurement. After visually estimating surface area, the team calculates the mean width from measurements taken at three or more locations parallel to the thalweg along the length of the unit, and then multiplies the mean width by the length. The choice of the interval between width measurements should depend on the complexity of the unit. A 5-meter, fixed interval may be appropriate for a 15-meter stretch of straight riffle. However, that same length of stream in an irregularly shaped pool might require a 2-meter measurement interval.

Team members should avoid trading assignments, and should take periodic breaks to maintain the consistency of observations. At the end of the reach, typically at the confluence of like-ordered channels, the team concludes the current survey and begins a new survey (complete with new independent starts for each habitat type) for each succeeding reach in the study area.

Table 1–Size classifications of woody debris

	Diameter (centimeters)			
Length (meters)	5 to 10	11 to 50	Over 50	Rootwad
1 to 5	Class 1	Class 2	Class 3	Class 7
over 5	Class 4	Class 5	Class 6	

Fish Survey

Fish surveys that use the BVET rely on the same general premise as BVET habitat surveys: if surveyors count a consistent fraction of the fish that are present, then there will be a strong correlation between their visual observations and the "true" numbers of fish. Unlike the habitat survey, which involves visual observations of area at every habitat unit, the fish survey is limited to a preselected number of habitat units. Visual observations are made by divers, who record the species, numbers, and in most instances the size classes of fish. These observations are calibrated by a more accurate method, such as multiple-pass depletion by electrofishing, on a preselected fraction of the units that were visited by divers.

Hankin and Reeves (1988) compared the cost effectiveness of population results from the BVET with those from electrofishing alone. They found that for the same cost, the BVET was 1.7 to 3.3 times more accurate. They attributed their results to the high cost of electrofishing, which limits the number of units that can be sampled. The overall accuracy of the BVET fish survey depends on the true variation in fish numbers among habitat units and on the errors in counting fish within selected units. When the true variation in fish numbers between habitat units is large, then it is necessary to sample many habitat units. Although fish counts by divers may be less accurate than estimates based on depletion

electrofishing, divers are faster and can examine more habitat units in a given time period. As long as diver counts are calibrated by a more accurate method such as depletion electrofishing, overall accuracy is acceptable.

In another study, Dolloff and Owen (1991) found that calibrated diver counts were more accurate than electrofishing results only for species, such as trout, that maintain position in the water column and are easily seen. Other species, such as sculpins and darters, were more cryptically colored and more likely to be in crevices of the streambed, making them more difficult for divers to see.

At present, visual observation by divers is the only practical technique for quickly estimating fish populations in connection with a BVET survey. However, the practicality of this technique is limited by several factors, including its dependence on water clarity (Griffith 1981; Hicks and Watson 1985; Schill and Griffith 1984), its tendency to be more effective on smaller than on larger streams (Northcote and Wilkie 1963; Slaney and Martin 1987), and the skills of individual divers.

Getting Started

Unless a recent habitat survey is available for the study area, the sampling team selects a classification system for identifying habitat types (see instructions for habitat survey) and stratifies the study area into reaches based on gradient, confluence of same-order channels, or other distinctive features.

The team then decides on the proportion of units from each habitat type that divers will sample for fish species, numbers, and sizes. If a habitat survey preceded the fish survey, the team may want to choose those units where they took precise measurements of surface area; these should have been marked with flags. The fraction they select need not be the same for every habitat type and can vary with the objectives of the study and any limitations in time, funding, or personnel. Teams often choose to have higher sampling percentages for those habitat types that seem to be preferred by the species of interest. For example, if the species of interest prefers pools, the team might sample 25 percent of the pools and only 10 percent of the riffles and cascades in a study area. This does not mean that a habitat type may be eliminated from sampling, even if the team does not expect fish to be present. There is only one way to confirm the presence or absence of fish in a habitat type: sample it.

After determining the sampling fraction, the team randomly selects the first habitat unit to survey. They then use the sampling fraction to determine the spacing between succeeding survey units. For a 25-percent sample of 400 pools (or one out of every four units), the starting point could be any of the first four habitat units and the interval between survey units would be four. If they drew lots and settled on the 3d unit for the first diver count, their next would occur on the 7th unit, followed by the 11th, the 15th, and so on until the survey is complete; for a total sample of 100 pools.

From this set, the team then decides on the fraction of units they will use to calibrate diver counts. As with the habitat survey, this percentage is not based on the accuracy of diver counts when compared with more-accurate measurements, but on the degree of consistency between these paired observations among similar habitat units. The "rule of thumb" sampling fraction for teams that are unfamiliar with the BVET is 10 percent, and at least 10 units should be sampled for each habitat type.

The team next makes a random selection of the starting point; they use the starting point and the sampling fraction to identify succeeding units to be designated for diver calibration. Continuing with the example of the 400 pools, 10 percent of 100 pools sampled by divers equals 10 pools to be sampled by electrofishing. If, by drawing lots, the team selected eight as the starting number, the first unit they would sample by electrofishing would be the 8th pool that was sampled by the diver, or the 31st pool in the reach, followed by the 71st, 111th, and so on through 391.

Field Work

The sampling team starts the day by recording general weather conditions. They measure and record water temperature, an important factor in the effectiveness of underwater fish counts (Gardiner 1984) because fish come out from hiding and are more active in warmer water. The team also records visibility, which Platts and others (1983) define as the distance that a trout-size object can be identified underwater. They record water temperature at noon, visibility during the afternoon, and any changes in weather as they occur.

The team generally moves from downstream upward to avoid disturbing the fish. Unless a habitat survey was completed earlier, they classify each habitat unit by type and assign it a unique number (see instructions for habitat survey).

When the team arrives at a unit that has been designated for visual observation of fish populations, the diver enters the water and records species composition and the number and size of fish. The diver records impediments to visibility–such as unusually deep water, turbidity, or cover–and notes any other factors that might affect fish counts, such as decreased maneuverability in shallow water, difficulty in maintaining position in strong currents, or a tendency to double-count in wide stretches of stream. Before leaving the unit, the team determines whether it has been designated for a calibration count; and, if so, leaves a piece of flagging tape marked with the date and unit number.

At any given habitat unit, the divers may need to adjust their methods according to the conditions in the unit or the species and sizes of fish that they find. Hankin and Reeves (1988) found that in the pools of Cummins Creek, diver counts of coho salmon were more accurate than diver counts of steelhead trout aged 1 year or older. They attributed this discrepancy

to species-specific microhabitat distribution and behavioral responses to divers. Coho salmon are easier to see because they tend to stay out in the open, whereas steelhead tend to stay closer to the bottom and are more likely to seek cover, especially in smaller pools. To overcome this dilemma, the divers began scanning the bottom for trout as soon as they entered the stream and then counted the salmon later.

As soon as diver counts are complete for the study area, the sampling team returns to those units that were designated for calibration by the more accurate method.[1] To assure an accurate estimate in all units selected for calibrations, teams typically use multiple-pass (at least three) depletion sampling with electrofishing equipment (Zippin 1958). For each fish (including nonsalmonids), team members record the species, length, and weight before returning it to the place of capture.

[1] Sometimes it is not possible to sample a preselected unit, for example if the depth of the unit exceeds the safe limit for electrofishing. In these situations, the team may substitute another unit that the diver has surveyed as long as the adjusted sample reflects the full range of size and complexity in the reach.

Data Entry and Analysis

Data Entry

Basinwide habitat surveys generate large amounts of data. However it is a simple matter to enter, store, and manipulate data in a computer spreadsheet such as LOTUS or a database management system such as DBase or with any of the statistical packages that are being marketed for microcomputers.

To sequence the habitat units of the study area for mapping, the spreadsheet format requires that data be entered in the order of collection (for example: POOL-1, RIFFLE-1, POOL-2, CASCADE-1, POOL-3). Once data are entered, the spreadsheet format allows sorting by habitat type and any manipulations and calculations that are associated with the BVET.

Although most survey teams enter data on paper forms (see the appendix for examples), the time from data collection to analysis and production of a final report can be greatly reduced by using one of the recently developed data entry programs for field data recorders and notebook computers. Programs such as Microfish (VanDeventer and Platts 1989) and Pop/Pro (Kwak 1992) also are available to help analyze population data collected by removal methods.

Estimating Habitat Area

The procedure and equations for calculating total habitat area can best be explained by an example. In 1989, Dolloff and Owen (1991) completed a basinwide habitat survey for Basin and Cove Creeks on the Blue Ridge Parkway in North Carolina. The main branch of Basin Creek measured 2398 meters long from the Park boundary up to the confluence with Cove Creek; it contained 139 pools (table 2) and 55 riffles (table 3). The procedure for calculating total habitat area with 95-percent confidence intervals for two habitat types–pools and riffles–is presented below.

The first step was to plot all observations of measured and estimated habitat unit areas by habitat type on x/y axes to check for coding errors and outliers, and to be sure that lines through the data appeared to

Table 2–Estimated area (x_i), measured area (m_i), calibrated area ($\widehat{Q}x_i$), and summary statistics for the pools in a basinwide survey of Basin and Cove Creeks in western North Carolina [The calibration ratio ($\widehat{Q}$) is 1.06. Totals for x_i and $(m_i - \widehat{Q}x_i)^2$ are 7,426.3 and 4,493.24 respectively.]

x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$	x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$	x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$
130.0	.	137.8	.	45.0	.	47.7	.	190.0	163.0	201.4	1474.56
26.0	.	27.6	.	14.0	.	14.8	.	30.0	.	31.8	.
23.0	.	24.4	.	19.0	14.2	20.1	35.28	6.5	.	6.9	.
110.0	149.3	116.6	1069.29	18.0	.	19.1	.	20.0	.	21.2	.
105.0	.	111.3	.	21.0	.	22.3	.	61.0	.	64.7	.
67.0	.	71.0	.	70.0	.	74.2	.	18.0	21.8	19.1	7.40
40.0	.	42.4	.	21.0	.	22.3	.	92.0	.	97.5	.
26.0	.	27 6	.	50.0	50.4	53.0	6.76	17.0	.	18.0	.
26.0	31.5	27.6	15.52	19.0	.	20.1	.	31.0	.	32.9	.
60.0	.	63.6	.	38.0	.	40.3	.	11.0	.	11.7	.
63.0	.	66.8	.	29.0	.	30.7	.	80.0	84.1	84.8	0.49
11.0	.	11.7	.	66.0	.	70.0	.	14.0	.	14.8	.
12.0	.	12.7	.	31.0	29.9	32.9	8.76	23.0	.	24.4	.
14.0	17.2	14.8	5.57	73.0	.	77.4	.	21.0	.	22.3	.
13.5	.	14.3	.	280.0	.	296.8	.	128.0	.	135.7	.
29.0	.	30.7	.	33.0	.	35.0	.	38.0	49.4	40.3	83.17
58.0	.	61.5	.	28.0	.	29.7	.	23.0	.	24.4	.
5.0	.	5.3	.	32.0	34.5	33.9	0.34	23.0	.	24.4	.
19.0	25.5	20.1	28.73	245.0	.	259.7	.	255.0	.	270.3	.
25.0	.	26.5	.	37.0	.	39.2	.	66.0	.	70.0	.
125.0	.	132.5	.	30.0	.	31.8	.	10.0	.	10.6	.
48.0	.	50.9	.	91.0	.	96.5	.	32.0	34.8	33.9	0.77
19.0	.	20.1	.	57.0	52.0	60.4	70.90	10.0	.	10.6	.
25.0	22.1	26.5	19.36	60.0	.	63.6	.	23.0	.	24.4	.
9.0	.	9.5	.	20.0	.	21.2	.	9.5	.	10.1	.
110.0	.	116.6	.	58.0	.	61.5	.	49.0	.	51.9	.
65.0	.	68.9	.	50.0	.	53.0	.	37.0	40.3	39.2	1.17
100.0	.	106.0	.	26.0	35.8	27.6	67.90	46.0	.	48.8	.
46.0	.	48.8	.	8.5	.	9.0	.	40.0	.	42.4	.
12.0	16.3	12.7	12.82	25.0	.	26.5	.	9.0	.	9.5	.
104.0	.	110.2	.	37.0	.	39.2	.	5.5	.	5.8	.
31.0	.	32.9	.	68.0	.	72.1	.	190.0	167.9	201.4	1122.25
220.0	.	233.2	.	19.0	16.0	20.1	17.14	180.0	.	190.8	.
40.0	.	42.4	.	40.0	.	42.4	.	31.0	.	32.9	.
17.0	17.6	18.0	0.18	95.0	.	100.7	.	108.0	.	114.5	.
14.0	.	14.8	.	39.0	.	41.3	.	15.0	.	15.9	.
25.0	.	26.5	.	210.0	.	222.6	.	11.0	21.8	11.7	102.82
28.0	.	29.7	.	13.5	17.3	14.3	8.94	4.5	.	4.8	.
93.0	.	98.6	.	30.0	.	31.8	.	60.0	.	63.6	.
140.0	163.5	148.4	228.01	12.0	.	12.7	.	185.0	.	196.1	.
210.0	.	222.6	.	32.0	.	33.9	.	8.0	.	8.5	.
72.0	.	76.3	.	4.8	.	5.1	.	21.0	25.6	22.3	11.16
58.0	.	61.5	.	30.0	24.4	31.8	54.76	40.0	.	42.4	.
27.0	.	28.6	.	50.0	.	53.0	.	12.0	.	12.7	.
64.0	74.1	67.8	39.19	26.0	.	27.6	.	24.0	.	5.4	.
190.0	.	201.4	.	30.0	.	31.8	.				
4.0	.	4.2	.	29.0	.	30.7	.				

Table 3–Estimated area (x_i), measured area (m_i), calibrated area ($\widehat{Q}x_i$), and summary statistics for the riffles in a basinwide survey of Basin and Cove Creeks in western North Carolina [The calibration ratio ($\widehat{Q}$) is 0.96. Totals for x_i and $(m_i - \widehat{Q}x_i)^2$ are 9,238.0 and 203.84 respectively.]

x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$	x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$	x_i	m_i	$\widehat{Q}x_i$	$(m_i - \widehat{Q}x_i)^2$
63.0	.	60.5	.	314.0	.	300.5	.	217.0	.	208.3	.
565.0	.	542.4	.	187.0	175.6	179.5	15.37	22.0	.	21.1	.
86.0	.	82.5	.	112.0	.	107.5	.	238.0	.	228.5	.
159.0	.	152.6	.	217.0	.	208.3	.	53.0	.	50.9	.
791.0	.	759.4	.	32.0	.	30.7	.	75.0	70.4	72.0	2.56
78.0	.	74.9	.	75.0	.	72.0	.	307.0	.	294.7	.
11.0	.	10.6	.	255.0	.	244.8	.	390.0	.	374.4	.
29.0	.	27.8	.	173.0	.	166.1	.	218.0	.	209.3	.
66.0	66.8	63.4	11.83	380.0	.	364.8	.	247.0	.	237.1	.
37.0	.	30.7	.	85.0	.	81.6	.	91.0	.	87.4	.
115.0	.	110.4	.	175.0	.	168.0	.	49.0	.	47.0	.
24.0	.	23.0	.	127.0	.	121.9	.	35.0	.	33.6	.
99.0	.	95.0	.	173.0	177.8	166.1	137.36	55.0	.	52.8	.
178.0	.	170.9	.	303.0	.	290.9	.	75.0	.	72.0	.
42.0	.	40.3	.	171.0	.	164.2	.	480.0	.	460.8	.
172.0	.	165.1	.	102.0	.	97.9	.	386.0	364.5	370.6	36.72
109.0	.	104.6	.	293.0	.	281.3	.	31.0	.	29.8	.
25.0	.	24.0	.	77.0	.	73.9	.	123.0	.	118.1	.
				252.0	.	241.9	.				

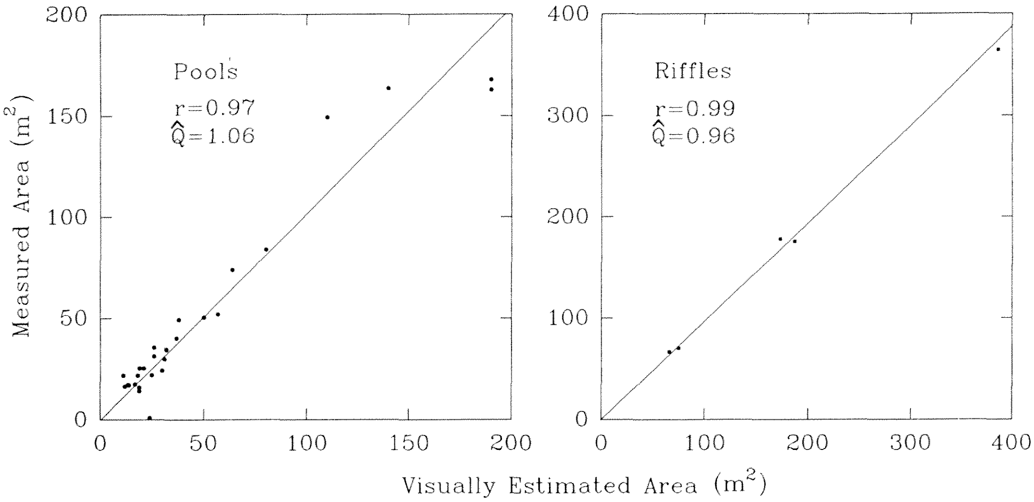


Figure 1–Plots of accurately measured and visually estimated areas for the pools and riffles in Basin Creek (n = 27 for pools, n = 5 for riffles).

pass through the origin (fig. 1). For the Basin Creek example, the lines intercepted the y axis very close to the origin and the correlation (r) between measured and visually estimated area was high, 0.97 for pools and 0.99 for riffles.

The basic premise of the BVET is that if there is a strong, positive correlation between actual measurements and visual observations, then it should be possible to "correct" visual observations by calculating a calibration ratio. Equation (1) shows that the calibration ratio ($\widehat{Q}$) for habitat surface area is calculated as the ratio of the true area to the visually estimated area for n paired observations:

$$\widehat{Q} = \sum_{i=1}^{n} m_i / \sum_{i=1}^{n} x_i \qquad (1)$$

where

m_i = true (measured) area of unit i; $i = 1, 2, .., n$, and

x_i = visual estimate of area of unit i; $i = 1, 2, .., n$.

In Basin Creek, the calibration ratios for pools and riffles were:

$$\widehat{Q}_{(pools)} = \frac{1{,}400.3}{1{,}321.5} = 1.06, \text{ and}$$

$$\widehat{Q}_{(riffles)} = \frac{855.1}{887.0} = 0.96.$$

The true total area of all the units in a habitat type ($\widehat{M}$) can be estimated as the product of the sum of all visual estimates (T_x) for a habitat type and the calibration ratio:

$$\widehat{M} = T_x \widehat{Q} \qquad (2)$$

where

$T_x = \sum_{i=1}^{N} x_i$, and

N = total number of units of a given habitat type.

For Basin Creek, the estimates of total area for pools and riffles were:

$$\widehat{M}_{(pools)} = 7\ 426.3(1.06) = 7\ 871.88 \text{ square meters,}$$

$$\widehat{M}_{(riffles)} = 9\ 238.0(0.96) = 8\ 868.48 \text{ square meters.}$$

The uncertainty of the estimated total surface area can be calculated from sample data using Equation (3):

$$\widehat{V}(\widehat{M}) \approx \frac{N(N-n)}{n(n-1)} \sum_{i=1}^{n} (m_i - \widehat{Q}x_i)^2 \qquad (3)$$

Equation (3) is a large sample approximation for the variance of a ratio estimator. Because it may underestimate the variance of the estimated total habitat area when the sample size is small, Hankin and Reeves (1988) recommend that the number of paired observations be 10 or more.

Equation (3) shows that variance depends on two very different factors–sample size and consistency of visual observations. First, variance decreases as sample size increases, through the term $N(N-n)/n(n-1)$. As the number of precisely measured units approaches the total number of units–as $(N-n)$ gets smaller–variance approaches zero.

Second, the summation term expresses the squared differences between the measured area of habitat units (m_i) and the predicted area of habitat units ($\widehat{Q}x_i$).

If measurements of area and visual observations are highly correlated and if they seem to pass through the origin when plotted on x/y axes, then $(m_i - \widehat{Q}x_i)^2$ will be small, indicating a small variance. However, if there is no consistent relationship between measured and estimated area, then predictions of true habitat area from visual observations will be poor, and variance will be large. In Basin Creek, the variances for total pool and riffle area were:

$$\widehat{V}(\widehat{M})_{pools} = \frac{139(112)}{27(26)}(4\ 493.24) = 99\ 660.06,$$

$$\widehat{V}(\widehat{M})_{riffles} = \frac{55(50)}{5(4)}(203.84) = 28\ 028.00.$$

Approximate 95-percent confidence intervals for the estimated total area for the habitat type:

$$\widehat{M} \pm t_{0.05;\ n-1} \sqrt{\widehat{V}(\widehat{M})}\ .$$

In Basin Creek, the confidence interval for pools was 7 871.88 ±2.056(315.69), or between 7 222.82 and 8 520.94 square meters. The confidence interval for riffles was 8 868.48 ±2.776(167.42), or between 8 403.72 and 9 332.24 square meters.

To estimate the total area and variance for all habitat units, simply add the estimates for each habitat type. Because the area estimates and the variances for each habitat type are based on independent samples, they are statistically independent and therefore additive.

In Basin Creek, the total habitat area was 7 871.88 + 8 868.48 or 16 740.36 square meters. The variance was 99 660.06 + 28 028.00 or 127 688.06.

Construction of a confidence interval about this estimate of total habitat area in pools and riffles requires the calculation of the approximate degrees of freedom in stratified sampling. According to Cochran (1977), the approximate degrees of freedom lies somewhere between the smallest sample size drawn from any stratum and the total sample drawn from all strata combined:

$$df' = \frac{(\sum g_h\ s_h^2)^2}{\sum \frac{g_h^2\ (s_h^2)^2}{n_h\ -\ 1}} \qquad (4)$$

where

$$g_h = \frac{N_h(N_h - n_h)}{n_h},$$

N_h = total number of habitat units in the hth stratum,

n_h = number of sampled habitat units in the hth stratum,

$$s_h^2 = \frac{\sum_{i=1}^{n} (y_{ih} - \bar{y}_h)^2}{n-1},$$

s_h^2 = sample variance of the measured habitat area in the hth stratum,

y_{ih} = measured area of the ith unit in stratum h,

$\bar{y}_h$ = sample mean in stratum h.

In the Basin Creek example, given a total number of habitat units (N_h) of 139 for pools and a total number of habitat units (N_h) of 55 for riffles:

$$g_{(pools)} = \frac{139(139-27)}{27} = 576.59,$$

$$g_{(riffles)} = \frac{55(55-5)}{5} = 550.00,$$

$$s^2_{h(pools)} = \frac{63\ 567.93}{27-1} = 2\ 444.92,$$

$$s^2_{h(riffles)} = \frac{58\ 487.65}{5-1} = 14\ 621.91,$$

$$df' = \frac{[576.59(2\ 444.92) + 550(14\ 621.91)]^2}{576.59^2(2\ 444.92)^2/26 + 550^2(14\ 621.91)^2/4} = 5.5.$$

To find the approximate degrees of freedom, round to the nearest integer; there were 6 degrees of freedom in the Basin Creek example. The 95-percent confidence interval with 6 degrees of freedom was 16 740.36 ±2.447(357.33) or between 15 865.96 and 17 614.76 square meters.

Estimating Fish Populations

The premise of the BVET fish survey is the same as the habitat survey: if there is a consistent relationship between actual measurements and visual observations, then it is possible to calculate a calibration ratio and "correct" for the bias associated with visual observations. The method of estimation is based on the standard double-sampling design outlined by Cochran (1977). Double sampling involves a large first-phase sample–in this instance, counts by a single diver–to produce a good estimate of the mean number of fish that can be visually counted in the units of a habitat type. Although Hankin and Reeves' (1988) BVET protocol called for two divers to make independent counts in all habitat units, subsequent experience has shown that between-diver variation is very small so that this source of error may be safely ignored. Using a single diver is more practical and cheaper.

A smaller second-phase sample establishes the relation between the diver counts and the "true" numbers of fish present. It is therefore important that these second-phase samples produce estimates of fish populations that have very small confidence intervals. In most situations, accurate estimates of the true number of fish can be obtained by multiple-pass depletion sampling (Ricker 1975) with electrofishing equipment.

The procedure for developing fish-population estimates from field data–counts by a single diver and results of depletion electrofishing–are outlined below. The example is a hypothetical population of juvenile coho salmon on a reach that contains 1,000 habitat units, half of which are pools. The diver samples 20 percent of the units (or 100 pools), counting all fish age 1+ and older. Afterward, a team returns to subsample 10 percent of the diver-counted units (10 units) by multiple-pass depletion with electrofishing equipment (tables 4 and 5).

The first step is to plot all diver and electrofishing results by habitat type on x/y axes to check for outliers and coding errors, and to check that a line drawn through the origin–with slope based on Equation (5)–appears to provide a good representation of collected survey data (fig. 2). In the hypothetical example, the correlation (r) between diver counts and electrofishing counts is 0.96 and the data are close to a line through the origin, suggesting that the diver counts are precise. However, high precision does not necessarily mean that the results are accurate or free from bias.

Figure 2–Diver counts and electrofishing results for a hypothetical population of coho salmon in pools.

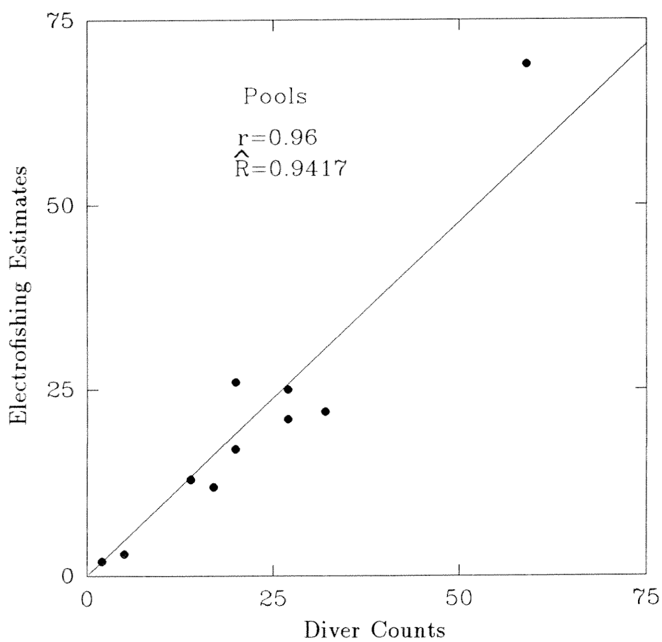


Table 4–First phase diver counts (x_i) for a hypothetical population of coho salmon (The sum of x_i is 3,443.)

Pool	x_i	Pool	x_i	Pool	x_i	Pool	x_i
1	16.0	26	0.0	51	12.0	76	2.0
2	58.0	27	17.0	52	11.0	77	3.0
3	59.0	28	44.0	53	64.0	78	14.0
4	40.0	29	27.0	54	54.0	79	54.0
5	37.0	30	14.0	55	10.0	80	59.0
6	4.0	31	208.0	56	11.0	81	10.0
7	125.0	32	33.0	57	4.0	82	40.0
8	90.0	33	0.0	58	22.0	83	47.0
9	10.0	34	7.0	59	92.0	84	29.0
10	20.0	35	31.0	60	27.0	85	23.0
11	11.0	36	21.0	61	133.0	86	26.0
12	8.0	37	0.0	62	8.0	87	23.0
13	24.0	38	15.0	63	17.0	88	9.0
14	127.0	39	124.0	64	14.0	89	52.0
15	25.0	40	32.0	65	47.0	90	17.0
16	5.0	41	27.0	66	78.0	91	23.0
17	17.0	42	89.0	67	11.0	92	10.0
18	18.0	43	18.0	68	39.0	93	69.0
19	25.0	44	31.0	69	66.0	94	52.0
20	2.0	45	53.0	70	5.0	95	46.0
21	1.0	46	2.0	71	50.0	96	6.0
22	12.0	47	5.0	72	56.0	97	93.0
23	35.0	48	79.0	73	4.0	98	4.0
24	31.0	49	25.0	74	50.0	99	34.0
25	22.0	50	27.0	75	42.0	100	20.0

Table 5–Diver counts (x_i), second-phase electrofishing estimates (y_i), and summary statistics for a hypothetical population of coho salmon

Pool	x_i	y_i	$(x_i - \bar{x}\prime)^2$	$(y_i - \bar{y}\prime)^2$	$(x_i - \bar{x}\prime)(y_i - \bar{y}\prime)$
10	20.0	26.0	5.29	25.0	- 11.5
20	2.0	2.0	412.09	361.0	385.7
30	14.0	13.0	68.89	64.0	66.4
40	32.0	22.0	94.09	1.0	9.7
50	27.0	21.0	22.09	0.0	0.0
60	27.0	25.0	22.09	16.0	18.8
70	5.0	3.0	299.29	324.0	311.4
80	59.0	69.0	1346.89	2304.0	1761.6
90	17.0	12.0	28.09	81.0	47.7
100	20.0	17.0	5.29	16.0	9.2
Total	223.0	210.0	2304.10	3192.0	2599.0

The next step is to calculate the calibration ratio ($\widehat{R}$) by dividing the total number of fish estimated by multiple-pass removal electrofishing (y_i) by the total number of fish counted by the diver (x_i) in the same habitat units:

$$\widehat{R} = \sum_{i=1}^{n'} y_i / \sum_{i=1}^{n'} x_i = \bar{y}'/\bar{x}' \tag{5}$$

where

$$\bar{y}' = \sum_{i=1}^{n'} y_i/n',$$

$$\bar{x}' = \sum_{i=1}^{n'} x_i/n',$$

n' = number of units sampled both by the diver and by electrofishing.

Using the hypothetical data (table 5), the second-phase sum is 210 for y_i and 223 for x_i, and:

$$\widehat{R} = \tfrac{210}{223} = 0.9417.$$

The estimated mean number of fish ($\bar{y}_{d,r}$) per habitat unit is the product of the calibration ratio from the second-phase sample multiplied by the mean diver count from the first phase ($\bar{x}$), with the subscripts d and r indicating double sampling and ratio estimation:

$$\bar{y}_{d,r} = \widehat{R}\bar{x}. \tag{6}$$

where

$$\bar{x} = \sum_{i=1}^{n} x_i/n, \text{ and}$$

n = number of units sampled by the diver.

Using the hypothetical data, the estimated mean number of fish is:

$$\bar{y}_{d,r} = 0.9417(34.43) = 32.42$$

The total number of habitat units (N) multiplied by the estimated mean number of fish per habitat unit ($\bar{y}_{d,r}$) produces an estimator for the total number of fish ($\widehat{Y}$) in that habitat type:

$$\widehat{Y} = N\bar{y}_{d,r}. \tag{7}$$

Using the hypothetical data, the estimated total number of fish is:

$$\widehat{Y} = 500(32.42) = 16,210.00.$$

Equation (8) provides a sample based estimator of uncertainty for the estimated mean number of fish in a given habitat type (Cochran 1977, Equation 12.72):

$$\widehat{V}(\bar{y}_{d,r}) \approx \frac{s_y^2 - 2\widehat{R}s_{xy} + \widehat{R}^2 s_x^2}{n'} + \frac{2\widehat{R}s_{xy} - \widehat{R}^2 s_x^2}{n} - \frac{s_y^2}{N} \tag{8}$$

where

$$s_y^2 = \frac{\sum_{i=1}^{n'} (y_i - \bar{y}')^2}{n' - 1},$$

$$s_x^2 = \frac{\sum_{i=1}^{n'} (x_i - \bar{x}')^2}{n' - 1},$$

$$s_{xy} = \frac{\sum_{i=1}^{n'} (x_i - \bar{x}')(y_i - \bar{y}')}{n' - 1}.$$

Although lengthy, the calculations required to compute estimated variance are not complex. Using our example, (s_y^2) is 3,192.0/9 or 354.67; (s_x^2) is 2,304.1/9 or 256.01; and (s_{xy}) is 2,599.0/9 or 288.78. The estimated variance $\widehat{V}(\bar{y}_{d,r})$ is:

$$\frac{354.67 - 2(0.9417)(288.78) + 0.9417^2(256.01)}{10} + \frac{2(0.9417)(288.78) - 0.9417^2(256.01)}{100} - \frac{354.67}{500} = 6.24.$$

Finally, an estimator for the variance of the estimated total number of fish in all habitat units of a given type is simply:

$$\widehat{V}(\widehat{Y}) = N^2\widehat{V}(\bar{y}_{d,r}). \tag{9}$$

Using the hypothetical data, the estimated variance for the total number of fish in the habitat unit is:

$$\widehat{V}(\widehat{Y}) = 500^2(6.24) = 1,560,000.$$

Approximate 95-percent confidence intervals for the total fish population in all pools:

$$\widehat{Y} \pm t_{0.05;\, n-1} \sqrt{\widehat{V}(\widehat{Y})}\ .$$

In the hypothetical example, the confidence interval is 16,210 ±2.262(1,249.00) or between 13,385 and 19,035.

If other intervals were constructed in this way, in 95 out of 100 samples, the true number of fish would be included in the interval.

The importance of calibrating diver counts by electrofishing or some other accurate technique cannot be overstated. The number of units sampled by the more accurate method will be a tradeoff between the need for accuracy and the cost of the "extra" sampling. One way of illustrating the importance of sample size is to double the number of electrofishing units in the hypothetical example to 20 percent, or one out of every five units that were sampled by the diver. The more intensive sampling would result in new estimators: $\widehat{R}$ is 0.9392, $\bar{y}_{d,r}$ is 32.34, $\widehat{V}(\bar{y}_{d,r})$ is 4.71, $\widehat{Y}$ is 16,170, and $\widehat{V}(\widehat{Y})$ is 1,177,500. The confidence interval is reduced to 16,170$\pm$ 2.093(1,085.1) or between 15,085 and 17,255.

In this hypothetical example, the sampling variance is reduced by about 25 percent when the size of the second-phase sample is doubled. Of course, different samples of the same size will yield different results, but as a general rule, sampling variance decreases as the sample size increases.

In summary, the procedure for estimating fish populations in a habitat type consists of two distinct phases. In the first phase, a diver counts fish in a sample selected from the total number of habitat units of a particular type, such as pools, riffles, or cascades. The size of the sample should depend on the variation in the numbers of fish counted by the diver. As variation increases, the number of units sampled should also increase.

The second-phase sample provides a way to evaluate the linear correlation between the "true" numbers of fish and the diver counts. In this phase, a team determines the true number of fish (typically by electrofishing) in a subsample of 10 (or more) of the habitat units sampled by the diver in the first phase.

Optimizing Sample Size

Because budgets and time are always limited, teams conducting BVET fish surveys must be efficient. Given finite resources, teams need to determine the optimal allocation of effort they will devote to the second phase (electrofishing) and to the first phase (diver counts) of sampling. The objective is to minimize the sampling variance produced by estimating the total number of fish in a habitat type, **subject to a total fixed survey cost,** C. If estimates of the costs and variance of previous or exploratory surveys are available, it is possible to calculate the optimal allocation of the total sampling effort. The first step is to assume a simple cost function, adding first-phase costs cn to second-phase costs $c'n'$:

$$C = cn + c'n' \qquad (10)$$

where

c = cost per unit of sampling in first phase, and

c' = cost per unit of sampling in second phase.

Cochran (1977) presented the optimal allocation of sampling effort for double sampling using regression estimation (Equation 12.59). In double sampling with ratio estimation, the optimal ratio of the second-phase sample size (n') as compared with the first-phase sample size (n) is:

$$\frac{n'}{n} = \sqrt{\frac{c}{c'}\,\frac{(S_y^2 - 2RS_{xy} + R^2S_x^2)}{(2RS_{xy} - R^2S_x^2)}}. \qquad (11)$$

This optimal allocation fraction ($\frac{n'}{n}$) can be estimated from sample data by substituting second-phase sample estimates of all quantities defined in Equation (11). In the hypothetical example, the assumption that electrofishing is 10 times as expensive as diving produces a 1 to 10 ratio of per unit diving costs (c) to electrofishing costs (c'). The optimal fraction (n/n') would be about 11 percent, as calculated by:

$$\sqrt{\frac{1}{10}\,\frac{(354.67 - 2(0.9417)(288.78) + 0.9417^2(256.01))}{2(0.9417)(288.78) - 0.9417^2(256.01)}} = 0.1095.$$

The actual size of the first and second-phase samples depends on the resources available to defray the total cost, C. For the hypothetical reach, C is assumed to be 400. By substituting $0.1095n$ for (n') in Equation (10):

$$n = \frac{400}{1+10(0.1095)} = 190.93 \text{ or } 191 \text{ units},$$

$$n' = 0.1095(190.93) = 20.91 \text{ or } 21 \text{ units},$$

$$C = 1(191) + 10(21) = 401.$$

The value for C (401) is very close to the original fixed cost of 400. These estimates and cost assumptions produce optimal sampling fractions of 191/500 or 38 percent for first-phase diver counts, and 21/500 or 4.2 percent for second-phase electrofishing.

BVET Maps

In addition to providing an inventory of total habitat area, data collected in a BVET survey can be used to produce detailed maps that show the size, sequence of occurrence, and position of all habitat units. Although based on visually estimated data, BVET maps can be valuable for stream inventory and monitoring and for identifying limiting factors related to habitat. Such maps could also be used to compare habitat unit areas across seasons or to evaluate the effects of various habitat alterations.

Figure 3 shows examples of such maps. The habitat units in the first stream–Fish Creek, OR–were surveyed in 1985 immediately after installation of habitat enhancements and again in 1986 after a winter storm. The storm-caused changes are evident in the 1986 map, which shows that many small habitat units were either blown out or combined into fewer but larger units. This bar code type of mapping, which indicates types, sequence, and even relative size of habitat units, can be an effective monitoring tool or a means of demonstrating the need for habitat modifications. Bar maps are simple to construct; they only require the estimates from a habitat survey and a few hours of plotting time.

The second and third streams (both located in the Southern Appalachian Mountains) illustrate a slightly more complex version of the bar map, showing two-dimensional plotting of habitat sequence. The addition of a width axis shows the approximate shape of the habitat as well as the estimated area. Note that for any given length of stream, the sampling team found more habitat units in Little Santeetlah Creek, which drains the never-harvested Joyce Kilmer Memorial Forest, than for Sassafras Creek, which flows through a forest that was clearcut 80 to 90 years ago (24 versus 19 units).

Other, more complex versions of bar mapping are possible. To emphasize particular aspects of a stream reach, sampling teams can add special symbols for large woody debris loading, substrate composition, or even composition and relative abundance of fish species.

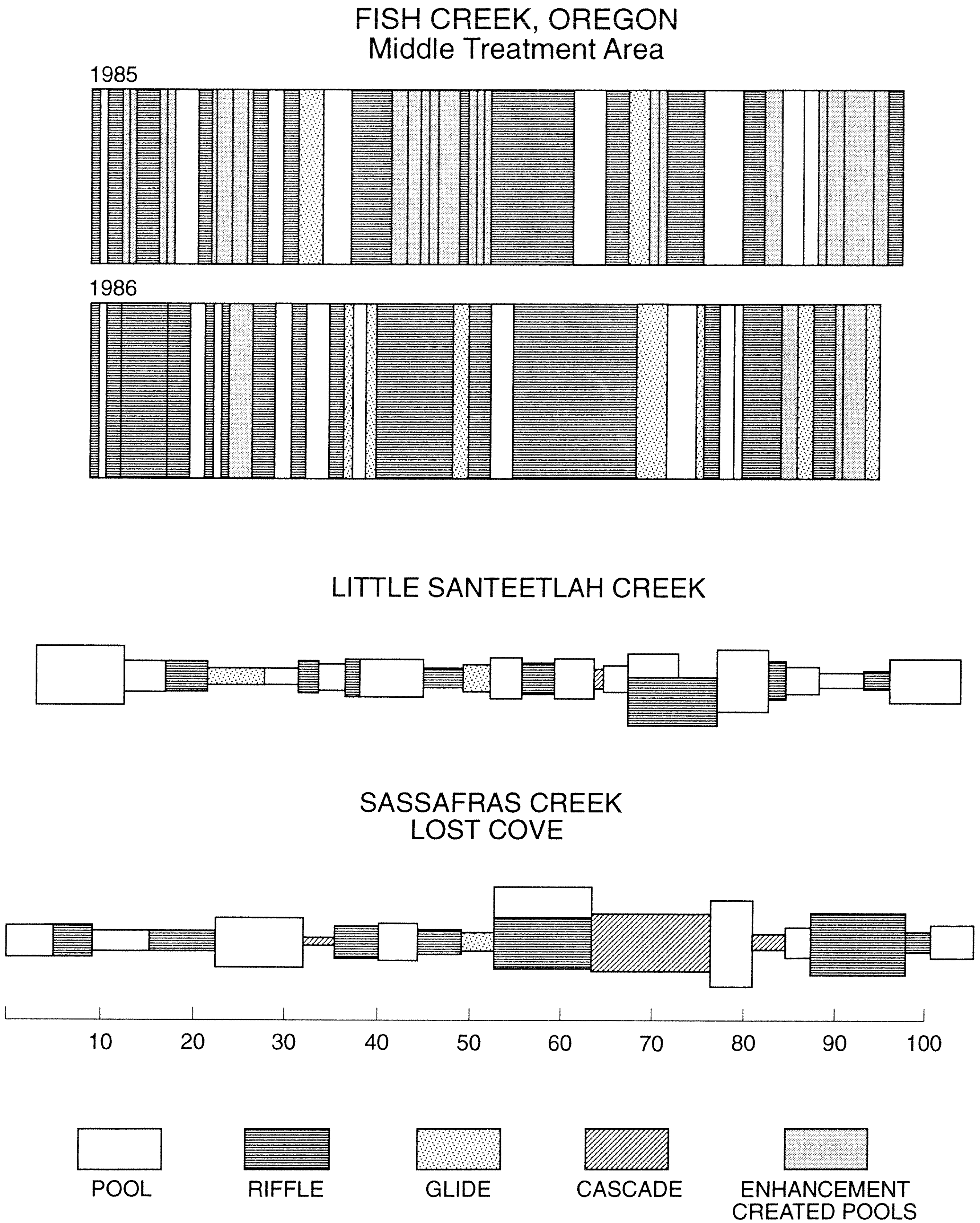


Figure 3–Schematic maps from BVET data (units in meters).

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Appendix

Equipment Checklist

HABITAT SURVEY
Felt-soled waders or wading boots
Measuring tape
Hip chain
Belt
Pencils
Waterproof data forms or water-resistant electronic field-data recorder
Waterproof paper
Wading rod (with depth scale, laminated for sliding)
Flagging tape
Waterproof markers
Clinometer
Topographic maps
Compass
First aid kit

FISH SURVEY

Diving	Electrofishing
Wet (dry) suit	Backpack electrofishing unit
Face mask	Electrodes (2)
Snorkel	Dip nets (insulated handles)
Felt-soled wading boots	Fuel can or extra batteries
Neoprene socks	Lineman's insulated rubber gloves
Neoprene or cotton gloves	Waterproof waders
Dive light	Earplugs
Data form	Buckets
Writing slate	Measuring board
Pencils	Balance
Flagging	Scale envelopes
Waterproof markers	Fish anaesthetic
Measuring tape	Thermometer
Thermometer	Data forms
First aid kit	Pencils
Canteen	Measuring tape
Snack foods	Pocketknife
	First aid kit

Useful Definitions

Basin – All the land drained by a river or stream and its tributaries; often used synonymously in place of watershed.

Cascade – Typically occurring at the uppermost reaches of a stream, cascades are characterized by swift current, steep gradient, and exposed rocks and boulders. The streambed of cascades can range from steep bedrock slides to step-pools bounded by small waterfalls; water flowing through the upstream pools falls over large rocks, boulders, or woody debris into downstream pools.

Multiple-Pass Depletion – A method of estimating the population of fish in a habitat unit by successive removals, usually three or more (Schnute 1983, Zippin 1958).

Pool – Because of their concave bottom profiles, pools have the greatest depth and the slowest water velocity of the habitat types. The water surface gradient under conditions of low-flow is typically near zero. Pools may have eddies or other irregularities in flow caused by large protrusions from the streambed or woody debris, but the water surface is generally smooth. The residence time of objects floating on the surface of pools is longer than in riffles. Fish in pools expend little energy to maintain their position.

Reach – A stretch of water in a stream or river, such as the distance between confluences of like-ordered or otherwise similar channels or the distance between barriers to movement.

Riffle – Riffles have convex or straight bottom profiles, relatively steep gradient, fast water, and the least depth of the habitat types. Compared with pools, the surface of riffles is turbulent and marked by numerous protrusions from the streambed. Fish living in riffles expend considerable energy in maintaining their position against typically fast currents.

Thalweg – Literally "valley way," the deepest part of a stream cross section.

Watershed – The land area drained by a stream or river.

Sample Data Form for Habitat

BASIN SURVEY DATA SHEETS

PAGE 1 OF

LOCATION: Chattahoochee N.F. DATE: 6 / 25 / 89 CREW: J. Smith

STREAM: Tottery Pole RECORDER: R. Jones R. Jones

QUAD MAP: Satolah TIME: 8:45

WATER TEMP: 14.8°C START POINT: confluence with Metcalf Cr.

HAB. UNIT	DISTANCE	ESTIMATED AREA/WIDTH	ACTUAL AREA/WIDTH	MAX/AV. DEPTH	DOMINANT SUBSTRATE	WOODY DEBRIS 1	2	3	4	5	6	7	COMMENTS
R1	11.9	5.0		30/20	7	ll							
G1	15.9	20.0		50/35	4								
P1	21.3	12.0		60/45	9	l					l		
C1	24.0	1.2		3/1	9								
G2	27.4	6.0	5.6	65/40	4			l					
R2	35.8	2.3	2.1	35/20	7						l		
TRIB	29.6	in on	left										
G3	38.1	6.0		40/30	4	卌 |||					l		log jam
P2	57.7	80.0	72.4	65/45	7	lll				l			
R3	62.8	3.0		35/20	7								

RECORDERS INITIALS: RJ

Sample Data Form for Diving

SNORKELING COUNT DATA SHEET

LOCATION: Chattahoochee NF DATE: 10 / 10 / 90 DIVERS: S. Harris

STREAM: W. Fork Overflow RECORDER: J. Smith

WATER TEMP: 16° C TIME: 1230 VISIBILITY: good

HABITAT UNIT	SPECIES	NUMB.	AGE	DIVER/ COMMENTS
P2	RBT	1	0+	
	BND	2	1+	
R2	NONE	—		
G2	RBT	1	1+	
P7	RBT	8	1+	
	RBT	10	0+	
	BND	10	1+	
P12	RBT	2	1+	
	RBT	3	0+	
P17	RBT	1	1+	
	RBT	2	0+	
	BKT	1	1+	
	BND	2	1+	
C2	NONE	—		

HABITAT UNIT	SPECIES	NUMB.	AGE	DIVER/ COMMENTS

Sample Data Form
for Electrofishing

ELECTROFISHING DATA SHEETS

PAGE 1 OF

LOCATION: ChattahoocheeNF DATE: 6/21/91 CREW: J. Smith

STREAM: EastFork Overflow RECORDER: B. Edwards

WATER TEMP: 15°C TIME: 1120

HABITAT UNIT	PASS NUMB.	SPECIES	FORK LEN.	TOTAL LEN.	WEIGHT	NOTES	HABITAT UNIT	PASS NUMB.	SPECIES	FORK LEN.	TOTAL LEN.	WEIGHT	NOTES
P24	1	BND	53	58	1.8								
	1	RBT	142	150	33.2								
	2	BND	85	90	8.8								
	2	BND	65	69	3.8								
	3	NONE											
R24	1	BND	74	79	5.6								
	1	BND	41	43	0.9								
	1	BKT	55	57	2.4	0+							
	2	BKT	115	122	16.3								
	2	BKT	99	105	11.3								
	3	BND	45	48	1.2								
P74	1	NONE											
	2	BKT	141	148	26.7								
	2	BKT	52	56	1.6	0+							
	3	NONE											

Dolloff, C. Andrew; Hankin, David G.; Reeves, Gordon H. 1993. Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 pp.

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Keywords: Visual observations, sampling for trout, diving, electrofishing, monitoring, area measurements on watersheds.

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