Snorkel Surveys

Jennifer S. O'Neal

Background and Objectives

Snorkeling is the underwater observation and study of fish in flowing waters. Snorkeling gear is worn by biologists who, individually or in small teams, survey fish abundance, distribution, size, and habitat use while slowly working in (generally) an upstream direction. This technique is most commonly used to survey juvenile salmonid populations but can also be used to assess other species groups. This document discusses the critical elements necessary for the design and implementation of a snorkel survey program to encourage a standardized procedure for the use of underwater techniques to survey fish species in streams. Much of the information in this paper was adapted from Thurow (1994), who provided vital information for use in standardized snorkel surveys.

Snorkel surveys are widely used to monitor fish populations in streams and to estimate both relative and total abundance (Slaney and Martin 1987). Snorkeling can also be used to assess fish distribution, presence/absence surveys, species assemblages (i.e., diversity), some stock characteristics (e.g., length estimation), and habitat use. Each objective will affect how the survey should be conducted. Specific directions for implementing snorkeling to address various objectives are presented in this chapter.

A variety of fish species can be assessed using snorkel surveys; however, salmonids, due to their territorial nature in freshwater and propensity for using habitats with high water clarity, are the group for which snorkel surveys are most frequently conducted. Snorkel surveys have recently been used to assess sculpin diversity (C. Jordan, NOAA Fisheries, personal communication). Snorkel surveys are often selected as the best method for surveying salmonids because they result in relatively little disturbance to the target species, reasonable accuracy, and less cost outlay. Cost optimization methods are discussed at the end of this protocol and explained in detail in Dolloff et al. (1993).

Rationale

Snorkeling is often feasible in places where other methods are not; for example, deep, clear water with low conductivity makes electrofishing prohibitive. Because of the small amount of equipment required for snorkeling, the method can be used in remote locations where it may be difficult to use other methods, such as traps, nets, and electrofishing. Because fish are not handled and disturbance is minimized, snorkeling is especially useful for sampling rare or protected stocks. Snorkel surveys provide an alternative to traditional and more disruptive methods, such as electrofishing and gillnetting (Mueller et al. 2001). Information on individual or group movement, behavior, and habitat associations can also be collected (Mueller et al. 2001). Snorkel surveys can be combined with other methods such as sonar and tools such as geographic information systems (GIS) to generate three-dimensional maps of habitat use by fish species (Mueller et al. 2001). Less time and cost are required for snorkeling than for methods such as mark–recapture or removal, which are often used to estimate abundance (Schill and Griffith 1984; Thurow 1994; Hankin and Reeves 1988;). Snorkelers can observe fish behavior such as spawning, feeding, and resting with minimal disruption.

Objectives

Snorkel surveys can provide quantitative information on the abundance (Schill and Griffith 1984), distribution (Hankin and Reeves 1988), size structure (Griffith 1981), and habitat use (Fausch and White 1981) of salmonids. Snorkel surveys can also be used to provide estimates of salmonid populations within the reaches surveyed (Thurow 1994) and of species distribution within a habitat. In fact, underwater observational techniques are one of the few methods that enable scientists to assess how fish actually use habitats and structural components within habitats, such as boulders and large woody debris. Diversity of species can be assessed using observational surveys for salmonids or transect and quadrant surveys for benthic-dwelling species such as sculpin. With proper training, snorkelers can make relatively precise (within 25 mm) visual estimates of length (Griffith 1981).

Presence/absence

Generally, snorkeling works well in detecting presence/absence of most salmonid species. One exception is bull trout *Salvelinus fontinalis*, which are elusive and difficult to detect using snorkel surveys. Rodgers et al. (2002) provides a detailed discussion on determining presence and detection probabilities for bull trout using three different methods: day snorkeling, night snorkeling, and electrofishing. Snorkeling does not work well when water is turbid or tannic-stained (due to the inability to see the fish). When water temperatures are less than 9°C, fish are generally inactive and therefore not visible for counting during daylight hours, so night snorkeling should be used.

Relative abundance and mark–recapture counts

If a closed population estimate is needed in order to calibrate surveys with another method within a single habitat unit, block nets can be used with snorkel surveys to prevent fish from entering or leaving the unit (Hillman et al. 1992). Hankin and Reeves (1988) list formulas for estimating total fish abundance and calculating confidence limits around the estimates.

If the area to be surveyed is too large for one snorkeler, additional snorkelers can be added to cover the entire channel width. The counts from all snorkelers are then summed for the total count for the reach sampled. This method, called an expansion estimate, assumes that counts are accurate and that snorkelers are not counting the same fish twice (Thurow 1994).

Snorkel surveys can be used with other techniques to estimate abundance using mark–recapture techniques. The use of snorkel surveys for mark–recapture estimates provides a calibration factor for the counting efficiency of snorkel surveys as compared to other methods such as electrofishing and seining. For this technique to be used, the system should be closed off with block nets so that the total population observed is constant. For mark–recapture estimates, fish need to be collected, marked, and released back to the sample area. Collection occurs with electrofishing, seining, or trapping; marking is done using tags or dyes with color coding or patterns; and release is into the sample reach. Snorkel surveys can then be conducted in the same sample reach to count the number of marked fish. The ratio of the number of fish resighted (i.e., those with marks that are counted) can be used as a calibration factor for the effectiveness of a snorkel survey compared to other survey methods. Fish can be marked differently based on size-class and species recorded by observers, which can help identify those species and size-classes that may have been undercounted using a snorkel survey approach.

Habitat Use

Snorkel surveys can be used to observe the direct use of habitat by fish species. This method is especially effective for determining the use of habitat improvement structures placed to benefit rearing juvenile salmonids. Direct use of specific structures can be measured by counting fish within a small radius (1–2 m) of each structure. This method can also be used to determine the relative effectiveness of different types of structures placed in the same stream in providing cover for juvenile fish (O'Neal 2000).

Recommendations for implementation of snorkel surveys

TABLE 1a. — Staff requirements.

Habitat	Staff requirements
Wadable stream	One surveyor (if water clarity allows observation from one bank to the other)
Nonwadable river or stream	Add surveyors as sight distance requires

TABLE 1b. — Water temperature recommendations

Water temperature	Survey timing
Between 10°C and 18°C	Daytime survey
Less than 10°C or greater than 18°C	Night survey (1 h after sunset)

TABLE 1c. — Objective-based recommendations

Objective	Approach
Distribution and average density	One pass, no calibration
Habitat use (baseline)	One pass, no calibration
Species assemblage (diversity)	One pass, no calibration
Relative abundance	One pass with calibration
Total abundance	One pass with controls such as block nets to close the system; mark–recapture

Sampling Design

This protocol addresses snorkel surveys of resident and anadromous salmonids in streams. Before implementing a snorkel survey program, the specific objectives of the study must be identified. Once the research question is clearly defined, the program designer can select the appropriate implementation techniques, equipment, and training methods (Thurow 1994).

Site Selection

The ability to view fish in the water is critical to the survey, so site characteristics must be chosen to facilitate viewing. Reach length to be surveyed is also a concern. A reach is defined as "a section of a stream at least twenty times longer than its average channel width that maintains homogeneous channel morphology, flow, and physical, chemical, and biological characteristics" (Flosi and Reynolds 1994). Within a reach, habitat units are identified as pools and riffles; reaches may or may not contain side channels. As side channels are often used by juvenile salmonids, these areas should be considered for snorkeling if assessing juvenile use of habitats. Generally, a trained snorkeler can survey a maximum of 1.6 km of stream per day, assuming the stream is wadable. In larger rivers, where teams of surveyors are floating downstream, more than 1.6 km may be surveyed. In either case, a reach length with start and end points that can be accessed by surveyors is required. Reach selection for snorkel surveys includes consideration of stream depth and width, velocity, water clarity, and temperature. It is recommended to sample all habitats within a sample reach (not just pools) and report fish observed as fish per square meter of surface area snorkeled.

Several factors can bias results, including the behavior of target fish species and attributes of the physical habitat (e.g., stream size, water clarity, temperature, and cover) (Thurow 1994). Thurow (1994) notes that smaller fish and bottom-dwelling fish that use camouflage are more difficult to count in a snorkel survey. Differences in fish behavior and the amount of cover available may also affect the accuracy of counts (Rodgers et al. 1992; Thurow 1994). Surveyors may misidentify fish, double-count fish, or fail to see all fish. Other limitations of snorkel surveys include the need for estimates of length instead of direct measurements and the inability to weigh or tag fish.

Minimum criteria for depth, temperature, and visibility need to be met for snorkel surveys to be optimal. Surveyors need to be able to submerge a mask to see fish. A minimum recommended water depth for successful surveys is 20 cm. Water temperature influences fish behavior and may bias counts. As temperature falls below 10°C many salmonids will seek cover (Edmundson et al. 1968; Bjornn 1971; Hillman et al. 1992). At water temperatures below 9°C most juvenile salmonids hide during the day and night surveys are likely to be more effective. Hillman et al. (1992) found that above 14°C snorkelers counted about 70% of the juvenile salmonids present; below 14°C they observed less than half of the juvenile fish present. Below 9°C daytime snorkelers observed less than 20% of the juvenile fish present (Dolloff et al. 1993). Water temperature also affects the species composition found within a given habitat.

Visibility or water clarity can severely affect the accuracy of surveys. The minimum recommended visibility for surveys is 1.5 m (P. Roni, NOAA Fisheries, personal communication). Visibility during typical summer base-flow periods is often much greater. Snorkelers can evaluate clarity by using a silhouette of a salmonid with parr marks and spots, as described in Thurow (1994). A surveyor should approach the silhouette until the parr marks are clearly visible and then move away from the silhouette until the marks cannot be distinguished. The average of these two distances provides the water visibility (Thurow 1994). Turbulence may also affect visibility and should be avoided if it affects the surveyor's safety. In small or wadable streams, fish often use turbulence or bubble curtains for cover or have nearby feeding stations along an eddy fence or at the head of a pool. If the surveyor can do so safely, it is recommended to make observations in these areas.

Sample reach selection may also be influenced by the overall sample design. For example, for programs with a probabilistic and spatially balanced sample design, snorkel survey locations may be generated randomly, as in programs such as the U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (Peck et al. 2003). In these cases snorkelers may be sent to a randomized location and may have to snorkel the most appropriate habitat at that location using some of the guidelines previously recommended.

The selection process for sample units and the number of units that need to be surveyed vary based on study objectives and precision requirements. Sample units used in snorkel surveys range from single habitat units to large sections of a stream or river. Investigators may stratify watersheds into sections and survey units within each section. Streams may also be stratified into habitat units, and abundance can be extrapolated from surveys of a subset of the units (Hankin and Reeves 1988, Thurow 1994). Sampling by habitat type may reduce the variance of the expanded estimate by accounting for the influence of habitat type on fish abundance. Surveys of a single habitat unit or sample reach should be completed within 1 to 2 d to reduce the effect of changes in environmental conditions such as rainfall events (WSRFB 2003).

Dolloff et al. (1993) recommend that 25% of the total habitat units in the sampling universe be sampled to estimate fish populations. For example if 400 total pools are within the sample reach, snorkel surveys should be conducted in every fourth pool, starting with a randomly selected pool from the first four. Surveyors should note when units are unsafe or inaccessible, skip to the next unit of that type, and then return to their original sequence. For stratified samples of habitat units, at least 10 units should be sampled for each habitat type, and 10% of the units sampled should be calibrated using another method, such as electrofishing. Dolloff et al. (1993) provide data from Bull Creek in California. Their findings suggest that when snorkel surveys monitored juvenile steelhead *Oncorhynchus mykiss* abundance once a year within a 2.5 km reach, surveyors detected a 10% change in fish density at a power of 0.8 in 3 years with 17 sample habitats. Adding habitats to increase the sample size to 25 did not significantly improve the power of detection. Decreasing the sample size to 9 required that 5 years of sampling be conducted at each reach to detect a 10% change in fish density at a power of 0.8 (Dolloff et al. 1993).

If sample reaches are to be resurveyed, the reach should be permanently marked using physical objects, such as rebar markers or monuments. Additional methods, including photo points, a reach map, and a global positioning system (GPS) location, should also be used.

For additional insights on sampling design aspects, readers are strongly encouraged to review the applicable sections in the electrofishing protocol by Temple and Pearsons (2006).

Sample Timing and Frequency

Timing of snorkel surveys depends on the objectives of the study and the behavior of the target fish species. If life stage–specific information is desired, timing of the survey must match the use of the surveyed habitat by that life stage. Knowledge of behavior and life history of the target species is essential for effective survey design. Snorkel surveys are most effective during minimal fish migration. The juvenile rearing period of the target species is often the most effective season to obtain data on juvenile populations. The low-flow season is generally selected for summer estimates of population density.

Daytime water visibility is generally best between late morning and early afternoon, when the sun is directly overhead. Cloudy or overcast days are generally better for sampling reaches with significant cover to reduce the dark shadow that may be cast by cover elements. A small waterproof light may be useful to search for fish in dark conditions or shady areas. If criteria for depth, water clarity, and temperature are met, direct sunlight may be less of a critical factor.

Night surveys may be more effective for studying salmonids under certain conditions. During winter and when water temperatures fall below 10°C, night surveys are generally considered to have greater effectiveness. In addition, in any habitats in which temperatures are greater than 18°C, night surveys should be considered (Roni, personal communication). Night surveys in the winter months often have better results than daytime surveys (Campbell and Neuner 1985; Goetz 1997). Surveys should be conducted starting no sooner than 1 h after sunset to allow fish to emerge from hiding. If night survey data are to be compared, the surveys should be conducted during the same moon phase to avoid bias due to the effects of moonlight on fish behavior.

Field/Office Methods

Basic Survey Procedures

For preselected sample reaches, field crews should use GPS units and maps, aerial photos, or landmarks such as road bridges or trail crossings to find the sample reach location (Rodgers 2002). If sample reaches are on private land, landowner permission must be granted before the reach is accessed (Rodgers 2003).

Before conducting a field survey, available information should be collected on species that are likely to be encountered. This effort should include information requests to local, state, or federal resource management agencies that may have fish distribution information or jurisdiction over aquatic species. Where snorkelers expect to find protected species or species listed under the Endangered Species Act, they should avoid fish spawning areas. Snorkelers should not touch or otherwise disturb protected fish while conducting surveys.

The sampling team should record the reach location information, weather conditions, water temperature, and water visibility at the start of the day and several times throughout the day. Each unit sampled should be classified by type and assigned a unique number (Dolloff et al. 1993). Rodgers (2002) recommends ranking turbidity at each reach surveyed. Data can then be segregated for precision based on visibility.

Considerations in field sampling include the size of the water body, which will affect the number of snorkelers needed for the survey and the direction of the survey, and the objective of the study. Surveying in the upstream direction is the most effective technique for small streams where this is feasible (Figure 1). Most salmonids hold position facing the current, so upstream sampling is less likely to cause disturbance (Thurow 1994). Some salmonids such as steelhead tend to hold close to the bottom of the stream and quickly seek cover if they detect a disturbance. Upon entering the water, observers should survey the bottom for any trout that may quickly take cover, as opposed to starting with other species, such as coho salmon *O. kisutch*, that are more resistant to disturbance (Dolloff et al. 1993). Movements should be controlled and sudden movements should be avoided to reduce disturbance to fish. Fish are counted as the snorkeler passes them to reduce double counting. In larger systems, upstream counts may not be possible; in these cases snorkelers may conduct counts while floating downstream and remaining as motionless as possible (although some swimming may be required to maintain lane position relative to other snorkelers).

FIGURE 1. — Snorkel survey conducted in the upstream direction in a small stream.

The number of observers needed to complete the survey is dependent upon water clarity, the size of the stream or river system, and the objectives of the study. Thurow (1994) recommends using enough snorkelers to complete the survey in a single pass. It is recommended that one surveyor be used for streams less than 2 m bank-full width, two surveyors be used for 2–5 m bank-full width, and more than two surveyors should be used in places greater than 5 m bankfull width. During the survey, any impediments to observation, such as deep water, turbidity, or significant cover elements, should be noted (Dolloff et al., 1993).

For smaller streams in which one observer can see the entire channel width, Thurow (1994) recommends proceeding in a zigzag pattern across the channel to see both sides, especially in the margins of the streams where small fish will hold in slow water areas. Other areas that deserve intense scrutiny are eddies behind logs and boulders and underneath logjams and under cut banks (see Figure 2). For these surveys, the surveyor generally proceeds upstream, against the current.

FIGURE 2. — Snorkeler investigating area under logjam.

If two observers are employed (due to stream/river size, water clarity, or habitat complexity), the observers should remain adjacent to one another and move at the same speed. These surveys are generally conducted in the downstream direction with the current, due to the size of the river. Observers should mentally divide the channel into "lanes" in which each observer will look for fish and only count fish that pass within his/her snorkeling lane (Thurow 1994). If two observers are used, each surveyor should be in the middle of the channel looking towards the bank to cover his/her lane. If more than two surveyors are used, middle lanes will have to be designated. Diagrams of these configurations are shown in Thurow (1994). In these situations, snorkelers should frequently check on each other for safety and to maintain position.

If a downstream survey is required, a length of polyvinyl chloride (PVC) pipe can be held between observers to maintain distance, but the distance should never be greater than the water visibility. If rocks, debris, or variable current conditions are present in the channel, it may not be feasible to use PVC pipe, and visual distances between observers should be maintained. If visibility is limited, observers may subsample a portion of the channel and use the estimate to extrapolate an estimate for the entire channel (Thurow 1994).

Measurement Details

Data on fish species and size-class can be collected and recorded on a PVC cuff or diver's slate (see Figure 3) and later transferred to a data sheet or database. Data can also be called out to an onshore observer who records the information on a data sheet or in a digital data collector. After completing the count of fish, observers should measure the surface area of the snorkeled unit. The total length of the unit should be recorded as well as the width at three or more equally spaced intervals. Maximum pool depth should be recorded (Rodgers 2002) if additional habitat surveys are not being conducted. The surface area can be calculated by multiplying reach length by average width or by summing the surface area of individual habitat units, which the crew can measure as it moves upstream. Density of fish is typically expressed as the number of fish per square meter (Thurow 1994). An example of a field form for data collection is offered in Appendix A.

Information on reach location, water temperature, weather conditions, and water clarity should be recorded for each survey (Washington Salmon Recovery Funding Board 2004). Additionally, the staff collecting the data should be identified on the data sheet.

Data Handling, Analysis, and Reporting

Record Keeping

Snorkel surveys require special considerations for record keeping. Fish counts, species identification, and lengths can be recorded directly by a diver or communicated to an assistant on shore. Preformatted data sheets should always be used to ensure that all pertinent information is collected and that it is in a standard format for data entry when the time comes (interpreting nonstandardized field notebooks or PVC cuffs months after the fact is problematic). Waterproof slates or cuffs are likely the most popular method for recording data during a survey. Slates can be made of plastic, Formica board, or Plexiglas, and cuffs are often fashioned from PVC pipe and surgical tubing. Electronic data recording devices are also used but are more costly (Dolloff et al. 1996).

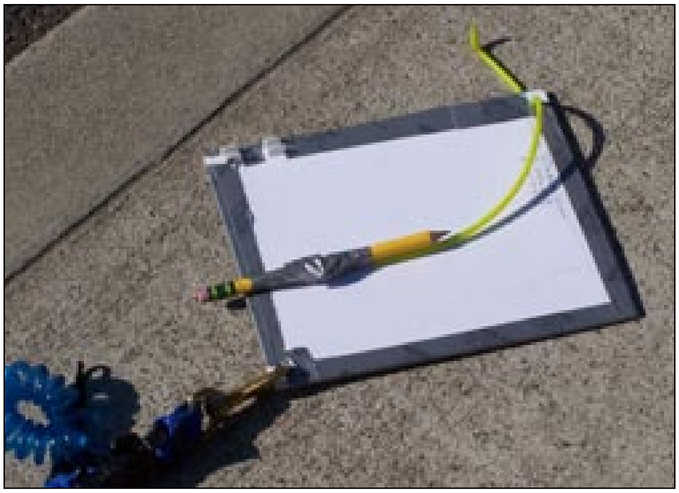

FIGURE 3.— Diving slate for recording data underwater.

Mark–recapture estimates

If sample sizes are sufficient, population estimates are calculated for each size class using Chapman's modification of the Peterson mark–recapture technique (Ricker 1975) as shown in equation 1.

$$N = (M+1)\ (C+1) / (R+1) \qquad \text{(eq 1)}$$

where M = Number marked
where C = Number captured (observed)
where R = Number recaptured (observed)
where N = Population estimate

Summing the estimates for each size-class results in a total population estimate. Ricker (1975) lists the formulas for calculating confidence intervals around the estimate.

Accuracy and Precision Considerations

Accuracy of snorkel surveys can be estimated by replicating the surveys or using other methods to calibrate the surveys (Northcote and Wilkie 1963; Zubik et al. 1988; Rodgers et al. 1992; Thurow 1994). Replication of snorkel surveys should be done after fish have had time to recover from disturbance but before conditions that would affect the survey results (such as light levels or turbidity) change. Calibration of team member estimates offers a good opportunity to resample the same habitat unit to determine the precision of the survey method (Thurow 1994). Data in Thurow (1994) show close alignment of snorkeling estimates from two different snorkelers at 22 reaches on the South Fork Salmon River.

Since variation among repeated counts is small, snorkel survey data can be readily compared, but the question remains: how accurately does the survey data reflect the true abundance of the sample unit? Rodgers et al. (1992) suggest that snorkel survey data should be calibrated with other methods because accuracy varies by sample reach and sampling conditions. Accuracy of snorkel counts is 90% for juvenile salmon in clusters of fewer than 40 fish, but coho salmon and chinook salmon *O. tshawytscha* were undercounted when in mixed groups of fish species (Hillman et al. 1992). Small steelhead (less than 100 mm) were undercounted by

40% in water less than 15 cm in depth and in areas with abundant cover (Hillman et al. 1992). Of 13 studies reviewed by Thurow (1994), 11 produced snorkel estimates within 70% of other methods; results, however, varied by species, life stage, and sample reach conditions such as water temperature and surveyor experience (Hillman et al. 1992). Dolloff and Owen (1991) found that calibrated snorkel counts were more accurate than electrofishing results for species that maintain position in the water column and are easily seen, such as trout. Other species, such as sculpin and darters, which are cryptically colored or hide in the crevices of the streambed, are more difficult for observers to count during snorkeling (Dolloff et al. 1993).

It is recommended that snorkel surveys be conducted using standard procedures and calibrated periodically with estimates from other methods. Methods for calculating population estimates using calibrated snorkel surveys are detailed in Dolloff et al. (1993).

Personnel Requirements and Training

Safety and training

As with any field activity, safety is of paramount importance. Swift rivers, cold temperatures, poor visibility, contaminants, and other environmental factors may affect divers conducting snorkel surveys. Surveyors should always assess the potential hazards of the reach before entering the water (Dolloff et al., 1996). In addition, a health and safety plan should be developed for any surveys of this type in which a risk assessment is conducted and for which appropriate countermeasures are identified and implemented during the survey.

Several risk issues and recommendations are offered here:

1. Never attach ropes or lines to divers in areas where currents or tidal action are factors.
2. Divers should avoid areas of extreme water velocity and turbulence because appendages and/or equipment may become wedged against rocks or debris.
3. Always enter and leave the study area from low-velocity waters (Dolloff et al. 1996).
4. If turbulent stream reaches are within the survey area, surveys should be completed along the channel margins and the most turbulent areas should be avoided. If a snorkeler becomes caught in strong turbulent flow, the safest position is to float feet first and steer by "back paddling" with the arms. The surveyor should not try to stand in swift water because feet or legs could be caught or entrapped on the bottom and the current can force the surveyor underwater.
5. If debris jams are surveyed, snorkelers should remain alert to ensure that they do not become entangled in debris (Thurow 1994). For safety and counting accuracy, debris jams are best approached from downstream where there is frequently an eddy and the snorkeler can make a slow, controlled, safe approach.

6. Hypothermia is one of the most common hazards for snorkel surveys. Divers in all conditions are at risk, although night surveys and surveys conducted during low temperatures pose a greater risk (Dolloff et al. 1996).

Basic safety in snorkel surveys requires that surveyors are comfortable in water and can effectively use a snorkel and mask. Surveyors should be instructed on how to use and clear their snorkels before beginning any survey. Adequate insulation in the form of a wet or dry suit should be used depending on water temperature and season of survey, and whether the survey is conducted during the day or at night. For night surveys, handheld dive lights should be used for safety and to view fish species. Crew members should all be trained in cardiopulmonary resuscitation (CPR) and first aid, with an emphasis on recognizing and treating hypothermia. Swift-water rescue training would also be useful for crew members working in larger river systems.

Identification and length estimation

Several identification keys are helpful for correct identification of juvenile and adult fish observed during snorkel surveys (Carl et al. 1959; McConnell and Snyder 1972; Martinez 1984; Thurow 1994; Pollard et al. 1997). There are limits on the ability to identify very small fish accurately, but fish as small as 25 mm can often be identified correctly in ideal conditions, so limits to young of the year (Thurow 1994) seem unnecessary (Roni, personal communication).

Training and practice are required to identify fish correctly underwater, to estimate fish sizes accurately, and to complete precise species counts. Annual training should be required for all surveyors. Surveyors should clearly understand the objectives of the study and review a standard protocol before beginning practice sessions. Practice sessions should be conducted at reaches similar to those that will be encountered by snorkelers during the field surveys. Snorkelers should practice identifying, counting, and estimating the size of target species. Fish identification practice can be done using known species in live cages or by having the instructor point to a fish to be identified and estimated by the staff member and then comparing the results with the instructor (Thurow 1994).

It is important to note that objects viewed underwater are magnified 1.3 times. A calibration technique for length estimates, such as marking centimeters on the dive slate or PVC pipe used to record data as a comparison, can be helpful. Snorkelers can also carry a ruler or use a known distance such as index-finger-to-thumb for reference. It is recommended that a measuring tape be fixed to the diver's glove to use as a calibration tool for length measurements (Roni, personal communication) (Swenson et al. 1988). Snorkelers should practice estimating the length of objects or fish of known size before conducting surveys. For example, measured wooden dowels can be used as training aids for learning to estimate length underwater (Roni, personal communication). Blocks of wood or plastic can be cut into fish shapes at varying lengths (50 mm, 100 mm, and 150 mm) and carried with the team to be used for frequent quick calibration and for calibration at varying distances. Training can greatly improve surveyors' accuracy in length estimation. One hour of practice allowed observers to increase their percentage of accurate (+/−25 mm) estimates from 62% to 90% (Griffith 1981).

Surveyors should be familiar with the size of sampling units to be surveyed and the method to be used to estimate fish abundance. The selection of sample units is dependent on the study objectives and the habitat conditions in the stream. Training should provide snorkelers with several opportunities to count the total number of fish in a sample unit; results should be compared across surveyors. Sampling units that contain known numbers and sizes of fish are ideal for training.

Operational Requirements

Operational requirements for snorkel surveys will vary based on the width of the habitat to be surveyed and conditions during the survey. Larger streams will need more than one surveyor, while smaller streams can be surveyed with one observer and an assistant on shore.

Equipment

Daytime surveys (water temperature greater than 9°C).

- Full neoprene wet suit (6.4 mm) or dry suit with knee pads, preferably black or blue or brown
- Wet suit hood
- Neoprene gloves
- Neoprene socks
- Wading boots with felt soles
- Fins (can be useful in large systems when surveys must be conducted downstream)
- Mask (can be worn over contact lenses or ordered with a prescription lens) with side window to increase visibility
- Snorkel
- Extra mask and snorkel for remote reaches
- Data recorders such as a dive slate scroll (Ogden 1977) or a plastic cuff (10-cm PVC pipe in 20-cm lengths will work and can be secured with surgical tubing [Helfman 1983])
- Grease pencil
- Knee and elbow pads (for turbulent or shallow streams)
- Wet suit cement or Aquaseal® for repairing suits
- Thermometer
- Small halogen light
- Canteen
- Food
- First-aid kit
- Mobile phone and/or radio for emergency contact
- Data forms
- Measuring tape
- Flagging

Nighttime surveys or daytime surveys where water temperature is less than 10°C. Everything listed above and the following

- Dry suit (required) (should not have valves if possible)
- Adequate insulation under dry suit (one-piece fleece suits are available at dive shops, or layers of wool or synthetic fabrics can be used)
- Handheld halogen dive lights (a red filter can be helpful for reducing fish disturbance; filters can be made from red Plexiglas) (Thurow 1994).

Budget Requirements

Hankin and Reeves (1988) compared the cost effectiveness of using snorkel surveys calibrated by multiple pass removal electrofishing against electrofishing alone and found that for the same cost, the combination of snorkel surveys and electrofishing was 1.7–3.3 times more accurate than electrofishing alone (Dolloff et al. 1993). They attributed their results to the high cost of electrofishing. Although fish counts by divers may be less accurate than estimates based on depletion electrofishing, snorkelers can move faster and can examine more habitat units in a given time period (Dolloff et al. 1993). Cost optimization methods are explained in detail in Dolloff et al. (1993).

Literature Cited

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover, and population density. Transactions of the American Fisheries Society 11:324–438.

Carl, G. C., W. A. Clemens, and C. C. Lindsey. 1959. The freshwater fishes of British Columbia. Handbook 5. British Columbia Provincial Museum, Department of Education, Victoria.

Campbell, R. F. and J. H. Neuner. 1985. Seasonal and Diurnal shifts in habitat utilized by rainbow trout in western Washington Casade mountain streams. In F. W. Olson, R. G. White and R. H. Hamre (eds), Proc. of the Symp. on Small Hydropower and Fisheries, American Fisheries Society, Bethesda, Maryland. 39-48.

Dolloff, A. C, and M. D. Owen. 1991. Comparison of aquatic habitat survey and fish population estimation techniques for a drainage basin on the Blue Ridge Parkway, Completion Report. U.S. Department of the Interior, National Park Service, Cooperative Agreement CA-5000-3-8007, Blacksburg, Virginia.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-GTR-83, Asheville, North Carolina.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service, Southeastern Forest Experiment Station, General Technical Report SE-GTR-83, Asheville, North Carolina.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observation. Pages 533–554 in B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda Maryland.

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

Fausch, K. D., and R. J. White. 1981. Competition between brook trout (Salvelinus fontinalis) and brown trout *(Salmo trutta)* for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences. 38:1220–1227.

Flosi, G., and F. L. Reynolds. 1994. California salmonid stream habitat restoration manual. California Department of Fish and Game, Technical Report, Sacramento.

Goetz, F. 1997. Diel behavior of juvenile bull trout and its influence on selection of appropriate sampling techniques. Pages 387–402 in Mackay, W. C., M. K. Brewin, and M. Monita (eds.). Friends of the bull trout conference proceedings. Bull Trout Task Force (Alberta), c/o Trout Unlimited Canada, Calgary.

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

Griffith, J. S., D. J. Schill, and R. E. Gresswell. 1984. Underwater observation as a technique for assessing fish abundance in large rivers. Proceedings of the Western Association of Fish and Wildlife Agencies 63:143–149.

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

Helfman, G. S. 1983. Underwater methods. Pages 349–370 in L. A. Neilson and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

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

Martinez, A. M. 1984. Identification of brook, brown, rainbow, and cutthroat trout larvae. Transactions of the American Fisheries Society 113:252–259.

Mc Connell, R. J., and G. R. Snyder. 1972. Key to field identification of anadromous juvenile salmonids in the Pacific Northwest. NOAA Technical Report NMFS Circular 366.

Mueller, K. W., D. P. Rothaus, and K. L. Fresh. 2001. Underwater methods for sampling the distribution and abundance of smallmouth bass in Lake Washington and Lake Union. Washington Department of Fish and Wildlife, Fish Management Program, Technical Report # FPTO1-17, Olympia.

Northcote, T. G., and D. W. Wilkie. 1963. Underwater census of stream fish populations. Transactions of the American Fisheries Society 92:146–151.

Ogden, J. C. 1977. A scroll apparatus for the recording of notes and observations underwater. Marine Technology Society Journal 11:13–14.

O'Neal, J. S. 2000. Biological evaluation of stream enhancement: a comparison of large woody debris and an engineered alternative. University of Washington, Masters Thesis, Seattle, Washington 103 p.

Peck, D. V., J. M. Lazorchak, and D. J. Klemm. 2003. Environmental Monitoring and Assessment Program: Surface Waters–Western Pilot Study Operations Manual for Wadeable Streams. U.S. Environmental Protection Agency, Corvallis, Oregon.

Pollard, W. R., G. F. Hartman, C. Groot, and P. Edgell. 1997. Field identification of coastal juvenile salmonids. Harbour Publishing, Madeira Park, B.C.

Ricker, W. E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bull. Fish. Res. Board. Can. 191:1–382.

Rodgers, J. 2002. Abundance monitoring of juvenile salmonids in Oregon coastal streams, 2001. The Oregon Plan for Salmon and Watersheds: Report No. OPSW-ODFW-2002-1. Oregon Department of Fish and Wildlife, Corvallis.

Rodgers, J. 2003. Protocols for conducting Oregon Plan surveys of juvenile salmonid in Oregon coastal streams. Oregon Department of Fish and Wildlife, Corvallis.

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

Schill, D. J., and J. S. Griffith. 1984. Use of underwater observations to estimate cutthroat trout abundance in the Yellowstone River. North American Journal of Fisheries Management 4:479–487.

Slaney, P. A., and A. D. Martin. 1987. Accuracy of underwater census of trout populations in a large stream in British Columbia. North American Journal of Fisheries Management 7:117–122.

Swenson, W. A., W. P. Gobin, and T. D. Simonson. 1988. Calibrated mask bar for underwater measurement of fish. North American Journal of Fisheries Management 8:382–385.

Temple, G. M., and T. N. Pearsons. 2007. Electrofishing: backpack and drift boat. Pages 95–132 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons. Salmonid field protocols handbook—techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. U.S. Forest Service, Intermountain Research Station, General Technical Report INT-GTR-307, Odgen, Utah.

Washington Salmon Recovery Funding Board. 2004. Protocol for monitoring the effectiveness of fish passage projects. Washington Salmon Recovery Funding Board, Olympia.

Zubik, R. J., and J. J. Fraley. 1988. Comparison of snorkel and mark–recapture estimates for trout populations in large streams. North American Journal of Fisheries Management 8:58–62.

Appendix A: Snorkeling Survey Data Sheet

Station		**Time**	Start / End
Date			
Reach ID		**Snorkeler**	
Visit #		**Weather**	
Team ID			
Reach Name			

Species	0 to 50 mm	51 to 80	80 to 100	100 to 120	120 to 150	150 -200	200 - 250
Chinook							
Coho							
Steelhead							
Rainbow							
Cutthroat							
Cut-bow							
Sculpin							

Turbidity **Reach Area** (m^2)

0 = not snorkelable due to high turbidity or hiding cover

1 = high amount of hiding cover and/ or poor water clarity

2 = moderate hiding cover and/or moderate water clarity

3 = little hiding cover and good water clarity

Comments