Rotary Screw Traps and Inclined Plane Screen Traps

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Background and Objectives

Inclined plane screen traps and rotary screw traps have long been used by biologists to capture downstream migrating juvenile anadromous salmonids from medium- and large-sized streams (Schoeneman et al. 1961; Seiler et al. 1981; Kennen et al. 1994) and from small tributary streams (Solazzi et al. 2000). In its original fixed screen design, the floating inclined plane screen (scoop) trap has been used to capture juvenile migrants for more than 40 years (Schoeneman et al. 1961). William Humphreys replaced the fixed screen with a traveling screen powered by a paddle wheel and added a debris drum at the back of the live well (Humphreys trap) in 1966 (McLemore et al. 1989). The rotary screw (screw) trap was developed and patented by two biologists from the Oregon Department of Fish and Wildlife (ODFW) in the late 1980s. All these traps are anchored at a fixed point in the stream channel and intercept a portion of the juvenile salmonids or smolts migrating downstream.

Traditionally, fishery managers have relied on escapement estimates to monitor anadromous salmonid population status and management effectiveness (Ames and Phinney 1977; Beidler and Nickelson 1980; Hilborn et al. 1999); however, estimation of population abundances at earlier life stages enables partitioning survival among life stages and developing hypotheses for restoration actions (Moussalli and Hilborn 1986; Mobrand et al. 1997). Juvenile fish traps have often been used to estimate the abundance (Tsumura and Hume 1986; Baranski 1989; Orciari et al. 1994; Thedinga et al. 1994; Letcher et al. 2002; Johnson et al. 2005), timing (Wagner et al. 1963; Hartman et al. 1982), size (Orciari et al. 1994; Olsson et al. 2001), survival (Schoeneman et al. 1961; Wagner et al. 1963; Tsumura and Hume 1986; Olsson et al. 2001; Letcher et al. 2002), and behavior (Brown and Hartman 1988; Roper and Scarnecchia 1996) of downstream migrant anadromous salmonids. In many salmon-bearing systems, population abundance is only monitored during the adult (spawner) stage. Additional monitoring of smolt abundance is a particularly powerful tool because it enables partitioning mortality between the freshwater life stages (egg-to-smolt) and marine life stages (smolt-to-adult).

While estimating smolt abundance is the most common reason for operating an inclined plane screen trap or screw trap, the capture of downstream migrants has wide utility. Traps can be used to monitor the effects of river management on wild stocks, such as the effectiveness of diversion, lock, and dam management. They are powerful tools for validating assumptions regarding the effects of watershed restoration programs and land-use policies on fish populations (Solazzi et al. 2000; IMW SOC 2004; Johnson et al. 2005). They can also be used to assess survival between life stages, such as egg-to-smolt survival or parr-to-smolt overwinter survival (Solazzi et al. 2000; Seiler et al. 2003; Johnson et al. 2005). Smolt-to-adult survival estimates can be developed for wild populations by coded wire tagging smolts that are captured in inclined plane screen traps and screw traps and estimating the escapement and fishery impacts on the tagged population.

In addition to serving as a tool to monitor wild populations, inclined plane screen traps and screw traps are useful for evaluating hatchery programs and hatchery/wild fish interactions. Such studies may include evaluating the instream survival of hatchery production following release and evaluating treatments such as rearing strategy, release timing, release location, and flow manipulation on groups of hatchery fish. These latter uses can be applied to evaluate a variety of projects or actions, ranging from hatchery supplementation strategy to avoidance of hatchery and wild fish interactions. In addition to abundance estimates, investigators use inclined plane screen traps and screw traps to collect samples of downstream migrants for purposes such as genetics sampling, fish disease research, predation (gut content) evaluations, and wild stock marking and tagging projects.

Operating a downstream migrant trap allows the investigator to sample wild salmonids produced in a watershed or tributary over time. The sample in itself is valuable because it documents the presence/absence of migrating juveniles and enables determination of age and size at migration, condition, timing, species, and genetic characteristics. Furthermore, catch of a given species or catch-per-unit-effort (CPUE) can be used as an index of downstream migrant production if the location of the trap, its placement, and hours of operation are sufficient and held reasonably constant from year to year.

More importantly, trapping information can also be used to create estimates of total freshwater production by use of simple mark–recapture methods to estimate abundance. The rationale is simply that the proportion of marked fish appearing in a random sample is an estimate of the marked proportion in the total population. The proportion captured (trap efficiency) is estimated by conducting a series of trap efficiency experiments throughout the trapping season.

On the west coast of the United States and Canada, juvenile fish traps have been used primarily to estimate the natural production of juvenile coho *Oncorhynchus kisutch,* sockeye *O. nerka*, and steelhead *O. mykiss* from fifth-order and smaller basins (Nickelson 1998). Nevertheless, with careful planning, reasonably accurate production estimates have been obtained when sixth-order and larger systems have been trapped (Schoeneman et al. 1961; Thedinga et al. 1994). For example, side-by-side scoop and screw traps have been successfully used to make estimates of yearling coho and sub-yearling chinook *O. tshawytscha* migrants since 1990 in the Skagit River (a seventh-order basin) (Seiler et al. 2003) (see Figure 1).

This protocol describes methods to estimate wild downstream migrant salmonid production using either an inclined plane screen trap or a rotary screw trap. Because the traps strain the upper portion of the water column, they are generally not very useful for capturing species that migrate along the bottom of the river (e.g., lamprey). The traps can be scaled to operate in various-sized streams but are most commonly used in streams that are too large or powerful to employ a fence weir (i.e., ~10–15-m or larger channels).

FIGURE 1. — Skagit River screw and scoop traps.

Inclined plane screen trap

The design of inclined plane screen traps permits trapping a range of stream velocities and depths. There may be any number of derivations from the basic scoop trap design, which is simply a wedge-shaped screened rectangular tube suspended in the water column from a pontoon barge. The screen section is typically constructed of galvanized woven-wire mesh (hardware cloth) or perforated plate aluminum sheet metal riveted to a frame. All seams are coated with a sealant so that no sharp metal edges are exposed that can injure fish. The scoop trap is typically suspended inside a pontoon barge from support winches at the corners of the fore and aft decks (see Figure 2). The trap position is fixed using anchor lines that extend from each pontoon to shore, a fixed in-stream structure (e.g., bridge), or a high lead that extends across the river.

FIGURE 2. — Scoop trap mounted on a pontoon barge, shown in the nonfishing position (Clearwater River, Washington).

Other inclined plane screen trap designs been developed to reduce debris buildup on the trap and to adapt to specific site characteristics. The traveling screen trap or Humphreys trap, originally designed by William Humphreys (ODFW), uses a traveling screen instead of a fixed screen along with a trash drum at the back of the livewell to reduce debris buildup on the trap (McLemore et al. 1989). The basic Humphreys trap uses a paddle wheel and gear assembly attached to one or both of the pontoons supporting the trap to power the traveling screen and trash drum. A similar design, the motorized Humphreys trap, uses a 12-V DC motor instead of paddle wheels to power the traveling screen (see Figure 3). This design is best suited to smaller streams that lack the hydraulic power to drive the Humphreys trap or a rotary screw trap. In another variation of the fixed screen design, the upstream end of the inclined plane screen is attached to a low-head dam or weir and collects fish passing over the structure (e.g., DuBois et al. 1991). A lightweight inclined plane trap for sampling salmon smolts has also been used in Alaska (Todd 1994).

FIGURE 3. — Motorized incline plane trap used in small Oregon coastal streams to monitor downstream migration of juvenile salmonids.

FIGURE 4. — Fishing scoop trap showing the fore and aft winches used to raise and lower the trap, the trap apex, live well, and catch processing station (Chehalis River, Washington).

FIGURE 5. — Close-up of a motorized incline plane trap's moving screen with attached cups that help keep juvenile fish from escaping off the screen.

When the inclined plane screen trap is lowered into the current, water is strained through the screens and downstream migrants are swept up the screen incline and deposited into a protected, solid-sided and floored live box at the back (see Figure 4). To capture and retain migrants in a scoop trap, water velocity through the trap must exceed swim speed. As swimming ability is directly related to body length, higher velocities are required to trap large migrants. Fry (less than 50 mm fork length) may be captured at relatively low velocities, whereas trapping the larger migrants, such as steelhead smolts (up to 250 mm), requires velocities greater than 2 m/s (mps). At less-than-optimal velocities, larger migrants may avoid or swim out of the trap. Velocity requirements may be partially mitigated with a traveling screen trap since the screen can be fitted with baffles or perforated L-shaped cups to help carry fish to the livewell and reduce the chance of escape (see Figure 5). As velocity increases, the volume of water and suspended debris passing through the trap also increases, requiring more frequent inspection and cleaning of the trap and live box.

Flow into the trap is regulated by positioning the trap (laterally and longitudinally) in the stream and by adjusting the level and angle of the inclined screen through its four support winches. Proper adjustment of a scoop trap is indicated by a smooth flow over the apex of the incline into the holding chamber, with a water depth over the apex of 1.5 to 2 cm. As the screen accumulates debris, its ability to pass water decreases and the depth and velocity over the incline increases, causing turbulence in the holding chamber. Debris load is affected by streambank vegetation, weather (rain and wind transport debris into the river) and, most importantly, river discharge. Trap operation through a freshet requires that the screens are carefully monitored and regularly cleaned and that the catch is frequently removed from the live box and processed.

Traveling screen traps fitted with baffles may be adjusted so that the top of the screen extends slightly out of the water, since the movement of the screen and baffles carries the fish to the live well (see Figure 5).

Rotary screw trap

The screw trap consists of a cone covered in perforated plate that is mounted on a pontoon barge (see Figure 6). Within the cone are two tapered flights that are wrapped 360 degrees around a center shaft. The trap cone is oriented with the wide end facing upstream and uses the force of the river acting on the tapered flights to rotate the cone about its axis, similar to an Archimedes screw (see Figure 7). Downstream migrating fish are swept into the wide end of the cone (typically either 1.5 m or 2.5 m in diameter) and are gently augured into a live box at the rear of the trap (see Figure 8). A winch is used to adjust the forward elevation of the screw, and an additional winch may be used to raise and lower the aft end of the screw if desired. A small drum screen, powered by the rotating cone or a paddle wheel, may be located at the rear of the live box to remove organic debris.

FIGURE 6. — Screw trap mounted on a pontoon barge in the nonfishing position (Puyallup River, Washington).

FIGURE 7. — Two rotary screw traps in the nonfishing position suspended from a three pontoon barge (Wenatchee River, Washington).

When positioned in the river, both inclined plane screen traps and screw traps are navigation hazards to boaters, float tubers, and swimmers. Signage should be positioned upstream to instruct river users how to avoid the trap safely. Other protective measures may include installing flashing lights to improve the visibility of the trap (see Figure 8) and deflectors to help prevent water users and large woody debris from entering the trap (see Figure 9).

FIGURE 8. — Back end of the screw trap showing the auger cone, live well (covered), and trash drum (Green River, Washington).

FIGURE 9. — Screw trap with deflector (Green River, Washington).

Rationale

While scoop traps and other inclined plane screen trap designs have been used to capture downstream migrants for more than 40 years, screw traps have only been in use since the early 1990s. Screw traps and traveling screen traps incorporate a number of improvements over the older scoop trap. For example, since the screened surface of a screw trap rotates about an axis in and out of the water, small debris falls off of the screen and is flushed into the live well. The frequency of trap cleaning is greatly reduced for screw and traveling screen traps compared to the scoop trap, which more readily accumulates debris on its screened surfaces. Another shortcoming of scoop traps is that they are effective only where water velocity exceeds the burst swimming speed of the target species. This problem is most apparent for strong swimmers such as steelhead and cutthroat smolts, which often can swim out of a scoop trap. As screw traps rotate about their axes, the tapered flights block captured fish from swimming back out of the trap; therefore, screw traps can be more effective for capturing larger migrants. Traveling screen traps employing baffles or other capture aids are typically more effective in retaining larger migrants than scoop traps but are less effective than screw traps.

Despite these deficiencies, scoop traps are attractive for their simplicity. The lack of moving parts makes them very reliable. Scoop traps are generally more effective than are screw traps at capturing smaller migrants (i.e., <80 mm for salmonids). For example, the Washington Department of Fish and Wildlife (WDFW) has operated a scoop trap and a screw trap side by side to evaluate anadromous salmonid production in the Skagit River, Washington. Although these traps strain nearly equal volumes of water, the scoop trap consistently traps a higher proportion of subyearling migrants, and the screw trap consistently traps a higher proportion of larger, older age migrants, such as steelhead and cutthroat trout trout *O. clarkii*. Yearling migrants such as coho are captured at about equal rates. A potential explanation is that downstream migrants are more likely to avoid the screw trap because of the noise it generates; therefore, the quieter scoop trap probably has a higher initial capture rate. Nevertheless, because larger migrants are not retained as well in the scoop trap, the screw trap is less size-selective.

Site characteristics are another important consideration for trap selection. In general, screw trap operation is better accommodated in larger streams, where sufficient water depth and velocity are available to accommodate and power the screw. E. G. Solutions, the patent-holding company of the screw trap design, currently produces only 1.5- and 2.5-m-diameter traps, which limit the size of stream in which these traps can be operated. Nevertheless, screw traps can be operated in streams of variable size by scaling the size of the pontoon barge that supports the trap. Whereas pontoon barges supporting scoop and screw traps on large rivers may be 9–13 m in length and fabricated from steel, those used on small streams are fabricated from aluminum and are much smaller (e.g., 4 m in length). For example, ODFW has successfully employed screw traps in streams with catchments as small as 14 km^2. Inclined plane screen traps are often built by the investigator and can be scaled to operate in very small streams. Because of their adjustable screen depth, traveling screen traps and scoop traps are less constrained by shallow water depths (i.e., smaller streams) than are screw traps.

Sampling Design

The sampling design will depend on the objectives of the study. Since considerable effort is required to install and operate inclined plane screen traps and screw traps, most investigators will use these gear types only if sampling over many days is desired. Although there are many potential uses, most investigators will use these traps either to estimate the total freshwater production of wild salmonids or, where conditions preclude this, to develop an index of production. The following discussion is oriented towards estimating freshwater production; however, in most cases, investigators will be able to adapt these methods to meet the objectives of their studies.

Site Selection

Selection of trapping sites should be viewed from a variety of scales. If the natural production of salmon is to be monitored at the watershed scale, no hatchery fish should be present in the river or stream; if they are, all hatchery fish should be identifiable so that wild fish may be enumerated. Precision of the estimates increases with higher trap efficiency (i.e., proportion of migrants captured);

therefore, it is generally better to select sites where a higher proportion of the total flow can be screened through the trap. This becomes a trade-off, however, if the trap is placed below a hatchery release site, since higher trap efficiencies can result in very large numbers of hatchery fish entering the trap following release. When this occurs, good communication between trap operators and hatchery staff must be maintained to avoid a fish kill. In general, it is best to avoid these situations when choosing a trap site.

Another consideration when selecting watersheds (or catchment basins) is the stream hydrograph. Flow is dependent on such variables as landform, geology, land cover, climate, and precipitation patterns, which of course cannot be controlled. The effect of these factors on the stream discharge needs to be considered when attempting to estimate total freshwater production. Streams and rivers exhibiting a flashy hydrograph are very difficult to trap due to high fluctuations in flow conditions and debris loads. Because trap efficiency and migration rates often change dramatically with discharge, it is very difficult to estimate migration accurately. Furthermore, traps may become difficult to access safely without prior planning and preparation.

If the monitoring objective is to measure total abundance within a watershed, the trap should be placed as low in the watershed as is practicable. It is vital to take into account the life history and in-river migration patterns of your target species. Species exhibiting a stream-type life history pattern, such as coho salmon and steelhead, often migrate within basin and rear away from their natal streams; therefore, the smolt production measured from a tributary trap may represent a variable proportion of the progeny from the adults that spawned upstream of the trap. Species with an ocean-type life history pattern (e.g., pink salmon *O. gorbuscha*) often spawn lower in the watershed, so it is prudent to place traps as low in the system as possible in order to estimate production. Tributary traps are often used in a before-after monitoring design to evaluate differences in abundance resulting from changes in management or restoration. Care must be taken in interpreting the results, however, since improved smolt production could be the result of parr movement into the enhanced tributary for rearing rather than increased egg-to-smolt survival.

At the site scale water velocity, depth, and proportion of the flow screened are also important considerations for trap placement. Velocity is an especially relevant consideration if trapping strong swimming species such as steelhead, and becomes less so when trapping newly emerged fry. For most species, water velocities of at least 1 m/s are desirable for scoop trap operation; for most steelhead smolts, velocities greater than 2 m/s may be required for capture and retention. For Humphreys traps, McLemore et al. (1989) suggest a minimum water velocity of 0.9 m/s, with most efficient operation at 1.5–2 m/s. We have found that water velocities of 0.8–2 m/s work well for screw traps operated in Oregon coastal streams. Ideally, screw trap sites should have sufficient velocity to conduct at least 5–6 trap rotations per minute (rpm) for capturing larger smolts. Velocity does have its limits: 2.5-m diameter screw traps can be damaged at rotation speeds greater than 14–15 rpm. Trap avoidance is minimized in cases where higher velocities occur; nonetheless, fish can certainly be captured at lower velocities. For example, researchers in California have found that successful capture and retention of steelhead smolts occurs at speeds as slow as 1.67 rpm.

Care must be taken that the water depth under the trap and live well will be sufficient over all flow conditions that are expected during the outmigration period. To achieve the highest possible trap efficiency, it is usually best to select a site where a relatively high proportion of the total flow can be screened through the trap. The requirement for adequate velocity, depth, and trap efficiency usually argues for placing the trap in the thalweg of the channel. Consideration must be given, however, to the number and behavior of migrants captured. The investigator may choose to operate the trap in a slightly less advantageous position to avoid causing stress or predation in the live well by capturing and holding too many migrants. In addition, a substantial proportion of the migrants from some species/age-classes may migrate along the channel margins. If these fish are targeted, placing the trap nearer to margin habitats and using weir panels to lead these fish to the trap entrance may achieve higher capture rates.

Stream flow should be moving in a straight line as it enters the trap. Pools with sharp changes in direction that result in large back-eddy currents should generally be avoided. Streamflow in smaller streams may diminish to the point that water velocity is not sufficient to turn a rotary screw trap. Operating a trap in low-flow situations presents its own challenges and requires prior planning for successful trapping. Small boulders, sandbags, or screened weir panels can be used to improve the hydrodynamics of a site. Where bedrock is the predominant substrate upstream from the trapping location, tripods can be bolted directly to the bedrock, providing a firm foundation for attaching screen panels to direct flow towards the trap (see Figure 10). Tripods and screen panels can also be erected in gravel-dominated streams to improve trapping conditions, but these sites usually require substantial reinforcement with sandbags in front of and behind the panels to minimize the stream's ability to undercut the panels in high-flow events. These types of channel modifications or treatments can also be used to increase the functionality of locations with poor site characteristics; however, the researcher should evaluate whether these actions are subject to regulatory authority.

FIGURE 10.—Tripods and screen panels bolted to bedrock substrate to improve screw trap operation in a low-gradient coastal stream.

Additional consideration needs to be given to site selection for screw traps because of the noise they generate. Migrants will avoid the trap if they are aware of its presence; therefore, it is best to select a site where the trap noise can be masked to maintain higher trap efficiency. Fortunately, higher velocity reaches are generally noisy reaches. In smaller rivers, these conditions occur at the head end of a pool or chute where water velocities over an elevation drop (e.g., riffles, cascades, falls) can be directed into the trap. In larger rivers, channel constrictions may afford the best sites.

In addition to the aforementioned criteria, consideration must be given to anchoring the trap in the stream. Scoop and screw traps can be anchored by cables to the base of stout trees on each bank; to anchors affixed to bridge abutments, retaining walls, or bedrock; or to a high lead suspended across the river. Where anchoring structures are unavailable, some researchers have created anchors by burying 4–6 fence posts tied together with a steel cable or by driving a series of 6 fence posts into the substrate in a triangular arrangement. In the early 1960s the mainstem Columbia River was trapped using a series of scoop traps cabled to large concrete blocks submerged in the river (Schoeneman et al. 1961).

Finally, investigators need to consider access and security when selecting trapping locations. Traps anchored in the river are a curiosity, which can draw theft or vandalism when not attended. Ideally, the trap site will be located near a launch/recovery site to ease trap installation and removal.

Period of operation

The time frame for trap operation varies with the target species and trapping location. Table 1 provides general migration timing for anadromous salmonids in Oregon and Washington rivers. Downstream migration timing in specific rivers can vary from these general guidelines. Timing may need to be investigated during the first year of monitoring where it is not well known.

TABLE 1. — Generalized migration timing for anadromous salmonids in Oregon and Washington.

Species	Age	Migration period
Chinook	0, 1	January–July/August
Coho	1	March/April–June
Sockeye	0	January–May
Chum	0	February–April
Pink	0	January–May
Steelhead	2	March–May
Cutthroat	0, 1, 2	January–December*

* Migration timing for cutthroat varies widely.

To estimate production, traps should be operated throughout the migration period for the target species. For most species, migration rates are often highest at night; yet daytime migration rates can also be high on some streams, particularly where turbidity levels are high. At a minimum, the investigator should stratify trapping periods to reflect different migration/capture rates. This often means checking the trap and processing the catch at dawn and at dusk to measure day and night catch rates. These are not, however, the only times to check the trap; the frequency of catch processing and trap maintenance should be determined by catch rates and debris loads. Stratification facilitates subsampling and estimating catches during periods when trapping is suspended.

Field/Office Methods

Before trapping can begin, all equipment and supplies must be assembled to accomplish project objectives. At a minimum, these include the trap/pontoon structure and anchor cables, a means to get to the trap (e.g., boat, gangplank), dip nets for removing and handling fish, data forms, fish anesthetic, a marking device (e.g., scissors, dye), tanks or buckets for working up captured fish, a trap cleaning device (e.g., brooms, water pump, nozzle), and lights for night work. Permits may also need to be secured for placement of the trap and/or handling fish from various jurisdictions. Sufficient time must be allotted during the planning period to secure permits.

The approach for trap installation depends on the size and weight of the trap used. Small inclined plane screen traps and screw traps that use lightweight aluminum pontoons can be transported in pickup beds and assembled on-site. Components of larger, heavier traps, such as the scoop trap shown in Figure 2, can be trucked to the site using a low-boy trailer. In this case, onsite assembly requires the use of a loader or other heavy equipment to move the components into place. A third option is to truck an assembled trap to the site and position it in the water using a boom truck or crane.

Once in the water, the trap is ready to be positioned in its fishing location. The approach used to accomplish this will depend on the size of the trap and stream and the distance from the launch point to the fishing site. Small traps operating on small streams can be moved into position by hand. Bow-mounted cables or ropes can be attached to trees or other anchoring structures on the banks. Movement of the trap into its final position can be accomplished using hand winches or chainfalls. If the trap is anchored to trees, the load needs to be distributed over the trunk to prevent girdling. Fabric straps make useful attachments.

If the launch point is some distance from the fishing site, the trap can be "walked" into position by alternating port and starboard attachment points either upstream or downstream and tightening or loosening the bow cables as necessary using winches. In navigable waters, a boat can be used to push the trap to a site where one of the methods described can be used to secure the trap to its fishing position.

Larger traps may use bow winches mounted port and starboard to store attachment cables (see Figure 2). The most direct approach is to run the cables out to the attachment points and pull the trap into position using the winches. Another approach is to attach cabling directly from the trap to a highline that has been strung over the river (see Figure 11). The use of bow-mounted winches is the preferred approach, since it makes repositioning the trap much easier.

FIGURE 11. — Example of a highline anchoring system for two screw traps operating side by side (Wenatchee River, Washington).

Traps on larger streams and rivers are accessed primarily by boat. On large rivers an aluminum flat-bottomed skiff powered by a motor outfitted with a jet pump can be used to reach traps. To reach traps on smaller rivers, WDFW uses a pulley that attaches the bow of an aluminum skiff to a cable extending from the bank to the trap. Also, extending from the trap to shore is a rope, which is suspended over the skiff and used by the operator to ferry the boat back and forth along the cable from shore to trap. When traps are located 3 m or less from a steep bank, a portable gangplank bridge can sometimes be constructed and used for access (see Figure 9).

Although traps on small streams are generally accessed by wading, a cabling configuration may also used to bring the trap to shore when high flows preclude wading access. For example, researchers often use a highline system for anchoring the trap (see Figure 11). A bridle is attached to the front of the trap, and a main line from the bridle is routed through a pulley on the highline crossing the stream upstream of the trap. The main line then runs through another pulley attached to a tree or anchor on the bank. An additional rope-and-pulley setup is also attached to the front of the trap and brought directly to the bank, allowing the trap to be positioned from side to side. This method exerts tremendous tension on the highline that spans the stream, so the cable size and anchors need to be sized accordingly. Alternatively, single lines may be led from each pontoon through blocks mounted on each shore. With this configuration, downstream force is spread between two lines instead of one main cable. The line attached to the pontoon opposite the access side of the river should be led back across the river so that both lines can be controlled from the same bank. Depending on the site, additional pulleys can be added on each line so that one person can manipulate the position of the trap. Using these rope riggings, operators can safely manipulate the trap's position during high-flow events from the bank of the stream. A safety cable should also be attached to the downstream end of the trap and to the pontoon farthest from the bank to which the cable is attached. With this configuration, if the trap breaks free from the main front cable, the trap should rotate and face downstream with the trap held against the bank by the safety cable.

Trap operation

Inclined plane screen trap

Once the pontoon barge is in position, trap operation begins by lowering the trap into the water using the cables or rope attached to each of the four corners of the trap. On larger traps, winches are used to raise and lower the corners (see Figure 4). For scoop traps, the trap's apex—the point where fish riding up the scoop screen drop over the top and into the live box—should have about 1.5–2 cm water depth. The two forward corners should be level and straining the top meter or less of water, depending on the size of the trap. The two aft corners should be laterally level, and the live well should have sufficient water to maintain the captured fish. Water in the live well should be relatively quiet. Most of the streamflow entering the scoop will pass through the trap screens, but sufficient sweeping flow must be available to carry fish up the incline and into the live well. These conditions are usually met when the trap is level fore to aft or slight higher at the forward end (see Figure 4). When the trap is properly set for fishing, marking the leading edge of the scoop at the water's edge so that the trap can be reset to fish at the same depth each time can reduce variation in trap efficiency.

When checking the trap, the forward end of the trap is raised until the bottom of the scoop is above the water level and no longer fishing. Then, the aft end is raised as needed to remove the catch for processing. Brooms or a water pump with nozzle are used to clean the trap screens before lowering the trap back into its fishing position. The date and time that the trapping is suspended and resumed are recorded. The catch is enumerated by species, and other data and samples are taken as appropriate to the study.

Operation of the traveling screen traps is similar to the scoop trap. Because these traps must operate during high streamflows, there is always a risk that the traps will become jammed with debris. At these times, traps require constant or frequent attention to minimize potential mortalities and to ensure that traps are functioning properly. Still, there may be times when traveling screen traps stop rotating while no one is on-site. To determine the length of time a motorized Humphreys trap actually runs, a 12-V clock is connected to a fuse in line with the trap motor. If the trap is jammed with debris, the fuse is blown, stopping the clock. By recording the starting and ending time on the clock, the length of time the trap was fishing before becoming jammed can be determined. The fuse has the additional benefit of preventing motor burnout by cutting off power to the motor when the trap becomes jammed.

Screw trap

The screw trap is lowered into its fishing position by cables attached to the forward and/or aft ends of the trap structure. Typically, one or two hand winches or chainfalls are used to raise and lower the forward end (see Figure 12) or both ends (see Figure 8), depending on trap design. The forward end of the screw should be lowered until the axle is at the water's surface (see Figure 13). The aft end is lowered so that fish can swim from the aft screw chamber into the live well, but not so low that they can ride the debris drum (if there is one) over the back of the trap.

FIGURE 12. — Rotary screw trap outfitted with a single forward winch in the nonfishing position.

FIGURE 13. — Rotary screw trap in fishing position.

Since the screw is constantly rotating, relatively little debris builds up on the screw's outer screen. As the debris drum removes much of the debris entering the trap, this gear requires less cleaning than a scoop trap. During each trap check, debris remaining in the live well is removed and captured fish are dipnetted out. The trap can usually remain in operation during this procedure. The date and time of the trap check is recorded. Catch is enumerated by species and other data/ samples are taken as required by the study.

Debris can also prevent operation of rotary screw traps. To estimate when rotation of the trap ceased, we recommend using a trucking industry hub-odometer. The hub-odometer is placed on the front or rear of the central shaft of the trap (see Figure 14) and records the "distance" that the screw turns between trap checks. By monitoring the number of revolutions per minute, and knowing the distance that the screw turned, the length of time the trap fished before jamming can be estimated. The hub-odometer that we use records 1.6 km for every 500 revolutions of the trap shaft. Thus, the length of time the trap fished can be estimated by

$$\text{hours trapped} = [\text{total revolutions}/(\text{measured revolutions/minute})] \div 60,$$

where

$$\text{total revolutions} = (\text{ending odometer reading} - \text{beginning odometer reading}) \times 500$$

FIGURE 14. — Hub-odometer attached to shaft of rotary screw trap. Hub-odometer readings are used to determine the number of hours the trap fished if trap is stopped by debris when staff is not present.

As stream discharge diminishes in the Spring, screw trap operation can become increasingly difficult in small streams or in stream reaches with marginal site characteristics (e.g., pool depth, velocity). These reduced flows may create a situation where there is insufficient velocity to turn the trap screw. Decreasing stream discharge may also reduce pool depth at the trapping site so that the screw cone encounters the bottom, either stopping the cone from turning or damaging the cone as it scrapes on the bottom. Considerable effort should be made to find sites that enable trap operation over an anticipated range of streamflows. If such a site cannot be found, a trap design more conducive to site characteristics (e.g., smolt fence) should be considered. Nevertheless, if screw trap operation is necessary at a marginal site, there are a number of actions that can be attempted until conditions improve.

For example, adjustable legs can be added to the trap to prevent the trap cone from contacting the streambed during low-flow periods (see Figure 15). Screen panels can also be extended to force the entire streamflow in front of the trap to generate enough water velocity to turn the trap screw (see Figure 10). Loosening or disconnecting the mechanism that drives the drum screen will reduce friction on the cone and help the cone spin in low-flow situations. Additional "wings" or "flights" can also be fabricated and attached inside the cone between the permanent wings to increase the surface area contacting the water entering the trap, thus helping to keep the cone rotating.

FIGURE 15. — Rotary screw trap in operation during low stream flows with the pontoon barge supported above the water on adjustable legs that allow the trap to spin during periods when the trap cone would normally contact the bottom of the stream.

If these measures fail to adequately turn the screw, rotation can be achieved using equipment similar to that which runs the motorized Humphreys traps described by McLemore et al. (1989). The upstream end of the shaft provides an attachment point for a sprocket gear that can be driven by a motor assembly, applying rotational force to the drum. The sprocket gear mounted to the drum shaft is driven by a riveted roller chain leading to a smaller sprocket gear mounted on a motor and speed-reducer assembly, which in turn is mounted on the front cross-member (see Figure 16). The 92:1 speed reducer allows the power transfer between the high rpm of the motor and the low rpm of the trap drum. The sprocket gear mounted to the front drive shaft is 34.3 cm in diameter with 84 1.27-cm pitch teeth. A section of pipe of a diameter that will fit either inside or over the trap drum shaft is centered and welded square to the sprocket gear. Once fitted, a hole is bored through the shaft and the pipe/gear is held in place with a 10-mm stainless steel bolt. This combination of gears, speed reducer, and a standard 1,750-rpm motor will turn the drum at a calculated speed of 3.2 rpm, but with some force provided by the stream flow, the actual rpm is generally closer to 3.5–4 rpm.

FIGURE 16. — Rotary screw trap with 12-V motor turning the drum when stream flows are insufficient.

For remote sites where high-voltage power is not available, the trap may be motorized using 12-V equipment. A 1/14 hp, 12-V motor that draws 6.9 A s at full load may be powered by several high-amperage deep-cycle batteries wired in parallel. The amperage capacity must be matched to the anticipated run time with no more than 50% discharge on the battery pack. For 24-h operation, a minimum capacity of 330 amp-hours is needed. Alternatively, limiting trap operation to sample only at night, if previous sampling has indicated little migration occurs during daylight hours, could reduce capacity requirements. The simplest method to achieve this is to wire in a 12-V photo switch that closes at low light, turning the trap on at dusk, and then opens the circuit in light, turning the trap off at dawn. Another option would be to use a 12-V programmable timer switch. This type of switch can be programmed for several on-off operations in a 24-h period. For any type of motorized configuration, the circuit should contain an in-line fuse to protect the motor should debris cause the drum to jam. A 10-A thermal fuse should be wired between the motor or photo switch and the battery pack.

Use of a motor to provide driving force to the drum also permits deployment of a rotary screw trap in tidal reaches of a stream, where gradient is low and streamflows are generally inadequate to drive the trap drum. In this circumstance, motorizing the drum during the tidal flood is inefficient because fish are unlikely to migrate downstream against the current. A motorized trap deployed in a tidal channel can be controlled by installing a float switch in the motor circuit that turns the drum on during ebb and low tide and off during flood and high tide. When deployed in a tidal channel, it is usually necessary to construct a plywood or screen weir in front of the trap to focus flow and migrating fish towards the trap drum. This weir provides a location to mount a float switch. The base of the switch is attached to either the weir or a freestanding mount next to the trap. A pole is mounted horizontally to the switch base with a pivot bolt near one end of the pole. A foam crab-pot buoy is mounted to the pole at the end farthest from the pivot bolt, and a copper contact plate is mounted to the end closest to the pivot bolt. A second copper contact plate is attached to the base, forming a switch. The base is mounted such that when the pole is near horizontal, the switch plates are in contact, completing the circuit and permitting the drum to be powered. When the flood tide lifts the crab float and pole, the circuit breaks and the drum stops.

The wires leading to the switch need to be long enough to remain slack during the highest spring-series tides. A float switch, in conjunction with a 12-V photo switch, limits hours of trap operation to ebb and low tide only at night and makes most efficient use of batteries.

Fish handling

Traps are checked as often as necessary to provide for the safe holding and handling of captured fish and to maintain the efficient operation of the gear. At a minimum, the trap should be checked at dawn and at dusk to evaluate day versus night capture rates. Where subyearlings are captured, holding them in close proximity to larger piscivorous fish such as cutthroat smolts and sculpins increases the likelihood that catch counts on the subyearlings will be biased low due to live-box predation.

Some investigators have placed tree branches or other debris in the live well to provide a refuge for small fish. Care must be taken when using this approach since the debris may cause descaling as turbulence in the live well increases. The safest approach for maintaining fish health and minimizing predation is to frequently check and remove fish from the trap.

Creating a workstation for employees to collect data on the catch will alleviate stress, both on the fish and the sampler. The workstation can be built on the pontoon deck of larger traps (see Figure 7) or built to stand in the stream or along the shoreline when processing fish from small traps (see Figure 17). Although this equipment will vary depending on the site and trap design, constructing a sampling table with adjustable legs and racks to hold screened buckets will often allow the sampler to process the catch while remaining in the stream. This will reduce the need for maintaining adequate oxygen and water temperature for the fish as they are being processed. Workstations mounted on larger traps can be supplied with water from generator or battery-powered sump pumps. Since capture and handling often occur at night, workstations should be provided with artificial lighting.

FIGURE 17. — A workstation at a trapping site in an Oregon coastal stream is used to process screw trap catches and record data.

Generally, all fish are anesthetized prior to processing (e.g., marking, mark recovery, length/weight measurement). Tricaine Methanesulfonate (MS222), CO_2, and clove oil are the most common anesthetics used. When anesthetizing fish, it is important to remember that water temperature, anesthetic concentration, and fish density and size can all increase the stress load on the fish. Care needs to be taken so that no more fish are anesthetized at one time than can be safely processed. This will vary with the experience of the sampler and the amount of information being collected. Fewer fish should be anesthetized at one time as water temperature increases, since higher temperatures generally increase the effectiveness of the anesthetic as well as handling stress on the fish. Anesthetic water should be regularly changed to keep it cool and well oxygenated. Once all fish are processed, the recaptured marked fish and fish not needed for trap efficiency experiments are released far enough downstream to minimize the potential for recapture.

A convenient approach for anesthetizing fish with MS222 involves employing a premixed concentrated solution. For example, in a dark plastic bottle, mix 5 g of powdered MS222 in 500 mL of water. The bottles we use are 500 mL-squeeze-and-pour dispenser bottles. These bottles incorporate a graduated cup on the cap to measure out the concentrated anesthesia. To mix anesthesia for field use, combine 25 mL solution from the bottle with 5 L of river water (50-mg/L MS222) in a dishpan (premarked at 5 L). We have found that this concentration does not fully anesthetize the juvenile fish but partially sedates them and enables rapidly mixing anesthetic to consistent concentrations.

Data Handling, Analysis, and Reporting

Trap efficiency testing

Procedures

Trap efficiency is measured by the rate that marked fish released above the trap are recaptured. A variety of techniques can be used to mark fish for trap efficiency testing. Probably the simplest approach is to anesthetize the fish and apply a partial fish clip (e.g., upper or lower caudal lobe, posterior/anterior anal lobe, various caudal punches). Other approaches include dyeing, freeze branding, panjet marking, and tagging. Fish should be fully recovered from the anesthetic and handling prior to release.

Mark groups can be composed of hatchery fish or fish that have been previously captured in the trap. Using hatchery fish complicates the study since one must assume their probability of capture is the same as for naturally reared fish. Groups of marked fish representing each targeted species and age-/size-class are released upstream of the trap over the period of their migration. The release point selected should be far enough upstream to provide for a similar distribution across the channel compared to unmarked fish (at least 2 pool/riffle sequences), but not so far upstream that predation on marked fish is substantial. Each group of marked fish should be released evenly across the river to avoid biasing their lateral distribution. To reduce predation subsequent to recapture, marked fish should be released during the time strata that they migrate.

In small streams, migration primarily occurs at night and smolt traps are typically checked in the morning. Instead of making additional trips back to the trap at night to release mark groups held during the day, some researchers have used a timer-activated, self-releasing live box to release the marked fish automatically at dusk (Miller et al. 2000). This device consists of three recovery chambers. Dark-colored 5-gal buckets work well for fish less than 120 mm. When larger steelhead and cutthroat trout migrants are being held for trap efficiency tests, fabricating larger recovery chambers from perforated plate is more appropriate. The recovery chambers are suspended between two small floating pontoons. A spring-wound timer is connected to a 12-V automobile door lock actuator. At the appropriate time, the timer energizes the door lock actuator, which pulls a pin to release the recovery chambers. The recovery chambers pivot on a pipe inserted through holes in their base, turn upside down, and release the fish. To avoid predation, fish are separated by size into the three recovery chambers, which are set to release the fish at different time intervals. In trapping small streams, marked fish are typically released at least 2 pool/riffle units, but no more than 300 m, above the trap.

Factors affecting trapping efficiency

Flow is the dominant factor affecting downstream migrant trapping operations in any system. It affects trapping efficiency and migration rates since high flows often stimulate fish to migrate; therefore, minimal trap efficiencies may occur at the same time that peak flow events are causing migration rates to increase.

Visibility, fish size, and noise are other factors that affect trapping efficiency. Larger downstream migrants, especially steelhead and cutthroat trout, may be able to avoid capture when the trap is visible by swimming around the trap or back out the mouth of the trap, especially when velocities are low. Some portion of ocean-type chinook and chum salmon may rear upstream for a short period of time and grow prior to migration; therefore, efficiency for a species may change over time. Behavior may also be important. Some species may primarily migrate down the thalweg of the channel, whereas a higher proportion of others may use the channel margins. Noise created by the trap causes an avoidance response. This is mitigated through proper site selection, as previously discussed.

Of course, human actions also affect trap efficiency. On larger streams and rivers, researchers may be forced to move the trap away from the thalweg during high-flow events to avoid debris entrainment and subsequent trap damage as well as for safety concerns. On small streams, temporary hydraulic modifications (e.g., screen panels) are often erected over the course of the season to direct flow to the trap. This is often necessary to keep a trap turning, and it obviously influences the trap efficiency.

These factors indicate that efficiency tests should, if possible, be conducted over the entire migration period, over a range of flows and turbidity levels, and for each species whose production is to be estimated. Human actions such as trap repositioning and installation of hydraulic modifications call for stratification of tra-efficiency tests. If possible, treatments should be done consistently each time to minimize the number of efficiency strata created.

Selection of calibration test fish

Fish marked and released for trap efficiency trials should be representative of the entire target population. Care should be taken to minimize bias relative to such factors as size and origin. For example, although hatchery fish used for calibration may be of the same species and age as their wild counterparts, they may be larger or behave differently and consequently may be captured at different rates than wild fish. Rates of in-stream predation and residualism are likely higher for hatchery fish. For these reasons, trap efficiency estimates resulting from release groups using hatchery fish may be biased low.

The importance of expanding trap counts by appropriate measures of trap efficiency is illustrated for a small Oregon coastal stream in tables 2 and 3. In the examples shown, inferences of abundance would be incorrect if trap efficiency estimates based on species and size-class characteristics had not been used to adjust the estimate of downstream migrants. These effects would be greatly magnified in larger streams and rivers where fewer than 10% of the downstream migrants are typically captured.

TABLE 2. — Comparison of unadjusted trap catches and adjusted estimates of total migrants for three species of salmonids in Tenmile Creek, Oregon, Spring 1993.

Species	Catch	Seasonal trap efficiency	Migration
Coho (age 1+)	2,429	48%	5,050
Steelhead (>120 mm)	1,298	17%	7,591
Chinook (fry)	242	63%	387

TABLE 3. — Comparison of unadjusted trap catches and adjusted estimates of total migrants for three size groups of juvenile steelhead in Tenmile Creek, Oregon, Spring 1993.

Length strata	Catch	Seasonal trap efficiency	Migration
60–89 mm	952	26%	3,719
90–119 mm	546	22%	2,516
120–200 mm	637	13%	4,977

Estimating total migration

Estimating migration for any period, whether a short time interval or an entire season, involves mark–recapture experimentation that requires a catch and an estimate of trap efficiency. A number of approaches are available to estimate population size by use of mark–recapture techniques. The simplest approach is a Petersen equation written as follows:

$$N_i = \frac{\hat{n}_i M_i}{m_i} = n_i \hat{e}_i^{-1} \qquad \text{(eq 1)}$$

where

$$\hat{e}_i = \frac{m_i}{M_i} \qquad \text{(eq 2)}$$

and where

$\hat{N}_i$ = Estimated number of downstream migrants during period *i*
M_i = Number of fish marked and released during period *i*

n_i = Number of fish captured during period i
m_i = Number of marked fish captured during period i
$\hat{e}_i$ = Estimated trap efficiency during period i

The six basic assumptions for the Petersen estimate are:

1) The population is closed;
2) All fish have an equal probability of capture in the first period;
3) Marking does not affect catchability;
4) All fish (marked and unmarked) have an equal probability of being caught in the second sample;
5) The fish do not lose their marks; and
6) All recovered marks are reported.

Seber (1982) discusses these assumptions in detail and provides tests for validating the assumptions. Results from these tests will help determine the best approach for data analysis. In many cases, the most appropriate approach will not become apparent until after all the fieldwork has been completed and the data examined. The biologist always needs to temper his/her decision on the approach with knowledge of the behavior of the targeted species. A plausible rationale should be developed to explain and support these decisions. Four general approaches are outlined in this section.

1. Stratified mark–recovery approaches

This approach estimates migration over a season by stratifying the mark and recovery data into a number of discreet time periods. Time strata can be a day, a week, or longer in some cases. Three conditions are described:

a. Two partial capture traps are used: an upstream trap for marking and a downstream trap for recovery of marked migrants;
b. One total capture (upstream) trap for marking and one partial capture (downstream) trap for recovery of marked migrants are used; and
c. A single partial capture trap is used where a portion of the catch is marked and released upstream for efficiency trials or marked hatchery fish are used for the efficiency trials.

1a. Use of two partial capture traps

This approach employs an upstream partial capture trap such as an inclined plane screen trap, screw trap, or fyke trap to capture and mark or tag downstream migrants and a downstream partial capture (inclined plane screen or screw) trap to recover the marked or tagged fish. Migration over the discreet period,$\hat{N}_i$, is estimated using the Petersen equation (equation 1). Chapman (1951) found this estimate to be biased and suggested the following modification:

$$\hat{N}_i = \frac{(M_i + 1)(n_i + 1)}{(m_i + 1)} - 1 \qquad \text{(eq 3)}$$

This estimate is exactly unbiased when ($Mi + ni$) $\geq \hat{N}_i$, and approximately unbiased when ($Mi + ni$) $< \hat{N}_i$. An unbiased estimate of the variance, , was developed by Seber (1970):

$$V(\hat{N}_i) = \frac{(M_i + 1)(n_i + 1)(M_i - m_i)(n_i - m_i)}{(m_i + 1)^2(m_i + 2)} \qquad \text{(eq 4)}$$

Regular discreet time periods (e.g., 1, 2, 3 . . . 7 days) should be established a priori. The length of the time period is dictated by assumption 2 on page 254 (constant probability of capture in the first sample). Since trap efficiency changes with stream discharge and other factors, it becomes difficult to meet this assumption with longer time periods. Marks used in efficiency trials (e.g., partial fin clip) must be changed between time periods. Although most recaptures typically occur soon after release, some recaptures may occur along with those from subsequent mark groups. Because strata are nonoverlapping and independent, estimated total juvenile production, , is calculated by the sum of *n* migration period estimates as follows:

$$\hat{N} = \sum_{i=1}^{n} \hat{N}_i \qquad \text{(eq 5)}$$

with associated variance

$$V(\hat{N}) = \sum_{i=1}^{n} V(\hat{N}_i) \qquad \text{(eq 6)}$$

The 95% confidence interval (CI) is then estimated using

$$\hat{N} \pm 1.96\sqrt{V(\hat{N})} \qquad \text{(eq 7)}$$

1b. Use of a total capture trap and a partial capture trap

Assumption 2 (constant probability of capture in the first [upstream] trap), can be difficult to meet as streamflow conditions change using a partial capture trap; however, effect of streamflow on trap efficiency is negated if a total capture trap (e.g., smolt fence) is used as the upstream trap. In this case, one smolt fence (or more) is installed in tributaries upstream of the scoop or screw trap. Downstream migrants captured in the tributary traps are marked and released downstream, where a portion are recovered in the scoop or screw trap. The estimated migration and variance are calculated using equations 3 and 4, respectively. Using this approach, temporal stratification of the mark–recapture data is not required. A single time period (i.e., the entire out-migration period) can be used, since marking rates at the upstream trap integrate the effects of changing environmental conditions and migration timing.

This approach is most useful where the target species originates in streams where a total capture trap can be used (e.g., coho salmon). Technically, assumption 2 is still not met, since every fish will not have an equal chance of being marked (not all tributaries upstream of the partial capture trap will be trapped); however, if one assumes that the migration timing from the trapped tributaries is the same as for the untrapped tributaries, then a constant proportion of the total population is marked throughout the migration period and the desired outcome addressed by assumption 2 is achieved.

1c. Use of a single partial capture trap

In most cases, researchers will use a single trap and will conduct trap efficiency experiments by marking and transporting/releasing part of the catch or hatchery fish upstream of the trap. In this case, the marked fish captured in the trap must not be included in the population estimate since they were either counted as unmarked fish before being marked or were of hatchery origin and not part of the migration estimate. Carlson et al. (1998) advocate the following in lieu of equations 3 and 4:

$$\hat{U}_i = \frac{u_i(M_i + 1)}{m_i + 1} \qquad \text{(eq 8)}$$

$$V(\hat{U}_i) = \frac{(M_i + 1)(u_i + m_i + 1)(M_i - m_i)u_i}{(m_i + 1)^2(m_i + 2)} \qquad \text{(eq 9)}$$

where

U_i = Number of unmarked fish migrating during discreet period i
u_i = Number of unmarked fish captured during discreet period i

Total juvenile production$\hat{U}$ and associated variance $V(\hat{U}_i)$ are estimated by Equations 5 and 6, respectively, substituting$\hat{U}$,$\hat{U}_i$, $V(\hat{U})$, and $V(\hat{U}_i)$, for$\hat{N}$,$\hat{N}_i$, $V(\hat{N})$, and $V(\hat{N}i)$ in the equations. The 95% CI is estimated by

$$\hat{U} \pm 1.96\sqrt{V(\hat{U})} \qquad \text{(eq 10)}$$

Alternatively, variance and confidence intervals can be estimated using bootstrap methodology (Thedinga et al. 1994).

Other considerations

Stratified mark–recapture approaches assume that each estimate of trap efficiency is an accurate measure of the proportion of downstream migrants caught in the trap. Since each test actually represents a single measure, it would be expected to include error. Assuming that error is normally distributed with zero mean, this approach argues for estimating discrete periods of short duration (e.g., 1 d) since the expected error over many samples should approach zero. Conversely, small sample sizes (mi) can greatly bias trap efficiency estimates, which argues for marking more fish, if available, or for strata of longer duration so that larger numbers of fish can be marked and recaptured. Researchers often balance these opposing elements by setting the duration of strata from 3 d to a week, depending on trap efficiency and the number of fish available for marking. A rule of thumb from mark–recapture studies is that at least five recaptures should occur for each stratum to minimize bias (Schwarz and Taylor 1998).

During some strata, fewer than five marked fish may be recovered. On small streams, this is most likely early and late in the migration period, when few fish are captured and marked; however, this can also happen during other times when trap efficiency is low. To avoid biasing the estimate, adjacent strata can be pooled to achieve at least five recaptures. Yet this approach should not be used when dissimilar recapture rates are likely to have occurred between the adjacent strata (e.g., dissimilar streamflows). If pooling is not appropriate, the researcher should consider using the estimated trap efficiency for the stratum and accepting the bias or dropping the efficiency test and using another approach for estimating efficiency for the stratum (e.g., mean of all tests, alternative stratification [see approach 3 on page 261]). Every effort should be made to avoid the situation of low sample size in the stratum.

2. Modeling trap efficiency

This approach estimates trap efficiency from an independent variable, typically streamflow. A series of trap efficiency tests are conducted over a range of flows and analyzed to determine if a significant relationship can be established (see Figure 18). When using regression analysis, it has been suggested that the observed F statistic should exceed the chosen test statistic by a factor of four or more for the relationship to be considered of value for predictive purposes (Draper and Smith 1998). Furthermore, a wide range of flows reflecting conditions across the entire season would maximize precision.

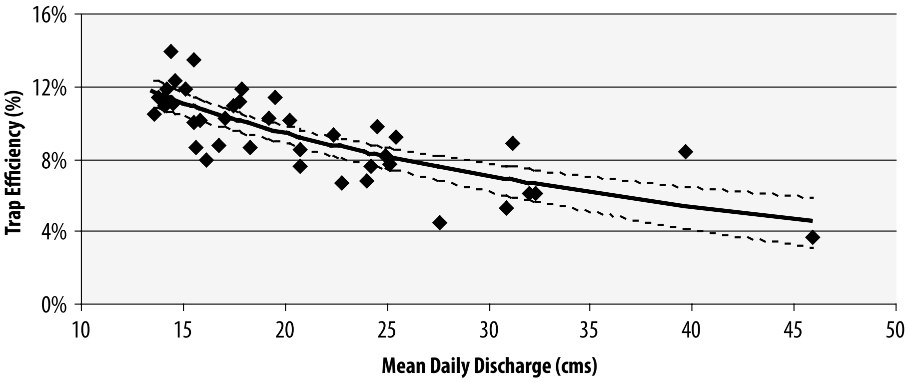

FIGURE 18. — Age-0 sockeye trap efficiency and 95% confidence intervals as a function of stream discharge. (Cedar River, Washington.)

Using this approach, migration on day *i* is calculated using equation 1, and its variance, $V(N_i)$, is estimated by;

$$V(\hat{N}_i) = V(\hat{e}_i)\left(\frac{\hat{n}_i}{\hat{e}_i^2}\right)^2 + \frac{Var(\hat{n}_i)}{\hat{e}_i^2} \qquad \text{(eq 11)}$$

If linear regression is used to estimate trap efficiency, the variance is estimated as follows:

$$V(\hat{e}_i) = MSE\left(1 + \frac{1}{n} + \frac{(X_i - \bar{X})^2}{\sum_{i=1}^{k}(X_i - \bar{X})^2}\right) \qquad \text{(eq 12)}$$

where:

$\hat{e}_i$ = The trap efficiency predicted on day *i* by the regression equation, $f(X_i)$
MSE = The mean square error of the regression
k = The number of trap efficiency tests used in the regression
X_i = The independent variable on day *i*

If catch n_i is not estimated, the second part of equation 11 reduces to zero and is not part of the calculation.

Estimating catch

Unlike the previous equations, equation 11 introduces variance in the unmarked catch estimate. Up to this point, we have treated catch as a count, but there are usually times during the season when the trap is not operated (e.g., debris stops the trap). Catch must be estimated during these periods—with the exception that approaches 1a, 1b, and 4 (see page 259–262) integrate unfished periods into the population estimate so that estimates of missed catch are not needed. Catch expansion may or may not be required using approach 1c, depending on whether the efficiency trials encompass nonfishing periods.

Generally catch can be estimated by interpolating catch rates from the previous and following fishing periods. Complications occur, however, when the unfished period extends through periods of rapidly changing catch rates (e.g., from night to day periods). When this occurs, the researcher may need to evaluate the magnitude of the catch rate change in the interpolation. Catch may also need to be extrapolated to account for migration before and/or after the period of trap operation. The variance of these catch estimates can have a substantial effect on the variance of the population estimate when estimated missed catches are high.

3. Stratifying trap efficiency

Like approach 2, this approach predicts trap efficiency using an independent variable or condition class. In this case, efficiencies are fairly constant over some range of the independent variable or condition class. As the independent variable passes some threshold or another condition class occurs, efficiencies change or "step" to a new level. For example, if the trap is placed in a U-shaped channel adjacent to a wide gravel bar, trap efficiencies may be at one level when flows are contained in the channel and at another when higher discharge causes a substantial portion of the flow to spread out across the gravel bar. Fish size may change over the trapping season, causing changes in trap efficiency by time strata. Turbidity levels may cause changes in efficiencies as well. In some locations, fish are better able to avoid traps during day fishing periods. In this case, efficiency data would be stratified by diel period (see Figure 19).

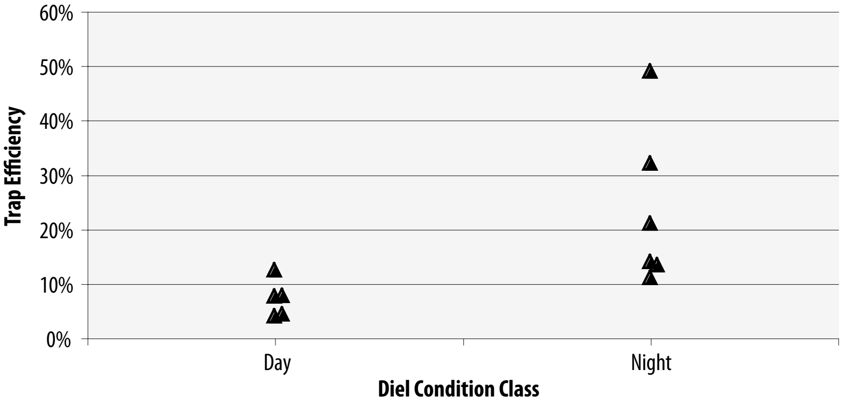

FIGURE 19. — Range and mean trap efficiencies stratified by diel fishing periods (Issaquah Creek, Washington)

Another cause for stratification is when human actions over the course of the season affect efficiency. Obvious examples include adding screen panels upstream of the trap to increase flow and direct more fish into the trap, and repositioning the trap, whether to increase or reduce catch rates or avoid damage during freshets.

Mean trap efficiency is calculated for each stratum, $\bar{e}_j$, and the means are tested for significant differences. The investigator may consider pooling strata where the means are not significantly different. Migration is estimated for discreet periods, when the independent variable is within a defined stratum, $\hat{N}_j$, by dividing the sum of the catch, n_j, or estimated catch, $\hat{n}_j$, by the mean trap efficiency for the stratum, under the assumption of homogeneous trap efficiencies. The variance of the estimate is estimated using the delta method (Goodman 1960) by

$$Var(\hat{N}_j) = \hat{N}^2_j \left(\frac{Var(\bar{e}_j)}{\bar{e}_j^2} + \frac{Var(\hat{n}_j)}{\hat{n}_j^2} \right) \qquad \text{(eq 13)}$$

4. Back-calculating production

Using this approach, fish captured in the scoop or screw trap are marked or tagged and released downstream. Recapture occurs at another life stage, and a Petersen estimate of production is made. Typically, recapture occurs when the returning adults are sampled in a fishery or upon the spawning grounds. The term "back-calculating production" was coined as a result of the length of time between trapping and when the migration estimate was made (Seiler et al. 1994).

Production and variance are estimated using equations 3 and 4, respectively. The analysis is similar to approach 1b, since the data are not stratified. This approach is most useful where trap efficiency estimates are difficult to make. This method is more easily applied where nearly the entire cohort returns in a single year (e.g., coho). Age sampling would be required for this approach to work for species that return to spawn in multiple year-classes.

Other tools

This section focuses on the basic analysis of downstream migrant mark–recapture data for the estimation of smolt abundance using the Petersen equation and its derivations. Software is readily available on the Internet for analyzing stratified mark–recapture data. For example, Bjorkstedt (2005) describes the use of DARR 2.0, a software application that develops smolt abundance estimates using the Darroch (1961)-stratified Petersen estimator discussed in approach 1. This document and software are from the NOAA Fisheries Southwest Regional Fisheries Science Center–Santa Cruz Web site, <http://santacruz.nmfs.noaa.gov/publications/date_2000.php>.

Another application available online is the Stratified Population Analysis System (SPAS) described by Arnason et al. (1996). This program can analyze mark–recapture data using the Darroch moment estimate (Chapman and Junge 1956), a maximum likelihood method for the Darroch estimate (Plante 1990), the Schaefer estimate (Schaefer 1951; Warren and Dempson 1995), and the pooled Petersen estimate described by Seber (1982). It also includes a simulation capability that can be used for planning experiments and assessing the properties of the estimates. Arnason et al. (1996) and SPAS are available from the University of Manitoba Population Analysis Software Group Web site, <www.cs.umanitoba.ca/~popan>.

Additional information on the analysis of smolt trapping data is provided in Schwarz and Dempson (1994), MacDonald and Smith (1980), Mäntyniemi and Romankkaniemi (2002), Carlson et al. (1998), and Thedinga et al. (1994).

Personnel Requirements and Training

A successful trapping operation requires a team of professional and technical staff that is dedicated to the success of the project. This statement is easily set aside since, after all, "Aren't we all dedicated to the project's success?" Nevertheless, when put to the test, many projects have failed to develop precise estimates of smolt production as a result of poor decision making or lack of tenacity during critical periods in the trapping season. Spring storm events increase river discharge and debris loads, making trap operation more difficult, dangerous, and time consuming. Like river discharge, catch rates can also steeply increase and decrease over a relatively short period of time. Trap operation during these periods often requires working extremely long and physically taxing periods.

The number of personnel required to operate a trap over a smolt outmigration period depends on the objectives of the study and the size of the river. On small systems where only an index of production (e.g., catch-per-unit-effort) is desired, a field crew of one may be all that is necessary. When operating a trap continuously or counting large numbers of fish, a larger crew is required. Three people make up a good-sized crew during the peak of the migration, when the workload is high. Each person can be put on an alternating 6-d-on/3-d-off schedule so that there are always two people available to work the gear. Later in the season when fewer fish migrate and flows subside, the crew can be reduced to two.

Crew

The crew is responsible for day-to-day trap operations, deciding when and how often to check the trap and process the catch, record data, and evaluate/maintain the gear. The crew also conducts trap-efficiency tests to measure the proportion of downstream migrants captured.

Project Leader

The project leader, typically a fish biologist, supervises the field crew. The project leader oversees the project, schedules the crew, and maintains communication with crew members over the trapping season. The project leader may also help with the fieldwork as needed.

Protocols

The protocols discussed in this section, although not exhaustive, should provide researchers with a basic understanding of how production is assessed using floating inclined plane screen traps or rotary screw traps; however, no matter how complete the protocols are, much of the knowledge for successfully operating this gear can only be gained through experience. Inclined plane screen traps and screw traps are operated by nearly all agencies that manage anadromous salmonid populations. Project leaders are well advised to receive mentoring from experienced investigators or gain experience from successful programs before starting projects.

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