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An Anchoring System For Fish Habitat Structures: Field Technique, Evaluation, and Application

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Abstract

Steel cable can be used to bind rocks and logs together to construct fish habitat structures in streams. Cables must be securely anchored if structures are to withstand floods. This paper describes a way to anchor cables into bedrock or ballast boulders. Anchor tensile strength ranged from 7,500 to 36,500 pounds and was related to type of resin and embedment depth. After a major flood, we examined 127 instream structures that had been secured to rock with this technique; only 0.02 percent of the 300 individual anchor points had pulled out. The resin was toxic to rainbow trout *{Salmo gairdneri)* fry in bioassays, but exposure to the toxicant is minimal under field conditions.

Keywords: Fish habitat improvement, polyester resin, fish habitat structures.

Introduction

Many "stream improvement" efforts along the west coast have failed because instream structures did not withstand severe freshet conditions (Hall and Baker 1982). Congress has been steadily increasing funding for restoration and enhancement of streams that support anadromous fish. The dramatic increase of instream structure work prompted Frissell and Nawa (in press) to examine the fate of 150 stream habitat structures constructed between 1981 and 1985 in 14 streams of southwest Oregon and southwest Washington. They report that anchor failure is the reason for the loss of many instream structures.

An effective, yet relatively simple system of anchoring stream habitat structures was needed. The objective of this study was to examine the effectiveness and possible applications of bonding steel cable into rock with polyester resin.

The Technique

Instream structures such as logs, rootwads, and boulders were anchored with cable secured with cartridge-dispensed polyester resin. Galvanized cable was glued directly into rock. Holes 10 to 12 inches (25.4 to 30.5 cm) deep were drilled into bedrock or boulders with an electric or gasoline-powered, roto-hammer drill. Polyester resin was injected into the hole, and cable was inserted. This system eliminated the need to prepare concrete and use eyebolts with cable clamps. This anchoring technique

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saves time, allows for innovative structure design, and provides superior strength. Either bedrock or boulders are needed as an anchoring substrate. Hauling ballast boulders to the work site may be necessary if neither exposed bedrock nor native boulders are present.

Polyester resin is designed to bond with only a thin layer of resin. The drill bit must be no more than 1/16 inch (1.6 mm) larger than the diameter of the cable. We tested the bond of a 1/2-inch (1.2-cm) cable in a 3/4-inch (1.9-cm) hole, and the bond failed at less than 200 pounds (90.7 kg) of pull. This anchoring system will not work if the anchor holes are more than 1/16 inch (1.6 mm) larger than the cable diameter.

The use of small-diameter anchor holes simplifies anchoring of stream structures because a lightweight, 16-pound (7.3-kg) roto-hammer rock drill can be used. A light drill allows the operator to drill at a variety of angles and in restricted spaces where a larger Pionjar-type[1] rock drill (57 to 80 pound [26 to 36 kg]) would not be appropriate. In addition, small-diameter holes can be drilled quickly; on average, less than 1.5 minutes are needed to drill an anchor hole in igneous bedrock.

Roto-hammer drills can be used in the water, but the water depth that drilling can be accomplished in is limited by the length of the drill bit. The drill bits are available up to 21 inches (53 cm) long for some models. If an electric drill is used, a portable generator is needed along with extra safety precautions. The generator should be wired with a ground fault interrupter, extension cord connections must be kept dry, and waders with traction shoes are recommended. A gasoline-powered drill is recommended over an electric drill because it is safer and more portable; the need for a generator is eliminated.

The site and cable must be prepared before any gluing is done. The drill holes must be thoroughly cleaned of all rock powder-a by-product of drilling. The resin will not properly adhere to the rock if the hole is inadequately cleaned. Cleaning is done by pouring water into the hole while plunging it with a circular nylon brush. The hole is clean when the water plunges out clear and free of sediment. Underwater holes are simply plunged with the brush. The cable must be cut cleanly so that the end can be inserted into the tight fitting rock hole. We used a sharp, hammer-type cable cutter and replaced the blade as soon as it was dull. We wrapped the cable with duct tape before cutting to help make a neat cut. The cable surface to be bonded should be free of dirt and grease. Most galvanized cable is not lubricated and will not need cleaning. Nongalvanized cable is oiled, and the oil may cause bonding problems unless the cable is thoroughly cleaned. Acetone can be used to clean cable.

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Two brands of cartridge-dispensed polyester resin were tested: Hilti C-10 and Upat Molly Parafast. The resins can be applied either in or out of water with a caulking gun or similar device, following the manufacturers directions for the particular resin chosen. We fitted a piece of plastic tubing over the nozzle of the resin cartridge so that the resin would enter the hole from the bottom up. The hole must be filled with resin so that when the cable is inserted, a small amount of excess resin will ooze out the top of the hole. Once the cable is inserted in the hole, it should not be disturbed until the resin has cured. Sometimes the cable must be held in the hole until the resin begins to set (a few minutes). This prevents the cable from pulling slightly up from the hole. Chemical-resistant gloves (latex-nitrile) should be worn to prevent skin contact with the resin.

Evaluation

Tests were conducted to determine the relative tensile strength of 1/2-inch (1.27-cm) galvanized steel cable bonded in bedrock (metamorphic greenstone) with two differ ent brands of polyester resin: Hilti C-10 and Upat Molly Parafast. A calibrated, 30-ton (27,210-kg) Simplex hydraulic pump with a ram (mounted on a steel platform) was used to apply a load to the bonded cables. All test anchors were installed underwater within a 50-foot (15-m), homogeneous bedrock reach of Calf Creek, a tributary to the North Umpqua River in Oregon. The test anchors were installed at least 7 days before pull-out testing. Most holes were thoroughly cleaned to eliminate rock powder, and all but two of the test cables were cleaned with acetone to eliminate surface oil. Two cables were installed in partially cleaned holes. These holes were cleaned for only half of the time it took to thoroughly clean the holes for other tests.

Anchor integrity was also tested under field conditions. Hilti C-10 resin was used to anchor 127 instream habitat structures during summer 1985. All the structures were examined the following year (after a winter flood) to determine how many anchors failed.

A toxicity test was conducted in the laboratory at Oregon State University on hatchery rainbow trout *{Salmo gairderni)* fry exposed to Hilti C-10 resin. Seven fry (2 weeks after yolk sac absorption) were held for 17 days in each of six individual 2-quart (1.89-L) exposure chambers. A steady flow of fresh, chilled 52 °F (11 °C), dechlorinated water passed through three chambers at 0.01 ft^3/s (320 mL/s) and three chambers at 0.005 ft^3/s (160 mL/s). The fry were acclimated in the chambers for 3 days. Then, 0.5 oz (14.2 g) of polyester resin was dispensed directly into four chambers (two at each flow rate) with the remaining two serving as controls. The fry were fed daily and checked for mortality and abnormal behavior.

Results and Discussion

Pull-Out Tests

Pull-out tests showed that resin type, embedment depth, and hole cleaning affected bonding strength (fig. 1). Cables installed with Parafast resin generally withstood greater loads than those installed with Hilti resin. Maximum bond strength of Parafast was determined for only two of the eight test anchors because the cable broke rather. than the bond on six parafast anchors. At comparable embedment depths, Hilti bonds generally broke before the cable did. Cables bonded in shallow holes failed under substantially lower loads than those embedded deeper. Anchors installed in improperly cleaned holes failed under much lower loads than comparable anchors installed in thoroughly cleaned holes. Based on these tests, we suggest embedment

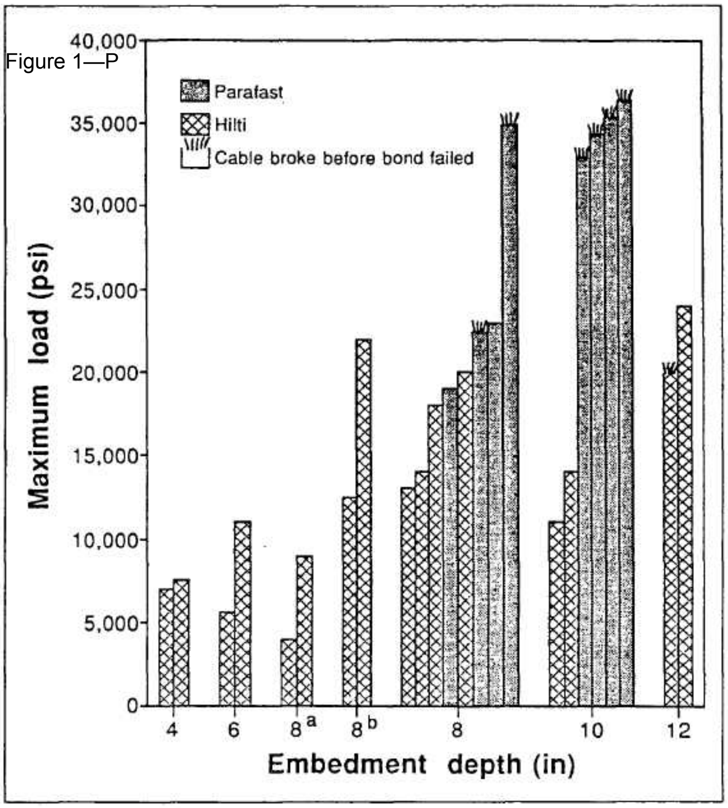

Figure 1--pull-out tests for 1/2-inch (1.3-cm) galvanized cable bonded in igneous bedrock with polyester resin, Calf Creek, Douglas County, Oregon. The maximum loads are shown in pounds per square inch. Cable embedded in partial ly cleaned anchor holes is shown in 8a. Cable that was not dipped in acetone is shown in 8b.

of 10 to 12 inches (25.4-30.5 cm) for Hilti C-10 resin and 8 to 10 inches (20.3-25.4 cm) for Molly Parafast resin. The bond and the cable ideally should have equal strength to avoid a weak link and to make the best use of the products.

Similar pull-out tests were conducted by the Pittsburgh Testing Laboratory (1969) on the tensile strength of 1- by 12-inch-long (2.54- by 30.5-cm) wedge anchors set in aggregrate concrete. The anchors sustained average loads of 18,300 pounds (830 kg). The average load sustained by polyester resin in our pull-out tests was generally greater than those loads sustained using concrete. Also, the cost of anchoring with resin is less than anchoring with concrete. Wedge anchors or eyebolts of adequate strength cost about $13.00 each, and polyester resin costs about $3.00 per anchor hole. With concrete, cable clamps are necessary, adding to installation time and expense. A much larger rock drill is needed to drill large-diameter holes for concrete; portability and flexibility are lost.

The long-term holding strength of Parafast resin was tested by the Molly Company (Upat Gmbh & Co. 1980). After 18 years, anchors exposed to operational stress and the weather did not lose holding strength.

Field Test

In February 1986, 5 months after the stream habitat structures were anchored, two 5-year flood events occurred within 24 hours. Because of shallow soils, steep topography, and high winter precipitation, these streams typically experience rapid runoff rates with high stream energies. Structures anchored into bedrock or large boulders with Hilti polyester resin on upper Steamboat Creek (order 5) and Calf Creek (order 3) withstood about 7,200 and 1,700 ft^3 s^{-1} mi^{-2} (204 $m^3 5^{-1}$ and 48 $m^3 5"^{1}$), respectively. Six of the anchor points on the 127 structures pulled out of their bedrock or boulder anchors. None was the result of resin failure. The failures appeared to be the result of the ballast rock fracturing under the load.

Toxicity Test

Lethal and sublethal effects were observed when fish were exposed to Hilti C-10 resin. Rainbow trout fry in the chambers with the high flow rate (320 ml7s) had 12 percent mortality. In the low-flow chambers, 40 percent of the fry died during the 17-day exposure test. Generally, the smallest fry had the highest mortality. Sublethal effects were lethargy and loss of appetite. No mortality occurred in the control chambers where the fish maintained their vigor and good appetites. Fry that showed sublethal effects appeared to regain their appetite and vigor during the last 3 days of the experiment.

The toxicity experiment was set up to simulate worst-case field conditions. Investigators have found that fish in the early fry stage are generally more susceptible to toxic substances than during other life history stages (Daye and Garside 1979, Meehan and others 1974). Furthermore, the fry were confined in close proximity (2-quart [1.89-L] chambers) to the resin and held in slow-flowing water. Flow conditions characterized by slow mixing rates and a low dilution potential are found in stream margin habitats used by young salmonids just after emergence.

The results of this toxicity experiment may overstate the risk to juvenile salmonids in field conditions. Because the exposure chambers were so confining, fish were unable to avoid the substance. It is not known, however, if fish can detect the toxicant and avoid it. We anchored our habitat structures in the late summer when fry were larger and apparently less susceptible to the toxic effects of the resin, and the older fry had moved from stream margins to faster water where the dilution potential was higher.

We did not test the relative toxicities of other products in use, such as mortar or epoxy. These may also pose a risk. If the resin is used sparingly, only a small amount will ooze out of the hole and exposure will be minimal.

Applications

Boulders

Boulders within a boulder cluster can be anchored together (fig. 2A). Anchoring boulders together is especially useful where large boulders are not available or if they are too costly to obtain. Cabling boulders together adds to the overall density of a structure and decreases the likelihood of loss during floods. We observed that midchannel boulder clusters not cabled together tended to separate from one another, and the desired lateral scour pools with interstitial cover were lost. Boulder wing deflectors and berms can also be anchored to increase structure integrity and longevity (fig. 2D).

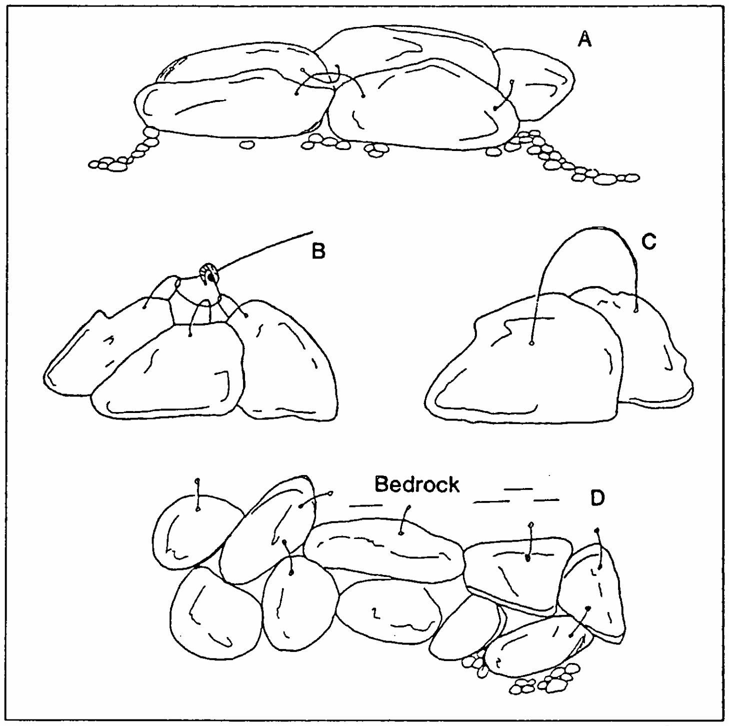

Figure 2—Boulders anchored with polyester resin. A. In
dividual boulders of a cluster are cabled together. B. Handles
are bonded into boulders and set with a choker. C. Boulder
pair are cabled together with extra length of cable so they
can be draped over a log for ballast. D. Boulders in a berm
are cabled together and cabled to bedrock (top view).

"Handles" can be glued into boulders so that the boulders can be moved with heavy equipment (fig. 2B). A handle is made by drilling two holes in a boulder and gluing in a loop of cable. We moved many boulders from roadside dump sites to the stream with this method. A choker can be set through the handles and several boulders can be moved at one time. Also, a pair of boulders glued together with cable can be draped over a log structure as an anchor.

Logs and Root Wads

Logs and root wads can be effectively held in place with proper anchoring (figs. 3 and 4). Proper anchoring is especially critical to counteract the buoyancy of wood and the hydraulic forces on relatively large surface areas. Wooden structures tend to experience hydraulic bouncing at high flows; this is minimized if the logs are tightly anchored. It is essential that fracture-resistant bedrock or ballast boulders are used. Heavily weathered rock with visible fractures or thinly layered sedimentary rock will not provide successful, long-term anchors. If adequate rock is not available on the site, more fracture-resistant rock should be hauled to the site to serve as ballast.

We suggest a chainsaw auger for drilling holes 1 inch (2.54 cm) in diameter through the wood at each anchoring point. The cable is threaded through the wood and glued into bedrock or ballast boulders. Cable can be wrapped around logs and rootwads rather than threaded, but this threading increases the potential of rolling and shifting with later slackening of the cable.

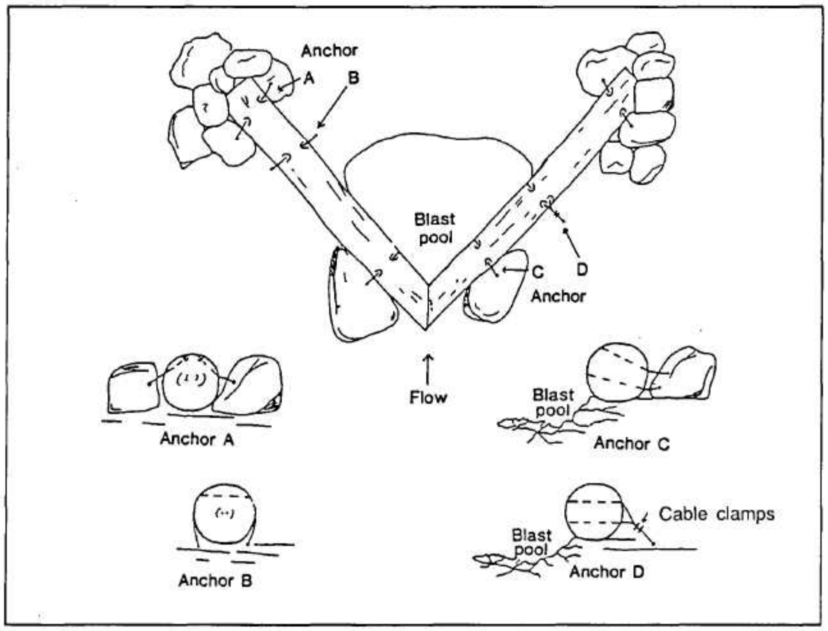

Figure 3—Anchoring an upstream, V-shaped log weir on bedrock with a blast pool located directly downstream. **Anchor A.** Riprap boulders are used as anchor points. **Anchor B.** Solid bedrock is used for anchor points on both sides of the log. **Anchor C. A** ballast boulder is used as an anchor where bedrock is fractured. Parallel holes are augered through the log and the cable is bonded into the boulder in two places. **Anchor D.** An anchor point is installed upstream of the fracture zone. Cable is threaded through parallel auger holes and clamped to itself with a pair of cable clamps.

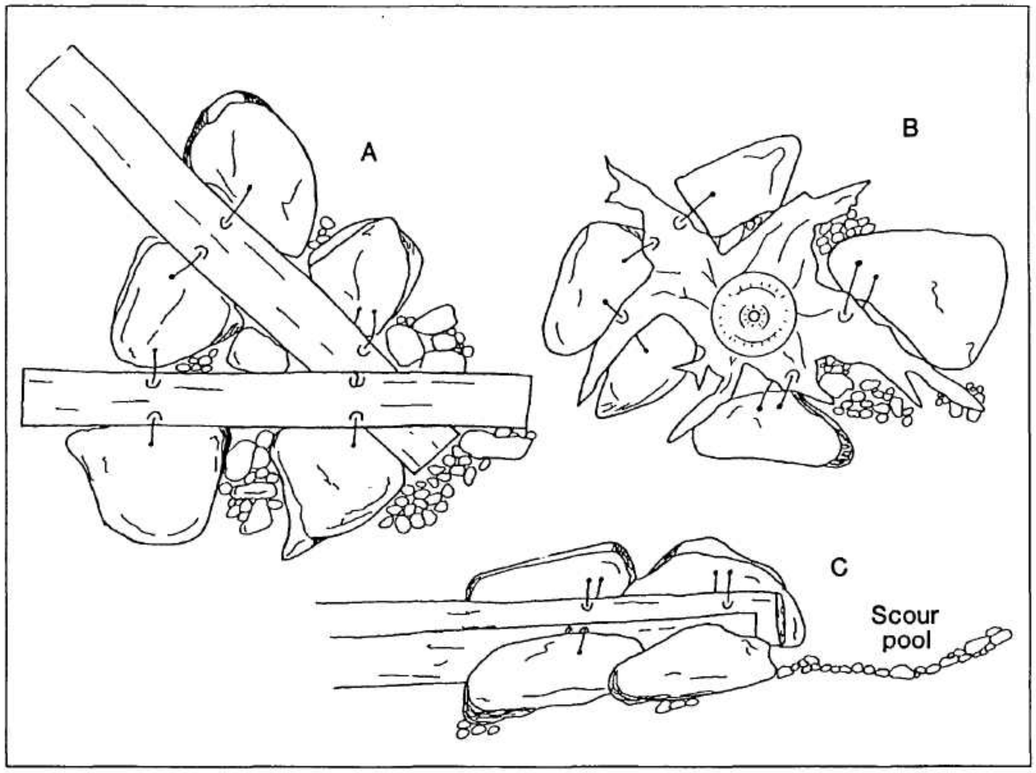

Figure 4—Anchoring stream habitat structures made from wood and boulders. A. Boulder-log cluster (top view). B. Root wad-boulder cluster (top view). C. Angle logs are cabled to a live tree on the bank and to ballast boulders in the stream.

Log weirs (also called sill or digger logs) are conventionally secured by keying the ends into streambanks. This involves excavating bank material with a backhoe. We eliminated excavation and simply placed the log ends so that they butted against the shore. Riprap was placed around the log-shore interface with the largest riprap used as anchor rocks. Additional ballast rocks may also be needed midchannel if fracture-resistant bedrock is not present (fig. 3). This technique should not be used near highly erosive streambanks.

Ballast rocks, used to anchor log structures (such as angle logs and log weirs), should be on either the upstream side or both sides of log structures. If ballast rocks are placed on only the downstream side of logs, a tight anchor cannot be rigged. The log will rise with the stream stage and likely end up perched on top of the ballast boulders.

Generally, each instream log structure needs more than one anchor point (fig. 4). Angle logs are often cabled to a live tree on the bank and to ballast boulders or bedrock on the stream end. Log weirs, or boulder-log combinations placed in or near the thalweg, will experience extreme hydraulic force, so they should have several anchor points. Ballast boulders should have adequate mass to hold the wood in place. Native stream boulders, in place for many years (identified by the presence of moss), can be used as an indicator of the size of boulders needed at that site. Everest and others (1985) caution against relocating native stream boulders to build fish habitat structures. They report that native boulders in Fish Creek were relocated in the stream to build berms and that the relocation of the boulders decreased the total available overwintering habitat for age 1+ steelhead trout. Several anchor points will often be necessary, depending on the degree of stream energy anticipated at the site. Stream drainage area and local channel conditions, such as the degree of channel constriction, gradient, and channel sinuosity, need to be taken into account when the number of individual anchor points needed per structure is determined. Adding extra boulders to a log structure will assure a more secure anchor and provide habitat complexity. An evaluation of structure use during both summer and winter revealed that age 1+ steelhead trout prefer complex structures provided by numerous boulders (Fontaine 1988). Boulders are also important overwintering habitat for both age 0+ and 1+ steelhead trout.

In reaches of solid bedrock, blast pools may be needed on the downstream side of a weir (fig. 3). If so, the pool must be blasted before weir installation to avoid damaging the wood. Anchoring is slightly more complicated around blast pools than in other places. Several feet of fractured bedrock can be expected around the perimeter of a blast pool. Ballast boulders may have to be hauled to the site to serve as anchor points when bedrock cannot be used.

In Perspective

The anchoring system we devised has worked well in stable and well-defined, volcanic, Cascade Range streams. This technique is not a standard solution to all problems associated with stream habitat manipulation, however. A log weir that is "properly anchored" according to our technique may become buried with bedload and lack the desired scour pool habitat as a result of improper (too close) placement of additional weirs. Or, in an alluvial stream system, a habitat structure may be left high and dry because of a channel or thalweg shift. The anchoring of stream structures is just one critical step in the process of fish habitat enhancement. Successful habitat enhancement begins with investigating the year-round habitat needs of the target fish species and age class. Once the most likely limiting habitat types are determined for specific stream systems, managers must apply a knowledge of natural stream processes to achieve desired habitat changes. The principles of stream dynamics and energy dissipation (Beschta and Platts 1986) must be anticipated and used to help create and maintain stream habitat changes. A thorough job of information gathering and synthesis is a prerequisite for effective habitat enhancement. Extremely valuable insights can be gained empirically by underwater observation of fish-habitat relations and by observing the results of stream hydraulics associated with naturally occurring structural elements, such as logs and boulders.

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Appendix

Checklist of items needed to anchor habitat structures in streams.

- o Roto-hammer rock drill
- o Twerity-one-inch drill bit to fit roto-hammer drill (should have at least two bits on hand)
- o Polyester resin (cartridge dispensed)
- o Latex/nitrile blend gloves to be used when applying resin
- o Tygo.n tubing for extending length of resin outlet

- Two-gallon bucket with spout used for hole cleaning
- Nylon brushes (should have several on hand because they wear out)
- Copper tubing for rigging an extension on nylon brushes
- Galvanized wire rope, 1/2 or 9/16 inch recommended; rope must be clean and free of grease
- Hammer-type cable cutter, with extra blades
- Sledge hammer with soft steel head (prevents flying bits of steel)
- Duct tape to wrap cable
- Chainsaw auger
- Two auger bits; a 30-inch bit for large-diameter wood and a 20-inch bit for other wood
- Gas to run chainsaw auger
- Regular gas for generator, if used
- Two Allen wrenches to fit auger chuck
- Eye protection; ear protection
- Chainsaw wrench
- Cable clamps
- Long-handled ratchet and deep-well sockets to tighten nuts on clamps

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