A Review of Capture Techniques for Adult Anadromous Salmonids

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SUMMARY

Many techniques for capturing adult salmon and steelhead have been tried in the Pacific Northwest. Capturing adult fish is necessary for monitoring run size, evaluating compliance with the Oregon’s Wild Fish Management Policy, or developing and maintaining brood stock programs. The objectives of capturing salmon or steelhead should be identified before a technique is chosen. Differences among characteristics of streams (size, substrate) and among target species mean that no one method can be recommended for all streams. Therefore, the choice of a method will depend on factors such as duration of the project, expense, necessary capture efficiency, presence of existing structures (fishways or concrete sills), and stream conditions.

Management biologists should evaluate the potential for capturing adult salmon or steelhead in their streams. For example, streams with existing structures (such as fish ladders) can be modified to capture fish at a relatively low cost. These streams should be a high priority for capturing fish. In addition, streams with existing concrete sills, such as irrigation diversions or other types of low dams, can be converted into a trapping site using a horizontal picket weir.

A general overview of some capture techniques covered in this report is presented in Table 1. Measured costs and capture rates are given where available. Subjective estimates are also given and are based on information in the literature or from communication with experienced biologists. Because the effectiveness of a capture method depends on many factors such as the purpose of capturing fish, it cannot be measured solely by the capture rate. For example, if the purpose of capturing fish was to collect fish for a brood stock program, a method that had a low catch rate might be adequate.

INTRODUCTION

Fishery biologists often find it necessary to capture adult anadromous salmonids for data collection or for hatchery programs. Capture techniques vary from relatively simple means, such as angling, to construction of large, permanent structures. Some overviews of capture techniques exist in the literature, although they are generally specific to a purpose (such as escapement; Cousens et al. 1982) or they cover a broad array of general sampling techniques for many species (Cleary and Greenbank 1954; Welcomme 1975; Backiel and Welcomme 1980; Casselman et al. 1990). Although an attempt was made to provide a comprehensive review of techniques used to capture adult anadromous salmonids, some methods have undoubtedly been overlooked, especially given the ingenuity of biologists to devise new methods.

The purpose of this report is to compile current information on techniques for the capture of anadromous adult fish. Recent developments in Oregon will likely result in a greater need for capturing adult salmonids. Implementation of the Oregon Wild Fish Management Policy (OAR 635-07-525 through 529) will require collection of adult fish for development and maintenance of local brood stocks. In addition, compliance with the policy will require data on hatchery:wild ratios, which may necessitate capture of adult salmon and steelhead where fishery data are not available.
<table>
<thead>
<tr>
<th>Method</th>
<th>Construction cost</th>
<th>Capture rate/efficiency</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picket weir (vertical, panel, horizontal)</td>
<td>$40-100/ft</td>
<td>25%; 60%&lt;sup&gt;a&lt;/sup&gt; (90%+)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>c</td>
</tr>
<tr>
<td>Fish wheel</td>
<td>$10,600-16,000</td>
<td>1-9%</td>
<td>d</td>
</tr>
<tr>
<td>Hoop trap</td>
<td>$630-1,000</td>
<td>1-15%</td>
<td>d</td>
</tr>
<tr>
<td>Fishway trap - Denil steeppass</td>
<td>$500-1,500, $49,000</td>
<td>high (7-20%)&lt;sup&gt;e&lt;/sup&gt;</td>
<td>c</td>
</tr>
<tr>
<td>Floating weir (commercial)</td>
<td>$500-3,250/ft</td>
<td>medium-high</td>
<td>d</td>
</tr>
<tr>
<td>Non-commercial</td>
<td>$110/ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent picket</td>
<td>$800-1,600/ft</td>
<td>high</td>
<td>f</td>
</tr>
<tr>
<td>Gabion barrier</td>
<td>low-moderate</td>
<td>medium-high</td>
<td>f</td>
</tr>
<tr>
<td>Concrete barrier</td>
<td>$1,300-2,200/ft</td>
<td>high</td>
<td>f</td>
</tr>
<tr>
<td>Electric barrier</td>
<td>$200-2,000/ft</td>
<td>medium-high</td>
<td>d,f,g</td>
</tr>
<tr>
<td>Boat electrofishing</td>
<td>--</td>
<td>1-39 fish/day</td>
<td>g</td>
</tr>
<tr>
<td>Gill nets</td>
<td>--</td>
<td>1-8%</td>
<td>g</td>
</tr>
<tr>
<td>Seines</td>
<td>--</td>
<td>1-5%</td>
<td>g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt;1-60 fish/set</td>
<td></td>
</tr>
<tr>
<td>Angling</td>
<td>--</td>
<td>2-20 hrs/fish</td>
<td>g</td>
</tr>
</tbody>
</table>

<sup>a</sup> Average efficiency of picket and panel weirs in the Siuslaw River, Oregon, for basins >10 mi<sup>2</sup> (25%) and for basins <10 mi<sup>2</sup> (60%) - measured.

<sup>b</sup> Estimated efficiency of horizontal picket weirs in the Siuslaw River, Oregon - not measured.

<sup>c</sup> Specific structures required: sill with 3-4 ft drop for horizontal picket weir; fish ladder for a fishway trap.

<sup>d</sup> Specific stream conditions required such as depth, velocity, gradient.

<sup>e</sup> Measured efficiency of a Denil steeppass trap for catching salmon and steelhead on the Deschutes River, Oregon.

<sup>f</sup> Potential safety hazard: public safety or hazard to boat traffic.

<sup>g</sup> Potential public relations problem with injury or mortality to fish.
The emphasis in this report will be on relatively low-cost methods, such as temporary structures or modified, existing structures. However, other more expensive methods that require construction of permanent facilities will also be discussed. The focus will be on techniques that have been used in the Pacific Northwest (including British Columbia and Alaska) to capture adult salmon or steelhead. Emphasis will also be on techniques that have the potential to capture adequate numbers of adult fish for development and maintenance of local brood stocks. Although costs of some methods are presented in Table 1 and in APPENDIX C, these costs should be considered in the context of the overall cost of a program and the effectiveness of a capture technique. In many cases, the cost of capturing fish is likely to be a small proportion of the total cost of a brood stock development program or a tag-recovery program to collect data on abundance, escapement, or migration.

Two basic types of capture techniques are "passive" methods in which fish swim into a trap on their own at some point during their upstream spawning migration, and "active" methods in which fish are pursued during their migration. Discussion of each technique is organized by a description of the method, areas where the method has been used (current and historic, where appropriate), effectiveness of the method in capturing adult fish, and advantages and disadvantages of the method. A list of contact persons or manufacturers is contained in APPENDIX B and is organized by capture method. Mention of manufacturers or products in this report does not imply endorsement by the Oregon Department of Fish and Wildlife.

PASSIVE METHODS

Low Cost or Temporary

Picket Weir

Description: Picket weirs are designed to diffuse water, yet block upstream fish passage. Fish are caught in an instream trap or are diverted into an off-channel trap. Picket weirs (also called fences or racks) have basic components of vertical weir supports, pickets that block the passage of fish while allowing water to pass, a trap, and an apron to provide a foundation for the weir or to prevent erosion and scour. These weirs have been made of netting (Blair 1956; Murray 1968), wire fence (Schaefer 1951), polyethylene fence (Noltie 1987), wood (Hunter 1954; Craddock 1958; Senn et al. 1984), metal tubing (Anderson and McDonald 1978), or steel (Kerswill 1971; Clay 1995). This report will concentrate on weirs that use steel pickets.

Good site characteristics for picket weirs are a solid stream substrate, either bedrock or compacted cobble or boulders, high banks that are not easily eroded, and a wide reach of stream. A wide reach of stream is generally shallower than a narrow reach. Given the same flow, a wide, shallow site will have a lower head difference between the upstream and downstream sides of a weir than a narrow, deep site. The head difference of a weir will increase when debris begins to clog the weir. Turbulence and erosion below the weir are reduced when the head difference is reduced (Clay 1995). Unless a weir is constructed on bedrock or large substrate, an apron is necessary to prevent erosion underneath the weir. Aprons can be hardware cloth or wire fencing.
secured to the weir and stream bottom (Hill and Matter 1991), aprons of timber planks anchored by gabion baskets (Nelson 1976), or rock-filled timber cribs with sheet-piling on the upstream and downstream face of the apron (Clay 1995). The river bank can also be armored with rock-filled gabions (Nelson 1976), timber boxes filled with rock (Clay 1995), or fence material such as wire mesh. Armoring river banks can prevent erosion around the end of the weir and, if incorporated into the apron, can add stability to the weir.

In addition to the factors mentioned in the preceding paragraph, some design criteria can be used to reduce head difference and to secure a weir. Rounded pickets and the widest possible spacing of pickets will allow more water to pass through the weir. However, the spacing of pickets will depend on the size of the smallest fish targeted for capture. A short weir will allow flood water to more quickly crest the weir, which reduces scour around the end of the weir and reduces the maximum head difference that could develop during flood stages. The weir supports and trap should be cabled securely to trees on the bank, or to eyebolts or anchors set in bedrock, immovable boulders, or in the substrate. Turnbuckles can be used to tighten cables, which is important in preventing downstream shift of the weir or trap.

**Vertical Picket Weir:** The vertical picket weir is composed of horizontal railings attached to tripods or other supports, and vertical pickets of metal pipe or tubing that go through holes in the railings. An instream trap is incorporated into the weir (Figure 1). The more vertical a weir is constructed, the more the force of water will try to push the weir downstream during floods. The top of the weir should be angled downstream to transfer some of the force of water onto the leg supports. Additional construction details are presented in **APPENDIX A**.

![Figure 1. Vertical picket weir on Nelson Creek (Siuslaw River), Oregon, 1995.](image)
Panel Weir: As the name implies, pickets of these weirs are supported by preconstructed panel frames (Figure 2). Pickets within the panel frames can be oriented vertically (Kerswill 1971; Hill and Matter 1991; Clay 1995) or horizontally (Kenaston et al. 1990). Panels are attached together across the width of a stream and are supported with tripods, fence posts, or other methods. A panel weir can be vertical (Kenaston et al. 1990; Hill and Matter 1991) or can be angled (Summer 1953; Hunter 1954) depending on the method used to support the weir. An instream trap is incorporated into the weir. Additional construction details are given in APPENDIX A.

Horizontal Picket Weir: A design using an existing concrete sill to attach a horizontal picket weir was described in Kenaston et al. (1990). The railings and pickets of this weir are similar to a vertical picket weir. The weir is supported on the upstream end by a punched rail bolted to stop logs on a concrete sill, and on the downstream end by monopod supports bolted to a second punched rail. A trap is installed on the upstream side of the concrete sill to one side of the horizontal weir (Figure 3). Additional construction details are given in APPENDIX A.

Traps: Fish traps used with picket weirs are usually a preconstructed cage placed on the upstream side of a picket weir (Figures 1 and 2) or a floorless cage whose sides are constructed of framing and pickets similar to materials used for the weir. Traps should be incorporated into the angle of the weir and should have V-shaped fyke openings to guide fish into the trap and to prevent escape. Traps should be placed in areas deep enough to hold fish during minimum flows, and where flow is sufficient to attract fish. During high flows, a resting area can be provided by placing a board or boulder on the upstream side of the trap. A panel of pickets and channel iron was cabled on the upstream side of a trap in Alaska to create an eddy between the panel and the trap during periods of high water velocity (Schmidt 1984). Additional description of trap design is in APPENDIX A.

Areas of use: Vertical picket weirs are the most common type of picket weir for trapping adult anadromous fish. They have been used recently in Oregon to sample adult winter steelhead in the Siuslaw Basin (Kenaston et al. 1990; Lindsay et al. 1994), and in the Mollala, Alsea, and Yaquina River basins. A vertical picket weir has also been used to sample adult steelhead and salmon in Elk Creek (Rogue River) and to sample chinook salmon in the Imnaha River (Messmer et al. 1992). These weirs have also been used in Idaho to capture steelhead (Senn et al. 1984; S. Rubin, U.S. Fish and Wildlife Service, Seattle, 1992, personal communication), in Alaska to capture salmon and steelhead (Merrell 1964; Jones 1984; Schmidt 1984; Elliott and Sterritt 1990), and in eastern Canada to capture Atlantic salmon (Anderson and McDonald 1978; Whelan et al. 1989; Mullins et al. 1991).

Panel weirs have been used in Oregon in the Siuslaw and Trask River basins to capture adult steelhead (Lindsay et al. 1989b; Kenaston et al. 1990), and in Sand Creek to capture salmon and steelhead (Summer 1953). They have also been used in Northern California (Hill and Matter 1991), British Columbia (Schaefer 1951; Foerster 1953; Hunter 1954; Vernon et al. 1964; Clay 1995), and in eastern Canada (Hayes 1953; Kerswill 1971).
Figure 2. Panel weir on West Fork Indian Creek (Siuslaw River), Oregon, 1990.

Figure 3. Adult steelhead trap at a horizontal picket weir on Whittaker Creek (Siuslaw River), Oregon, 1992.
A horizontal picket weir was used to capture steelhead in Oregon (Kenaston et al. 1990) and a variation of this type of weir was used in British Columbia (Andrew and Geen 1960; Clay 1995).

Native Americans of the Pacific Northwest and indigenous people in other areas with migratory fish used weirs to capture fish (Ruggles 1980; Clay 1995). These weirs were made of brush or were constructed of branches lashed onto vertical posts that were driven into streambeds (Clay 1995). An early description of a weir used by biologists to study fish is provided by White (1939).

**Effectiveness:** Effectiveness of picket weirs depends on stream size and stream dynamics such as frequency and intensity of floods. Effectiveness also depends on the run size of target species and run distribution. Summer (1953) reported that steelhead and sea-run cutthroat trout found the entrance of a trap more easily than did salmon. Effectiveness of weirs also depends on the primary purpose of capturing fish. For example, weirs that are under water for short periods during floods might be sufficient to collect fish for brood stock, but would be inadequate for a complete measure of escapement.

Picket weirs can be 100% effective in blocking fish passage and trapping fish. Picket weirs or fences have been the standard against which other estimates of escapement were measured in some streams in Alaska and British Columbia (Howard 1948; Schaefer 1951; Brett 1952; Vernon et al. 1964; Cousens et al. 1982). Mullins et al. (1991) reported that a vertical picket weir on a 25 mi² basin in Newfoundland remained fully operational for five sample seasons during Atlantic salmon migrations. Weir counts on some Alaska streams have also been considered complete (Nelson 1976; Schmidt 1984; Elliott and Sterritt 1990).

Picket weirs can fail during high water because of holes scoured beneath the weir or trap, erosion around the end of the weir, failure of the weir under the force of water, or water cresting the top of the weir. Operating weirs in some areas can present unique challenges, such as the case reported in Alaska where a brown bear partially destroyed a weir (Nelson 1976).

Based on tagging studies of adult winter steelhead in the Siuslaw River, the average capture efficiency of weirs was almost 60% for seven basins under 10 mi² and under 25% for two larger basins (Table 2). A picket weir on Sand Creek in Oregon (5 mi long with a maximum flow of 300-400 cfs) was estimated to be about 50% effective in capturing upstream migrants (Sumner 1953). Based on tagging and recovery studies in several southeast Alaska streams, the effectiveness of vertical picket weirs in capturing adult coho salmon has been estimated at 54% (Schmidt 1984), 79% (Elliott and Kuntz 1988), and 92% (Elliott and Sterritt 1990). A panel weir operated for two years in British Columbia captured 10% and 21% of the estimated run, with the difference attributed to the degree of flooding in the two years (Schaefer 1951). Horizontal picket weirs in two streams of the Siuslaw River were believed to be over 90% effective in capturing adult winter steelhead during two sample seasons. Effectiveness of these weirs could not be directly measured from tagging because no downstream trap was installed at the trap sites and downstream migrants were able to pass over the weir.
Table 2. Efficiency of picket weirs in capturing adult winter steelhead in the Siuslaw River, December-May, 1991-95.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Year</th>
<th>Percent operational&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Percent efficiency&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Number trapped&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Basin size (mi&lt;sup&gt;2&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>1991</td>
<td>94</td>
<td>51</td>
<td>37</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1994</td>
<td>97</td>
<td>73</td>
<td>55</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>1995</td>
<td>89</td>
<td>20</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Greenleaf</td>
<td>1993</td>
<td>91</td>
<td>21</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>1994</td>
<td>98</td>
<td>39</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Meadow</td>
<td>1995</td>
<td>90</td>
<td>50</td>
<td>8</td>
<td>2</td>
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<tr>
<td>Pataha</td>
<td>1994</td>
<td>100</td>
<td>100</td>
<td>70</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>1995</td>
<td>87</td>
<td>46</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>San Antone</td>
<td>1994</td>
<td>100</td>
<td>82</td>
<td>51</td>
<td>4</td>
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<tr>
<td></td>
<td>1995</td>
<td>88</td>
<td>62</td>
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<tr>
<td>Thompson</td>
<td>1994</td>
<td>95</td>
<td>44</td>
<td>9</td>
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<tr>
<td></td>
<td>1995</td>
<td>90</td>
<td>77</td>
<td>10</td>
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<tr>
<td>Turner</td>
<td>1995</td>
<td>86</td>
<td>60</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>West Fork Indian</td>
<td>1995</td>
<td>69</td>
<td>16</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Panel Weir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turner</td>
<td>1991</td>
<td>92</td>
<td>57</td>
<td>37</td>
<td>5</td>
</tr>
<tr>
<td>West Fork Indian</td>
<td>1991</td>
<td>89</td>
<td>14</td>
<td>63</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td>81</td>
<td>7</td>
<td>58</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Percentage of days weir was operational during winter steelhead migration.
<sup>b</sup> Number of marked steelhead captured above the weir or in downstream traps divided by the total number of steelhead captured above the weir or in downstream traps. Includes only the years in which three or more marked steelhead were recaptured.
<sup>c</sup> Includes mortalities and fish kept for brood stock or transport.

Capture efficiency can be influenced by the size and flow of the stream, the amount of time the trap remains operational, and the run size and run timing of the target species. The capture efficiency of picket weirs in the Siuslaw River basin was negatively correlated with basin size ($r = -0.76; P = 0.02$) and positively correlated with the percentage of time the traps were operational ($r = 0.62; P = 0.01$; Table 2). However, with the exception of the Thompson Creek weir, the efficiency of the traps decreased by an average of 50% with only a small decrease (10%) in the amount of time a trap was operational during the sample season (Figure 4). Because migration of adult fish is not distributed equally through the season (i.e., short periods of peak migration usually correspond to high water flows), capture success will be increased by keeping a weir operational as much as possible during peak migration.
Figure 4. Capture efficiency of six weirs in two consecutive years under two levels of operational success, Siuslaw River, Oregon.
Advantages: Picket weirs can be very effective in capturing adult salmonids in certain streams and at certain sites. Sampling can be conducted over the course of a run, thus capturing all or a representative portion of the run, depending on the efficiency of the weir and variation in efficiency through the sampling season.

Most picket weirs are portable and relatively easy to set up. Assembly time for picket weirs has been reported as two hours for panel weirs to six hours for vertical and horizontal picket weirs with 4-6 people (Kenaston et al. 1990). Anderson and McDonal (1978) reported that a 100-ft vertical picket weir with three traps took an experienced crew two days to install. Hill and Matter (1991) described a design for a 30-ft panel weir that took one person eight hours to install. A relatively permanent panel weir in Alaska that measured 130 ft took six people about 20 days to construct and install, which included bank abutments and a rock shield apron (Nelson 1976). Portable weirs are relatively inexpensive to construct (APPENDIX C). Costs depend on the size, the design, and the purpose of the trapping facility.

Picket weirs and traps cause little injury or mortality to fish if adequate protection from high water velocity is provided in the trap. For example, the average mortality of 14 traps in the Siuslaw River basin was about 2% from 1990-95. Mortality was generally associated with floods. Schmidt (1984) reported some problems with mortality and injury at a vertical picket weir in Alaska because of high water velocity in the trap, and because of stress from tagging and handling fish.

Some types of picket weirs have advantages over other types. The vertical picket weir can be built on uneven substrate because each picket rests on the stream bottom. Vertical picket weirs can withstand floods better than panel weirs, especially when constructed on a solid foundation of bedrock or another type of apron. Vertical picket weirs require fewer and less extensive repairs than panel weirs. The percentage of time vertical picket weirs were operational was slightly higher than that of panel weirs in the Siuslaw River basin (Table 2). Vertical picket weirs were generally inoperable because water crested the weir rather than from structural failure. Vertical picket weirs take less manufacturing time than panel weirs, although panel weirs can be installed in the stream somewhat faster than picket weirs because of their modular design. However, if a weir is fished for several years, the tripods and railing of a picket weir can often be left in place, thus the time required to reinstall the weir is significantly reduced. A horizontal picket weir is least susceptible to damage by floods. This type of weir remained operational a greater percentage of time in the Siuslaw River basin than the vertical picket or the panel weirs, and was believed to be highly effective in capturing adult winter steelhead.

Disadvantages: Although picket weirs can be quite effective in capturing adult salmonids, they are not usually suitable for trapping fish on large rivers. Picket weirs can require frequent maintenance during high flows and if damage is sustained, the weirs may remain out of operation for several days before stream levels recede enough to make necessary repairs. This can result in uncounted fish migrating past the weir during peak migration. Migration of fish can be delayed by picket weirs (as can be the case with any instream barrier), which could result in a redistribution of spawners to less
suitable spawning areas downstream of the weir or to another stream (Sumner 1953; Ruggles 1975). Adult fish may need to be passed downstream of a weir such as spawned steelhead (Jones 1984), early returning salmon that move between salt water and fresh water until they become physiologically adjusted to fresh water (Schmidt 1984), or fish that correct their migration. Unless picket weirs are built with upstream and downstream traps (Hayes 1953; Kerswill 1971; Anderson and McDonald 1978) or with a two-way trap (Whelan et al. 1989; Mullins et al. 1991), fish migrating downstream will need to be passed through an opening in the weir, or netted and passed downstream. If picket weirs are installed on large streams, they may pose a navigational hazard for boat traffic. As with any trapping technique, picket weirs should be operated throughout the run to representatively capture adult fish and are, therefore, somewhat labor-intensive.

Installation of vertical picket weirs may take more time than panel weirs, although vertical picket weirs usually withstand floods better. Horizontal picket weirs are the best design for withstanding high water, but a concrete sill with a 3-4 ft drop is necessary for attaching and suspending the weir. Generally, panel weirs are installed in smaller stream basins than are vertical or horizontal picket weirs, unless they are installed on an apron. Although the height of panel weirs could be increased to allow them to operate over a greater range of flows, the weight of such panels would make them difficult to install. A fairly even stream bottom or a constructed apron is needed for panel weirs because of the flat bottom edge of the panel.

Fishway or Fish Ladder

Description: Fishways or fish ladders can be modified to trap adult fish. Fishways built to aid or provide passage around waterfalls or dams are relatively common throughout the Pacific Northwest and offer opportunities to capture adult anadromous fish. Fishways are usually pool and weir type or vertical slot type (Andrew and Gleen 1960; Bell 1986; Clay 1995). They can be open or enclosed.

Many fishways can be fitted with an adult fish trap or steps of the fishway can be converted into a trap. In cases where the inflow to the fishway cannot be controlled or the steps are too deep, a false floor (which can be raised) may be installed to more easily net fish. Most fishways are protected from debris, therefore the trap can be constructed of light gauge steel or aluminum.

A cage trap can be constructed similar to designs described under Picket Weirs (see Traps and APPENDIX A) and made to fit into a fishway step. Another method to trap fish is to convert a step into a trap. The trap entrance for a pool and weir fishway can be either a v-shape fyke fitted to the upstream side of the step opening (Figure 5), or a finger weir of metal or PVC tubing attached to the step (Figure 6; see also Clay 1995, Figure 4.8). The trap entrance for a vertical slot fishway can be a v-shape fyke bolted to the sides of the step. The fyke should be tall enough to hold fish at high flows. For both types of fishways, bar grates or screens are installed at the upper end of the step to prevent fish from escaping once they have entered the step.
Figure 5. V-shape wooden fyke used to trap adult salmon and steelhead in a fishway step at Powerdale Dam on the Hood River, Oregon.

Figure 6. Finger weir in an adult fish trap in a fishway step, Powerdale Dam, Hood River, Oregon.
An alternative means of trapping fish at fishways was used on the Deschutes River with a Denil-type steepass (Jonasson and Lindsay 1988). Water was pumped from the river into the steepass. The entrance of the steepass was in the top step of the fishway (Figure 7). Fish ascending the fishway were blocked by grates at the top step and were diverted into the steepass where they swam up the steepass and into an anesthetizing tank. The trap was operated 6-8 hours per day, 5 days per week. When the trap was not operated, a gate in the stop step was raised to allow passage. Steeppasses have been used in other locations to pass fish around natural or artificial barriers and could be fitted with a trap at the exit of the steepass. Descriptions and evaluations of steeppasses can be found in Andrew and Geen (1960), Ziener (1962), Slatick (1975), and Bell (1986).

Kupka (1964) described a fishway trap where fish jumped at a false waterfall and into an anesthetic tank. A sealed plywood trap was installed into a fishway step. Water was piped through a conduit and discharged beneath the sealed trap, which then wellled up and over the fishway step, creating the false waterfall. Several types of discharge were used to find the best flow to attract fish and cause them to leap at the overflow.

Areas of use: Fishway traps have been frequently used in Oregon. Some streams where these traps have been used include the Rogue River (Everest 1973), South Umpqua River, Smith River, Tahkenitch Creek, Siuslaw River, Drift and Cascade creeks (Alsea River), Siletz River, Mill Creek (Yaquina River), Fishhawk Creek (Nehalem River), Clackamas River, North Santiam River, Hood River, Deschutes River, Walla Walla River, and Umatilla River.

Figure 7. Denil steepass used to trap adult salmon and steelhead at the Sherars Falls fishway, Deschutes River, Oregon.
Effectiveness: Effectiveness of a fishway trap depends on whether alternative passage is available at the barrier. Some fishways provide the only means of ascent for migrating adults whereas other fishways provide an easier, alternate route over a waterfalls. In the former case, a fishway trap can be 100% effective in trapping the run if continuously operated. The effectiveness of a fishway trap where other passage is available depends on flow and on the attraction of the fishway to upstream migrants.

A steep pass trap in the Deschutes River was more effective at low flow than at high flow, where alternative passage over the waterfalls was possible. The effectiveness ranged from 7% for spring chinook trapped in the spring (Lindsay et al. 1982) to 21% and 17% for fall chinook (Lindsay et al. 1982) and steelhead (Lindsay et al. 1980), respectively, trapped in the summer and early fall. Casselman et al. (1990) reported that fishways in Ontario had lower sampling variability than other passive methods of capture and were the most efficient means for capturing migrating fish in a large river system.

Advantages: The effectiveness of fishway traps makes them an attractive trapping method. Traps that are fitted into fishway steps can usually be constructed at a low cost and usually require a small amount of labor. Maintenance and repair of fishway traps are often minimal because flow into fishways can be controlled, or because the fishway can be protected with a trash rack to prevent large debris from damaging the trap. Fishways are relatively common on many rivers and streams in the Pacific Northwest, thus providing opportunities to capture adult fish and monitor fish runs.

Disadvantages: Fishway traps may require daily operation, depending on the size and temporal distribution of the run. Because some fishways are on waterfalls that are not a complete barrier, the effectiveness of the traps can vary with flow. If a trap is 100% effective, handling all of the run could be a problem with some species and stocks that are low in abundance. Knowledge of run timing and run size would be necessary to determine when to operate the trap, and when and how many fish to collect for brood stock. Another disadvantage is that the location of a fishway dictates where adult fish are trapped.

Hoop or Wire Fyke Trap

Description: The hoop trap (or wire fyke trap) consists of a framework of hoops covered with wire mesh or nylon netting (Figure 8). Two internal fykes or funnels direct fish toward a closed end (Figure 9). Most hoop traps described in the literature for catching adult salmon or steelhead are large; 8-10 ft in diameter and 18-20 ft long (Hallock et al. 1957; Morgan and Henry 1959; Tait et al. 1962). Adult fish enter the open downstream end of the trap and swim through two fykes or funnels until they reach the closed upstream end of the trap. Captured fish are removed from the closed end through an access door. The exit of the first internal fyke is larger in diameter (40-45 in) than the exit of the second or upstream fyke (20-26 in; Figure 9). The external frame of the traps is commonly constructed of five rings of metal pipe connected with metal or wood stringers. The external frame and the internal fykes are covered with wire mesh or netting.
Figure 8. Hoop trap used to capture adult coho salmon in the Chehalis River, Washington.

Figure 9. Downstream (larger) and upstream (smaller) fykes inside a hoop trap used to capture adult coho salmon in the Chehalis River, Washington.
Hoop traps are fished in water that is generally as deep or deeper than the diameter of the trap opening. They are usually fished off steep banks (Figure 10), which facilitates raising and lowering the trap. Hoop traps in the Sacramento River were most effective where the river was 20 ft deep a few feet from shore and in velocities of 2-3 fps with flows of 5,000-10,000 cfs (Hallock et al. 1957). They also reported that the best fishing sites were on the deep side of the river where the river first straightened after a sharp bend. Usually several traps are fished in one location, either side by side or along the shore (Hallock et al. 1957; Seiler et al. 1992).

Hoop traps are held in place by a cable on the upstream end and by two cables (called runner wires) that run from the trap to the bank (Hallock et al. 1957). The two runner wires also keep the trap parallel to the current. When the trap is rolled up the bank, it is rolled onto these wires. A third cable (called the pull cable) is attached to the center of the trap and rolls up on the trap as the trap is lowered. At the same time, the runner wires unroll as the trap is lowered.

Areas of use: Hoop traps have been used recently in the Chehalis River of Washington to capture coho salmon (Seiler et al. 1992). They have also been used in Alaska (Tait et al. 1962) and California (Hallock et al. 1957). Hoop traps were used in Oregon to capture coho salmon in the Temmille Lakes system (Morgan and Henry 1959). Hoop traps were fished for a while in the tidewater zone of the Siletz River, but were unsuccessful in capturing salmon (Morgan 1964), although they did capture numerous surf perch (Morgan 1961). Attempts to capture winter steelhead in the Sandy and Grays rivers with hoop traps were abandoned because of operational difficulties and because gill nets were more efficient in capturing adult fish (Mendler et al. 1956; Korn 1961). Small hoop traps (8-10 ft long) have been used in Oregon to capture cutthroat trout in tributaries of the Willamette River. Hoop traps have also been used to capture channel catfish (Gerhardt and Hubert 1989), burbot (Bernard et al. 1991), and striped bass (Hopkins and Cech 1992). Hallock et al. (1957) reported that hoop traps had been historically used by commercial fishermen in the Sacramento River before the traps were declared illegal.

Effectiveness: Two to three hoop traps fished at the mouth of Temmille Lake captured 674 jack and 443 adult coho salmon, or about 2% and 1% of the jack and adult population, respectively (Morgan and Henry 1959). The hoop traps caught a higher number of jacks than a fixed trap one mile downstream. The efficiency of six or seven hoop traps used to capture coho salmon in the Chehalis River over a six-year period was about 3% (D. Seiler, Washington Department of Fish and Wildlife, Olympia, 1992, personal communication). For example, the efficiency at these traps in 1990 was 4% based on the ratio of 685 marked adult coho salmon to the estimated escapement (Seiler et al. 1992). Seven traps were fished constantly that year from early October through late December except for a two-week period of high water (after the coho salmon catch had tapered off). The traps also caught 452 jack coho salmon, 36 adult chinook salmon, 25 jack chinook salmon, 33 adult chum salmon, and 5 winter steelhead adults (Seiler et al. 1992). They also reported that the hoop traps appeared to capture a relatively constant proportion of the run past the trap site. Some tagged fish from the Chehalis traps were held to assess post-handling mortality and none was observed.
Hoop traps fished in the Sacramento River primarily captured steelhead, chinook salmon, coho salmon, striped bass, and shad (Hallock et al. 1957). The seven Sacramento traps captured 10-20% of an estimated run of 15,000-31,500 steelhead and 11% of the estimated run of 3,000 coho salmon. Only 1% of the estimated run of 124,000-446,000 chinook salmon were captured in these traps. The traps were somewhat selective in capturing smaller steelhead, but less so than with chinook salmon. Marked fish placed in the trap did not escape through the fykes. Trapped salmon and steelhead were in good condition and no mortality was observed.

Hoop traps used in Alaska appeared to catch sockeye salmon in direct proportion to their abundance without size selectivity (Tait et al. 1962). In addition to sockeye salmon, the Alaska traps also captured chinook, pink, coho, and chum salmon as well as Dolly Varden. These traps caught chinook salmon without size selectivity.

**Advantages:** Hoop traps are relatively inexpensive to construct and require little labor to operate or maintain. Several traps can be operated in a section of river without impeding boat traffic. Because the traps are submerged during high flow, they escape major damage from floating debris, although hoop traps in Washington were removed during high flow to prevent damage (Seiler et al. 1992). Depending on the size of the fish run, traps could be left in place for several days, thus reducing the time and labor needed to check them.
Although capture efficiency varies by site and by species, hoop traps probably catch enough fish for most brood stock programs. For example, the average catch in hoop traps in the Sacramento River was 3,266 chinook salmon, although the capture efficiency was just 1% (Hallock et al. 1957). Because hoop traps can be fished near the mouths of rivers, they representatively sample a fish run destined for various streams in the basin and throughout the duration of the run. Capture and tagging of fish from hoop traps can also be used to collect information on run timing, run size, migration, length and age distribution, or other life history characteristics (Seiler et al. 1992).

Disadvantages: Site characteristics for hoop traps include enough depth close to shore to submerge the trap (generally off a steep bank), access for installing and checking the traps, and adequate attraction flow. Several sites with these requirements would likely be needed to sample a river because several traps are usually operated. These criteria limit the number of streams that can be sampled with hoop traps. Daily cleaning of the traps may be required in some rivers during certain times of the year because of the amount of submerged debris such as algae or alder leaves. Some turbidity in the river would likely be required for effective trapping to prevent fish from avoiding the trap entrance. Although a submerged lead could be built to guide more fish toward the trap entrance, maintenance of this lead during high water would be time-consuming. Based on trapping in the Siletz River, hoop traps are not effective at capturing salmon in tidewater (Morgan 1964).

Fish Wheel

Description: The floating fish wheel has three basic components: the floating support structure or raft, the wheel, and the fish box (Figure 11). The raft is usually constructed of two parallel pontoon floats that are held together by crosspieces on the ends of the pontoons (Figure 11). Pontoons must have enough flotation to support the weight of the wheel, the fish box, and workers. They can be made of large logs (Lynch 1979), foam-filled barrels (McGregor and Clark 1988), or foam-filled aluminum (Hammarstrom and Larson 1984). The wheels are attached to and revolve around a central axle. Wheels are composed of three baskets or of two baskets and two paddles (Figure 11). Framing for the baskets can be spruce or birch poles (Lynch 1979), metal pipe (Clay 1961), or lumber (Lynch 1979; McGregor and Clark 1988). The baskets are lined with nylon netting (Clay 1961; McGregor and Clark 1988), tarp mesh netting (Hammarstrom and Larson 1984), or wire mesh (Meehan 1961; Lynch 1979). At the bottom of the basket is an angled slide or chute that guides captured fish to a fish box, which is usually attached to the outside of the pontoons, although it can also be a live well in the middle of the pontoons (Meehan 1961). Chutes have been built of stovepipe (Meehan 1961), wood (Clay 1961; Lynch 1979), and foam-padded wood (Hammarstrom and Larson 1984). The fish box is approximately in line with the axle.

Fish wheels are placed in deep water, either in a fast slot or along the bank, generally on the outside of a meander and just upstream of an eddy (Clay 1961). They are attached to the shore with a cable on the upstream end of the fish wheel. A log boom or gin-pole is used to hold the downstream end of the fish wheel away from shore. A second cable is attached to the upstream end of the inside pontoon to keep the fish wheel parallel to the river current.
The force of water on the upstream side of the baskets and paddles turns the wheel. As each basket rises out of the water, it picks up fish that are in front of it. As the basket continues to rise out of the water and becomes more vertical, the fish slide down the basket, drop into the chute, and slide into the fish box. On models with two paddles and two baskets, the size of the paddles helps determine the speed at which the wheel turns. Boards may be added to or removed from the paddles to adjust the speed of rotation. The ideal rotational speed of fish wheels depends on the site and has been reported as 2.5 rpm (Hammarstrom and Larson 1984); 3-5 rpm (Donaldson and Cramer 1971), and 4 rpm (Meehan 1961). Fish wheels with two baskets and two paddles tend to move less smoothly than those with three baskets (T. Dress, NMFS, Auke Bay Laboratory, Juneau, 1993, personal communication).

Because fish wheels should be fished as close to the river bottom as possible, some are attached to an adjustable axle to allow the wheel to be raised or lowered with a change in water level (Lynch 1979; Bentz 1984; Hammarstrom and Larson 1984). The axle can be mounted on a bearing block that is raised or lowered on an axle stand (Hammarstrom and Larson 1984).

![Fish wheel in the mainstem Siuslaw River](image)

Figure II. Fish wheel in the mainstem Siuslaw River (RM 26), Oregon, 1990.
Areas of use: Fish wheels have been used for commercial and subsistence fisheries, and for fish research and management in Alaska and British Columbia (Ward 1959; Clay 1961; Meehan 1961; Lynch 1979; Williams and Potterville 1983; Bentz 1984; Hammarstrom and Larson 1984; McGregor and Clark 1988; Eiler et al. 1992). They are generally used on large rivers.

The origin of fish wheels has been traced to 1829 in North and South Carolina and were principally used to catch shad (Donaldson and Cramer 1971). Most of these were fixed devices in rock dams, but some were attached to catamaran rafts. The most intensive use of fish wheels was on the Columbia River from 1887 until they were eliminated by law in 1927 (in Oregon) and in 1935 (in Washington; Johnson et al. 1948; Donaldson and Cramer 1971). Many of these were fixed wheels with picket fences to guide fish to the wheel, but some early wheels were attached to catamaran rafts. Later, fish wheels were built on twin-boom scows with the wheel section projecting beyond the scow so it could be fitted into an opening of a picket fence. These were often constructed so the wheel could be raised or lowered to fish at various depths.

Effectiveness: Fish wheels have been used principally to catch salmon. Salmon caught in an Alaska fish wheel were tagged and released in a quiet slough one mile below the fish wheel site (Meehan 1961). Based on recovery of these fish, the recapture rate was lowest for chinook and coho salmon (1% and <0.5%, respectively), higher for sockeye and chum salmon (2%), and highest for pink salmon (9%; Meehan 1961). McGregor and Clark (1988) estimated that 3% of a sockeye salmon run was caught in a fish wheel in the lower Taku River. Catch of coho salmon in two fish wheels in the Taku River was about 3% of the estimated escapement (Elliott and Bernard 1994; McPherson et al. 1994). Fish wheels in British Columbia rivers captured salmon and steelhead in roughly the same proportion as their abundance (Clay 1961). Meehan (1961) reported that the size of chinook salmon in fish wheels was smaller than the size of carcasses collected at a weir or on spawning grounds. He suggested that large chinook salmon avoided the fish wheel or migrated in swifter and deeper water than small chinook salmon. Selective capture of small coho in a fish wheel was also reported by Bentz (1984), although the sample size was small. Although the catch rate may be low for some species of salmon, the overall catch can be high because of run size and because fish wheels can be operated on large, mainstem rivers (Table 3).

Fish wheels operated on the Columbia River were the most efficient gear used to catch salmon (Johnson et al. 1948). However, because fish wheels were relatively few in number they accounted for less than 5% of the annual catch. For example, from 1928-1934, fish wheels accounted for 16% of the sockeye salmon catch, 2% of the chinook salmon catch, 1% of the steelhead catch, and <0.1% of the coho and chum salmon catch (Johnson et al. 1948). Picket fences were used on some Columbia River fish wheels to guide fish and to increase catch (Donaldson and Cramer 1971). A vertical picket weir was also used on a fish wheel in the Kenai River, but it interfered with the operation of the fish wheel because of debris on the weir and because the weir was attached to the pontoons and decreased flotation of the wheel (Hammarstrom and Larson 1984).
Table 3. Yearly catch of salmon and steelhead in fish wheels.

<table>
<thead>
<tr>
<th>River</th>
<th>Years</th>
<th>Weeks fished</th>
<th>Pink</th>
<th>Sockeye</th>
<th>Coho</th>
<th>Chinook</th>
<th>Chum</th>
<th>Steelhead</th>
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<tr>
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<td>5</td>
<td>585</td>
<td>14</td>
<td>147</td>
<td>18</td>
<td>2</td>
<td>9</td>
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<tr>
<td>Nass</td>
<td>1959</td>
<td>6</td>
<td>1,050</td>
<td>1,075</td>
<td>13</td>
<td>451</td>
<td>3</td>
<td>1</td>
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<tr>
<td>Mannock</td>
<td>1960</td>
<td>8</td>
<td>50</td>
<td>1,750</td>
<td>25</td>
<td>5</td>
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</table>

**British Columbia**

<table>
<thead>
<tr>
<th>River</th>
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<th>Weeks fished</th>
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<th>Sockeye</th>
<th>Coho</th>
<th>Chinook</th>
<th>Chum</th>
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<tr>
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<td>4- 8</td>
<td>7,591</td>
<td>308</td>
<td>403</td>
<td>1,273</td>
<td>971</td>
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<tr>
<td>Taku</td>
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<td>5-14</td>
<td>24,639</td>
<td>4,012</td>
<td>1,273</td>
<td>294</td>
<td>826</td>
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<tr>
<td>L. Susitna</td>
<td>1983</td>
<td>5</td>
<td>4</td>
<td>12</td>
<td>21</td>
<td>2</td>
<td>35</td>
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<tr>
<td>Copper</td>
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<td>3</td>
<td>--</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>e</td>
<td>32</td>
</tr>
</tbody>
</table>

**Alaska**

- From Clay (1961).
- From Meehan (1961).
- From Bentz (1984). Low clear water was thought to have reduced the catch. sockeye, coho, and chinook salmon also caught, but no numbers were given.

Fish wheels appear to work best in rivers that are silty, such as glacial rivers, and where changes in flow are gradual. Fish avoid fish wheels in clear water (Clay 1961; Bentz 1984). However, fish wheels may be effective in clear streams at night. Catch of salmon in Columbia River fish wheels was higher at night (Donaldson and Cramer 1971). The catch of salmon in an Alaska fish wheel slowed with a rapid rise in the river, because of a reduction in fish migration (Meehan 1961).

**Advantages:** Fish wheels are an effective means to capture certain species of salmon when operated in a suitable location (Table 3). Fish wheels can be operated near the mouths of rivers, thus sampling a representative portion of the run throughout the migration. Fish wheels in Alaska were the least stressful to adult salmon, when compared to other large-river capture techniques, such as hook and line and gill nets (Bentz 1984). Little mortality was observed in salmon that were caught in an Alaska fish wheel, tagged, and released in a clear water slough (Finger 1958). In addition to collecting adults for brood stock, fish wheels could be used to estimate run size or escapement and to collect life history data.

**Disadvantages:** Fish wheels require certain site characteristics to operate efficiently, such as sufficient water depth, velocity, and turbidity, which makes them infeasible in many rivers. For example, because many of
Oregon's coastal rivers lack sufficient depth and velocity along shorelines, fish wheels would have to be placed in deep slots in the center channel, thus making them more susceptible to damage in high water. An attempt to use a fish wheel in the Siuslaw River was short-lived because the fish wheel was torn from its anchoring cable during a severe winter flood and suffered substantial damage (Kenaston et al. 1990).

Meehan (1961) and Bentz (1984) reported a selectivity toward smaller fish with fish wheels, which could affect brood stock collection, escapement estimates, and other life history data. The effectiveness of fish wheels can be reduced by large fluctuations in flow because fish migration may slow (Meehan 1961) or because fish may alter their migration routes. Also, a river with rapidly fluctuating flow would likely carry much debris, which would make the fish wheel susceptible to damage.

Construction, assembly, and launching of fish wheels is labor-intensive. Operation of fish wheels can also be fairly labor-intensive at times, depending on the number of fish captured and on repairs needed after high water. Although fish wheels on the Taku River, Alaska, need to be frequently repaired (8–12 times a season) because of damage from large debris, spare paddle and basket framing is kept on hand and repairs can be quickly completed (T. Dress, NMFS, Auke Bay Laboratory, Juneau, 1993, personal communication).

High Cost or Permanent

Floating or Resistant Board Weir

Description: A floating or resistant board weir blocks the upstream passage of adult salmonids much like picket weirs (Figure 12). The floating weir is attached to a cement sill or other attachment point on or near the bottom of the stream. The flotation of the closed PVC pipes in the weir panel and the force of water on a resistant board near the top of the panel keep the weir afloat. As the water rises or drops, the weir floats up or down on the bottom attachment point. At some high flows, the weir will sink beneath the surface of the water, but will float again when flow drops.

The minimum and maximum flow at which a floating weir will operate depends on the length of the weir, the placement and angle of the resistant board, water velocity, and water depth. A Washington Department of Fish and Wildlife (WDFW) weir on the Tucannon River operated between 20 cfs and 3,500 cfs (R. Bogden, WDFW, Olympia, 1992, personal communication). Efficient passage of water through the weir is achieved with streamlined PVC pipes, thus minimizing head difference between the upstream and downstream side of the weir. This reduces scouring on the downstream side of the weir and prevents water from backing up and washing around the ends of the weir during high flow. Debris on the weir panels washes off when the weir sinks below the water surface, either by high flows or by a person walking on the weir panels.
Figure 12. A floating weir at Aberdeen Hatchery, Washington, used to capture adult salmon and steelhead, 1992.

Several techniques for anchoring weir panels are a cable stretched across the stream bottom, railroad rails, a concrete sill in streams with relatively stable substrate, or a submerged sheet pile sill with a steel cap in streams with a soft, shifting substrate. Several methods have also been used to effectively cover steep or sloping banks, including vertical walls of sheet piling (covered with wood to allow the weir to raise and lower; see Figure 12), netting between the end weir panels and the bank, or an additional cable or sill running upslope to the high water line to which additional weir panels are attached. Detailed descriptions of two floating weirs, one commercially available through a Japanese manufacturer and the other built by Alaska Department of Fish and Game (ADFG), are provided in APPENDIX A.

Areas of use: Commercial floating weirs have been used in several locations in Washington (Chiwawa, Twisp, Skagit, and Tucannon rivers, Barnaby Slough in the north Puget Sound, and Van Wickel Creek near Grays Harbor) and Idaho (Lochsa River, Kooskia Hatchery, Blackfoot River). A floating weir was recently completed in 1993 at Lookingglass Hatchery in Oregon. The commercial product has been used extensively in Japan and along the east coast of Russia. The first commercial floating weir used in the United States was installed in Alaska in 1985. These weirs have been used in Japan since the early 1980s.

A floating weir built by Alaska Department of Fish and Game has been used in the Little Susitna River since 1988 (L. Bartlett, ADFG, Palmer, 1993, personal communication). Several others are currently in use, including one on the Anchor River near Homer. These weirs are used to capture adult salmon, steelhead, Dolly Varden, and other smaller fish.
Effectiveness: Little data were found on the efficiency of floating weirs. Efficiency depends on the ability of the weir to stay afloat during high water. Flotation of the weirs depends on panel length, water depth, and water velocity. For example, the limit of operation for a 16-ft long weir at a velocity of 3 fps is 6.5 ft of water depth, according to the manufacturer. Although a weir may become partially submerged at high flows, it may still operate to some degree if water passing over the weir does not form a wave and pool that would entice fish to jump over the weir. Some fish may pass above a weir if it is submerged by high flows, but the weir would float again when high flows begin to subside. Floating weirs may be operational much sooner after a flood than a picket weir that required repair.

A floating weir could potentially capture all upstream migrants under certain conditions. Floating weirs developed by ADFG have been highly effective in trapping and counting adult salmon and other species (L. Bartlett, ADFG, Palmer, 1993, personal communication). For example, although the Little Susitna River has rapid runoff and can carry much debris during the trapping season, a floating weir has been self-cleaning most of the time. Large logs usually wash over the top of the weir during floods.

Some floating weirs in the Wenatchee River drainage have been relatively inefficient in capturing adult chinook salmon (B. Hevlin, National Marine Fisheries Service, Portland, 1993, personal communication). Floating weirs on the Chikwa and Twisp rivers allowed passage of large numbers of fish during high flow. For example, the Twisp River weir had a capture efficiency of about 25-35%. This efficiency was calculated from the number of fish trapped and the estimated run size to the weir site.

Advantages: Floating weirs appear to be highly adaptable to many streams and are effective for several species of salmonids. The biggest advantage over other methods of trapping an entire stream is that the floating weir operates during periods of peak migration on rising or descending flows. Debris that does not wash off the weir on its own can be removed by having one or two people walk on the panels to slightly sink the weir. In contrast, a fixed weir may be flooded or damaged during high flows and cannot be repaired until flows have substantially subsided. Unlike a fixed weir, a floating weir will allow upstream and downstream passage of boats by allowing boaters to partially sink some panels and drive or float over the top of the weir. In many large rivers, floating weirs may be the only feasible way of trapping the entire stream, short of major construction that could be an obstruction to boat traffic or may be esthetically undesirable.

Floating weirs can be easily installed once the sill is prepared. For example, a weir composed of 66 panels (about 200 ft) was installed in 3-4 hours by 7-8 people on the Lochsa River, and a weir of 42 panels (about 125 ft) took four people one day to install on the Chikwa River. Individual weir panels weigh about 80-90 pounds.

Because floating weirs are relatively new in the United States, information is lacking on the life of weir panels. Several weirs have been operated for 3-4 years with little noticeable deterioration. The ADFG weir was operated from 1988-1992 before the PVC pipes became brittle and the weir panels needed to be rebuilt (L. Bartlett, ADFG, Palmer, 1993, personal
communication). Although the weir did require some maintenance during this five-year period, the PVC pipes were easy to remove and replace. Installation of these weirs is fast, even when installed in remote locations. A large advantage of the Alaska version over the commercial version is its lower cost. A 100-ft weir with sill attachment and trap cost around $10,000 (L. Bartlett, ADFG, Palmer, 1993, personal communication).

Disadvantages: The floating weir is an evolving technology that is not yet perfected. Because floating weirs are relatively new in North America, questions remain about the durability of weir components such as the pickets, the lateral wood struts, the strap attachment to the lateral struts, and sill attachments. Some weir failures have occurred because of abrasion at the sill attachment or interference with the ability of the weir to pivot on the attachment point because of stream bedload movement during high flows.

Some commercial floating weirs have been relatively ineffective in capturing salmon. For example, a floating weir in the Twisp River was inefficient in spring flows because fish swam over the weir and because some fish worked through the pickets (B. Hevlin, NMFS, Portland, 1993, personal communication). Some fish also worked through the pickets at the Aberdeen Hatchery floating weir until additional lateral wood braces and attachment straps were added (B. Paulson, WDFW, Aberdeen, 1993, personal communication). Spawning distribution in the Twisp River was altered because a much higher proportion of fish spawned in downstream areas than had been previously observed (B. Hevlin, NMFS, Portland, 1993, personal communication).

Floating weirs cannot be adapted to all sites because they require certain stream characteristics to operate properly. They operate best where a stream is straight and wide with low gradient. Streams must often be confined within abutments to provide an even flow of water across the weir panels. The attachment sill must be horizontal and perpendicular to the flow to reduce uneven stress on the panels. However, some weirs in Alaska have been installed at an angle to the flow and have operated successfully by reattaching the resistant board so it remains perpendicular to the current (L. Bartlett, ADFG, Palmer, 1993, personal communication). Scouring can occur above and below the site unless an apron is provided. Damage to the PVC pipes can affect the operation of the weir and individual pipes are difficult to replace on the commercial weir. Therefore, most purchasers of the floating weir order extra panels.

A disadvantage of commercial floating weirs is cost, unless the weirs are planned for long-term use, such as at a hatchery or at a designated monitoring site. Weir panels 3 ft wide by 12-16 ft long cost around $1100-$1600 each from Mitsubishi. The total cost of a weir can be very high depending on the width of the stream and the amount of site preparation required, such as construction of an attachment sill and bank abutment work. For example, the total cost of a floating weir at Lookingglass Hatchery was $185,000, which, in addition to the weir, included engineering, site construction, contractor, and agency oversight (P. Johnson, ODFW Engineering, Portland, 1995, personal communication).
Permanent Picket Weir

Description: Picket weirs that have been constructed at fish culture facilities are usually permanent structures consisting of concrete piers and a concrete apron. Clay (1995) described several structures in which picket panels are supported by steel beams and concrete piers. These structures require construction of a substantial apron to prevent scour and erosion underneath and downstream of the weir, and use of bank abutments to prevent scour around the shoreline. A permanent weir was constructed at the Sawtooth Hatchery in central Idaho to trap steelhead and spring chinook salmon. Concrete piers in the river support three rows of steel picket panels that are stacked on top of each other. A small crane mounted on a rail at the top of the structure is used to lift panels and to winch large debris off the panels. The piers are constructed with ports, which allow the lateral passage of fish across the apron. Fish at these permanent weirs are blocked at the weir and diverted into a fish trap or a fishway leading to a capture facility.

A trapping technique that combines features of panel, horizontal, and floating weirs was developed in 1993 to trap adult spring chinook salmon at Chiwawa Hatchery (B. Hevlin, NMFS, Portland, 1993, personal communication). The barrier was designed after a floating weir failed to block the upstream passage of chinook salmon for several years during high flows. Four to five panels (10 ft long by 20 ft wide) are constructed of heavy-duty ABS plastic pickets that are further reinforced by cross braces. The pickets are wing-shaped to increase the efficiency of passing water. The panels are attached with strong hinges to an existing sill that is about 12 in high. On the downstream end, the panels are supported by hydraulic lifters (two per panel) set on concrete pads 3-4 ft downstream of the sill. When the lifters are at their maximum height, the panels are about 60° to the stream bottom, and when they are lowered, the panels are dropped below horizontal. The hydraulic lifters use canola oil for fluid and are operated simultaneously by controls on the bank. The lifters are set to give when a certain amount of pressure is reached. Therefore, if a large tree or a large amount of debris collects on the panels, the lifters give way and the weir lowers to wash off debris.

Areas of use: Clay (1995) described several permanent picket weirs used in Canada and Scotland. Sawtooth Hatchery on the upper Salmon River in Idaho uses a permanent construction of concrete piers and steel picket panels to trap adult spring chinook salmon and steelhead. The panels are removed during the period when adult fish are not migrating. As mentioned previously, a new barrier design was recently used on the Chiwawa River to trap spring chinook salmon.

Effectiveness: Permanent picket weirs can be 100% effective in capturing adult salmonids. The Chiwawa barrier has performed well as a fish barrier, although attraction to the trap has been of concern (B. Hevlin, NMFS, Portland, 1995, personal communication). The barrier has been operated in flows up to 2,000-2,500 cfs. At these flows, the end of the weir panels was still 6 ft above the water surface. Because the pickets were efficient at passing water, little turbulence was created downstream of the panels and the fish tended to work along the barrier rather than jump at it. The new barrier was successful at capturing the entire run in its first year of operation,
which outperformed the 24-35% efficiency of a floating weir used previously at the site. However, because of problems with attraction to the trap, some spring chinook may have been displaced to downstream areas. The weir was lowered every fifth day in 1995 to let fish migrate past the weir site because of concerns about the low number of returning adults and the possibility of displacing spawners to less suitable areas.

**Advantages:** The size and construction of permanent picket weirs enables them to withstand floods much better than temporary structures. The picket panels diffuse water, which minimizes flooding upstream of the trap when compared to other techniques that use concrete or other material to block fish passage. Whether they are built to block fish at all flows or to allow flood water and associated debris to wash over them, permanent picket weirs should require little post-flood maintenance other than cleaning.

**Disadvantages:** The cost and construction of permanent picket weirs limit their use to areas where long-term sampling will be conducted. The Sawtooth Hatchery facility cost $500,000 in mid-1980s dollars. The cost of the Chiwawa barrier was about $100,000. Although the Chiwawa barrier has performed well, it has not been subject to high flows, which have previously occurred at the site. Also, the durability and performance of the barrier has yet to be tested. Impoundment upstream of the weir may be a disadvantage in some areas. Because these weirs may be 100% effective, capturing and processing all fish may be a problem in streams where fish runs are low.

**Gabion Barrier**

**Description:** An adult capture technique that has been used for several years on the Millicoma and Coquille rivers uses the combination of rock-filled gabions to block upstream passage and a concrete trap for capturing fish (Figure 13). The gabions are angled toward the trap, which is located on one side of the river. Before the gabions are filled with rock, a cable is woven through them and attached to large trees along the shore. After the gabions are filled, they are capped with cement to extend wear. To prevent fish from jumping over the gabions at high flow, short pickets of PVC pipe are attached to the top of the gabions and extend downstream (Figure 13). These pickets also help facilitate the passage of boats during high flows.

The trap is constructed of concrete with three vertical walls and a floor (Figure 14). Each wall has slots that allow the installation of stop logs, finger weir, or picketed panels. One side of the trap dissipates flow, and stop logs are placed on this side to maintain a velocity barrier for fish. The other side is converted into a trap by installing a picketed panel on the upstream side, stop logs to control the flow, and a finger weir (see Figure 6) on the downstream side. Flow through the trap can be controlled by installing or removing stop logs on the trap or the dissipation side of the structure, or by raising or lowering the finger weir.
Figure 13. Barrier dam of rock-filled gabions for trapping adult salmon and steelhead, West Fork Millicoma River, Oregon (trap is in the foreground). Note PVC pipe extensions on top of the gabions to prevent fish from jumping over the barrier and to facilitate downstream passage of drift boats.

Figure 14. Adult trap at a gabion barrier dam, South Fork Coquille River, Oregon. Note that stop logs in photo are set to allow adult passage.
Fish ascending the river must swim into the trap because other passage is blocked by the vertical barrier of the gabion dam and by the velocity barrier of the dissipation side of the trap. During high flows, plywood is placed on the upstream side of the trap against the picketed panel to control the flow and to enable fish to be more easily netted. Fish can hold in the trap area for a couple of days, but the trap is generally checked twice during days it is operated.

**Areas of use:** Several of these traps have been built and operated on the Coos and Coquille systems. Their principal use is to collect salmon and steelhead for development of local brood stocks. Operation of these traps is coordinated by Coos-Coquille District of ODFW with much assistance from volunteers in the basin.

**Effectiveness:** Although no evaluation has been conducted on the effectiveness of these traps, they are generally believed to be highly efficient at most flows. During the highest floods of a year, some fish can pass over the gabions (T. Rumreich, ODFW, Charleston, 1993, personal communication). As long as the stop logs are properly adjusted, velocity on the dissipating side of the trap structure prevents upstream passage. Conceivably, these traps could be 100% effective at trapping fish during certain flows. However, the traps are generally operated only a few days a week to collect fish for hatchery programs.

**Advantages:** The principal advantage of these structures is that they can be used on large river systems where other traps might not be effective. Large debris washes over the top of the gabions during high flows, yet the gabions still have enough physical height on the downstream side to form a barrier to fish passage at most flows. Although the trap structure can be somewhat vulnerable to large trees, little damage has occurred to the traps (T. Rumreich, ODFW, Charleston, 1993, personal communication). The walls of the trap are low enough that they are submerged during highest flows and are therefore not exposed to large floating trees. Because gabion barriers can be installed on large river systems, they can be placed lower in a river basin than many other types of traps and can representatively sample throughout a run. Although the initial expense and labor is higher than with temporary weirs, the year-to-year costs may be less because of lower maintenance.

**Disadvantages:** The principal disadvantage of these structures is that they remain in place when not fishing, thus altering the appearance of the river. Such modifications may be unacceptable in certain rivers. Although these structures can be modified to allow passage of boats, they could create dangerous passage problems for boats at some flows and would require some warning and education of boaters. As with any structure that creates a height differential, these structures create a forebay and will flood some upstream areas, although the inclusion of a trap will minimize the flooded area at low flow. Over time the gabions will require some repair, which could be difficult because the structure is tied together.
Concrete Barrier

Description: Concrete barrier dams have generally been used to collect fish at fish culture facilities or to prevent upstream passage of unwanted fish species (Bulow et al. 1988; Clay 1995). These structures are usually expensive because they require extensive engineering and construction. Vertical barriers are built to create a height differential of 6-10 ft. A shallow sill downstream of the dam is built to prevent fish from jumping at the face of the dam. Clay (1995) and Senn et al. (1984) describe dams in which the face is sloped downstream (i.e., the bottom of the face is farther upstream than the top of the face - "Ambursen"-type dam). Fish that jump at the overflow go through the water and fall into a passageway beneath the sloped face rather than falling against the dam surface. Openings in concrete piers allow fish to move freely across the apron (see Clay 1995, Figure 3.1).

Velocity barriers are a variation of concrete barrier dams that use water velocity over a shallow surface, rather than height, to prevent fish passage. Water impounded by a small dam discharges onto a shallow sill below the dam or down a long slope face to create a velocity sufficient to prevent fish passage. Senn et al. (1984) reported desired water velocity as 16 fps, which exceeds the upper swimming ability of 10-13 fps for adult salmon and steelhead (Bjornn and Reiser 1991). The depth of water on the sill should be less than 6 in (Senn et al. 1984) and the flow should not exceed 8 cfs per linear ft of width to avoid an S-shape flow across the apron, which would allow fish to swim upstream. In some cases, adult fish might be able to maintain position or move laterally across the sill, but would not be able to swim the entire length of the sill or would not be able to jump at the impoundment face. A combination concrete barrier and velocity barrier is used at Warm Spring National Fish Hatchery to block upstream migration and to divert fish to a fish ladder and collection facility (Figure 15). Although fish at this site can sometimes jump onto the sill and swim up to the face of the impoundment dam, the shallow depth and velocity of water on the sill prevents fish from jumping at the second barrier and they eventually drop downstream.

Other variations of concrete barriers have been designed to prevent upstream passage of fish. A radial arm dam (a curved steel gate that pivots on two struts or arms) has been used in conjunction with a velocity barrier to prevent passage of adult salmon and steelhead on Little Sheep Creek, a tributary of the Immaha River in northeast Oregon (Figure 16). This structure was built by the Army Corps of Engineers and is used as an adult collection and juvenile acclimation facility. Other concrete barriers are capped with adjustable crest gates on top of the concrete weir to control outflow (Clay 1995). Some crest gates are operated with hydraulic cylinders. Other crest gates use rubber bladders under the hinge of gates (Obermeyer gate), which can be inflated or deflated with air to raise or lower the crest gate.

Areas of use: Concrete barriers are fairly common throughout the Pacific Northwest and are generally constructed for use at a fish culture facility.
Figure 15. Concrete barrier used to divert adult salmon and steelhead into Warm Springs National Fish Hatchery, Oregon.

Figure 16. Radial arm dam and velocity barrier used to divert steelhead into adult steelhead trap, Little Sheep Creek (Immaha River), Oregon.
Effectiveness: Theoretically, these structures should be 100% effective in preventing the passage of adult fish. Some designs may have temporary periods when passage might be possible, but most are highly effective in blocking passage and diverting fish into a capture facility.

Advantages: In addition to being highly effective in capturing adult fish, these structures withstand high flow and high debris loads. Some of the designs can be adjusted for varying flow, such as the radial arm dam and crest gate weir. Maintenance varies depending on the design; those with movable parts (such as hydraulic lifters) require more maintenance than designs such as the velocity barrier.

Disadvantages: The biggest disadvantage to these designs is the cost of engineering, materials, and construction. For these reasons, use of concrete barriers is confined to areas where long-term sampling will be conducted. Generally, these methods of fish capture have been constructed at fish culture facilities. Impoundment upstream of the barrier can be considerable and may be a disadvantage in some areas. Some of the designs, such as Obermeyer crest gates, are relatively new and have not been thoroughly tested. The hydraulic lifters used to operate some crest gates are positioned along the width of the apron and could pose injury risks to fish that jump through the outflow. Although crest gates can be operated individually to allow more flow at certain spots (thereby providing attraction flow), the effect of disproportionate flow moving over the gates and laterally under raised gates may affect passage of fish and may induce fish to jump at these areas. Finally, careful consideration should be given to any plan that calls for construction of a "small" dam to sample fish because of resultant changes in the river and possible effects on migration of non-target fish and on distribution of fish in the river.

Electric Barrier

Description: Electric barriers are used in conjunction with off-channel traps to capture adult salmonids. Fish swim into an electric field that is charged between suspended electrodes and a submerged ground. Once in the field, fish receive a mild shock and are prevented from continuing upstream. The adult fish eventually find their way into a fishway and trap, which are downstream of the electric field.

Clay (1961) and Senn et al. (1984) described similar setups for an electric barrier. A single row of electrodes, which are 1.5-in diameter galvanized pipe, are suspended from an overhead cable on 3-foot centers. They are located 15 ft upstream and parallel to a submerged ground. The barrier uses 110-volt, 60 cycle, single-phase alternating current (AC). The minimum barrier voltage should be 0.5 volts per inch over a 10-foot field length. Senn et al. (1984) reported that electric barriers have operated satisfactorily in streams as large as 200 ft wide and 8 ft deep. The velocity in the field should be at least 3 fps to wash stunned fish downstream and prevent mortality (Senn et al. 1984).
Other designs consist of submerged electrodes of metal strap that are mounted in a wooden platform, such as that used in Three Rivers, Oregon, to divert salmon and steelhead into Cedar Creek Hatchery. Because the electrodes are insulated, they do not ground to the substrate and the electric current flows through the path of least resistance in the water column. The field is evenly distributed in the water column from the submerged electrodes to the water surface. Electrodes are connected to individual pulsators to generate a pulsed direct current (DC) field. Pulsed direct current reduces stress on fish and minimizes the danger of electric shock to workers and the public. Each pulsator is adjusted differently to create a graduated field. Smith-Root, Inc. uses a similar design for an electric barrier, but the electrodes are encased in a special insulating cement that is poured as a sill on the stream bottom (Clay 1995).

The field from an electric barrier is oriented parallel to the stream flow, which is also parallel to a fish swimming upstream. This orientation transfers the maximum amount of power from the water into the fish as it swims upstream, which elicits a response in the fish ranging from fright to tetany (see Electrofishing). A fish receives minimal shock if it turns sideways to the current, but the velocity of water will sweep the fish downstream out of the field. The barrier offered by the Smith-Root, Inc. is a graduated electric field controlled by six or seven pulsators that are triggered simultaneously to create an additive electric field oriented with streamflow (Clay 1995). The graduated barrier allows fish that attempt to swim through the barrier at various speeds to be gradually slowed by the effects of electricity until they cannot keep their head into the flow and are swept downstream. This graduated field also affects fish of different sizes at different rates (because larger fish receive more voltage and are affected earlier than smaller fish). The graduated field helps prevent injury to fish.

Palmisano and Burger (1988) described a portable electric barrier that was used to divert adult chinook salmon into a small side channel where the fish were captured with a picket weir and trap. The barrier consisted of two galvanized cables (3/8 in) for electrodes that were connected to an electrofishing unit and a 4,000-W generator. The most successful setting was 168 V DC, 3.7 ms pulse width, 120 pulses/s, and 1 A current. The electrodes were secured to the stream bottom with sandbags with the cathode stretched across the river and the anode stretched upstream in shallow water parallel to the bank. The barrier was operated 50% of the time during the six weeks of operation to provide some unimpeded passage. The water velocity at the site was 2-5 fps.

Smith-Root, Inc. also offers a portable electric barrier that consists of electrodes made of stainless steel cables (5/16 in). The electrodes are held in a parallel array by sewn plastic netting on an insulated background of 18-oz reinforced vinyl. Insulated power cables from each electrode are attached to a pulsator unit and a power source. The array is secured to the stream bottom such that no water flows under the insulating vinyl. The mode of operation is like that for their permanent installations.

Areas of use: In Oregon, electric barriers have been at Bonneville, Salmon River, Nehalem River, and Cedar Creek hatcheries to divert adult salmon and steelhead into the hatcheries. Electric barriers have also been used in
Washington at Quinault National Fish Hatchery (Senn et al. 1984). A Smith-Root, Inc. electric barrier has been used at Quilcene Hatchery, Washington, since 1989. A Smith-Root, Inc. barrier was also used in Minnesota to prevent upstream migration of common carp and bigmouth buffalo (Ictiobus cyprinellus) into a lake system (Verrill and Berry 1995). A portable electric barrier was used to divert adult chinook salmon into a fish trap in the Kenai River drainage in Alaska to estimate escapement (Palmisano and Burger 1988).

Portable electric barriers made by Smith-Root, Inc. have been used to assess the feasibility of installing permanent electric barriers at irrigation diversions.

Holmes (1948, as cited in Andrew and Geen 1960) reported that the earliest use of an electric barrier to stop adult salmon was at Gold Ray Dam on the Rogue River, but it was subsequently removed because of mortality to fish. Other electric barriers were reported in the literature in the 1950s. They were often used in the Great Lakes region to stop spawning migrations of parasitic sea lampreys (Applegate et al. 1952). Because of excessive mortality of other fish species using alternating current, work was conducted with electric weirs operated by pulsed direct current (McClain 1956). Electric barriers in the Northwest were reported in the 1950s on the Entiat River to divert sockeye and chinook salmon into traps (Burrows 1957).

Effectiveness: The efficiency of electric barriers has not been extensively tested on adult salmon or steelhead. Andrew and Geen (1960) reported that although fish could be stopped at an electric barrier, the electric field was not very effective in guiding fish to a fishway. At the Three Rivers barrier, fish attempt to swim through the field, and at certain flows they school below the barrier rather than swim into the hatchery trap because of inadequate attraction flow (M. Traynor, ODFW, Cedar Creek Hatchery, 1993, personal communication). However, once flow increases from fall rains, the electric barrier is effective at diverting fish into the trap. Although electric barriers can be a complete barrier to upstream passage (Andrew and Geen 1960), some may be rendered temporarily ineffective during floods and during power outages. Because of the ability to pass debris, they should remain operational during most high water events, although debris can get tangled in suspended probes.

Smith-Root, Inc. reports in their literature that with uniform water velocity and depth, their barrier works well for adult salmon and steelhead in velocities ranging from 2-10 fps. A Smith-Root, Inc. barrier was effective in preventing upstream migration of common carp and bigmouth buffalo based on mark-recapture studies (Verrill and Berry 1995). A portable system used in Alaska was operated 40-90% of the week for six weeks and captured 157 adult chinook salmon or about 2% of the run (Palmisano and Burger 1988). This barrier caused some injury and mortality. Estimates of relative mortality were made by comparing counts of dead fish below the electric barrier to fish tagged at the trap. Relative mortality averaged 47% using AC when the barrier was operated 72% of the time, and dropped to an average of 7% using DC when the barrier was operated 40% of the time. The percentage of fish killed by the electric field under DC dropped from 12% to 3% when the anode was placed perpendicular to the cathode.
Advantages: Some electric barriers have relatively low construction costs compared to most permanent barriers, but cost depends on the type of electric barrier and on characteristics of the site. Electric barriers described by Clay (1961) and Senn et al. (1984) can be easily installed and dismantled. Maintenance is low because most debris passes through suspended electrodes. Senn et al. (1984) reported the electric demand of a 100-ft electric barrier averaged approximately 300 watts per day, although electric demand varies with the number of electrodes and their submerged depth.

Submerged electric barriers do not catch debris or alter water flow through the site. They are not subject to damage from high flows or from ice flows. A graduated electric field using pulsed DC reduces injury and mortality to fish. Use of low frequency pulsed DC with very short pulse durations also increases the safety to workers and the public.

Disadvantages: Although construction costs at some sites may be low, other sites may require a large expenditure. Sufficient electric power must be available, which makes an electric barrier infeasible in some areas. Construction is generally needed to confine the stream as it flows through the electric field. For example, the Smith-Root, Inc. barrier requires laminar flow to ensure all areas of the barrier have equal and sufficient velocity from shore to shore and from top to bottom. Bank abutments are constructed to confine the stream and are built to handle 50-to 100-year floods.

Power outages and some flood conditions can render the electric barrier ineffective. Some maintenance may be needed with suspended electrodes to keep them adequately spaced and free of debris. Protective fencing and adequate warning signs and lights are essential to protect the public where an electric barrier is used. Because boat traffic must be kept from the area, electric barriers are not feasible in some streams. Electric barriers also pose potential hazards for personnel working in the area.

Electric barriers can injure or kill adult fish. An electric barrier at Nehalem Hatchery was discontinued because of injury and mortality to adult salmon (G. Yeager, ODFW, Nehalem Hatchery, 1993, personal communication). Flow at the barrier was believed inadequate to sweep stunned fish out of the electric field. Andrew and Geen (1960) reported similar problems at other sites. Injury to adult fish at the Three Rivers barrier has occurred during low flow in the fall. Little mortality has been observed or reported from anglers in an intensive fishery just downstream of the barrier (M. Traynor, ODFW, Cedar Creek Hatchery, 1993, personal communication). Pulsators used at the Three Rivers barrier require frequent adjustment to maintain a proper field, which is affected by alder leaves and branches collecting on the electrodes at low flow. Where natural spawning occurs upstream of the electric barrier, electric barriers should not injure juvenile fish or interfere with their downstream migration.

The Smith-Root, Inc. electric barrier addresses some disadvantages of electric barriers through a back-up system for power outages, submerged electrodes to reduce damage by debris, and graduated pulsed DC field to reduce injury to fish and to increase safety. However, the cost of construction, computer control system, pulsators, and auxiliary power source makes the system feasible only for permanent installations, such as at fish hatcheries.
ACTIVE METHODS

Electrofishing

Description: Electrofishing for adult salmonids can be done with boat-mounted or backpack electrofishing gear. Because backpack electrofishing is effective only in small streams and is labor intensive for capturing adult salmon or steelhead, this report will concentrate on boat electrofishing. Boat-mounted electrofishing gear can be operated from a motorized craft such as a jet boat, or from a non-motorized boat such as a drift boat. The gear usually consists of a power source (generator or battery), a variable voltage pulsator, two electrodes (anode and cathode), and a foot switch in the front of the boat to activate the electrical field. The boat is equipped with a live box to hold captured fish.

Various materials and shapes of anodes have been used including copper cables, metal rings (Newberg 1973; Fessler et al. 1976), aluminum rings with steel dropper electrodes (Novotny and Priegel 1974), flat plates (Kolz 1993), and metal cylinders or spheres (Martinez and Tiffan 1992; Kolz 1993). Kolz (1993) evaluated 18 electrode types and found that vertical plates projected the farthest electric fields. However, he cautioned that the choice of an electrode type is dependent on a variety of electrical and biological factors such as size of the power source, desired size and intensity of the electric field, electroshock response of the target species, and working conditions of the sample area. On aluminum boats, the electrofishing unit is sometimes grounded to the boat, which then acts as the cathode (negative electrode).

Because size of the electric field is determined in part by the distance between electrodes, the anode for boat electrofishing is usually suspended from a boom as far as possible from the boat (usually 3-5 ft) while still allowing the person in the front of the boat to reach stunned fish. Gear descriptions for boat electrofishing can be found in Newburg (1973), Novotny and Priegel (1974), Hooton (1978), and Reynolds (1983). Sharber and Carothers (1987) described a suspended live box for use with a catamaran electrofishing raft that shields fish from electric shock. Information on electrofishing equipment can be obtained from manufacturers (see APPENDIX B).

Two people are usually involved in electrofishing from a boat. One person rows or steers the boat and the other operates the foot switch and nets fish from the water with a long-handled dip net. The boat is maneuvered so that sampling is done perpendicular along the shore or over likely holding water. If adult salmon or steelhead are being captured for brood stock, additional people may be needed to help transfer fish from the live box of the boat to a tanker truck. Alternatively, fish can be temporarily held in PVC tubes or collapsible cloth tubes (see Angling), secured along the shore, then picked up with a tanker truck at the end of the sampling run.

Electrofishing units use either alternating current (AC) or direct current (DC) to create an electrical or power field in the water. Generally, DC is more effective in attracting fish to the anode at the least harm to the fish. Electrical power disrupts internal neural responses in the fish and elicits a muscular response (Kolz 1989). Fish respond by voluntary and involuntary reactions including a fright response, galvanotaxis (attraction to the anode), galvanonarcosis (stunned immobility with slack muscles), pseudo-
forced swimming (cramped swimming with the fish on its side), and tetany (rigid immobility; Vibert 1963; Kolz and Reynolds 1989). These responses can cause injury in fish (see Disadvantages), but injuries may be reduced by adjusting properties of an electric field such as pulse frequency (McMichael 1993; Sharber et al. 1994).

Areas of use: Electrofishing with boats to capture adult salmon and steelhead has been conducted on several rivers in Oregon including the Rogue (ODFW 1990); Applegate (Fustish et al. 1989); Deschutes (Fessler et al. 1976); Siuslaw, Yaquina, and Coos (Hooton 1978); Trask (Lindsay et al. 1989b); and the Siuslaw (Kenaston et al. 1990).

Early reports of electrofishing in the United States were by Burr (1931) and Haskell (1940). Electrofishing has been fairly common as a sampling technique since the 1950s. Early accounts of electrofishing from a boat were reported by Larimore et al. (1950), Meyers (1951), and Rollefson (1958, as cited in Novotny and Priegel 1974).

Effectiveness: Several factors affect electrofishing efficiency including factors related to gear (type of current, waveform, amount of power, size, shape, and number of electrodes), properties of water (resistance or conductivity, electrolytes, temperature), physical characteristics of the stream (velocity, depth, and clarity), and size and species of fish (Novotny and Priegel 1974; Heidinger et al. 1983; Novotny 1990; Kolz 1993). Burkhart and Gutreuter (1995) suggested that standardizing the power output of electrofishing (adjusted for differences in water conductivity and water temperature) can reduce the variability in catch of fish. Detailed information factors affecting electrofishing on fish is given in APPENDIX A.

Electrofishing can be effective for capturing salmon and steelhead, although salmon appear to be more susceptible to injury than steelhead (Fessler et al. 1976). The efficiency of capturing adult salmon and steelhead must take into account injury to the fish (see Disadvantages). Fredenberg (1992) and Snyder (1992) presented recommendations for electrofishing that balanced efficiency of capture and minimal injury to the fish. The catch and catch rate of electrofishing in Oregon to capture adult salmon or steelhead is given in Table 4.

Catch efficiency or capture probability with electrofishing gear generally increases with size of the fish (Zalewski 1985; Schroeder and Smith 1989; Thurow 1990; Anderson 1995) because large fish are more susceptible to electric shock than small fish (Taylor et al. 1957; Flux 1967; Ellis 1975). Although electrofishing gear is selective for large fish, little data have been reported on selectivity within the size range of adult anadromous fish. The mean length of adult steelhead in the Siuslaw River captured by electrofishing was not significantly different (P<0.05) from those captured in traps, although the electrofishing sample size was low (Table 5).
Table 4. Catch and catch rate (fish/day) of adult salmon and steelhead with boat electrofishing gear in Oregon.

<table>
<thead>
<tr>
<th>Species</th>
<th>River</th>
<th>Years of sampling</th>
<th>Average sample days</th>
<th>Average catch</th>
<th>Fish/d</th>
<th>Source¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter steelhead</td>
<td>Rogue</td>
<td>3</td>
<td>15</td>
<td>398</td>
<td>28</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Applegate</td>
<td>5</td>
<td>12</td>
<td>156</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Trask</td>
<td>1</td>
<td>4</td>
<td>9</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Siuslaw</td>
<td>1</td>
<td>11</td>
<td>10</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Summer steelhead</td>
<td>Deschutes</td>
<td>2</td>
<td>48</td>
<td>1,567</td>
<td>33</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Deschutes</td>
<td>2</td>
<td>--</td>
<td>335</td>
<td>--</td>
<td>6</td>
</tr>
<tr>
<td>Spring chinook</td>
<td>Deschutes</td>
<td>2</td>
<td>--</td>
<td>88</td>
<td>--</td>
<td>6</td>
</tr>
<tr>
<td>Fall chinook</td>
<td>Yaquina</td>
<td>1</td>
<td>26</td>
<td>187</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Siuslaw</td>
<td>1</td>
<td>14</td>
<td>97</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Coos</td>
<td>1</td>
<td>5</td>
<td>61</td>
<td>12</td>
<td>7</td>
</tr>
</tbody>
</table>


Table 5. Mean length (cm) and range of adult winter steelhead captured by traps, electrofishing gear, and angling gear in the Siuslaw River, 1990.

<table>
<thead>
<tr>
<th>Method</th>
<th>Mean length</th>
<th>Standard deviation</th>
<th>Range</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traps</td>
<td>67.6</td>
<td>4.7</td>
<td>59-82</td>
<td>151</td>
</tr>
<tr>
<td>Angling</td>
<td>67.0</td>
<td>5.7</td>
<td>56-75</td>
<td>9</td>
</tr>
<tr>
<td>Electrofishing</td>
<td>66.6</td>
<td>7.1</td>
<td>57-78</td>
<td>10</td>
</tr>
</tbody>
</table>

Advantages: Because electrofishing gear can be adapted for various sizes and types of boats, it could be used on a variety of streams. Voltage, pulse shape, and pulse frequency can be adjusted to help compensate for differences in stream characteristics. Sampling can be conducted near the mouth of rivers, thus capturing a representative portion of the run destined for various streams in the basin. Sampling can also be conducted throughout the run. Electrofishing can be used to collect information on run timing, migration patterns, contribution to fisheries, run size or escapement, length and age distributions, or other life history characteristics. Because
electrofishing does not require obstruction of the river channel, it can be conducted on fairly large systems during variable flows without impeding boat traffic. With adequate background information on holding pools, flow, and run timing, electrofishing can be conducted for short periods of time in select sections of a river.

Disadvantages: Electrofishing can be labor-intensive. For example, collection of chinook salmon on three Oregon coastal streams required an average of 60 person-days for each stream to collect an average of 86 fish per stream (Hooton 1978). An additional 22 person-days were required for maintenance and repair of equipment. In addition to the time required to collect fish, a minimum of two vehicles would be needed for a shuttle at the end of the sample section. Electrofishing in popular angling water could lead to public relations problems, especially if fish are accidentally killed or are perceptibly injured.

Electrofishing can kill or injure fish. Snyder (1992) contains an overview of studies on injury and mortality, and an extensive bibliography. Another extensive bibliography on electrofishing is by Burridge et al. (1990). When direct current is used, it causes spasmodic swimming toward the anode (galvanotaxis). Effective capture with electrofishing gear requires some level of galvanotaxis to enable samplers to net fish. However, spasms in the musculature of the fish can cause hemorrhage in the muscle tissue and dislocated or splintered vertebrae (Northrop 1967; Sharber and Carothers 1988; Fredenberg 1992; McMichael 1993; Sharber et al. 1994). Other less noticeable effects can be stress responses and behavioral changes (Horak and Klein 1967; Bouck and Ball 1966; Schreck et al. 1976; Mesa and Schreck 1989). Additional information on electrofishing injury is given in APPENDIX A.

A change in river conditions can reduce the effectiveness of electrofishing. For example, highly turbid water during freshets decreases the ability of the sampling crew to see and net fish. Also, the distribution of fish can change with increased flow, thus decreasing the ability to capture fish (Pierce et al. 1985). The efficiency of capturing chinook salmon in the Coos River declined sharply after fall rains began because fish no longer concentrated in holding pools (Hooton 1978). Although electrofishing can be conducted low in a river system, tidal influence may decrease electrofishing success because of fluctuations in depth and flow (Hooton 1978) and because of changes in water conductivity.

Gill Net

Description: Monofilament or multifilament gill nets have been used to capture adult salmon and steelhead in the Pacific Northwest for brood stock and for escapement estimates. A gill net is a single wall net with a float line at the top and a lead line on the bottom. The choice of mesh size, depth of net, and amount of flotation depends on the target species and on the physical characteristics of the stream. Mesh size is measured as the internal size of one side of the square (square mesh, bar, or half mesh) or as the internal length along a stretched square (stretch mesh or extension; Garner 1968; Lagler 1969). Hanging a net to the float and lead lines determines the
degree of looseness of a net when it is fished. Gill nets are usually hung with mesh openings vertically elongated in a diamond shape rather than in a square shape (Garner 1968). Some net manufacturers are listed in APPENDIX B.

Gill nets capture fish that swim partway through the net and are unable to back out or that entangle themselves in the net by their teeth, operculum, or fins. Gill nets can be fished in a fixed manner (set) or in an active manner (drift). Set nets depend on the active movement of fish. Set nets are usually attached to the bank on one end and anchored offshore on the other end (Baranski 1980). Generally, nets are set in an eddy where the current is low (Johnson et al. 1948; Baranski 1980). In small coastal streams of Oregon, gill nets were hung in holding pools between two block nets and fish were scared into the gill net by divers (T. Unterwegner, ODFW, Gold Beach, now John Day, 1993, personal communication).

Drift nets can be fished on the surface (floater) or on the stream bottom (sinker; Craig and Hacker 1940; Lagler 1969). They are usually drifted perpendicular to the current and can be attached to two power boats (Baranski 1980), to a buoy on one end and to a power boat on the other end (Craig and Hacker 1940), or to a power boat on one end and free on the other end (Hammarstrom 1980). A technique similar to seining has also been used in Oregon to capture adult salmon and steelhead (T. Unterwegner, ODFW, Gold Beach, now John Day, 1993, personal communication). One end of a gill net is attached to a power boat and the other end is walked downstream along a gravel bar. At the lower end of the gravel bar, the boat end of the net is brought ashore and the net is bagged. The gill net is kept loose during the drift to entangle fish and to prevent fish from breaking through the net. Casselman et al. (1990) described a method where a gill net was attached to a power boat and drifted parallel to the bank about 15-20 ft offshore while a second boat was rowed between the bank and the net. Fish were scared into the net by splashing the water surface with oars. Biggins and Cressey (1973) described a method using both a drift net and a stationary net at the downstream end of a hole. The drift net was moved downstream by two people, while a third person in mask and snorkel kept the net free of snags. Fish were crowded between the two nets and became entangled.

Areas of use: Gill nets have been used recently in Oregon to collect steelhead and salmon for brood stock (Chetco, Coos, Coquille, Siltcoos rivers, and Hunter and Tahkenitch creeks). Drift gill nets have been used to collect brood stock in Washington (Baranski 1980) and Alaska (Jones 1981; Wallis and Ballard 1984). Gill nets have been used to capture and tag adult fish for escapement estimates in Oregon (Morgan and Cleaver 1954a, 1954b; Korn 1961; Henry 1964; Morgan 1964), Washington (Mendler et al. 1956), and Alaska (Bentz 1984; Wallis and Ballard 1984; Sonnichsen and Alexandersdottir 1991).

Effectiveness: Effectiveness of gill nets depends on the purpose of capturing fish, such as brood stock collection or abundance estimate, and on the variability of the target species, such as fish size and run timing. Effectiveness of gill nets is affected by characteristics of the stream and the abundance of the target species (Washington 1973). The efficiency of gill nets also depends on location in the river, the proper mesh size, the proper hang of the net, and the skill in setting the net (Johnson et al. 1948; Hamley
1975). Baranski (1980) found the effectiveness of drift gill nets was most affected by the rate at which fish moved into the area being netted. However, he also reported that effectiveness was reduced by high flow (nets moved too quickly) and by low flow (nets moved too slowly), and was increased with high turbidity. Effectiveness of gill nets in lower reaches of coastal rivers can be decreased by tidal fluctuations (Johnson et al. 1948; Peterson 1954).

The selectivity of gill nets is related directly to size of fish (Peterson 1954; Lagler 1968; Hamley 1975) and to factors associated to size such as girth, state of ripeness, and behavior (Lagler 1968; McCombie and Berst 1969; Hamley 1975; Rudstam et al. 1984). Gill nets can also be selective for sex of fish, especially if sexual dimorphism is pronounced (Peterson 1954; Ward 1959; Hammarstrom and Larson 1984). The degree of selectivity is affected by mesh size, visibility of the net, elasticity of the mesh, thickness of the mesh, net construction, and method of fishing (Washington 1973; Hamley 1975; Collins 1979; Henderson and Nepsy 1992).

Evaluating effectiveness must also consider injury and mortality (Thompson and Hunter 1973). For example, of the three mesh sizes of drift gill nets used to capture chinook salmon in Alaska (5 1/8 in, 7 in, 8 in stretched), the 8-in mesh was most effective in capturing large adult salmon, but was more harmful to the fish than smaller sizes (Hammarstrom and Larson 1984). The 5 1/8 in net entangled rather than gilled most chinook salmon, but was selective to males and gilled other species of salmon. Measures of effectiveness (catch, catch rate, injury rate, etc.) for capture of adult salmon and steelhead in the Pacific Northwest are given in Table 6.

Korn (1961) felt that a set net was best for capturing winter steelhead in the Columbia River because fish could be removed from the net immediately without pulling the entire net and fewer fish were killed by seals in set nets than in drift nets. However, Baranski (1980) reported that drift nets were more efficient in capturing adult chinook salmon in the Skagit River. Drift nets captured about 11 fish per net per day compared to a catch of under two fish per net per day in set nets. Set nets rely on the movement of fish through specific areas whereas drift nets are actively fished in several areas of a river. Drift nets can fish more water and effort can be easily relocated to find concentrations of fish. Costs were higher for drift nets than for set nets because of frequent replacement of damaged nets and because of increased use of gas and oil in the power boats (Baranski 1980). However, the increased catch and efficiency of drift nets offset the higher costs.

Advantages: Gill nets can be fished near the mouths of rivers, thus representatively sampling fish below spawning tributaries. Adequate representation of the run can be ensured if sampling is conducted throughout the run. Capture of fish for brood stock or for tagging can be quite effective with gill nets once good sampling areas are located. Information on life history, run timing, length, age, harvest, abundance, and escapement can be obtained. Gill nets do not obstruct the river channel and can be fished in large river systems and during variable flows. Gillnetting may provide an alternative means of capture where construction of traps or electrofishing is unacceptable. The cost of sampling with gill nets is relatively low, especially when compared to other methods.
Table 6. Gill net catch and other statistics of salmon and steelhead captured for brood stock or tagging in the Pacific Northwest.

<table>
<thead>
<tr>
<th>Location</th>
<th>Year</th>
<th>Species</th>
<th>Number (%)</th>
<th>Catch/day/net</th>
<th>Mortality rate (%)</th>
<th>Injury rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drift</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alsea</td>
<td>1951</td>
<td>Co</td>
<td>1,142 (1.3)</td>
<td>--</td>
<td>1.3</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>1951</td>
<td>Ch</td>
<td>153 (3.2)</td>
<td>--</td>
<td>--</td>
<td>21</td>
</tr>
<tr>
<td>Columbia</td>
<td>1954-55</td>
<td>StW</td>
<td>655</td>
<td>--</td>
<td>5.2</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>1955-56</td>
<td>StW</td>
<td>1,481 (0.7)</td>
<td>--</td>
<td>7.2</td>
<td>--</td>
</tr>
<tr>
<td>Tillamook</td>
<td>1953</td>
<td>Ch</td>
<td>491 (3.2)</td>
<td>2.4</td>
<td>--</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co</td>
<td>255 (1.2)</td>
<td>1.1</td>
<td>--</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CS</td>
<td>325 (0.6)</td>
<td>2.5</td>
<td>--</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>StW</td>
<td>62 (0.8)</td>
<td>0.5</td>
<td>--</td>
<td>24</td>
</tr>
<tr>
<td>Siletz</td>
<td>1954</td>
<td>Ch</td>
<td>194 (4.1)</td>
<td>2.3</td>
<td>--</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Co</td>
<td>445 (2.9)</td>
<td>5.3</td>
<td>--</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CS</td>
<td>58</td>
<td>0.6</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>StW</td>
<td>63</td>
<td>0.6</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Grays</td>
<td>1954-55</td>
<td>StW</td>
<td>164 (2.1)</td>
<td>2.1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>1955-56</td>
<td>StW</td>
<td>185 (4.6)</td>
<td>1.9</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Skagit</td>
<td>1976-79</td>
<td>Ch</td>
<td>102</td>
<td>11.0</td>
<td>1-2</td>
<td>--</td>
</tr>
<tr>
<td>Kenai</td>
<td>1983</td>
<td>Ch</td>
<td>1,535 (5.0)</td>
<td>18.3</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Anchor</td>
<td>1983</td>
<td>St</td>
<td>133 (7.9)</td>
<td>3.0</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Set</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbia</td>
<td>1954-55</td>
<td>StW</td>
<td>182</td>
<td>--</td>
<td>9.3</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>1955-56</td>
<td>StW</td>
<td>1,775 (0.8)</td>
<td>--</td>
<td>6.0</td>
<td>--</td>
</tr>
<tr>
<td>Skagit</td>
<td>1975</td>
<td>Ch</td>
<td>116</td>
<td>1.8</td>
<td>6.0^g</td>
<td>--</td>
</tr>
<tr>
<td>L. Susitna</td>
<td>1983</td>
<td>Co</td>
<td>49 (0.8)</td>
<td>2.4</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

---

a References by location: Alsea - Morgan and Cleaver (1954a, 1954b); Columbia River - Korn (1961); Tillamook Bay - Henry (1964); Siletz River - Morgan (1964); Grays River - Wendler et al. (1956); Skagit River - Baranski (1980); Kenai River - Hammarstrom and Larson (1984); Anchor River - Wallis and Balland (1984); Little Susitna River - Bentz (1984).

b Species codes: Ch=chinook salmon; Co=coho salmon; CS=chum salmon; St=steelhead; StW=winter steelhead.

c Catch as a percentage of the estimated population.

d Estimated from information in "Methods" section of reports when not directly reported.

e Combined for drift and set nets.

f Average catch for period.

g Mortality when netting late in the run and after moving upstream. Mortality from netting and handling was much higher downstream and earlier in the run.
Disadvantages: Collection of adult salmon and steelhead with gill nets can be labor-intensive, especially during initial efforts. Gill nets must be attended to remove fish immediately upon capture to minimize injury and mortality. Gill nets can be injurious or fatal to fish, even if fish are immediately removed from the nets (Table 5). Thompson and Hunter (1973) reported the mortality of sockeye salmon that became enmeshed and then disentangled from gill nets was about 55-65% when compared to a control group. About half of this mortality occurred on the first day. In this experiment, fish were exposed to gill nets overnight, therefore it was not known how long the fish were actually tangled in the net. In several Oregon tagging studies, salmon and steelhead that had been injured or stressed from gillnetting and handling were recovered at a lower rate than netted fish that had been uninjured, but the difference was not significant (Morgan and Cleaver 1954a, 1954b; Henry 1964). However, seriously injured fish were not always tagged and some mortality occurred in the nets. Korn (1961) reported that a disadvantage of gill nets was because fish became tangled and suffered damage to fins and gills as well as loss of scales. Stress in salmon or steelhead caught in gill nets has not been evaluated, but Hopkins and Cech (1992) reported that striped bass caught in gill nets exhibited a greater stress response than those caught in hoop traps.

Gill nets are selective for size and sex of fish, thus sampling may be biased depending on the target species and on the size range of the run (Hamley 1975). Although gill nets can be used low in a river system, unacceptable rates of injury and mortality may occur if the fish are not adequately acclimated to fresh water (Baranski 1980).

Gill nets may not be very effective in large rivers that flood frequently because of the difficulty in fishing nets during high flows and the difficulty in finding adequate areas to net. Baranski (1980) reported that driftnetting was not effective in a large, broad river that did not have well-defined slots, runs, and holes. Gill nets may not be effective where run timing is extended over several months, where run size is relatively small, or where fish do not congregate in any discernible areas of the river. Use of gill nets to capture fish may also lead to public relations problems, especially if fish are killed or perceptibly injured upon release.

Seine

Description: A seine is a vertical net that is pulled through the water to encircle and capture adult fish. Seines used in rivers are called beach, drag, or haul seines. These seines are used where fish congregate in numbers that are high enough to meet the objectives of capturing fish, such as collection of brood stock or tagging for escapement estimates. The best sites for seining are holding pools with a relatively smooth bottom that is free of debris, with current slow enough to not collapse the bag or lift the lead line, and with a shallow riffle downstream of the hole to confine the fish.

The characteristics of a proper seine depend on the target species and on the physical nature of the sample site. A seine must have enough weight to keep the lead line on the bottom and enough buoyancy to keep the float line on the water surface when it is pulled at the maximum force. However, a seine
that is weighted too heavily will be hard to pull through the water and will hang up if the bottom is irregular. The seine should be about one-third longer than the width of the seining area and about one-third deeper than the deepest part of the hole. The extra length and depth assures that the seine is loose as it is pulled through the water and that a good bag is formed. A beach seine is hung with varying degrees of looseness to obtain a bag, with the wings stretched more along the float and lead lines than the center so the center pouches when the seine is fished (Garner 1968). Proper mesh size is important because mesh that is too small is harder to pull through the water, thus increasing the opportunity for fish to escape.

A 300-ft. seine used to capture adult salmon and steelhead on the Rogue River in Oregon varied from a 2-in stretched mesh in the bag to a 5-in stretched mesh on the wings (ODFW 1991). The depth of this seine also varied from 18 ft in the bag to 9 ft on the outside edge of the wing panel (ODFW 1991). The seine was coated with a black net tar to decrease wear, to reduce water absorption of the net, and to reduce injury to fish by making the net surface smoother. Some net manufacturers are listed in APPENDIX B.

Seining encircles fish, leading them along the sides or wings and into the center of the seine as the net is bagged. Seines are laid out from the upstream end of the sample site, usually with a boat. The net is first laid out perpendicular to the bank and is then swept downstream to form a crescent, with the opening downstream. After the net is brought to shore, both ends are brought together and the net is drawn in until the lead line is on the shore. Fish move along the sides of the seine and into the center bag as the net is brought onto shore. The seine must be brought in quickly enough to maintain a bag, but not so fast as to the lift lead line off the bottom.

A variation of seining that also combines properties of electrofishing is the electric seine. Electric seines have been used principally in eastern and midwestern United States (Bayley et al. 1989; Angermeier et al. 1991). These seines have been used on relatively small streams for species composition or population densities of fish assemblages (Bayley et al. 1989; Angermeier et al. 1991). No reports were found on the use of electric seines to capture adult salmon or steelhead.

Areas of use: The principal areas where seines have been used recently in Oregon to capture adult salmon and steelhead are in the Rogue River (ODFW 1991; ODFW 1992; ODFW 1994) and in the Chetco River. Seining was previously used to capture steelhead in the Deschutes River (Fessler 1971) and in the Rogue River (Everest 1973). Seining has also been used to capture adult salmon and steelhead in British Columbia (Ward 1959; Vernon et al. 1964) and in Alaska (Jones 1981; Wallis and Ballard 1981; Bentz 1984).

Native Americans used a type of seine to capture adult salmon in the Columbia River below Celilo Falls (Craig and Hacker 1940). Commercial seining for salmon and steelhead occurred historically on the Columbia River, where teams of horses were often used to land the seines (Johnson et al. 1948; Donaldson and Cramer 1971).
Effectiveness: The effectiveness of seining depends on stream and site characteristics, proper mesh size and hang of the net, skill in setting and retrieving the seine, and abundance and run timing of the target species. Seines work best when fish can see the net and are led along the wings into the bag. Consequently, seines are most effective when the water is fairly clear (Johnson et al. 1948). Seining efficiency for coho salmon in the Rogue River was negatively related to flow above 1,700 cfs (ODFW 1991). Catch of adult salmon and steelhead in several rivers of the Pacific Northwest is given in Table 7.

Based on a comparison of commercial seine catch in the Columbia River to gill net catch, seines appeared to be most effective in capturing steelhead (accounting for 40% of the combined gill net and seine catch), moderately effective for chinook, coho, and sockeye salmon (accounting for about 20% of the catch), and least effective for chum salmon (accounting for 7% of the catch; Johnson et al. 1948). The efficiency of seine catches in the Columbia varied because of changes in migration routes of fish and changes in physical characteristics of seine sites (Johnson et al. 1948). The efficiency of seining was also least effective during spring because of high flows. Therefore, seining was less effective for spring chinook and sockeye salmon than for fish migrating in summer and fall (Johnson et al. 1948).

Table 7. Capture of salmon and steelhead with beach seines for brood stock or tagging in the Pacific Northwest.

<table>
<thead>
<tr>
<th>River</th>
<th>Years</th>
<th>Species</th>
<th>Number</th>
<th>Percent</th>
<th>Catch/set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraser</td>
<td>1957</td>
<td>PS</td>
<td>12,910</td>
<td>0.5</td>
<td>52</td>
</tr>
<tr>
<td>Fraser</td>
<td>1959</td>
<td>PS</td>
<td>10,356</td>
<td>1.0</td>
<td>--</td>
</tr>
<tr>
<td>Glendale</td>
<td>1961</td>
<td>PS</td>
<td>1,856</td>
<td>1.1</td>
<td>--</td>
</tr>
<tr>
<td>Rogue</td>
<td>1969-70</td>
<td>SLS</td>
<td>8,810</td>
<td>5.3d</td>
<td>4.4d</td>
</tr>
<tr>
<td>Rogue</td>
<td>1976-91</td>
<td>Co</td>
<td>120d</td>
<td>2.9d</td>
<td>0.4</td>
</tr>
<tr>
<td>Rogue</td>
<td>1976-91</td>
<td>ChF</td>
<td>963d</td>
<td>2.2d</td>
<td>1.4</td>
</tr>
<tr>
<td>Rogue</td>
<td>1976-91</td>
<td>StS</td>
<td>420</td>
<td>2.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Deschutes</td>
<td>1969-70</td>
<td>StS</td>
<td>103</td>
<td>--</td>
<td>0.3</td>
</tr>
<tr>
<td>Chetco</td>
<td>late 1980s</td>
<td>ChF</td>
<td>--</td>
<td>--</td>
<td>30-200</td>
</tr>
</tbody>
</table>

a References by river: Fraser 1957 - Ward (1959); Fraser 1959 and Glendale - Vernon et al. (1964); Rogue 1969-70 - Everest (1973); Rogue 1976-91 (coho) - ODFW (1991), Satterthwaite (1992); Rogue 1976-91 (chinook) - ODFW (1992), Satterthwaite (1992); Rogue 1976-91 (steelhead) - data from Tom Satterthwaite, ODFW, Grants Pass; Deschutes - Fessler (1971); Chetco - personal communication, Timothy Unterwegner, ODFW, Gold Beach (now at John Day).

b Species codes: ChF - fall chinook salmon; Co - coho salmon; PS - pink salmon; SLS = summer steelhead.

c Catch as a percentage of the estimated population.

d Estimated from data in the report.
Advantages: Adult salmon and steelhead can be seined below spawning tributaries, therefore the entire run can be representatively sampled if seining is conducted throughout the migration. Seining effectively captures fish for brood stock or for tagging if good sampling areas are available. Information on life history, run timing, length, age, harvest, abundance, and escapement can also be obtained. Cousens et al. (1982) reported that beach seines have minimal selectivity for size or sex of fish. However, factors such as size distribution of the species and variability in flow at the seining site might increase size selectivity. Seining does not obstruct the river channel and can be conducted on large river systems. Seining may provide an alternative means of capture where construction of traps or electrofishing is unacceptable. Under the right conditions, the cost of seining can be relatively low, especially when compared to other methods.

Disadvantages: Seining can be labor-intensive, particularly when conducted over the span of the run or during initial efforts. However, use of volunteers has reduced the cost of collecting chinook salmon brood stock in the Chetco River (T. Unterwegner, ODFW, Gold Beach, now John Day, 1993, personal communication). Variable environmental conditions, including flow and physical characteristics of a seine site, can alter the effectiveness of capturing fish (Johnson et al. 1948; ODFW 1991; Satterthwaite 1992). Seining can be selective for segments of a run if seining efficiency varies with flow. For example, adult chinook salmon congregate at a seining site on the Chetco River only until the first major freshet (T. Unterwegner, ODFW, Gold Beach, now John Day, 1993, personal communication).

The effectiveness of seines depends on river characteristics and run size of the target species. Seines may not be effective in large rivers that flood frequently because of difficulty in seining during high flows and because of inadequate areas to seine. Seining may not be effective where run timing is extended over several months, where run size is relatively small, or where fish do not congregate in any discernible areas of the river. Use of seines to capture fish may also lead to conflicts with anglers.

Angling

Description: Angling with conventional sport fishing gear to capture adult salmonids has been extensively used in British Columbia to collect steelhead for brood stock. Most of these programs require less than 50 fish. Use of professional guides generally provides the best results and fishery agencies occasionally contract with a few guides to collect a specified number of fish. Other volunteer anglers also assist in collecting fish. When contracted guides are used, they work directly with hatchery personnel after fish have been caught, thus minimizing the time biologists spend on the collection program. Most of the sites in British Columbia are accessible by boat or road, although some are reached by helicopter.

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1 Unless otherwise cited, information on angling is from personal communications, June 1993 with Rick Axford (Nanaimo) and Robert Hooton (Smithers), Ministry of Environment and Parks, British Columbia.
After fish are caught, they are temporarily held in the river or are put directly into a transport tanker. Fish held in the river are placed in a holding tube or holding pen. Holding tubes can be made of soft material or PVC pipe. Zippered, collapsible tubes made of soft material have been used for steelhead in British Columbia. A stainless steel ring and knotless netting is sewn into each end to maintain the shape of the tube and to ensure a good flow of water. The zipper runs lengthwise to provide easy access. These tubes have been made by project personnel or are available commercially (see APPENDIX B). Tubes of PVC pipe (Figure 17) have also been used to hold and transport fish in Oregon (Kenaston et al. 1990), Washington (Mongillo 1984), and British Columbia (Mongillo 1984; Senn et al. 1984). The length and width of the tubes varies according to the size of the fish. A 6-in diameter x 40-in long tube was used to hold adult winter steelhead on the Siuslaw River in Oregon (Kenaston et al. 1990). Squares of clear acrylic were used as gates on the ends of the tube, and were drilled with several 1-in diameter holes to allow water to flow through the tubes. One gate was removed to place fish in the tubes. Captured fish have also been tethered by passing a cord along the inside of the operculum, through the mouth, and tied to the lower jaw (Baranski 1980; Senn et al. 1984). The tethers are made of braided nylon line and have a section of rubber spliced in the center to allow play in the line (Baranski 1980). Fish are tied in quiet water to an overhanging branch.

Fish can be held in a hatchery trough in bundled tubes (Senn et al. 1984) or they can held in individual tubes suspended from a floating rack (Figure 17; Kenaston et al. 1990). Fish can also be held in net pens, which are floated to a spot where fish are loaded in a tanker (Senn et al. 1984).

Areas of use: The most extensive use of angling to capture steelhead has been in British Columbia. In addition to brood stock collection, steelhead have also been captured for tagging by using conventional angling gear (Caverhill 1977; Hooton and Lirette 1986). Angling for brood stock has been recently used in Oregon on the Necanicum River and on the Walla Walla River to collect steelhead. Angling was also tried briefly in the Hood and Siuslaw rivers to collect steelhead, but was dropped because of high mortality and because more efficient means were available. Angling for brood stock has also been used in Washington (Mongillo 1984). Angling has been used in Alaska to tag steelhead (Jones 1981; Wallis and Ballard 1981; Begich 1992) and coho salmon (Bentz 1984), and in Idaho to tag steelhead (Thurow 1987).

Effectiveness: The effort required to capture fish by angling varies with fishing conditions, such as flow and turbidity. Flow affected the catch of steelhead and chinook salmon in the Rogue River (Cramer et al. 1985; ODFW 1990; ODFW 1992), winter steelhead in the Applegate River (Fustish et al. 1989), and winter steelhead in the Grays River, Washington (Wendler et al. 1956). When fishing conditions are good, some guides in British Columbia have been able to fish a single day each week for a few weeks to capture enough fish for brood stock. To collect 40 adult steelhead in the Cowichan River, British Columbia, a two-person crew spent 150 hours angling, plus 53 hours in travel and 8 hours in transport of fish. Capture of 40 fish in the Nanaimo River, British Columbia, required 140 hours of angling and 13 hours of travel for two people. A brood stock collection in British Columbia that required a helicopter took four people two days to catch 20 steelhead.
In addition to flow, the effectiveness of angling gear in capturing adult salmonids is influenced by the abundance of fish. Catch of adult salmonids and angler success increased with increased abundance for spring chinook and summer steelhead on the Rogue River (Cramer et al. 1985), for winter steelhead on the Rogue River (ODFW 1990), and for spring and fall chinook on the Deschutes River (Jonasson and Lindsay 1988; Lindsay et al. 1989a). Shadbolt (1993) also reported that catchability of salmon increased with increased abundance. However, others have reported that the catchability of fish decreased as abundance increased (Peterman and Steer 1981; ODFW 1992).

On some rivers in British Columbia more effort was required to capture wild steelhead for brood stock after a hatchery run was established. Success in catching wild steelhead decreased because they represented a small percentage of the run. The catch of wild steelhead for two anglers was just one fish for every two days of angling on some rivers with large hatchery runs.

Effectiveness of angling to capture adult salmonids must consider injury and mortality. Hooking mortality of steelhead captured in British Columbia has been 3-5%, and sometimes no fish are lost even when they are held for several months before spawning. Hooton (1987) reported that mortality was under 4% for over 3,700 steelhead caught and held for brood stock. In another detailed study of hooking mortality on the Keogh River, the mortality for combined types of terminal gear was 5% (Hooton 1987). The survival through spawning of steelhead that were caught and released was 5% lower than that of steelhead captured at a weir (Hooton 1987). The holding mortality of summer
steelhead caught in the Coquihalla River, British Columbia, and held for up to five months averaged 1% (Caverhill 1977). Mortality of chinook salmon caught and released in the Kenai River, Alaska, ranged from 4% to 11% over three years, with small males having the highest mortality compared to large males and all females (Bendock and Alexandersdottir 1993).

In a review of hooking mortality studies on salmonids, Mongillo (1984) found that mortality of wild salmonids hooked with artificial lures was under 10%, and that wild fish had a higher rate of mortality than hatchery fish. Taylor and White (1992) reported that the overall hooking mortality in 18 reviewed studies was about 12%, and decreased to under 3% with use of barbless flies or lures. Mortality of steelhead caught with angling gear and tethered before transport was higher than for steelhead that were caught and placed in tubes (Mongillo 1984). Reingold (1975) found that hooked and released steelhead returned to a hatchery site in numbers roughly equal to a control group. Pettit (1977) reported that the reproductive success of caught and released steelhead was similar to a control group.

The above data indicate a relatively low mortality of fish caught and released by anglers, however mortality may be a problem in some areas. Although the sample size was small (n=9), the holding mortality of winter steelhead caught by anglers in the Siuslaw River was almost 70%, and was much higher than a small sample of fish (n=5) collected by electrofishing (0%) or a large sample of fish (n=73) collected in traps (8%; Kenaston et al. 1990). The angler-caught fish died after an average of 17 days. The holding mortality of winter steelhead caught by anglers in the Hood River was over 70% (n=18) and occurred from five days to several weeks after capture, although poor water quality of the holding pond may have affected survival (S. Pribyl, ODFW, The Dalles, 1993, personal communication).

When fish are injured from angling, most mortality appears to occur within 1-6 days. Most mortalities of chinook salmon caught and released in the Kenai River, Alaska, occurred within 72 hours (Bendock and Alexandersdottir 1993). Mortalities of hatchery rainbow trout played to exhaustion and released occurred within 2-6 days and increased with increasing water temperature (Dotson 1982). Fish that are exhausted or less seriously injured may die in a week to 10 days (Mongillo 1984). Ferguson and Tufts (1992) reported that exposure to air presented an additional stress to exhausted rainbow trout and led to increased mortality after 12 hours, when compared to a control group or to fish that were exhausted, but not exposed to air. Taylor and White (1992) examined several studies on hooking mortality and reported no significant relationship between mortality and water temperature, but a significant relationship between mortality and age size of the fish (the longer the fish, the higher the mortality), although data on fish size was limited. Most studies on hooking mortality of salmonids with conventional angling gear have been conducted on fish smaller than adult salmon and steelhead (for reviews see Wydoski 1977; Mongillo 1984; Taylor and White 1992).

Little data have been reported on selectivity of conventional angling gear as a capture technique for adult salmonids. The mean length of adult steelhead captured in the Siuslaw River was similar among three methods of capture, although some of the sample sizes were small (Table 5). Warner and Johnson (1978) reported that land-locked Atlantic salmon caught by angling
were somewhat smaller than fish caught in a fishway trap. Warner (1978) reported no significant difference in lengths of Atlantic salmon between those caught by angling and those caught by trap nets. Schroeder and Smith (1989) found the mean length and length distribution of rainbow trout ≥31.0 cm was not significantly different between captures by angling and electrofishing. However, Favro et al. (1986) reported that more brown trout over 33 cm and more rainbow trout over 25 cm were caught by angling than by electrofishing.

Selectivity of angling gear depends on the range and the variability of fish size in the target population. Selectivity may be reduced when sampling adult anadromous fish because even small fish are relatively large. Some of the largest individuals in a population may not be representatively sampled by angling because of difficulty in landing these fish. Size-selectivity of fishing gear has been reported by Leclerc and Power (1980), Ralston (1990), and Kenchington (1993). However, others found no selectivity of fishing gear (Pope et al. 1975; Ralston 1982).

Advantages: Conventional angling gear can be used low in a river system, thus sampling a representative portion of the run. In some cases, a small amount of effort over a short period of time may be sufficient to capture adults. Use of volunteers, guides, or contracted individuals can reduce the amount of time and expense that agency personnel must spend on brood stock collection programs. If fish are handled properly and catch rate is sufficiently high, angling is a good method of collecting fish for small brood stock programs. Involvement of the public can increase the awareness of an agency’s goals and provide opportunities for good public relations.

Disadvantages: Angling for brood stock has been used mainly to capture steelhead for small brood stock programs. Most brood stock programs that rely on angling to capture steelhead are conducted over a relatively short period of time. Effort would increase if fish were captured over the course of a run to representatively sample the population. Supervision and reliability of volunteers could pose a problem in some cases. Although most studies report low rates of injury and mortality caused by angling, these could be a problem in some cases and should be monitored. The effort required to collect wild fish may increase if they represent a small percentage of the run or if fishing pressure is high and wild fish are caught and released by anglers before they are collected for brood stock. Success of angling is highly dependent on water conditions and on the size of the run. Angling can be selective for fish size, run timing, and sex and should be evaluated before this technique is chosen.
ACKNOWLEDGMENTS

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APPENDIX A

Detailed Information on Some Capture Techniques

Vertical Picket Weir

Tripods are the most common support for vertical picket weirs. The single leg of the tripod is angled upstream from the pivot point. This leg can be wood, such as 4 x 4 in lumber, square steel tubing, or a metal pipe (Anderson and McDonald 1978). The horizontal railings of the weir are attached to this single leg. The two rear or downstream legs connect to the top of the front leg such that the legs can be collapsed or removed for easier transport. The legs can be constructed of wood, and can be a single piece or two pieces to allow better adjustment to the stream bottom (Anderson and McDonald 1978). Usually wood stringers are attached between the three legs of the tripod to provide stability.

Adjustable rear legs were used on tripods of a vertical picket weir to trap steelhead in the Siuslaw River basin. The legs were constructed of two sizes of drilled square steel tubing with the shorter, smaller tubing fitted inside the larger (stationary) tubing. The legs were pinned in place with a bolt after they were adjusted to the stream bottom (Appendix Figure A-1). The upper sections of both legs were welded at the top onto a short piece of angle iron. The front leg of the tripod was 4 x 4 in lumber, 8 ft long, which rested on the angle iron and was held in place by a lag screw (Appendix Figure A-1). A metal strap was welded between the two legs to provide additional stability. Tripods have been further modified by using 2 x 2 in metal tubing for the front leg and welding the rear legs directly to the front leg (Appendix Figure A-2).

Several means have been used to secure the weir supports and prevent downstream movement. Cables can be attached to the weir at each tripod and attached to large trees on the bank. Chain or cable wrapped around each tripod can also be attached to hooks or anchors set in the substrate upstream of the weir. The latter method reduces debris buildup on the cables and provides attachment points that are directly upstream of the weir. Platforms can be constructed between the tripod legs on which rocks or sandbags are piled to provide counterweight to the force of floodwater (Anderson and McDonald 1978). Boulders or sandbags can also be placed against the rear legs to keep them from sliding. The leg supports may be attached to an apron, although an apron is not constructed with most vertical picket weirs. Where bedrock is present, timbers (e.g., 4 x 6 in) can be pinned to the stream bottom by drilling into bedrock, setting a threaded rod with special glue (e.g., Hilti glue), and bolting the timber to the stream bottom to form an attachment sill. The single, upstream leg of each tripod support is attached to the sill with a bracket and lag bolt, which provides an anchor for the weir.

Railings are attached to the upstream leg of the tripod and are drilled or punched to accept metal bars or tubing. Railings are attached to the tripod with lag bolts (for wood legs) or with U-bolts (for metal legs;
Railings can be angle iron, channel iron, or channel aluminum (Schmidt 1984). The holes should be oversized to allow pickets to be inserted and removed with ease. Railings should be as level and as parallel as possible to make installation of the pickets easier (Appendix Figure A-3). The number of railings used in the vertical plane depends on the length and the flexibilty of the pickets. The bottom railing should be relatively close to the stream bottom (e.g., 6-12 in) to minimize the side-to-side play of individual pickets, thereby minimizing the chance that an adult salmon or steelhead can push through the pickets. Additional railings are spaced above the bottom railing such that the pickets cannot be easily spread by the force of water or by fish trying to squeeze through the weir. For example, Schmidt (1984) reported that some adult coho were gilled in a picket weir at high water because fish were jumping at the midpoint between two railings where the pickets had enough play to be spread apart by the fish.

After railings are attached to weir supports and cables are attached, pickets are inserted through the holes in the railings. Care should be taken to ensure the pickets are on the bottom and that no pickets have been bent at the bottom. Wire mesh fencing or similar material may be needed to seal the area between the end of the weir and the shore.

Appendix Figure A-1. Metal tripod with adjustable rear legs and wood front leg used with vertical picket weirs in the Siuslaw River, Oregon, 1993.
Appendix Figure A-2. Metal tripod with adjustable rear legs and metal front leg used with vertical picket weirs in the Siuslaw River, Oregon, 1995.

Appendix Figure A-3. Vertical picket weir on Nelson Creek, Oregon, with punched channel iron rails and metal tripods, 1995.
Panel Weir

Supports for panel weirs can be vertical, such as pipe (Hill and Matter 1991) or fence posts driven into the substrate at each end of the panel. Supports can also be sloped downstream such as tripods or A-frames. These sloped support structures can be wooden tripods (Summer 1953), steel tripods (Nelson 1976), freestanding wooden A-frames joined by stringers (Kerswill 1971), or wooden A-frames attached to an apron platform (Clay 1995; see also Hunter 1954; Craddock 1958).

Panel frames can be wood or angle iron, and pickets for weir panels have been constructed of steel pipe, steel rod (Kerswill 1971; Clay 1995), aluminum tubing (Nelson 1976); electrical metal conduit (Hill and Matter 1991), wooden dowels (Senn et al. 1984), or wooden slats (Hunter 1954; Clay 1995). Pickets are usually attached to the panel frame (welded or nailed). Hill and Matter (1991) described a panel design in which pickets made of tubing were slid into holes in the wooden panel frames after the frames were installed in the stream.

A panel weir used to trap adult steelhead in the Siuslaw River, Oregon, was constructed of 1 x 1 in angle iron frames with pickets of 3/4-in diameter metal pipe flattened on the ends and welded horizontally to the inside of the frame (Appendix Figure A-4). Two metal straps were welded vertically on the outside of the frame and the pickets to reduce play in the pickets (Appendix Figure A-4). The panels measured 3.5 x 6 ft.

Individual panel frames can be held together by cables (Hill and Matter 1991), attached directly to the supports (Hunter 1954), or attached to stringers that run between the supports (Kerswill 1971; Nelson 1976; Clay 1995). Individual panels of the weir used on the Siuslaw were joined by welding two offset sections of tubing (3 in) on each end of the panel (Appendix Figure A-4). When the panels were abutted, a rebar pin was passed through the offset tubing to hold the panels together. Weir panels were attached to the trap in a similar manner.

Clay (1995) described a trapping method that combined features of a panel weir and a horizontal weir. Vertically oriented panels constructed of steel bars were supported by concrete piers and steel beams between the piers. In addition, horizontal panels extended from the top of the vertical panels and sloped slightly downward in a downstream direction. These horizontal panels prevented fish from jumping over the vertical panels as the water approached the top. When water crested the vertical panels, much of the debris was swept off the horizontal panels. This design resulted in less cleaning than if taller vertical panels had been used.

Horizontal Picket Weir

A horizontal picket weir used on the Siuslaw River was constructed of two punched rails, metal pickets, and supports for the downstream rail. The upstream rail of the weir was bolted to stoplogs that were installed on a concrete sill (Appendix Figure A-5). The downstream rail was initially suspended horizontally above the stream by cables. The weir was later supported by several monopods bolted to the underside of the downstream rail. The monopods were adjustable and were similar in construction to the
adjustable rear legs of tripods used for vertical picket weirs (see Vertical Picket Weir). Advantages of the monopods over cable were that debris was more readily swept off the weir rather than caught in cables and the monopods were easier to install than cables. Steel pipe was slid through holes in the railings to form a barrier. The pipes were flattened on the upstream end to prevent them from sliding through the upstream railing.

Several modifications have been made to the horizontal weir since 1991. The overall length of the weir was shortened from 20 ft to 7 ft, the railings were changed from angle iron to channel iron, and the trap was moved to the upstream side of the sill. With the help of volunteers, a concrete platform and retaining wall was constructed on the upstream side of the sill to serve as the floor and one side of the trap (Appendix Figure A-6). A trap of steel panels was constructed and held in place by horizontal braces attached to the top of the panels and to the concrete retaining wall (Appendix Figure A-7). The downstream set of panels included a V-shaped fyke in the middle. The panels set into a preformed channel in the concrete floor (Appendix Figure A-6). A locking lid of 3/4-in plywood covered the trap.

Appendix Figure A-4. Detail of panel for panel weir showing welded sections of tubing used to attach panels together.
Appendix Figure A-5. Horizontal picket weir on Whittaker Creek (Siuslaw River), Oregon, showing attachment of upstream railing to stoplogs on top of the concrete sill, 1990.

Appendix Figure A-6. Concrete pad and retaining wall for floor and side wall of adult steelhead trap on Whittaker Creek, Oregon, 1992. Note deeper section in floor to retain more water in low flow and channel along outside edge of floor for setting picket wall panels (see Appendix Figure A-7).
Appendix Figure A-7. Adult steelhead trap on Whittaker Creek, Oregon, with picket wall panels and metal framing for wall support and plywood lid, 1992.

Traps

A common design of a trap used in conjunction with a picket weir is a square or rectangular box cage with a V-shaped fyke leading into the trap. These traps can be constructed of wood (Craddock 1958; Mullins et al. 1991; Clay 1995), wood frame and wire mesh (Anderson and McDonald 1978), wood frame and steel rod (Kerswill 1971), or metal (Whelan et al. 1989). The walls of the trap are usually constructed of prefabricated panels. Trap designs can be found in Craddock (1958), Anderson and McDonald (1978), Whelan et al. (1989), Mullins et al. (1991), and Clay (1995). A lead from the sloped vertical picket or panel weir to the trap can be constructed of wire mesh screen (Craddock 1958; Anderson and McDonald 1978), fencing material, or material similar to the weir pickets (Clay 1995). The floor of the trap can be constructed of boards (Kerswill 1971), wood laths (Anderson and McDonald 1978), steel grating (Whelan et al. 1989), or wood straps (Mullins et al. 1991). Unless the weirs have persons on site, a locking lid is usually installed on the trap to prevent poaching of adult fish.

Traps for vertical picket weirs in Alaska are often 8 x 8 ft enclosures constructed of railings and pickets that extend upstream from the vertical picket weir (Schmidt 1984). The stream bottom acts as the floor of the trap and the trap has no lid. In areas where the stream substrate is erosive, erosion cloth (Mirafi brand) is used as a floor (F. Burgander, ADFG, Commercial Fisheries Division, Juneau, 1993, personal communication). A triangular lead of 2 x 6 in framing covered with wire mesh is attached to the tripod and the downstream corner of the trap. In streams with fast water velocity, a few pickets are removed to create the opening into the trap, but where water velocity is slow, a V-shape fyke is constructed (F. Burgander, ADFG, Commercial Fisheries Division, Juneau, 1993, personal communication).
A metal trap with interlocking panels was used in conjunction with both vertical picket and panel weirs to capture adult winter steelhead in the Siuslaw River basin. Angle iron (1 x 1 in) was bent and welded to form 6 x 3 ft wall frames and a 6 x 6 ft floor frame. The floor can be either solid, such as plywood bolted to the angle iron framing, or picketed similar to the walls. The walls were the same construction as weir panels with tubing flattened on the end and welded horizontally to the angle iron frame (Appendix Figure A-4). Four short sections (3 in) of metal tubing were welded to the outside of the floor frame on the upstream and downstream sides (two per side), and to the outside framing of the side walls (Appendix Figure A-4).

Eight-inch pieces of steel rod were bent into U-shapes and one arm of the "U" was welded to the bottom and to the sides of the upstream and downstream wall frames (six per frame). The free arm of the "U" hooks welded on the sides of the frames pointed upward. These "U" hooks were welded so they lined up with the tubing on the floor frame and the side walls. Installation in the stream first required finding a fairly level area for the floor. The upstream and downstream walls were then attached to the floor by inserting the free arm of the "U" hooks on bottom of the walls into the corresponding tubing on the floor frame. Then the side walls (with tubing welded on the outside framing) were slid onto the free arms of the "U" hooks on the outside framing of the upstream and downstream walls. The walls were secured to each other with hose clamps and a hinged lid was bolted to the top of the side walls and the upstream wall.

A second design used to trap adult winter steelhead in the Siuslaw River was constructed of two 1 x 1 in angle iron frames that were welded to 4-ft sections of 1-in square tubing to form the top and bottom frames of the trap (Appendix Figure A-8). Additional angle iron was welded halfway between the top and bottom frames on the sides and on the upstream side to provide strength. The angle iron was punched to accept 1-in metal tubing. The tubing was inserted through the angle iron after the trap had been placed and cabled in the stream (Appendix Figure A-3).

Floating or Resistant Board Weir

A commercially available floating weir is manufactured in Japan and sold in the United States through Mitsubishi International (see APPENDIX B). This weir is composed of individual panels that are about 3 ft wide and 12-16 ft long depending on the size of the stream (Appendix Figure A-9). The panels are composed of pickets made of hollow PVC pipes. The PVC pipe has a slick surface and has a bullet-like shape that efficiently passes water. The PVC pipes are connected to wood braces by steel straps. The steel straps, which maintain the spacing of the pickets, are attached with wood screws to the wood frame on the underside of the panel (Appendix Figure A-10).
Appendix Figure A-8. Trap frame for vertical picket weir used in the Siuslaw River, Oregon. Angle iron is punched to accept metal tubing pickets.

Appendix Figure A-9. Floating weir panel showing resistant board with extra flotation and attachment clamps (right side of photograph).
Appendix Figure A-10. Underside of a floating weir panel showing resistant board in the foreground (without extra flotation) and wood framing, Aberdeen Hatchery, Washington.

C-shaped shackles on the upstream end of the weir panels are used to attach the panels to a cable or to a sill (Appendix Figure A-9). Panels of a Washington Department of Fish and Wildlife weir are attached to the top of a submerged sill with a stainless steel rod that is pinned to the shackles. The rod is then inserted into C-shaped steel holders that are welded on the sill cap. The open ends of the C-shaped holders face upstream and the force of the water helps hold the steel rod in place. Other floating weirs are attached to a steel cable on the stream bottom or on top of a sill. Panels are attached to the cable by a C-shaped shackle or can be attached with a climbing carabiner clipped to the cable and to the shackle, which allows the weir to more easily pivot. In the latter case, rubber conveyor belt is used to seal between the end of the weir panel and the cable. Weir panels are connected to each other by inserting a round PVC pipe through offset rings on the side of the panels and securing it with set screws (Appendix Figure A-11).

A resistant board, which floats the panel, is attached near the top of the panel and is roughly 1 ft wide (Appendix Figures A-9 and A-10). The board is attached to the panel with hinges and then hooked in place with a wire extending back to the next lateral wood crosspiece. Water filters through the PVC pipes and pushes against the resistant board until the wire is taut. The angle of the resistant board to the weir is set by the length of the wire, and this angle plus the placement of the board along the length of the panel determines the range of flows at which the weir will float.
Appendix Figure A-11. Attachment of two floating weir panels with round PVC pipe inserted through offset rings and held by set screws.

A floating weir developed by Alaska Department of Fish and Game¹ is similar to the Japanese model, but uses round PVC pipe and flexible plastic strap to attach the pipe to the lateral wood braces. The panels measure 4 x 20 ft and the braces are 2 x 2 in. The upstream end of the panel is a steel plate attached to a 2 x 4 in brace. Pickets are Schedule 40, round PVC electrical conduit (1 in diameter), are filled with foam, and are capped on both ends. The pipes are spaced at 1.5 in for chinook salmon and are held in place by plastic straps that are attached to the lateral wood braces with hex-head screws. Panels are attached to each other in a manner similar to the Japanese model and a resistant board is attached toward the downstream end of the panel. The boards are generally set at 45° to the panel and are about 3 ft from the end of the panel. Weir panels are attached to a steel cable with hooks on the upstream end of the panels. Cable is strung through eye bolts welded on top of railroad rails or set on top of a concrete sill. Wire hardware cloth or sandbags on the upstream and downstream side of the railroad rail prevents scouring.

Traps used with floating weirs are generally off-channel and fish are diverted there by the floating weir. However, traps have been incorporated into the Alaska floating weir on the upstream side. A 6 x 6 x 4 ft steel trap is set about midstream and a weir panel is removed at this point. Two weir panels and heavy netting are attached on either side of the trap. These bridge the gap between the weir and the trap to prevent passage of fish. The trap is cabled to duckbill anchors set into the substrate.

Electrofishing

Electrofishing relies on the reaction of fish to electrical power in water. Most electrofishing units use direct current that is supplied from a power source either directly or through a convertor built into a pulsator unit. Power from a generator or battery is routed through the pulsator, where pulse frequency, voltage, and pulse shape are adjusted. An electrical or power field is created in the water when electricity travels between the anode and the cathode. How much of the power is transferred to the fish depends on the conductivity of the water and of the fish (Whitney and Pierce 1975). Only when the two are equal will all the power be transferred into the fish.

Electrical power must first be transferred from electrodes into water, then from the water into fish (Kolz and Reynolds 1989; Kolz 1993). Electrofishing systems create electrical power in water through submerged electrodes. An electrical circuit is completed between a positive electrode (anode) and a negative electrode (cathode), although multiple electrodes are sometimes used (Novotny and Priegel 1974). The distribution and intensity of an electrical field in water is dependent on several factors including amount of electrical power; water conductivity; and size, shape, and spacing of electrodes (Novotny and Priegel 1974; Kolz 1993). Electrode design should consider the capacity of the power source, water conductivity, and working environment such as water current, water clarity, and maneuverability of the boat (Novotny and Priegel 1974; Kolz 1993). The design and placement of electrodes directly affect the shape, size, and distribution of electrical power in water (Kolz 1993). Electrodes with more surface area expose more metal to water, thus reducing the initial resistance and increasing the amount of voltage (and the electrical field) farther from the electrode (Kolz 1993). Aluminum boats can act as the cathode by grounding direct current electrofishing units to the boat. Because the surface area of the boat hull is large compared to that of the anode, little resistance will be associated with the cathode (Kolz 1993). Anode design should produce maximum current densities close to the surface of the water where fish will be attracted (Novotny and Priegel 1974), while maintaining voltage at a sufficient distance from the anode to extend the electrical field (Kolz 1993).

Conductivity of the water (or resistance) affects the efficiency of power transfer into the water and thus into fish (Whitney and Pierce 1957; Flux 1967; Kolz 1989). The conductivity of the water is affected by water temperature and the amount of electrolytes in the water (Novotny and Priegel 1974; Whitney and Pierce 1975; Novotny 1990). Kolz (1989) demonstrated that an increase in power could compensate for the inefficiency of power transfer into the water due to changes in conductivity. When resistance of water increases (i.e., conductivity is low), the efficiency of electrofishing gear decreases, as measured by the voltage gradient (V/cm) required to shock fish (Flux 1967). An increase in efficiency of the gear can be achieved by increasing the voltage output of the power source or by increasing the surface area of the anode. Alternatively, water that has very low resistance also requires high voltage because the current is dissipated within the electrolytes of the water. However, in this case more voltage output rather than anode size is needed to increase the size of the electrical field. Kolz (1993) stressed that on-board electrical measurements are no substitute for in-water measurements because fish respond only to the electrical field actually produced in the water.
Effectiveness of electrofishing also depends on factors such as physical characteristics of the water, the concentration of fish in the sample stream, and the experience of the crew. Casselman et al. (1990) reported that efficiency of electrofishing decreased markedly with deeper water, with faster water velocity, and with lower water transparency (because of difficulty in seeing and netting fish). Fustish et al. (1989) reported that electrofishing for steelhead was most productive at 500-1,800 cfs and turbidity of less than 6.0 JTU. Electrofishing for chinook salmon was two to three times more effective in the Coos River than in the Yaquina or Siuslaw rivers partially because fish were more concentrated at low flow (Hooton 1978). Hardin and Connor (1992) reported significant differences in the efficiency of two crews, which was attributed to variations in technique.

Electrofishing can injure or kill fish, thus this technique has been of concern to biologists. Adverse effects of electrofishing can be direct such as broken backs, hemorrhages, and respiratory failure, or indirect such as stress or behavioral changes. Spinal injuries and hemorrhages in electroshocked fish have been widely reported. Early detailed descriptions of electrofishing injuries in large rainbow trout was reported by Hauck (1949). Brands on fish have been associated with electroshocked fish (Horak and Klein 1967; Schroeder and Smith 1989; Holmes et al. 1990; Fredenberg 1992) and are believed to be discolorations of the skin indicating possible damage to the nervous system or hemorrhages associated with spinal injury.

Several investigators have reported spinal injuries in fish, although injury rates have varied. Fessler et al. (1976) reported an average injury rate of 21% in adult steelhead captured in the Deschutes River with various electrofishing gear using pulsed DC (60 Hz). Injury rates were based on necropsies of apparently injured and uninjured fish. Injury rates of adult steelhead electroshocked in hatchery ponds were 7% for DC, 28% for pulsed DC (5 Hz and 60 Hz), and 59% for pulsed DC (100 Hz; Fessler et al. 1976). They also reported that 2-3% of these fish died during a holding period of at least two weeks and that the mortalities usually had one or two severe breaks in the spinal column and extensive hemorrhage in muscle tissue. Fessler et al. (1976) also reported injury rates of about 80% in adult chinook salmon captured in the Deschutes River with pulsed DC (60 Hz) and 36% with DC.

Sharber and Carothers (1988) reported injury rates of 44–67% in adult rainbow trout (30-55 cm) captured with pulsed DC (60 Hz), with exponential and square pulse shapes producing the lowest injury rates. Sharber et al. (1994) reported injury rates of 43–65% with pulsed DC (60 Hz) using three different types of anodes. They also reported that rates of spinal injuries increased from 3% to 62% with pulse frequencies of 15 Hz to 512 Hz, respectively, and that complex pulse patterns also produced a low injury rate of 8%. Rainbow trout captured in three Montana rivers had spinal injury rates of 65-90% with pulsed AC, 78-98% with pulsed DC (60 Hz), 18% with smooth DC, and 31-54% with complex pulsed DC (Fredenberg 1992). McMichael (1993) found spinal injuries in 4-17% of rainbow trout captured seven days apart with DC, and in 35% and 53% of rainbow trout captured with pulsed DC at 30 Hz and 90 Hz, respectively. McCrimmon and Bidgood (1965) found spinal abnormalities in 8% of rainbow trout electroshocked with AC or DC, but they also found naturally occurring abnormalities in fish. Hudy (1985) found that 77% of rainbow trout and brook trout with swimming abnormalities had spinal injuries from electrofishing with AC, but that only 21% of fish examined immediately after capture had injuries.
Because the severity of the voltage gradient along the length of a fish increases with length (Taylor et al. 1957; Flux 1967; Ellis 1975), large fish may be more susceptible to injury than small fish. Schroeder and Smith (1989) reported that the average annual rate of electrofishing injury increased with size of fish. However, Fredenberg (1992) found no difference in the injury rate between fish 8-15 in and fish 15-22 in.

Although these studies have demonstrated that electrofishing can cause injury and mortality in individual fish, Schill and Beland (1995) point out that no studies have been conducted on the effect of electrofishing on fish populations. They presented estimates of electrofishing mortality for salmonid populations ranging from 0.1%-0.3%, with a high of 4.5%.

Tetany can cause cessation of respiration or long recovery time to normal respiration (Chmielewski et al. 1973, as cited in Synder 1992; Schreck et al. 1976). Schreck et al. (1976) reported increases in blood concentrations of plasma corticoid, lactic acid, and glucose as indicators of stress response to electrofishing. Bouck and Ball (1976) also reported that plasma protein concentrations in rainbow trout were affected by electrofishing (as well as by seining and hook and line). Handling can also lead to stress and mortality in electroshocked fish (Hudy 1985). Mesa and Schreck (1989) reported behavioral changes in electrofished wild trout including decreased activity and lack of feeding from electrofishing or from handling and marking of captured fish. Decreased swimming performance of electroshocked rainbow trout was reported by Horak and Klein (1967).

Dwyer and White (1995) reported that electroshocked adult rainbow trout had significantly lower growth than control fish over a 35-day period after only a 10-second exposure. However, others have reported no adverse effects on growth after a single electrofishing event (Maxfield et al. 1971; Kynard and Lonsdale 1975). Gatz et al. (1986) reported that average growth rates of wild rainbow trout and brown trout were lower for fish that had been electroshocked two to seven times within a 12-month period than for control fish of the same age and species. Marriott (1973) reported that electrofishing mature pink salmon caused a significant increase in egg mortality. Others have reported an effect of electrofishing on fertilized eggs, deposited eggs, or embryos (Godfrey 1957; Marriott 1973; Dwyer et al. 1993). The mortality of cutthroat eggs exposed to electric shock was significantly higher than control groups when higher voltages were used (>225 V), regardless of pulse rate or wave form (Dwyer and Erdahl 1995). However, Sorensen (1974) reported no effect of electroshock on spawning behavior of sexually mature brook trout and goldfish.
APPENDIX B

Contacts and Manufacturers

Vendors

Floating or Resistant Board Weirs
Mitsubishi Canada
2800–200 Granville St.
Vancouver, British Columbia V6C 1G6
Mariko Lo (604) 654–8127

Electric Barrier
Smith–Root, Inc.
14014 NE Salmon Creek Ave.
Vancouver, WA 98686
(206) 573–0202

Boat Electrofishing Pulsators
Smith–Root, Inc. (see above)

Coffelt Manufacturing
1311 East Butler Ave., Building B
Flagstaff, AZ 86001
(602) 774–8829

Dirigo Electronics Engineering
1307 NW Buchanan
Corvallis, OR 97330
(503) 752–5337

Gill Nets/Seines
Nichols Net and Twine
RR 3–Bend Road
East St. Louis, IL 62201

Memphis Net and Twine Co., Inc.
P.O. Box 8331
Memphis, TN 38108
(800) 238–6380

Nylon Net Co.
P.O. Box 592
Memphis, TN 38101
(800) 238–7529

Sterling Net and Twine Co., Inc.
18 Label St.
Montclair, NJ 07042

Erosion Control Cloth
Mirafi, Inc.
P.O. Box 2258
Redmond, WA 98073–2258
(206) 881–8806

or
Oregon Culvert Co.
P.O. Box 398
Tualatin, OR 97141
(503) 692–0410

Collapsible Fish Tube
Eric's of Nanaimo, Ltd.
General Delivery
Crofton, British Columbia
V0R 1R0
(604) 246–4977
Contacts

Picket Weirs
Oregon Dept. of Fish and Wildlife
28655 Highway 34
Corvallis, OR 97333
Ken Kenaston (541) 737-7626
e-mail: kenastok@ucs.orst.edu
Kirk Schroeder (541) 737-7627
e-mail: schroedk@ucs.orst.edu

Alaska Dept. of Fish and Game
Commercial Fisheries Division, Juneau
Fred Burgander (907) 465-4250

Fish Wheel
National Marine Fisheries Service
Auke Bay Laboratory, Juneau
Tom Dress (907) 789-6044 (construction)

Alaska Dept. of Fish and Game
Commercial Fisheries Division, Juneau
Andy McGregor (907) 465-4250 (operation)

Permanent Picket Weir
- hydraulically operated; Chiwawa River, WA
National Marine Fisheries Service
Portland
Bill Hevlin (503) 230-5407

Floating or Resistant Board Weirs
Lookingglass Hatchery
(503) 437-9723 (operation)
Paul Johnson (engineering) (503) 229-5400 ext. 523

Washington Dept. Fish and Wildlife
Engineering Section, Olympia
Roger Bogden (206) 753-5700

Angling
British Columbia Ministry of Environment and Parks
Nanaimo
Rick Axford (604) 751-3224
Craig Whightman (604) 751-3232

Hoop or Wire Fyke
Washington Dept. of Fish and Wildlife
Olympia
Dave Seiler (206) 586-1994

Oregon Department of Fish and Wildlife
Corvallis
Stan van de Wetering (541) 737-7635
APPENDIX C

Costs of Some Capture Techniques

Appendix Table C-1. General cost of eight types of techniques used to capture adult salmonids in the Pacific Northwest.

<table>
<thead>
<tr>
<th>Features</th>
<th>Size (ft)</th>
<th>Cost(^a)</th>
<th>Source(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Per foot</td>
<td></td>
</tr>
<tr>
<td><strong>Vertical Picket</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>conduit pickets</td>
<td>40</td>
<td>1,650</td>
<td>41</td>
</tr>
<tr>
<td>black pipe pickets</td>
<td>60+</td>
<td>5,860</td>
<td>98</td>
</tr>
<tr>
<td>black pipe pickets, metal tripods</td>
<td>40</td>
<td>2,470</td>
<td>62</td>
</tr>
<tr>
<td>temporary w/o trap</td>
<td>--</td>
<td>--</td>
<td>95</td>
</tr>
<tr>
<td><strong>Fish Wheel</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>w/ aluminum pontoons</td>
<td>--</td>
<td>10,600-16,000</td>
<td>--</td>
</tr>
<tr>
<td><strong>Hoop or Wire Fyke</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oregon, 6 ft diam./15 ft length</td>
<td>--</td>
<td>630</td>
<td>--</td>
</tr>
<tr>
<td>Washington, 10 ft diam./20 ft length</td>
<td>--</td>
<td>1,000</td>
<td>--</td>
</tr>
<tr>
<td><strong>Fishway Trap</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denil</td>
<td>--</td>
<td>47,000</td>
<td>--</td>
</tr>
<tr>
<td>Cage trap in ladder step</td>
<td>--</td>
<td>500-1,500</td>
<td>--</td>
</tr>
<tr>
<td><strong>Floating or Resistant Board</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Commercial (Mitsubishi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idaho, w/ cement sill</td>
<td>200</td>
<td>94,000</td>
<td>470</td>
</tr>
<tr>
<td>Wash., w/ cement sill</td>
<td>140</td>
<td>67,000</td>
<td>480</td>
</tr>
<tr>
<td>Oregon, w/ site preparation</td>
<td>60</td>
<td>195,000</td>
<td>3,250</td>
</tr>
<tr>
<td>Alaska - weir, w/o site work</td>
<td>100</td>
<td>11,150</td>
<td>112</td>
</tr>
<tr>
<td><strong>Permanent Picket</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent w/o trap</td>
<td>--</td>
<td>--</td>
<td>1,560</td>
</tr>
<tr>
<td>Weir w/ hydraulic lifters, cement sill</td>
<td>140</td>
<td>110,000</td>
<td>786</td>
</tr>
<tr>
<td><strong>Concrete Barrier</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity barrier</td>
<td>30</td>
<td>39,000</td>
<td>1,300</td>
</tr>
<tr>
<td>Vertical barrier</td>
<td>30</td>
<td>66,000</td>
<td>2,200</td>
</tr>
<tr>
<td><strong>Electric Barrier</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power on site, w/o bank work</td>
<td>&lt;75</td>
<td>--</td>
<td>360</td>
</tr>
<tr>
<td>&gt;75</td>
<td></td>
<td>--</td>
<td>215</td>
</tr>
<tr>
<td>Smith-Root, Inc.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>small-scale, little site work</td>
<td>--</td>
<td>30,000</td>
<td>&gt;1,000</td>
</tr>
<tr>
<td>large-scale, excavation, bank</td>
<td>--</td>
<td>300,000</td>
<td>&gt;2,000</td>
</tr>
</tbody>
</table>

1. Fred Burgander, Alaska Department of Fish and Game, Commercial Fisheries Division, Juneau.
2. Kirk Schroeder, Oregon Department of Fish and Wildlife, Research Section, Corvallis.
5. Dave Seiler, Washington Department of Fish and Wildlife, Olympia.
6. Grant Christenson, Idaho Department of Fish and Game, Engineering Section, Boise.
7. Paul Johnson, ODFW, Engineering Section, Portland.
10. Dave Smith, Smith-Root, Inc., Vancouver, WA.
Appendix Table C-2. Detailed cost of a 40 ft vertical picket weir used to trap adult winter steelhead in the Siuslaw River, Oregon (1995 dollars).

<table>
<thead>
<tr>
<th>Component (number)</th>
<th>Material</th>
<th>Size</th>
<th>Number</th>
<th>Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tripods (5)</td>
<td>square tubing</td>
<td>2 x 2 x 3/16 in</td>
<td>2</td>
<td>20 ft</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>square tubing</td>
<td>1.5 x 1.5 x 3/16 in</td>
<td>1</td>
<td>20 ft</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>(for adjustable legs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-wood leg</td>
<td>lumber</td>
<td>4 x 4 in</td>
<td>5</td>
<td>8 ft</td>
<td>42</td>
</tr>
<tr>
<td>-metal leg</td>
<td>square tubing</td>
<td>2 x 2 x 3/16 in</td>
<td>3</td>
<td>20 ft</td>
<td>118</td>
</tr>
<tr>
<td>Rails (6)</td>
<td>channel iron</td>
<td>3 x 3/16 in</td>
<td>6</td>
<td>20 ft</td>
<td>157</td>
</tr>
<tr>
<td></td>
<td>U-bolts</td>
<td>7 x 2 x 3/8 in</td>
<td>30</td>
<td>--</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>(for attaching rails to tripods)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pickets (200)</td>
<td>black pipe</td>
<td>3/4 in Schedule 40</td>
<td>67</td>
<td>21 ft</td>
<td>535</td>
</tr>
<tr>
<td>Traps (2)</td>
<td>angle iron</td>
<td>2 x 2 x 1/8 in</td>
<td>5</td>
<td>20 ft</td>
<td>53</td>
</tr>
<tr>
<td>(132/trap)</td>
<td>conduit pipe</td>
<td>3/4 in, .065 in thick</td>
<td>53</td>
<td>20 ft</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>square tubing</td>
<td>1 x 1 x 1/8 in</td>
<td>5</td>
<td>20 ft</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>(for vertical framing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CDX plywood</td>
<td>4 x 8 ft x 3/4 in</td>
<td>4</td>
<td>--</td>
<td>94</td>
</tr>
<tr>
<td></td>
<td>strap hinge</td>
<td>5 in</td>
<td>4</td>
<td>--</td>
<td>8</td>
</tr>
<tr>
<td>Holes punched</td>
<td>channel iron</td>
<td>1 3/16 in on 2 1/2 in centers</td>
<td>225</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>angle iron</td>
<td>13/16 in on 2 in centers</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Securing weir</td>
<td>Eyebolts</td>
<td>5/8 x 6 in</td>
<td>17</td>
<td>--</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>Turnbuckles</td>
<td>3/8 x 6 in (forged)</td>
<td>20</td>
<td>--</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>Quick Links</td>
<td>5/16 in</td>
<td>40</td>
<td>--</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Chain</td>
<td>3/16 in</td>
<td>--</td>
<td>60 ft</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Cable</td>
<td>3/8 in</td>
<td>--</td>
<td>150 ft</td>
<td>60</td>
</tr>
<tr>
<td>Total (with 1 wood leg on tripods)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,392</td>
</tr>
<tr>
<td>Total (with all metal tripods)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,468</td>
</tr>
</tbody>
</table>
Appendix Table C-3. Costs of a 60 ft resistant board weir at Lookingglass Creek Hatchery, Oregon (1995 dollars). Does not include agency costs for engineering oversight.

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weir panels (19, includes one extra)</td>
<td>26,000</td>
</tr>
<tr>
<td>Engineering consultant</td>
<td>31,000</td>
</tr>
<tr>
<td>Civil engineering (excavation, concrete, etc.)</td>
<td>138,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>195,000</td>
</tr>
</tbody>
</table>

Appendix Table C-4. Detailed costs of a hoop or wire fyke trap built in Oregon. The trap is 6 ft diameter, 15 ft long, with two fykes of 30 in and 12 in (source: S. Van de Wetering, ODFW, Corvallis, 1995, personal communication)

<table>
<thead>
<tr>
<th>Component (number)</th>
<th>Material</th>
<th>Size</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoops (4)</td>
<td>rolled square tubing</td>
<td>1 x 1 x 1/8 in 6 ft diameter</td>
<td>325</td>
</tr>
<tr>
<td>Runners (6)</td>
<td>square tubing</td>
<td>1 x 1 x 1/8 in 12 ft long</td>
<td>75</td>
</tr>
<tr>
<td>Fyke (2)</td>
<td>square tubing</td>
<td>1 x 1 x 1/8 in</td>
<td>65</td>
</tr>
<tr>
<td>Covering</td>
<td>wire fencing</td>
<td>1 x 1 in 100 ft</td>
<td>120</td>
</tr>
<tr>
<td>Fasteners</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-screws (200)</td>
<td>self-tapping</td>
<td>5/16 in</td>
<td>45</td>
</tr>
<tr>
<td>-washers (200)</td>
<td>fender</td>
<td>1 1/4 in diameter</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>630</td>
</tr>
</tbody>
</table>