12

General Technical Report PNW-138
June 1982

Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

REHABILITATING AND ENHANCING STREAM HABITAT:

1. REVIEW AND EVALUATION

JAMES D. HALL and CALVIN O. BAKER

U.S. Department of Agriculture Forest Service
Pacific Northwest Forest and Range Experiment Station

ABSTRACT

The literature and many unpublished documents on rehabilitating and enhancing stream habitat for salmonid fishes are reviewed. The historical development and conceptual basis for habitat management are considered, followed by a review of successful and unsuccessful techniques for manipulation of spawning, rearing, and riparian habitat. Insufficient attention to evaluation of past work has slowed the development of habitat management for anadromous salmonids in the West. Recent developments, including improved design of structures to accommodate variable streamflow, show promise of permitting increased application of these techniques. Past work in the West has emphasized management of spawning habitat. We recommend increased emphasis on rehabilitation and enhancement of rearing and riparian habitat. The importance of a strong program of habitat protection is emphasized.

KEYWORDS: Fish habitat, habitat improvement, riparian habitat, anadromous fish, salmonids.

USDA FOREST SERVICE
General Technical Report PNW- 138

INFLUENCE OF FOREST AND RANGELAND MANAGEMENTON ANADROMOUS FISH HABITAT IN WESTERN NORTH AMERICA

William R. Meehan, Technical Editor

12. Rehabilitating and Enhancing Stream Habitat:
1. Review and Evaluation

JAMES D. HALL
Department of Fisheries and Wildlife
Oregon State University
Corvallis, Oregon 9733 1

CALVIN 0. BAKER
U.S. Department of Agriculture, Forest Service
Hebo Ranger District
Hebo, Oregon 97 122

1982

PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION
Forest Service, U.S. Department of Agriculture, Portland, Oregon

PREFACE

This is one of a series of publications on the influences of forest and rangeland management on anadromous fish habitat in western North America. This paper describes and evaluates methods that have been used for rehabilitating and enhancing habitat. Our intent is to provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of scientists and resource managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.
2. "Impacts of natural events," by Douglas N. Swanston.
3. "Timber harvest," by T. W. Chamberlin.
4. "Planning forest roads to protect salmonid habitat," by Carlton S. Yee and Terry D. Roelofs.
6. "Silvicultural treatments," by Fred H. Everest and R. Dennis Harr.
7. "Effects of livestock grazing," by William S. Platts.
8. "Effects of mining," by Susan B. Martin and William S. Platts.
11. "Processing mills and camps," by Donald C. Schmiege.
13. "Rehabilitating and enhancing stream habitat: 2. Field applications," by Gordon H. Reeves and Terry D. Roelofs.

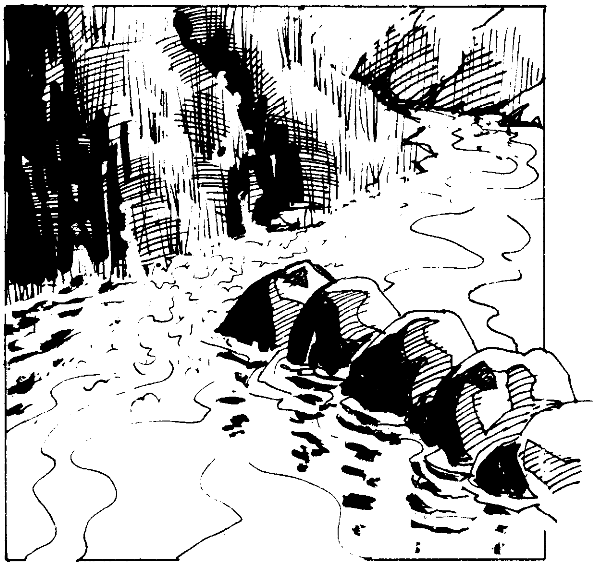
TABLE OF CONTENTS

Page

COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN TEXT”

Common name	Scientific name
Pink salmon	*Oncorhynchus gorhuscha* (Walbaum)
Chum salmon	*Oncorhynchus keta* (Walbaum)
Coho salmon	*Oncorhynchus kisutch* (Walbaum)
Sockeye salmon (kokanee)	*Oncorhynchus nerka* (Walbaum)
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
cutthroat trout	*Salmo clarki* Richardson
Rainbow (steelhead) trout	*Salmo gairdneri* Richardson
Atlantic salmon	*Salmo salar* Linnaeus
Brown trout	Salmo trutta Linnaeus
Brook trout	*Salvelinus fontinalis* (Mitchill)
Dolly Varden	*Salvelinus malma* (Walbaum)
Redside shiner	*Richardsonius balteatus* (Richardson)
Speckled dace	*Rhinichthys osculus* (Girard)

1/ From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication No. 12, Fourth Edition, 1980, 174 p.



INTRODUCTION

Techniques for rehabilitating and enhancing habitat have been used for over 50 years in fishery management, but to a relatively small degree in the management of anadromous salmonids on the west coast of North America. Present threats to many of these stocks call for intensified fishery management. Increased rates of harvest threaten the survival of many wild populations of salmon and trout. Increased use of other resources, including dam building, logging, grazing, and other agricultural practices, has diminished the quality and quantity of habitat available to these wild stocks. In principle, rehabilitating and enhancing habitat are attractive techniques for working toward restoring the abundance of anadromous salmonids.

A recently renewed interest in habitat management has been accompanied by several review articles and bibliographies (see Barton et al. 1972, Parkinson and Slaney 1975, Maughan et al. 1978, Nelson et al. 1978, Wydoski and Duff 1978, Canada Department of Fisheries and Oceans 1980). Nonetheless, a review focused more directly on anadromous fish habitat in the forested regions of western North America is needed. We present a general review and evaluation of past efforts in habitat management, both successful and unsuccessful. We have included techniques used for both resident and anadromous salmonids in streams throughout North America. A companion paper (Reeves and Roelofs 1982) reviews current practices in the West, outlining successful techniques and including specific recommendations on implementation.

The principal purpose of these reviews is to make practical information available to field managers wishing to rehabilitate damaged habitat or to enhance habitat that is naturally low in productive capacity. Thus, we include only techniques that require relatively little labor and expenditure. Such capital-intensive measures as spawning channels will not be included, even though they represent a manipulation of habitat.

The task was made more difficult by the scarcity of written documentation of past work. Too many projects have not been evaluated at all, or if any review has been undertaken, it has not been made generally available. As a result, we were forced to rely heavily on personal contact and may have missed some important developments. When reports on manipulation of stream habitat were completed, many of the studies did not provide an accurate assessment of the outcome. In addition, a bias probably exists in the published record because of administrative or editorial decisions against publication of inconclusive or unfavorable results. We hope that one outcome of our review will be increased awareness of the need to evaluate and document all projects--even those that are unsuccessful. Often valuable lessons can be learned from apparent failure.

In the historical development of the science of wildlife management, manipulation of habitat was the last in a sequence of techniques to be recognized as an important tool for the manager (Leopold 1933). The same has generally been true in fisheries. The first large-scale habitat management in streams was initiated during the 1930's in the Midwest (Hubbs et al. 1932). Stimulated in part by the availability of labor from the Civilian Conservation Corps, this pulse of activity led to a large number of projects (e.g., Davis 1934; Tarzwell 1935, 1937; Fearnow 1941). The apparent success of these efforts in the Midwest and East was followed by a number of projects in the West (e.g., Burghduff 1934, Madsen 1938, Tarzwell 1938). Many evaluations of west coast efforts concluded that failure was more common than success (Ehlers 1956, Richard 1963, Calhoun 1966). Rehabilitation and enhancement continued at a significant pace in the Midwest (Shetter et al. 1949; Hale 1969; Hunt 1969, 1976), and several manuals for habitat improvement were produced by State and Federal agencies (Davis 1935, USDA Forest Service 1952, White and Brynildson 1967, USDI Bureau of Land Management 1968). Over the years, modifications gradually made techniques more compatible with severe freshet conditions in western streams. For example, Sweet (1975 unpubl.) 1/ lists over 150 projects that have been completed in Alaska. We are optimistic about chances for success of habitat improvement for anadromous fish in this region.

Some of the early enthusiasm for stream improvement was probably misguided, in that project planners failed to take account of the factors that limited trout production in a particular stream. Many structures failed because they were not designed to withstand freshet conditions. For these reasons and others, some fishery biologists took a pessimistic view of the potential of stream "improvement" (see Mullan 1962, Richards 1964). Nonetheless, since 1932 several well-designed research studies have shown that the quality of habitat is an important determinant of salmonid biomass and production. Although nearly all this work has been done on nonmigratory populations, many conclusions can be related to anadromous species. The research effort has taken two related approaches: assessment of salmonid populations before and after habitat modification, and quantitative evaluation of habitat in relation to the abundance of salmonids.

One early, well-documented study evaluated the effects of deflectors in a small brook trout stream in Michigan (Shetter et al. 1949). The deflectors caused an increase in the number, size, and depth of pools. As a result, survival and stock size of young brook trout were increased, leading to a significant improvement in catch rate and total catch. Angling effort increased 64 percent, and anglers' catch increased 141 percent in total weight and 46 percent in weight caught per hour.

A study of cover manipulation in a Montana trout stream showed significant response of the trout populations (primarily rainbow and brook trout) to the treatments (Boussu 1954). Inventories before and after habitat manipulation showed that trout abundance increased more than three times after addition of brush cover to about 5 percent of the stream area. Removal of brush cover totaling about 10 percent of the stream surface area resulted in about a 40-percent reduction in trout biomass. Removal of undercut bank cover that provided shelter over less than 2 percent of the stream area resulted in a one-third reduction in trout abundance.

1/ Unpublished references are listed after the Literature Cited.

The best-documented study of habitat manipulation was undertaken on a Wisconsin brook trout stream (Hunt 1971). A 1.7-km section of Lawrence Creek was altered in 1964 by addition of structures for bank cover and current deflection. As a result, stream surface area was reduced by 50 percent, average depth was increased by 60 percent, the number of pools was increased by 52 percent, and the length of streambank with permanent overhanging cover was increased 416 percent. These changes in the physical habitat greatly increased overwinter survival and biomass of the trout population. A large increase in angler effort resulted in an even greater increase in total catch. Average harvest during 1965-67 was nearly three times the preimprovement average (Hunt 1971). The response of the trout population to habitat development continued through the period 1968-70, when the total trout biomass increased to 2.8 times the preimprovement value (Hunt 1976).

Several other evaluations have been made before and after habitat improvement, most of which have shown a positive response by the trout population. The results of many of these up through 1975 are summarized in table 1, taken from White (1975a).

Evaluating specific characteristics of trout habitat and relating such characteristics to trout abundance (usually through correlation techniques) has provided additional evidence of the importance of habitat quality to salmonid abundance. Studies by Lewis (1969) Stewart (1970), and Wesche (1976) found cover in some form to be the habitat characteristic most closely associated with abundance of brook, brown, and rainbow trout. More complex combinations of habitat variables have been included in multiple regression analyses that provided statistically significant predictors of abundance for juvenile cutthroat and steelhead trout in Oregon (Nickelson and Hafele 1978) and for four species of trout in Wyoming (Binns and Eiserman 1979). The Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service has been undertaking a large-scale effort designed in part to predict consequences to trout populations of incremental losses of streamflow (Bovee and Cochnauer 1977, Bovee 1978). Preliminary results have been encouraging but more work on validation of these models is needed.

A fundamental concept of habitat management deserves emphasis here. Care must be taken to identify aspects of habitat that limit production, and attention must be focused on improving those elements. Considering the timing of life-history events is also important. Increasing the quantity or quality of some aspect of habitat limiting the abundance of fry will generally be of little use if a critical shortage of cover or some other resource occurs at a later stage in the life cycle. A crude, but useful analogy to a bottleneck is shown in figure 1, adapted from Hall and Field-Dodgson (1981). Note that the neck is not necessarily at the end of the bottle; a critical limitation can occur well before migration to the ocean (fig. lb), or in the ocean after downstream migration.

An example illustrating the futility of enhancing numbers of fish before operation of the final limiting factor is provided by an experiment in a British Columbia stream supporting coho salmon (Mason 1976). In that system, most young coho go to sea as smolts after 1 year of stream rearing. Artificial feeding of juveniles during one summer increased their abundance six to seven fold over previously measured summer biomass. The number of smolts estimated to have left the system in the following spring, however, was within the range of previous values (fig. lc). In this stream, the ultimate limitation to smolt production appeared to be some aspect of winter habitat.

Table l--Management evaluations of in-stream habitat by measurements of trout abundance over several years (adapted from White 1975a)1/

Stream, wild trout species, reference	Primary management	Schedule of population inventories	Effects on trout populations and angling yield
Lawrence Creek, Wisconsin Brook trout Hunt (1971)	Bank-cover deflectors in 1.7 km (compared with 1.4-km control)	3 yr before, 3 yr after management	141 percent rise in age-II+ biomass from better overwinter survival. 156 percent more fish over 20 cm (8 in) in April. 200 percent greater anglers' catch.
Big Roche-a-Cri Creek, Wisconsin Brook few brown trout wnite (lY72, 1975b)	Bank-cover deflectors in 6 km (compared with 5 km of interspersed control areas), cattle fenced out, beaver dams removed	3 yr before, 2 yr during, 5 yr after management	200 percent rise in numbers of age-II+, comparing 3 pre- with 3 postmanagement years of similar flow regime in 3-km section of most intensive alteration. Greatest effect was improvement of drought (low-water) abundances of fish. 36 percent increase in catch per angler hour.
w. Branch Split Rock River, Minnesota Brook trout Hale (1969)	Deflectors, bank covers, low dams in 1.6 km (compared with 1.6-km control area)	3 yr before, 3 yr after management	g-fold increase in numbers of age-O. Doubling of number of age-I+. Angler success rose from 0.58 to 0.89 fish per angler hour in managed area, while declining in control area.
Hayes Brook, Prince Edward Island, Canada Brook trout Saunoers and Smith (1962)	Low dams, deflectors, covers of poles and brush in 0.4 km (no control area)	5 yr before, 1 yr after management	Number of age-I+ in year after construction was highest on record, nearly double the previous 5-yr average.
Hunt Creek, Michigan Brook trout Snetter et al. (1949)	Deflectors in 0.5 km (no control area)	1 yr before, 3 yr after (creel census 3 yr before, 5 yr after) management	35 percent increase in catch per angler hour. Little change in standing crop.
Pigeon River, Michigan Brook, brown trout Latta (1972)	Deflectors in 2 km (compared with 2-km control)	5 yr before, 5 yr after management, then 5 yr after dismantling	Managed-section trout abundance (in terms of fall population plus anglers' catch in previous summer) was originally lower than in control but rose to equality after management, then deteriorated when devices were intentionally destroyed.
Kinnikinnic River, Wisconsin Brown, brook trout Frankenberger (1968)	Rock deflectors, rock revetments, fences along 2.2 km (compared with an unmanaged control)	5 yr before, 3 yr after management	400-500 percent rise in numbers of brook trout over 14 cm (5.6 in) and 150-200 percent rise in numbers of brown trout over 14 cm (5.6 in), while populations in control area remained essentially static.
Bonemian Valley Creek, Wisconsin Brown trout Frankenberger and Fassbender (1967)	Floodwater detention dams, rock deflectors, rock revetments, low dams, fencing in 4.3 km (compared with 1.2-km control)	6 yr before, 4 yr after management	Originally negligible brown trout abundance (sometimes fewer than 5 per km) rose to about 250 per km.
McKenzie Creek, Wisconsin Brown trout Lowry (1971)	Deflectors, bank covers, brush covers, low dams in 5 km (compared with 0.6-km control)	2 yr before, 6 yr after management	10-15 percent rise in total biomass (25 percent rise for age-I+, 100 percent rise for age-II+). Inconclusive changes in numbers of fish larger than 15 cm (6 in).
Black Eartn Creek, Wisconsin Brown trout White (1975a)	Fencing, dam removal, few deflectors, bank revetments in 8 km (control: Mt. Vernon Creek)	3 yr during, 5 yr after management	3-fold increases in age-O, total biomass, and anglers' catch per hour of wild trout. 5-fold increase in spring (pre-angling) numbers of fish larger than 15 cm (6 in).
Mt. Vernon Creek, Wisconsin Brown trout Wnite (1975a)	Unmanaged control for Black Earth Creek (adjoining drainage basin), dam removed	Concurrent with Black Earth Creek	Relatively minor increases in age-O, total biomass, and anglers' catch per hour of wild trout. P-fold increase in spring numbers of fish larger than 15 cm (6 in) attributable to hydrologic events.

1/ Table was prepared for publication and referenced in White (1975a), but omitted from publication by editorial error (wnite, personal communication).

The single limiting-factor "bottleneck" concept is an oversimplification of a complex ecological process. In the context of a total system, the search for a single factor can be misleading. Not only may the ultimate limitation vary from year to year, it may be composed of interacting elements; when one is improved, others may take over. Such an interaction may account for the failure of some of the well-intentioned attempts at habitat improvement. Notwithstanding this caution, however, the general concept of limiting factors requires more attention in future habitat-improvement work.

In the following text, we have treated rehabilitation and enhancement methods under three headings: spawning habitat, rearing habitat, and riparian habitat. These categories represent a continuum in the salmonid environment and must be considered together in evaluating a particular situation.

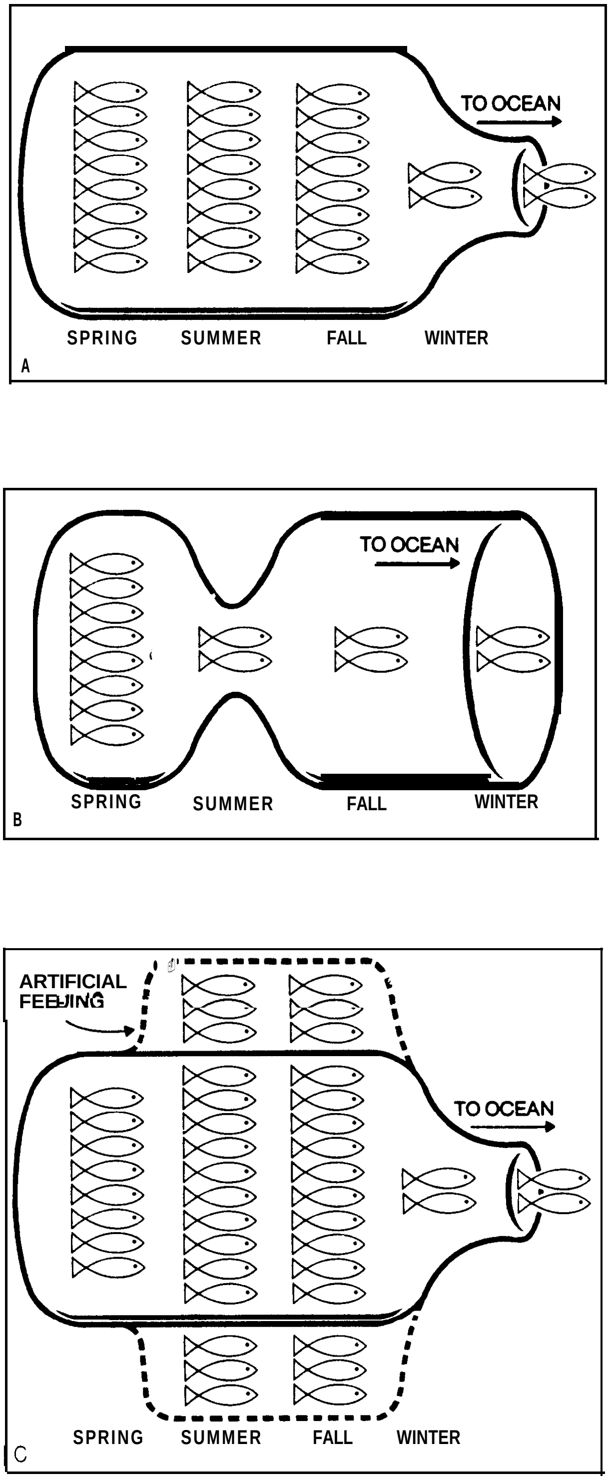
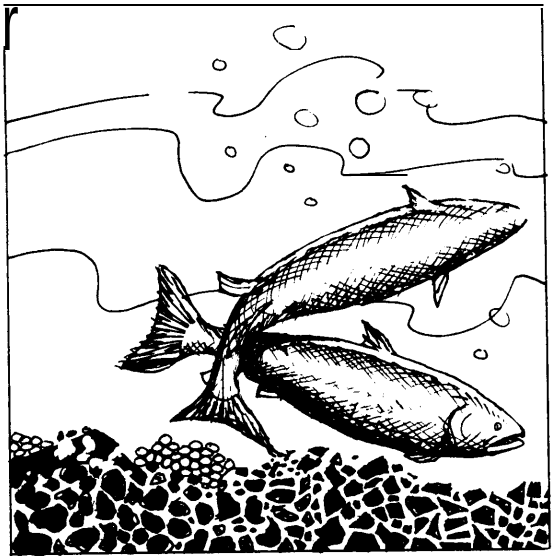


Figure 1. --A. Example of a limiting-factor "bottleneck" occurring during the winter just before migration of smolts to the ocean. B. Here the bottleneck occurs early in the life of the young salmon. Numbers are restricted by habitat conditions during summer, and this limitation carries through to smolt migration. C. Attempts to increase abundance early in the life history, before operation of a limiting factor, will usually not succeed. Artificial feeding resulted in a 6- to 7-fold increase in juvenile coho salmon during summer, but winter habitat limitations reduced smolt numbers to previously observed levels (Mason 1976).



SPAWNING HABITAT

Several approaches are available for improving spawning habitat. The three that have been most successful are:

- Improving the quality of spawning gravel by removing fine sediments;
- Increasing the amount of spawning gravel; and
- Providing access for spawning adults above barriers.

GRAVEL RESTORATION

An early development in restoration of spawning habitat was the design and testing of a self-propelled amphibious vehicle for cleaning fine sediment from spawning gravel. Known as the "Riffle Sifter," the machine was designed to remove sediment by action of high-pressure underwater jets (Outdoor California 1968). A suction pump forced sediment-laden water through a nozzle onto nearby streambanks. The "Riffle Sifter" was greeted with great enthusiasm (Sheridan et al. 1968 unpubl.), and early field tests in Alaska and northern California appeared promising (Meehan 1971). In the end, however, the machine had many mechanical problems and was abandoned as an expensive failure.

The concept of a hydraulic gravel cleaner has recently been revived on a somewhat smaller scale (Mih 1978, 1979, 1981). Field tests in the State of Washington during 1979 and 1980 indicated that the new machine could effectively remove fine sediments from spawning gravel, but significant mechanical problems remained to be solved (Allen et al. 1981). Further testing in 1981 has achieved promising results (Cowan, personal communication 2/). Work on another hydraulic gravel cleaner and other mechanical methods of cleaning gravel is also underway in British Columbia (Andrew 1981).

A bulldozer has been used to remove high concentrations of fine sediment in several important spawning areas used by pink and chum salmon in Puget Sound. In 1969, a pilot study was initiated in which 1840 m^2 of heavily silted spawning gravel in the lower Dungeness River were cleaned (Heiser 1972a unpubl.). Concentration of sediment less than 0.8 mm diameter was reduced dramatically, and survival of pink salmon fry was 90 percent greater in the cleaned area than in the immediately adjacent uncleaned area (Heiser 1972a unpubl.). Fine sediment concentrations continued to decline each year after the initial cleaning with a bulldozer (1971, 12.8 percent; 1972, 12.3 percent; and 1973, 10.4 percent). Gerke (1973) believed that this decrease resulted from natural hydraulic action, fine sand and silt being removed at a faster rate than they accrued from bedload transport. Similar observations have been made in other Pacific Northwest rivers and streams where sources of sediment input have been controlled (McNeil and Ahnell 1964, Shapley and Bishop 1965, Burns 1972, Platts and Megahan 1975).

2/ A directory for personal communications is provided at the end of the paper.

Cleaning with a bulldozer has also shown favorable results in some other Washington streams (Heiser 1971, 1972b, unpubl.; Gerke 1973). On the Cedar River, 29 000 m^2 of gravel were cleaned at a cost of $0.05/$m^2$. In the subsequent spawning season, 3,000 sockeye and 50 chinook salmon used the area, which in previous years supported almost no fish. Heiser (1972b unpubl.) estimated a benefit/cost ratio of 14.3:l for the year and felt that it would be economically justifiable to clean each year if necessary.

Not all attempts at gravel rehabilitation with bulldozers have met with the success of those mentioned above. The percentage of fine sediment in spawning areas on the Stillaguamish River, Washington, was reduced from 19 to 8.7 percent, but there was no significant use by spawning fish after cleaning (Heiser 1972a unpubl.).

Less complicated means of gravel cleaning can also be effective. Mundie and Mounce (1978) report on the successful use of a portable pump and firehose to clean gravel in a small channel. Youth Conservation Corps crews used shovels to turn over gravel to remove silt and debris that accumulated after beavers constructed a dam on Bear Creek, a small, spring-fed tributary of Upper Russian Lake, Alaska (Nelson, personal communication). The dam was then broken, producing a freshet that removed the released material. A fourfold increase in survival of sockeye salmon from egg to fry was recorded in the spawning season after this project was completed.

Under most circumstances, gravel cleaning will provide only a temporary benefit unless the source of sedimentation is identified and measures taken to reduce this input. Often the most effective rehabilitation measure for excessive instream sediment is increased watershed protection.

An example of the success of such a protection program in rehabilitating damaged spawning areas comes from the South Fork Salmon River in Idaho (Platts and Megahan 1975). The river channel had become choked with sediment that resulted from accelerated surface erosion and landslides. The problem was made worse when a period of intense rainfall from 1962 to 1965 followed logging activity and road construction on steep, unstable slopes. The resulting 3.5-fold increase in river bedload practically destroyed the spawning potential of the main river. As a result, the USDA Forest Service declared a moratorium on logging and road construction on National Forest lands in the watershed of the South Fork in 1965. Watershed rehabilitation was begun that year, including the planting of vegetation and stabilization of roads. Throughout the program, sediment levels in the river channel were monitored.

From 1966 to 1974, the percentage of fine sediments (less than 4.7 mm) in the spawning areas decreased progressively (Platts and Megahan 1975). Concentrations in four monitored areas decreased from an average of about 55 percent in 1966 (range 45 to greater than 80 percent) to about 21 percent in 1974 (range 12 to 26 percent). After the moratorium was declared, sediment sources for the river were drastically reduced because of dramatic reductions in surface and landslide erosion. When sediment input was curtailed, the energy of the river gradually moved the accumulated fine sediments downstream. The particle-size distribution in the South Fork was near optimum for spawning of chinook salmon in 1974 (Platts and Megahan 1975). Further improvement in the condition of fish habitat led to a cautious lifting of the moratorium on logging and road construction in 1978, with future activity to be closely monitored (Megahan et al. 1980).

GRAVEL PLACEMENT AND CATCHMENT

Where spawning area is limited, attempts have been made to provide additional spawning gravel by constructing catchment devices. These structures stabilize introduced gravel or allow the capture of bedload. Most of these early attempts on west coast streams were unsuccessful. Calhoun (1966) documented several of these efforts and suggested that high cost and short life would generally limit the use of instream structures on the Pacific slope of North America. In spite of considerable failure, the activity has continued, and some success has been reported.

Before 1972, adequate spawning gravel was lacking in Perkins Creek, Washington (Gerke 1973). Wooden weirs were installed at various points to provide an optimum gradient for spawning chum salmon, and graded gravel was introduced into the channel. After holes were drilled in the weirs to allow passage of intragravel water, the spawner density was twice as high in areas where gravel had been introduced than it was in unimproved areas, and fry output from the stream was also increased (Gerke 1974).

Gravel placement has also shown promise in rehabilitating streams dredged during gold mining. In 1961, the Oregon State Game Commission replaced over 10 000 m^3 of gravel and rock that had been dredged from 5.4 km of Clear Creek in northeast Oregon (West et al. 1965b). Rock sills were used to help stabilize the introduced gravel. Few fish were present to use the introduced gravel in the first year, but in the three following years, an average of 137 chinook redds was observed in the introduced gravel, compared to 34 in the small amount of original gravel that remained after dredging. In the 3 years before the project, an average of 24 redds was counted in this gravel. Since then, the modified sections of Clear Creek have been the subject of annual spawning surveys and habitat evaluation. Although the channel morphology and gravel accumulations have changed considerably during the years, some gravel deposits continue to provide spawning sites for salmon (Claire, personal communication).

In streams with adequate gravel bedload, but deficient in retention of this gravel, various structures have been used with some success to provide spawning areas. Gabions (rectangular wire-mesh baskets that can be filled with rock) have been most commonly used, but have only recently been successful. Several attempts have been made on the Oregon Coast, where bedrock forms a significant portion of the substrate of many streams. The Oregon State Game Commission constructed low-head gabions and introduced gravel behind the structures in an attempt to create spawning habitat for fall chinook salmon on the main stem of the Alsea River (Fessler 1970; Garrison 1971a, b). These structures, placed perpendicular to the flow in a large river, failed both to slow the rate at which introduced materials were carried downstream and to accumulate adequate replacement gravel. Ultimately, the project was abandoned.

Use of gabions also had little success in the Siuslaw River drainage. The Bureau of Land Management constructed 44 gabion dams of various design between 1968 and 1975 at a cost of about $40,000 (Hammer 1976 unpubl.). Washed gravel was introduced behind most of the structures. Despite the fact that many structures have washed out or rolled over and no longer hold gravel, the project has achieved some success (Hammer, personal communication). Limited spawning by chinook and coho salmon and steelhead trout has been recorded behind some of the gabion dams, and relatively more juveniles have been found near the structures than in surrounding bedrock areas (Hammer 1977 unpubl.). Although anadromous fish populations have not appeared to increase in the area, summer water temperatures are extremely high and may be at least in part the cause of low salmonid populations in the drainage (Johnson 1977 unpubl.).

Another gabion project that failed was located on Pass Creek, in the North Umpqua drainage in Oregon. This stream was the site of extensive rehabilitation efforts after logging including the introduction of 1025 m^3 of gravel in conjunction with placement of 11 gabion dams (Magill 1971). Initial evaluation of these structures was quite promising, with adult steelhead observed using the added spawning gravel. At least two of the gabion dams have since washed out, however, and the majority of the remaining structures no longer hold suitable spawning gravel (Oliver, personal communication).

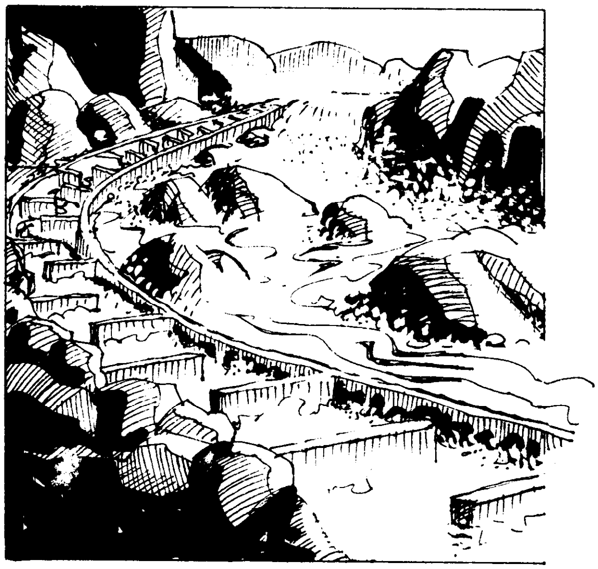
Despite many failures, some gabion installations have provided useful habitat enhancement. For example, 10 gabion dams were constructed on Johns Creek, a tributary of the Hamma Hamma River in Washington, a stream with a 3.05-m change in elevation in 222 m (Wilson 1976). These structures were successful in retaining gravel and providing suitable gradient for spawning.

Egg-to-fry survival of pink and chum salmon improved on Jorsted Creek, Washington, after installation of gabions designed to reduce gravel scour and shifting. The most dramatic differences between stabilized and unstabilized sections occurred in years of high flow; in years of low flow, survival was about the same in all sections (Wilson 1976). More than 4,000 adult chum salmon were counted in Jorsted Creek in December 1978 (Wilson, personal communication). This increase in abundance of spawning fish was thought to be because of improved spawning and rearing conditions resulting from gabion placement.

Recent developments in gabion design, which appear to have greatly improved chances for success, are discussed by Reeves and Roelofs (1982). One stimulus for these improvements was an excellent evaluation of problems experienced in gabion installations by Engels (1975 unpubl.). This report includes discussion of success and failure, and suggests modifications to improve gabion performance.

The use of log sills to capture spawning gravel has been successful. In Oregon five sills were constructed on Anvil Creek in the summer of 1973, and 350 spawning chinook salmon were observed in the improved area in January 1974 (Bender 1978 unpubl.). An average of 200 fish per year was recorded through 1978, in contrast to the previous long-term average of 50 spawners in that section. Steelhead trout have also made use of the spawning area (Bender and Mullarkey, personal communication).

The Canada Department of Fisheries and Oceans has recently begun a program to develop new spawning areas for chum salmon in southern British Columbia. Ground-water flow is enhanced in former flood channels now isolated from the main river. Preliminary assessment of fry production from these areas suggests that the technique has promise (Lister et al. 1980).



ACCESS IMPROVEMENT

Historically, improvement of access to spawning areas by removal of barriers to migration has been the most common form of habitat rehabilitation and enhancement for anadromous salmonids on the west coast. Unfortunately, however, it is also the least documented or evaluated of all techniques.

BARRIER REMOVAL

Debris and log jams pose a major threat to migration of anadromous salmonids. Jams were estimated to have prevented access to over 500 miles of usable stream habitat in Alaska in 1971 (Elliott 1978). More than 200 jams, ranging from partial to complete barriers to anadromous fish, were estimated to be present on a single Ranger District of the Siuslaw National Forest in western Oregon in 1978 (Heller, personal communication). Heller, however, noted the difficulty of providing an accurate inventory, because of substantial changes in debris location from one large storm to the next.

One of the earliest documented efforts to remove debris jams was reported by Merrell (1951). About 170 major and minor jams were removed from 43 km of the Clatskanie River system in Oregon. Stream clearance and access development were also an integral part of projects to improve coastal streams conducted in Oregon during the early 1960's (Summers and Neubauer 1965 unpubl.). More than a dozen fishways were installed or repaired and more than 50 log jams were removed.

Extensive stream clearance has also been undertaken in California. During the late 1950's and into the 1960's, a program to remove old log jams was carried out by the California Department of Fish and Game on nearly every major coastal river system that supported anadromous fish, from the Oregon border south to Santa Cruz (Evans, personal communication). This was a very extensive effort, involving large expenditures by the Wildlife Conservation Board, but very few of the reports submitted were published. An exception was the work on the Noyo River, where nearly 60 km of stream were cleared of log jams, partial barriers, and debris that threatened to form future jams (Holman and Evans 1964).

Log debris jams have also received attention elsewhere on the Pacific Coast. Roppel (1978 unpubl.) listed 88 major stream-clearance projects conducted in the State of Alaska by the USDA Forest Service and Alaska Department of Fish and Game between 1952 and 1978.

If published reports alone were considered, the scope of past log-jam removal operations would be greatly underestimated. One example from the Northwest can be found in the record of past removal projects in the Siuslaw River basin in western Oregon. Although Saltzman (1964 unpubl.) reports on major efforts to clear debris during 1962-64, 1948-50 was also a time of extensive undocumented stream cleanup, and numerous clearance projects have been undertaken since the winter of 1975-76. In addition, many small projects were conducted during 1936-38, 1944-46, 1957-58, and 1965-66, for which few records are available (Oregon State Game Commission, Fishery Division Annual Reports, numerous years). Added to this list are the many removal projects undertaken by private companies, of which no records at all were kept. If all the debris removal projects completed in this drainage over the past 45 years could be listed, the total would be large, possibly more than 1,000. The same conclusion would probably apply to other river drainages in Oregon, and to many other Pacific Northwest watersheds as well.

Although log jams have undoubtedly declined in both number and size, they are still a common feature of Pacific Northwest streams. In the past, jams were most often caused by poor logging practices and fires, but now large debris jams are most commonly caused by debris torrents during major storms. The large storms of 1964-65, 1972, 1975, and 1977 led to formation of many jams.

For many years, road construction was considered the major cause of mass soil failure leading to debris avalanches and torrents in the Pacific Northwest (Swanston and Swanson 1976). Recent evidence from steep lands in the Oregon Coast Ranges, however, suggests that clearcutting alone can also trigger a significant number of such events (Gresswell et al. 1979). Thus, as a result of past and future forest harvesting, log debris jams will continue to pose a significant threat to anadromous fish habitat in the steep lands of the Pacific Northwest, and jam removal will continue to be an important management activity.

Despite the extensive effort in debris jam removal, surprisingly little effort has been made to evaluate the impact of these stream clearance projects, either on the anadromous fish populations they are designed to enhance, or on habitat quality downstream from the removal area. Large amounts of fine sediment are usually stored behind debris jams, and complete removal of the jam results in transport of that material to downstream areas, Removal of one particularly large jam in the Oregon Coast Ranges resulted in the release of over 5000 m^3 of sediment to the stream channel below the removal site (Beschta 1979).

Moderate amounts of debris in a stream can provide favorable salmonid habitat, and excessive removal of debris may result in further habitat degradation (Hall and Baker 1975 unpubl.). An example of such an effect comes from a study in coastal Alaska. The numbers of juvenile sea-run Dolly Varden decreased immediately after complete removal of accumulated logging debris in Spring Pond Creek (Elliott 1978). Two years later, the population had decreased by 80 percent. Changes in species abundance and composition of the benthic macroinvertebrate population led to a shift in the diet of the fish. This study recommended that many debris removal projects be reevaluated.

Baker (1979) pointed out several constraints to a thorough analysis of operations to remove debris jams. In a study of seven removal sites in western Oregon, he found that the principal short--term impacts were release of sediment and debris trapped behind the jam and destruction of existing habitat within the jam. Sometimes these negative results can be offset by greatly increased use by anadromous fish above the jam, but the trade-offs are often hard to evaluate. Baker's work suggested increased emphasis on partial removal of debris jams.

A study of the role of large debris in streams examined the effects of removal of about 70 percent of the natural debris from one of two adjacent small tributaries in the Clearwater River drainage, Washington (Lestelle 1978). Nonmigratory cutthroat trout were the only salmonids present, and their numbers were little affected in the first few months after removal of debris in August. The major effect was destabilization of the streambed during the following winter, including widespread deposition and scouring. Changes in the physical habitat may have been responsible for the significant reduction in numbers of trout observed during the winter. Within a year of removal, however, most of the debris volume had reaccumulated, and the trout population had returned to its previous level.

Some debris jams may actually increase the amount of habitat available for rearing juvenile salmonids, providing they are not extensive enough to completely block passage upstream. A study currently underway in the Oregon Coast Ranges has identified at least one jam that formed a small impoundment and increasea density of juvenile coho salmon in the impoundment about lo-fold over that in the natural channel, based on lineal stream distance (Everest, personal communication). More thorough evaluation of the role of debris in streams and policies for its removal is needed.

Log driving, often involving the use of splash dams on smaller streams and rivers, was a common practice in the early days of the logging industry in the Pacific Northwest. The scouring of stream bottoms and blockage of salmonid runs by the dams were two prominent impacts on fish populations. The International Pacific Salmon Fisheries Commission (1966) documented many of the consequences of log driving on the Stellako River in British Columbia, including the formation of numerous log jams. Wendler and Deschamps (1955) provided an excellent account of the use of logging dams in Washington, including a map of their historical distribution. These barriers to migration have been gradually removed, by natural means and by various logging companies or the Washington State Department of Fisheries.

FISHWAY DEVELOPMENT

Removing log jams is relatively easy compared to some barriers; providing a passageway over and around natural and artificial obstructions has frequently been necessary. Among the devices employed have been fish ladders, locks, tramways and trolleys, and a variety of other methods of passing fish upstream and downstream (Clay 1961).

One of the many fish-passage techniques, the Denil fishway, has particular significance to field managers. A modification of this design that is adaptable to portable use has become known as the Alaskan steeppass (Ziemer 1962). This fish pass has been used to establish new runs of salmon to previously inaccessible Frazer Lake on Kodiak Island in Alaska (Blackett 1979). Eggs and fry of sockeye salmon from nearby stocks were planted in the tributaries beginning in 1951. In 1962, a four-step steeppass, 64 m long, was built to provide returning fish access over the 10-m falls that had previously barred anadromous fish. By 1978, the run had grown to 142,000 and plans are underway to provide additional passage facilities to accommodate a run expected to reach 300-400,000 in the 1980's (Blackett 1979). A small run of chinook salmon has also been developed in the system.

Because of the potentially large size of salmon runs in the region, barrier bypass projects have a favorable benefit/cost ratio in Alaska and British Columbia, and as a result are fairly common. Sweet (1975 unpubl.) lists over 20 steeppass projects in the Alaska region, and Narver (1976) records 28 fishways in British Columbia. Farther south, a large number of access projects have also involved laddering of barriers. Narver (1976) observed that Oregon alone had fish passage facilities at 56 natural and 79 artificial obstructions, excluding the dams on the main Columbia River. Few reports, however, have evaluated the success or failure of these facilities. This is particularly true of projects for improving fish passage on small isolated stream reaches such as those blocked by improperly installed culverts.

Culverts that are poorly designed or installed have been a major cause of impaired fish passage. An annotated bibliography of reports dealing with fish passage at road crossings has recently been prepared (Anderson and Bryant 1980).

REARING HABITAT

Most of the early work on development of rearing habitat was done in the Midwest, where increases in bank cover and pool area were shown to increase the abundance and harvest of legal-sized brook trout significantly (Shetter et al. 1949, Hunt 1976). Tarzwell (1938), however, observed that most midwestern and eastern techniques were not directly transferable to west coast streams. Highly variable flow regimes, including frequent floods and droughts, make many structures unsuitable or unstable. The use of instream boulders, however, did seem to have the potential for providing stable cover and small pools in these circumstances (Madsen 1938, Tarzwell 1938).

BOULDER PLACEMENT

One of the early west coast efforts involving boulder placement occurred in California trout streams (Calhoun 1964, 1966). Followup photographs clearly showed the potential for large boulders to survive major storms and continue to provide desirable habitat. Since then, several studies have emphasized the association between rock cover and abundance of anadromous fish (Hartman 1965, Chapman and Bjornn 1969, Everest and Chapman 1972, Narver 1976), and a few additional efforts have been made to use this technique in habitat enhancement. Bjornn (1971) found that the introduction of large rock into small headwaters near spawning areas increased the carrying capacity and retarded the downstream movement of pre-smolt chinook salmon and steelhead trout over the winter. Boulders were added to an Atlantic salmon stream in New Brunswick (Redmond 1975). In sections of the Tracadie River where large angular rock (up to 1.2 m in diameter) had been placed, the numbers of juvenile salmon increased dramatically-- in some instances, from no fish present to between 25 and 50/100 m^2 (Narver 1976). Large rock has been used effectively to enhance salmonid habitat in several locations in the John Day River basin in eastern Oregon (Claire 1978c, 1980, unpubl.).

A careful evaluation of boulder placement is presently underway on the Keogh River in British Columbia (Ward and Slaney 1979). Tests are being made on several different configurations of boulders, alone and in combination with log cover. Preliminary results from 1 year of evaluation suggest that groupings of boulders are most effective, both as to durability and provision of habitat. Significant increases in abundance of both steelhead trout parr and coho salmon fry occurred in improved sections of stream. Steelhead trout abundance was significantly correlated with the number of boulders placed in a reach. Placement of boulders by helicopter proved to be comparable in cost to placement with heavy equipment, and allows habitat development in inaccessible stream reaches. Although benefit/cost analysis is very uncertain at this stage in the project, early results are promising (Ward and Slaney 1979).

REARING POOLS

Some of the earliest efforts in habitat development in the West used various structures to create pools in streams of the Sierra Nevada in California during the early 1930's. An evaluation of 41 of these structures built on the East Fork of the Kaweah River in the Sequoia National Forest was conducted some 18 years later by Ehlers (1956). Although most of the other structures had failed, 9 of 15 log dams had survived and 6 were operating properly and providing added trout habitat. Flows as high as 70 m^3/s (2500 ft^3/s) were estimated to have occurred since construction.

Small log and rock dams were constructed to provide additional trout habitat in the headwaters of Sagehen Creek, California, in 1957. No trout were present in this area, so brook trout were introduced to the newly formed pools from the stream below. The trout survived and grew well, establishing a self-sustaining population (Gard 1961). After 12 years, the area was resurveyed; 6 of the 14 original dams were in good to excellent condition and the trout population had persisted (Gard 1972). The technique was believed cost-effective in enhancing headwater populations. In one Montana trout stream, however, the useful life of stepdams was very short, the majority lasting only about 1 year (Lund 1976).

The importance of pools as rearing habitat for juvenile coho salmon has stimulated several efforts to create new pools in the Oregon Coast Ranges. Pools are scarce during low summer flow in many streams with bedrock substrate along the coast. The Coos Bay District of the Bureau of Land Management used dynamite to blast a test pool in a sandstone bedrock section of Vincent Creek, Oregon (Anderson 1973). Initial results appeared favorable, and 12 additional pools were created in 1974. An excellent followup report was produced by Anderson and Miyajima (1975) that could provide a model for evaluation of many management-oriented projects. Diagrams of techniques and recommendations for improvement accompany an evaluation of fish populations before and after the project. Although resources were available for only one sample in the year before construction and two in the year after, some of the changes observed were large enough to be statistically significant.

Juvenile coho salmon populations in the new pools of Vincent Creek increased lo-fold over those inhabiting comparable areas before blasting (Anderson and Miyajima 1975). Coho salmon in the newly formed pools were significantly larger than those found in the control areas before construction, but fish in the control riffle were also larger than before. No change was found in cutthroat trout abundance, but those in the new pools averaged 8 cm larger than controls. These bigger fish have provided recreation for sport fishermen, but they may also have become predators on juvenile coho salmon (Anderson, personal communication). The data were too limited to assess changes in other fish species--age 0+ steelhead trout, the speckled dace, and the redside shiner. In some pool-blasting projects, the redside shiner and the speckled dace have increased in abundance.

Water temperatures at the bottom of one pool were up to 2.2°C cooler than peak temperatures in an adjacent riffle. Also, temperatures were above 22°C for a much shorter period each day in the pool than in the riffle (Anderson and Miyajima 1975). Other unanticipated benefits accrued from the newly formed pools. High numbers of crayfish were found in the pools (Anderson, personal communication). Crayfish are becoming increasingly sought after for sport and food in some areas of the coast. Another benefit has been the occasional deposition of gravel at the tail of a pool, which has been used by steelhead trout for spawning.

The Oregon Department of Fish and Wildlife created 15 pools with dynamite on six tributaries of the Siuslaw River (Hutchison 1973 unpubl.). Results there have not been favorable. No significant changes in populations have been observed, apart from small numbers of cutthroat trout in pools where none occurred before. One explanation for the failure of coho salmon to respond in this system may be the very low numbers of adult fish that have spawned there in the last few years (Hutchison 1978 unpubl.).

In a nearby area, however, results of pool blasting appeared more favorable. The USDA Forest Service blasted seven pools in Cedar Creek, tributary to the Siuslaw River, in 1978 and enlarged five natural pools in a tributary of the Smith River, Oregon, in 1979. The pools have been self-cleaning, as planned. Those on Cedar Creek in particular have resulted in substantial increases in the number of juvenile coho salmon rearing in an area that was predominantly bedrock. Evaluation of the project suggests the need for varying size and configuration of the pools, with possibly greater potential for small pools created with just a few sticks of dynamite (Heller, personal communication).

WINTER HABITAT

Evidence increasingly points to the importance of winter habitat in controlling production of salmonid smolts in some stream systems. The previously mentioned work of Mason (1974, 1976) with coho salmon in British Columbia provides some of the best such documentation.

Intermittent sidepools, back channels, and other areas of relatively still water that become inundated during high flows have recently been shown to provide valuable winter habitat for juvenile salmonids, particularly in coastal areas (Bustard and Narver 1975a, b; Kralik and Sowerwine 1977). Overwinter survival of juvenile coho salmon that moved into one side-channel tributary of Carnation Creek, British Columbia, in the fall averaged 74 percent for four winters. Comparable survival for those fish remaining in the main channel was 23 percent (Narver, personal communication).

In the early 1960's, suggestions were made to use bulldozers to excavate such channels in conjunction with logging operations (Narver, personal communication), but little or no enhancement work of this type has been carried out. Recent studies on winter growth and survival of juvenile coho salmon in natural spring ponds on the Olympic Peninsula of Washington (Peterson 1980) suggest that increasing the area of lowland ponds adjacent to salmonid streams has great potential for enhancing salmonid abundance. Juvenile salmon that had reared in streams during spring and summer moved into these spring ponds in large numbers during fall and winter. Fish in the ponds survived and grew better than those overwintering in tributary streams (Peterson 1980).

FLOW AUGMENTATION

Augmentation of low summer flow has been an effective and inexpensive approach to habitat enhancement for resident trout. Most of this work has occurred in the Sierra Nevada mountains of California, where low (l-2 m) flow-maintenance dams have been built at the outlets of natural lakes. The storage provided by these dams maintains permanent streamflow in downstream channels that formerly were dry during part of the summer. The first dam was built in 1925 by a private citizen, and five more structures were built in the early 1930's at a cost of $5,200 (Burghduff 1934). By 1954, 40 dams had been built, enhancing habitat in 540 km of stream (Cronemiller and Fraser 1954, Cronemiller 1955). By this time, many of the most desirable sites had been used, and costs had increased substantially. These small projects have resulted in significant increases in summer populations of resident trout, and flow augmentation could be applicable to enhancement of anadromous populations.

Although some evidence has been found to the contrary (Hall and Knight 1981), most data point to a strong positive association of streamflow with natural production of coho salmon (Smoker 1955, Matthews and Olson 1980, Scarnecchia 1981). Although the relation of salmonid abundance to streamflow seems complex, increased production of anadromous salmonids by supplementing low summer streamflow with upstream storage might be possible. One such project is reported on a 28-ha lake on Vancouver Island (Canada Department of Fisheries and Oceans 1980). An additional 0.04-0.06 m^3/s of flow is available downstream from the lake during the dry summer. Before any large-scale development of this kind goes forward, insuring that limits on carrying capacity in winter will not negate benefits gained during the summer and fall would be important. A more promising approach might be to augment flow in intermittent streams supporting anadromous fish.

At least one attempt has been made to augment flow in a steelhead stream in eastern Oregon (West et al. 1965a). Subterranean weirs, constructed with plastic sheeting placed in trenches, brought ground water to the surface and maintained surface flow for short distances above and below some of the structures, where the channel had previously been dry. The scheme was judged to be expensive and impractical, however, because of the large number of structures required and the damage sustained during spring runoff (Claire 1978b unpubl.).

Building dams may not be the only means of augmenting streamflow. An unexpected increase in low flow occurred when a heavily grazed section of stream in eastern Oregon was fenced to exclude livestock (Winegar 1977). A 4-km section was fenced in 1966, and 5.6 km of stream channel were added to the exclosure in 1974. In spite of the significant increase in riparian vegetation, summer low flow has increased. In addition, the stream no longer consistently freezes solid during winter (Winegar 1978 unpubl.). Although the cause of the increased flow is not certain, removal of the cattle reduced streamside soil compaction, apparently resulting in increased infiltration and greater ground-water recharge (Winegar, personal communication).

STREAM FERTILIZATION

Some evidence suggests that chemical properties of stream water influence abundance and growth rate of salmonids (Hall and Knight 1981). A few attempts have been made to increase biological production in streams by addition of nutrients. Stockner and Shortreed (1978) and Gregory (1980) showed significant response of attached algae to nutrient addition in streams in British Columbia and Oregon. An earlier fertilization experiment by Huntsman (1948) in an eastern Canadian stream showed a limited response in abundance of Atlantic salmon and associated fish species, as well as some increase in invertebrate numbers.

No conclusive evidence is available on the effectiveness of fertilization in enhancing salmonid populations in streams, but further experimental work like that now underway by the British Columbia Fish and Wildlife Branch (Slaney, personal communication) should be encouraged. This nonstructural approach to habitat enhancement has the advantage that it can be easily terminated if it proves ineffective or undesirable. No commitment must be made to a long-term program, such as accompanies most structural enhancement.

RIPARIAN HABITAT

Hynes (1975) has effectively made the case that a stream and its valley are an inseparable ecological unit. Many examples are available that demonstrate this interdependence as it relates specifically to the habitat of anadromous fish. Among the elements of habitat influenced by the riparian zone are temperature, cover, and food. Studies of effects of logging have shown the response of fish habitat to forest harvesting near streams (Hall and Lantz 1969, Burns 1972, Gibbons and Salo 1973). Most changes in habitat adversely affected salmonid populations, but in a few instances fish and invertebrate abundance increased after opening of the canopy along the stream (Newbold et al. 1980, Murphy and Hall 1981). One project in Wisconsin deliberately removed riparian vegetation as an enhancement measure for brook trout (Hunt 1979).

Conditions of the watershed away from the stream can also influence fish habitat, as noted in the earlier discussion of log debris jams in streams. In fact, one of the more impressive case studies of stream rehabilitation involved no direct action within or near the stream channel at all, simply protection of the watershed. This was the logging moratorium on the South Fork Salmon River, discussed earlier in relation to cleaning of spawning gravel (Platts and Megahan 1975). Other evidence that watershed protection is an effective rehabilitation measure comes from studies of the impact of livestock grazing on stream habitat and salmonid populations (Platts 1981).

Several studies have provided quantitative evidence of the serious impact of heavy grazing pressure on trout populations (table 2). The population size in control sections suggests that the average salmonid abundance might be tripled by controlling heavy grazing pressure. The evidence is not conclusive because few studies of fish populations have been carried out in the same section of stream before and after grazing. Differences in abundance between grazed and control areas in the studies summarized in table 2 are so large as to leave little doubt of a real impact, however.

Table P--Comparisons of trout populations in sections of stream where grazing pressure was absent or light (control) versus those heavily grazed (modified from Claire 1930 unpubl.)

Species	Location	Units	Percent greater in control	Reference
Brown trout	Rock Creek Montana 1/	kg/ha	236	Marcuson (1977 unpubl.)
Cutthroat and rainbow trout	Big Creek, Utah	kg/ha	263	Duff (1377 unpubl.)
brown trout	Little Deschutes River Oregon	kg/ha	269	Lorz (1974)
Steelhead trout	Camp Creek, Oregon	no/km	2/94	Claire (1980 unpubl.)

1/ An earlier stuay on the same stream by Gunderson (1968) is not comparable because of different base area.

2/ Based on 5 years of sampling. All other studies based on a single estimate.

An example of this impact is provided by studies in Camp Creek, an important producer of summer steelhead in the John Day drainage in eastern Oregon that had been heavily grazed for 70 years. In 1964, 0.8 km of stream was fenced to exclude livestock. By 1974, 75-80 percent of the stream was shaded by riparian vegetation, which had been virtually absent before fencing. An additional 9.6 km of stream were fenced in 1976. During 1 year, maximum stream temperature in the fenced section was 19°C, compared to 25.5°C in the heavily grazed section (Claire 1978a unpubl.). Numbers of spawning and rearing steelhead trout have increased significantly. Spawning surveys have been conducted in the drainage since 1956. In an ll-year period after fencing, 10.5 redds per km were counted in the heavily grazed area and 18.6 redds per km in the fenced section. In 5 years of sampling, from 1974 to 1979, the average number of juvenile steelhead was twice as high inside the enclosure as out, and dace populations were 6-7 times greater outside the fenced area (Claire 1980 unpubl.). Everest (1978 unpubl.) estimated the benefit/cost ratio of this fencing project to be between 2.3:1 and 3.3:1 (depending on interest rates and maintenance costs). A favorable benefit/cost ratio was also estimated by Olson and Armour (1979) for fencing riparian zones on all lands administered by the Bureau of Land Management.

In spite of apparently conclusive evidence on adverse impacts of grazing, progress in rehabilitating damaged streams has been slow. Fencing streambanks is expensive and, even where evidence shows that benefits exceed costs, resistance from land managers and owners is considerable. Nonstructural measures such as rotational grazing patterns may sometimes be a solution, but considerable controversy exists now and will probably continue for some time (Cope 1979).

CONCLUSIONS

The history of habitat rehabilitation and enhancement for stream-dwelling salmonids has been a mixture of failure and success. Where adequate documentation has been available, learning from failure has been possible and techniques and approaches improved. We believe that sufficient background is now available to recommend substantially increased emphasis on this phase of fishery management. Past work in the West has been weighted in favor of spawning habitat; future work should put more emphasis on rehabilitation and enhancement of rearing habitat.

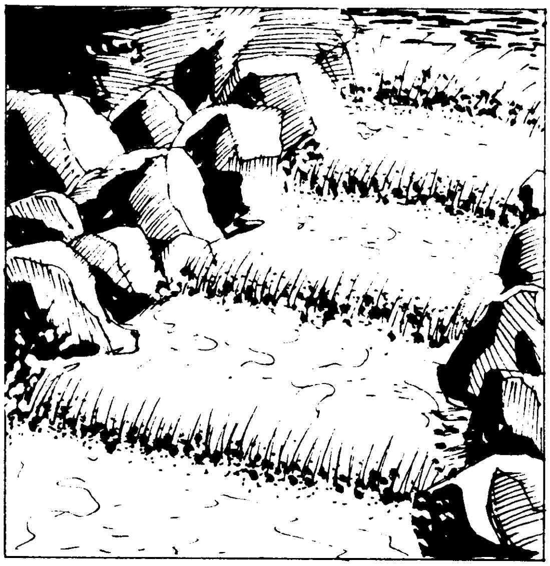
From an ecological perspective, these techniques of habitat management are soundly based. They are ideally suited to the goal of maintaining such natural wild stocks as still exist and preserving genetic variability where possible. In the face of increasing concern about impacts of large-scale hatchery production on both genetic constitution of stocks and carrying capacity of the environment, this rationale may be one of the strongest arguments for emphasis on improving quality and quantity of stream habitat.

Finally, we join with Reeves and Roelofs (1982) and Narver (1973) in emphasizing that habitat rehabilitation must never be viewed as a substitute for habitat protection. Communication between fishery managers and foresters is an essential element of habitat protection (see Toews and Brownlee 1981, for example). Habitat management can now be cost effective, and as we learn more, it should become more so. In almost every instance, however, preventing initial habitat degradation would be more economical of total resources than repairing it, and some damage simply is not reversible. Past mistakes require efforts to rehabilitate many streams, but our efforts in habitat management must continue to put an equally strong priority on protection of watershed and stream resources.

ACKNOWLEDGMENTS

This paper owes much to constructive comments of others. In particular, we acknowledge the contributions of Gordon Reeves and Terry Roelofs. Their paper in this series (No. 13) was originally planned to be independent from ours. When the two manuscripts were complete, we reorganized them to separate evaluation of past work from description of successful techniques. For a complete assessment of the field, the two papers must be used together.

We thank those biologists who provided unpublished data for this review; in addition, we appreciate comments on one or more versions of the manuscript by J. W. Anderson, A. R. Cargill, C. J. Cederholm, E. W. Claire, W. A. Evans, J. M. Hutchison, W. R. Meehan, J. F. Orsborn, and P. A. Slaney. James D. Hall is grateful for use of space and library facilities of the Fisheries Research Division, New Zealand Ministry of Agriculture and Fisheries, made available through the courtesy of Dr. R. M. McDowall. This is Technical Paper 6127, Oregon Agricultural Experiment Station.



LITERATURE CITED

Allen, R. L.; Seeb, J. E.; King, D. D. A preliminary assessment of field operations with a salmon-spawning gravel cleaning machine. In: Salmon-spawning gravel: a renewable resource in the Pacific Northwest? Rep. 39. Pullman, WA: Washington State Water Research Center; 1981: 1-14.

Anderson, J. W. Evaluation of excavated fish rearing pool in Vincent Creek. Tech. Note. Coos Bay, OR: U.S. Department of the Interior, Bureau of Land Management; 1973. 5 p.

Anderson, J. W.; Miyajima, L. Analysis of the Vincent Creek fish rearing pool project. Tech. Note 274. Coos Bay, OR: U.S. Department of the Interior, Bureau of Land Management; 1975. 26 p.

Anderson, L.; Bryant, M. Fish passage at road crossings: an annotated bibliography. Gen. Tech. Rep. PNW-117. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 10 p.

Andrew, F. J. Gravel cleaning to increase salmon production in rivers and spawning channels. In: Salmon-spawning gravel: a renewable resource in the Pacific Northwest? Rep. 39. Pullman, WA: Washington State Water Research Center; 1981: 15-31.

Baker, C. O. The impacts of logjam removal on fish populations and stream habitat in western Oregon. Corvallis, OR: Oregon State University; 1979. 86 p. M.S. thesis.

Barton, J. R.; Peters, E. J.; White, D. A.; Winger, P. V. Bibliography on the physical alteration of the aquatic habitat (channelization) and stream improvement. Provo, UT: Brigham Young University Publications; 1972. 30 p.

Beschta, R. L. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. Northwest Sci. 53(1): 71-77; 1979.

Binns, N. A.; Eiserman, F. M. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108(3): 215-228; 1979.

Bjornn, T. C. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover, and population density. Trans. Am. Fish. Soc. 100(3): 423-438; 1971.

Blackett, R. F. Establishment of sockeye (*Oncorhynchus nerka*) and chinook (O. *tshawytscha*) salmon runs at Frazer Lake, Kodiak Island, Alaska. J. Fish. Res. Board Can. 36(10): 1265-1277; 1979.

Boussu, M. F. Relationship between trout populations and cover on a small stream. J. Wildl. Manage. 18(2): 229-239; 1954.

Bovee, K. D. Probability-of-use criteria for the family Salmonidae. Instream Flow Inf. Pap. 4, FWS/OBS-78/07. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1978. 80 p.

Bovee, K. D.; Cochnauer, T. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. Instream Flow Inf. Pap. 3, FWS/OBS-77/63. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1977. 39 p.

Burghduff, A. E. Stream improvement. Calif. Fish and Game. 20(2): 113-118; 1934.

Burns, J. W. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101(1): 1-17; 1972.

Bustard, D. R.; Narver, D. W. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32(5): 667-680; 1975a.

Bustard, D. R.; Narver, D. W. Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. J. Fish. Res. Board Can. 32(5): 681-687; 1975b.

Calhoun, A. *Homo* vs. *Salmo*. Proc. West. Assoc. Game and Fish Comm. 43: 243-245; 1964.

Calhoun, A. Habitat protection and improvement. In: Calhoun, A., ed. Inland fisheries management. Sacramento, CA: State of California, Department of Fish and Game; 1966: 40-48.

Canada Department of Fisheries and Oceans; British Columbia Ministry of the Environment. Stream enhancement guide. Vancouver, BC: Canada Department of Fisheries and Oceans; British Columbia Ministry of the Environment. Salmonid Enhancement Program; 1980. 82 p.

Chapman, D. W.; Bjornn, T. C. Distribution of salmonids in streams with special reference to food and feeding. In: Northcote, T. G., ed. Proceedings, symposium on salmon and trout in streams: H. R. MacMillan Lectures in Fisheries; 1968 February 22-24; Vancouver, BC. Vancouver, BC: University of British Columbia; 1969. 388 p. (p. 153-176).

Clay, C. H. Design of fishways and other fish facilities. Ottawa, ON: Canada Department of Fisheries; 1961. 301 p.

Cope, 0. B., ed. Grazing and riparian/ stream ecosystems: Proceedings of the forum; 1978 November 3-4; Denver, CO. Washington, DC: Trout, Unlimited; 1979. 94 p.

Cronemiller, F. P. Making new trout streams in the Sierra Nevada. In: U.S.D.A. Yearbook of Agriculture. Washington, DC: Superintendent of Documents (Government Printing Office); 1955: 583-586.

Cronemiller, F. P.; Fraser, J. Stretching our Sierra trout streams. Outdoor Calif. 15(4): 3-7; 1954.

Davis, H. S. The purpose and value of stream improvement. Trans. Am. Fish. Soc. 64: 63-67; 1934.

Davis, H. S. Methods for the improvement of streams. Memorandum I-133. Washington, DC: U.S. Bureau of Fisheries; 1935. 27 p.

Ehlers, R. An evaluation of stream improvement devices constructed eighteen years ago. Calif. Fish and Game 42(3): 203-217; 1956.

Elliott, S. Ecology of rearing fish. Juneau, AK: Alaska Department of Fish and Game, Federal Aid in Fish Restoration; 1978; Annual report 1977-1978, Proj. F-9-10, 19(D-I): 39-52.

Everest, F. H.; Chapman, D. W. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Board Can. 29(l): 91-100; 1972.

Fearnow, T. C. An appraisal of stream improvement programs of the National Forests of the northeastern states. Trans, North Am. Wildl. Conf. 6: 161-168; 1941.

Fessler, J. L. Spawning area development for fall chinook salmon. In: Rayner, H. J.; Campbell, H. J.; Lightfoot, W. C., eds. Progress in game and sportfish research 1963-1970. Res. Div. Rep. Portland, OR: Oregon State Game Commission; 1970: 16-17.

Frankenberger, L. Effects of habitat management on trout in a portion of the Kinnikinnic River, St. Croix County, Wisconsin. Rep. 22. Madison, WI: Wisconsin Department of Natural Resources, Bureau of Fish Management; 1968. 8 p.

Frankenberger, L.; Fassbender, R. Evaluation of the effects of the habitat management program and the watershed planning program on the brown trout fishery in Bohemian Valley Creek, La Crosse County, Wisconsin. Rep. 16. Madison, WI: Wisconsin Department of Natural Resources, Bureau of Fish Management; 1967. 9 p.

Gard, R. Creation of trout habitat by constructing small dams. J. Wildl. Manage. 25(4): 384-390; 1961.

Gard, R. Persistence of headwater check dams in a trout stream. J. Wildl. Manage. 36(4): 1363-1367; 1972.

Garrison, R. L. Spawning area development for fall chinook and subsequent survival from egg deposition to seaward migration. Portland, OR: Oregon State Game Commission; 1971a; Job final report, Proj. AFS-27-1. 10 p.

Garrison, R. L. Fall chinook rehabilitation on the Alsea River. Portland, OR: Oregon State Game Commission; 1971b; Annual progress report, Proj. AFS-57-1:33-38..

Gerke, R. J. Spawning ground improvement study. Olympia, WA: Washington State Department of Fisheries; 1973; Progress report, Proj. AFC-59-2. 18 p.

Gerke, R. J. Salmon spawning habitat improvement study. Olympia, WA: Washington State Department of Fisheries; 1974; Project completion report, Proj. l-93-D. 15 p.

Gibbons, D. R.; Salo, E. 0. An annotated bibliography of the effects of logging on fish of the western United States and Canada. Gen. Tech. Rep. PNW-10. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 145 p.

Gregory, S. V. Effects of light, nutrients, and grazing on periphyton communities in streams. Corvallis, OR: Oregon State University; 1980. 151 p. Ph. D. thesis.

Gresswell, S.; Heller, D.; Swanston, D. N. Mass movement response to forest management in the central Oregon Coast Ranges. Resour. Bull. PNW-84. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1979. 26 p.

Gunderson, D. R. Floodplain use related to stream morphology and fish populations. J. Wildl. Manage. 32(3): 507-514; 1968.

Hale, J. G. An evaluation of trout stream habitat improvement in a north shore tributary of Lake Superior. Minn. Fish. Invest. 5: 37-50; 1969.

Hall, J. D.; Field-Dodgson, M. S. Improvement of spawning and rearing habitat for salmon. In: Hopkins, C. L., comp. Proceedings of the salmon symposium; 1980 August 30-31; Christchurch, N. Z. Occas. Publ. No. 30. [City of publisher unknown]: N. Z. New Zealand Ministry of Agriculture and Fisheries, Fisheries Research Division; 1981. 98 p. (p. 21-28).

Hall, J. D.; Knight, N. J. Natural variation in abundance of salmonid populations in streams and its implications for design of impact studies. EPA-600/S3-81-021. Corvallis, OR: U.S. Environmental Protection Agency; 1981. 85 p.

Hall, J. D.; Lantz, R. L. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. In: Northcote, T. G., ed. Proceedings, symposium on salmon and trout in streams: H. R. MacMillan Lectures in Fisheries; 1968 February 22-24; Vancouver, BC. Vancouver, BC: University of British Columbia; 1969. 388 p. (p. 355-376).

Hartman, G. F. The role of behavior in the ecology and interaction of underyearling coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Board Can. 22(2): 1035-1081; 1965.

Holman, G.; Evans, W. A. Stream clearance project--completion report Noyo River, Mendocino County. Inland Fish. Adm. Rep. 64-10. Sacramento, CA: California Department of Fish and Game; 1964. 13 p.

Hubbs, C. L.; Greeley, J. R.; Tarzwell, C. M. Methods for the improvement of Michigan trout streams. Bull. 1. Ann Arbor, MI: Michigan Department of Conservation, Institute for Fisheries Research; 1932. 54 p.

Hunt, R. L. Effects of habitat alteration on production, standing crops and yield of brook trout in Lawrence Creek, Wisconsin. In: Northcote, T. G., ed. Proceedings, symposium on salmon and trout in streams: H. R. MacMillan Lectures in Fisheries; 1968 February 22-24; Vancouver, BC. Vancouver, BC: University of British Columbia; 1969. 388 p. (p. 281-312).

Hunt, R. L. Responses of a brook trout population to habitat development in Lawrence Creek. Tech. Bull. 48. Madison, WI: Wisconsin Department of Natural Resources; 1971. 35 p.

Hunt, R. L. A long-term evaluation of trout habitat development and its relation to improving management-related research. Trans. Am. Fish. Soc. 105(3): 361-365; 1976.

Hunt, R. L. Removal of woody streambank vegetation to improve trout habitat. Tech. Bull. 115. Madison, WI: Wisconsin Department of Natural Resources; 1979. 36 p.

Huntsman, A. G. Fertility and fertilization of streams. J. Fish. Res. Board Can. 7(5): 248-253; 1948.

Hynes, H. B. N. The stream and its valley. Verh. Int. Ver. Limnol. 19: 1-15; 1975.

International Pacific Salmon Fisheries Commission. Effects of log driving on the salmon and trout populations in the Stellako River. Vancouver, BC: International Pacific Salmon Fisheries Commission; 1966; Prog. Rep. 14. 88 p.

Kralik, N. J.; Sowerwine, J. E. The role of two northern California streams in the life history of anadromous salmonids. Arcata, CA: Humboldt State University; 1977. 68 p. Joint M.S. thesis.

Latta, W. C. The effects of stream improvement upon the angler's catch and standing crop of trout in the Pigeon River, Otsego County, Michigan. Res. and Dev. Rep. 265. Lansing, MI: Michigan Department of Natural Resources; 1972. 57 p.

Leopold, A. Game management. New York: Charles Scribner's Sons; 1933. 481 p.

Lestelle, L. C. The effects of forest debris removal on a population of resident cutthroat trout in a small headwater stream. Seattle, WA: University of Washington; 1978. 86 p. M.S. thesis.

Lewis, S. L. Physical factors influencing fish populations in pools of a trout stream. Trans. Am. Fish. Soc. 98(1):14-19; 1969.

Lister, D. B.; Marshall, D. E.; Hickey, D. G. Chum salmon survival and production at seven improved groundwater-fed spawning areas. Can. Manuscr. Rep. Fish. Aquat. Sci. 1595; 1980. 58 p.

Lorz, H. W. Ecology and management of brown trout in Little Deschutes River. Fish Res. Rep. 8. Portland, OR: Oregon Wildlife Commission; 1974. 49 p.

Lowry, G. R. Effect of habitat alteration on brown trout in McKenzie Creek, Wisconsin. Res. Rep. 70. Madison, WI: Wisconsin Department of Natural Resources; 1971. 27 p.

Lund, J. A. Evaluation of stream channelization and mitigation on the fishery resources of the St. Regis River, Montana. FWS/OBS-76/06. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1976. 49 p.

McNeil, W. J.; Ahnell, W. H. Success of pink salmon spawning relative to size of spawning materials. Spec. Sci. Rep. 469. Washington, DC: U.S. Fish and Wildlife Service; 1964. 15 p.

Madsen, M. J. A preliminary investigation into the results of stream improvement in the inter-mountain forest region. Trans. North Am. Wildl. Conf. 3:497-503; 1938.

Magill, A. R. Rehabilitation problems. In: Krygier, J. T.; Hall, J. D., eds. Forest land uses and stream environment: Proceedings of a symposium; 1970 Oct. 19-21; Corvallis, OR. Corvallis, OR: Oregon State University; 1971: 230-231.

Mason, J. C. A further appraisal of the response to supplemental feeding of juvenile coho (0. kisutch) in an experimental stream. Tech. Rep. 470. Nanaimo, BC: Canada Fisheries and Marine Service; 1974. 26 p.

Mason, J. C. Response of underyearling coho salmon to supplemental feeding in a natural stream. J. Wildl. Manage. 40(4): 775-788; 1976.

Matthews, S. B.; Olson, F. W. Factors affecting Puget Sound coho salmon (Oncorhynchus kisutch) runs. Can. J. Fish. Aquat. Sci. 37(9): 1373-1378; 1980.

Maughan, 0. E.; Nelson, K. L.; Ney, J. J. Evaluation of stream improvement practices in southeastern trout streams. Bull. 115. Blacksburg, VA: Virginia Water Resources Research Center; 1978. 67 p.

Meehan, W. R. Effects of gravel cleaning on bottom organisms in three southeast Alaska streams. Prog. Fish-Cult. 33(2): 107-111; 1971.

Megahan, W. F.; Platts, W. S.; Kulesza, B. Riverbed improves over time: South Fork Salmon. In: Proceedings, symposium on watershed management; 1980 July 21-23; Boise, ID. New York: American Society of Civil Engineering; 1980: 380-395.

Merrell, T. R. Stream improvement as conducted on the Clatskanie River and tributaries. Fish. Comm. Oreg. Res. Briefs 3(2): 41-47: 1951.

Mih, W. C. A review of restoration of stream gravel for spawning and rearing of salmon species. Fisheries. 3(l): 16-18; 1978.

Mih, W. C. Hydraulic restoration of stream gravels for spawning and rearing of salmon species. Rep. 33. Pullman, WA: Washington State Water Research Center; 1979. 34 p.

Mih, W. C. Research and development of a salmon spawning gravel cleaner (Gravel Gertie). In: Salmon-spawning gravel: a renewable resource in the Pacific Northwest? Rep. 39. Pullman, WA: Washington State Water Research Center; 1981: 140-153.

Mullan, J. W. Is stream improvement the answer? W. Va. Conserv. 26(6): 25-30; 1962.

Mundie, J. H.; Mounce, D. E. Application of stream ecology to raising salmon smolts in high density. Verh. Int. Ver. Limnol. 20: 2013-2018; 1978.

Murphy, M. L.; Hall, J. D. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38(2): 137-145; 1981.

Narver, D. W. Are hatcheries and spawning channels alternatives to stream protection? Circ. 93. Nanaimo, BC: Fisheries Research Board of Canada; 1973. 11 p.

Narver, D. W. Stream management for west coast anadromous salmonids. Trout. 17(l): 7-13 (Suppl.); 1976.

Nelson, R. W.; Horak, G. C.; Olson, J. E. Western reservoir and stream habitat improvements handbook. FWS/OBS-78/56. Washington, DC: U.S. Fish and Wildlife Service, Office of Biological Services; 1978. 250 p.

Newbold, J. D.; Erman, D. C.; Roby, K. B. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37(7): 1076-1085; 1980.

Nickelson, T. E.; Hafele, R. E. Streamflow requirements of salmonids, Portland, OR: Oregon Department of Fish and Wildlife; 1978; Annual progress report, Proj. AFC-62. 26 p.

Olson, R. W.; Armour, C. L. Economic considerations for improved livestock management approaches for fish and wildlife in riparian/stream areas. In: Cope, 0. B., ed. Grazing and riparian/stream ecosystems: Proceedings of the forum; 1978 November 3-4; Denver, CO. Washington, DC: Trout, Unlimited; 1979: 67-71.

Outdoor California. It's new. The "riffle sifter." Outdoor Calif. 29(6): 12-13; 1968.

Parkinson, E. A.; Slaney, P. A. A review of enhancement techniques applicable to anadromous gamefishes. Fish. Manage. Rep. 66. Victoria, BC: British Columbia Fish and Wildlife Branch; 1975. 100 p.

Peterson, N. P. The role of spring ponds in the winter ecology and natural production of coho salmon (Oncorhynchus kisutch) on the Washington. Seattle, WA: University of Washington; 1980. 96 p. M.S. thesis.

Platts, W. S. Influence of forest and rangeland management on anadromous fish habitat in western North America: 7. Effects of livestock grazing. Meehan, W. R., tech. ed. Gen. Tech. Rep. PNW-124. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1981. 25 p.

Platts, W. S.; Megahan, W. F. Time trends in channel sediment size composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Trans. North Am. Wildl. Nat. Resour. Conf. 40: 229-239; 1975.

Redmond, M. A. Natural production. In: Bohne, J. R.; Sochasky, I., eds. Proceedings, New England Atlantic Salmon Restoration Conference; 1975 January 14-16; Boston, MA. Spec. Publ. Ser. 6. St. Andrews, NB: International Atlantic Salmon Foundation; 1975: 134-135.

Reeves, G. H., Roelofs, T. D. Influence of forest and rangeland management on anadromous fish habitat in western North America: 13. Rehabilitating and enhancing stream habitat: 2. Field applications. Meehan, W. R., tech. ed. Gen. Tech. Rep. PNW-140. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1982. 38 p.

Richard, J. B. Log stream improvement devices and their effects upon the fish population, South Fork Mokelumne River, Calaveras County, California. Inland Fish. Adm. Rep. 63-7. Sacramento, CA: California Department of Fish and Game; 1963. 12 p.

Richards [Richard], J. You can't build a trout stream. Outdoor Calif. 25(7): 3-4; 1964.

Saunders, J. W.; Smith, M. W. Physical alteration of stream habitat to improve brook trout production. Trans. Am. Fish. Soc. 91(2): 185-188; 1962.

Scarnecchia, D. L. Effects of streamflow and upwelling on yield of wild coho salmon (Oncorhynchus kisutch) in Oregon. Can. J. Fish. Aquat. Sci. 38(6): 471-475; 1981.

Shapley, S. P.; Bishop, D. M. Sedimentation in a salmon stream. J. Fish. Res. Board Can. 22(4): 919-927; 1965.

Shetter, D. S., Clark,). H.; Hazzard, A. S. The effects of deflectors in a section of a Michigan trout stream. Trans. Am. Fish. Soc. (1946) 76: 248-278; 1949.

Smoker, W. A. Effects of streamflow on silver salmon production in western Washington. Seattle, WA: University of Washington; 1955. 198 p. Ph. D. thesis.

Stewart, P. A. Physical factors influencing trout density in a small stream. Fort Collins, CO: Colorado State University; 1970. 78 p. Ph. D. thesis.

Stockner, J. G.; Shortreed, K. R. S. Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. J. Fish. Res. Board Can. 35(l): 28-34; 1978.

Swanston, D. N.; Swanson, F. J. Timber harvesting, mass erosion and steepland geomorphology in the Pacific Northwest. In: Coates, D. R. ed. Geomorphology and engineering. Stroudsburg, PA: Dowden, Hutchinson and Ross, Inc.; 1976: 199-221.

Tarzwell, C. M. Progress in lake and stream improvement. Trans. Am. Game Conf. 21: 119-134; 1935.

Tarzwell, C. M. Experimental evidence on the value of trout stream management in Michigan. Trans. Am. Fish. Soc. (1936) 66: 177-187; 1937.

Tarzwell, C. M. An evaluation of the methods and results of stream improvement in the Southwest. Trans. North Am. Wildl. Conf. 3: 339-364; 1938.

Toews, D. A. A.; Brownlee, M. J. A handbook for fish habitat protection on forest lands in British Columbia. Vancouver, BC: Canada Department of Fisheries and Oceans; 1981. 173 p.

U.S. Department of Agriculture, Forest Service. Fish stream improvement handbook. Washington, DC: U.S. Department of Agriculture, Forest Service; 1952. 21 p.

U.S. Department of the Interior, Bureau of Land Management. Stream preservation and improvement. In: U.S. Bureau of Land Management Manual. Washington, DC: U.S. Department of the Interior, Bureau of Land Management; 1968: Section 6760. [49 p.]

Ward, B. R.; Slaney, P. A. Evaluation of in-stream enhancement structures for the production of juvenile steelhead trout and coho salmon in the Keogh River: progress 1977 and 1978. Fish. Tech. Circ. 45. Vancouver, BC: British Columbia Ministry of the Environment; 1979. 47 p.

Wendler, H. 0.; Deschamps, G. Logging dams on coastal Washington streams. Wash. State Dep. Fish. Res. Pap. l(3): 27-38; 1955.

Wesche, T. A. Development and application of a trout cover rating system for IFN determination. In: Orsborn, J. F.; Allman, C. H., eds. Instream flow needs: Proceedings of a symposium; 1976 May 3-6; Boise, ID. Bethesda, MD: American Fisheries Society; 1976: 224-234. Vol. 2.

West, D. C.; Reeher, J. A.; Hewkin, J. A. Habitat improvement to enhance anadromous fish production. Portland, OR: Oregon State Game Commission; 1965a; Closing report, Clear Creek Proj. 11, Columbia River Fisheries Development Program. 10 p.

West, D. C.; Reeher, J. A.; Hewkin, J. A. Habitat improvement to enhance anadromous fish production. Portland, OR: Oregon State Game Commission; 1965b; Closing report, Tex Creek Proj. 10, Columbia River Fisheries Development Program. 20 p.

White, R. J. Responses of trout populations to habitat change in Big Roche-a-Cri Creek, Wisconsin. Madison, WI: University of Wisconsin; 1972. 296 p. Ph. D. thesis.

White, R. J. In-stream management for wild trout. In: King, W., ed. Wild trout management. Denver, CO: Trout, Unlimited; 1975a: 48-58.

White, R. J. Trout population responses to streamflow fluctuation and habitat management in Big Roche-a-Cri Creek, Wisconsin. Yerh. Int. Ver. Limnol. 19: 2469-2477; 1975b.

White, R. J.; Brynildson, 0. M. Guidelines for management of trout stream habitat in Wisconsin. Tech. Bull. 39. Madison, WI: Wisconsin Department of Natural Resources; 1967. 65 p.

Wilson, D. A. Salmonid spawning habitat improvement study. Olympia, WA: Washington State Department of Fisheries; 1976; Project completion report, Proj. l-93-D. 20 p.

Winegar, H. H. Camp Creek channel fencing--plant, wildlife, soil and water response. Rangeman's J. 4(l): 10-12; 1977.

Wydoski, R. S.; Duff, D. A. Indexed bibliography on stream habitat improvement. Tech. Note 322. Denver, CO: U.S. Department of the Interior, Bureau of Land Management; 1978. 35 p.

Ziemer, G. L. Steeppass fishway development. Inf. Leafl. 12. Juneau, AK: Alaska Department of Fish and Game; 1962. 9 p.

LITERATURE CITED - UNPUBLISHED

Bender, R. Log sills. Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978. 17 p. (p. 7).

Claire, E. Fencing: Camp Creek. Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978a. 17 p. (p. 9-10).

Claire, E. Flow recovery. Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978b. 17 p. (p. 8).

Claire, E. Rock work. Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978c. 17 p. (p. 2-3).

Claire, E. W. Stream habitat and riparian restoration techniques: guidelines to consider in their use. 1980. Manuscript prepared for Workshop for Design of Fish Habitat and Watershed Restoration Projects.

Duff, D. A. Livestock grazing impacts on aquatic habitat in Big Creek, Utah. Manuscript prepared for Livestock and Wildlife/Fisheries Workshop; 1977 May 3-5; Reno, NV; 1977. 33 p.

Engels, J. D. Use of gabions in stream habitat improvement. Eugene, OR: U.S. Department of the Interior, Bureau of Land Management; 1975. 18 p.

Everest, F. H. Economics of fencing streams to protect fish. Corvallis, OR: U.S. Department of Agriculture, Forest Service, Forestry Sciences Laboratory; 1978. 9 p.

Hall, J. D.; Baker, C. 0. Biological impacts of organic debris in Pacific Northwest streams. In: Logging debris in streams: Proceedings of a workshop; 1975 September 9-10. Corvallis, OR: Oregon State University; 1975. 13 p.

Hammer, R. Aquatic habitat improvement (district summary). Eugene, OR: U.S. Department of the Interior, Bureau of Land Management; 1976. 2 p.

Hammer, R. Fishery evaluation for Eugene District stream improvement structures. Eugene, OR: U.S. Department of the Interior, Bureau of Land Management; 1977. 3 p.

Heiser, D. W. Bear River rehabilitation: pink and chum salmon investigations. Olympia, WA: Washington State Department of Fisheries; 1971. 9 p. Progress report.

Heiser, D. W. Cedar River gravel improvement: pink and chum salmon investigations. Olympia, WA: Washington State Department of Fisheries; 1972a. 9 p. Progress report.

Heiser, D. W. Spawning ground improvement --gravel loosening, 1971-1972. Olympia, WA: Washington State Department of Fisheries; 1972b. 6 p. Progress report.

Hutchison, J. Use of dynamite to create fish rearing pools in Siuslaw River tributaries. Portland, OR: Oregon State Game Commission; 1973. 10 p.

Hutchison, J. Blasting bedrock pools. In: Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978. 17 p. (p. 6-7).

Johnson, D. E. Analysis of post-project temperatures and of fish species and populations of the Siuslaw River drainage. Eugene, OR: U.S. Department of the Interior, Bureau of Land Management; 1977. 5 p.

Marcuson, P. E. The effect of cattle grazing on brown trout in Rock Creek, Montana. Helena, MT: Montana Department of Fish and Game; 1977; Spec. Rep. Proj. No. F-20-R-21, 2a. 26 p.

Roppel, P. Existing and currently proposed fisheries rehabilitation and enhancement projects in Southeast Alaska. Juneau, AK: Alaska Department of Fish and Game, Fisheries Rehabilitation, Enhancement, and Development Division; 1978. 22 p.

Saltzman, W. 0. A report of the stream clearance activities conducted by the Oregon State Game Commission on the Siuslaw River system. Portland, OR: Oregon State Game Commission; 1964. 21 p.

Sheridan, W. L.; Wilke, R. W.; Olson, S. T. The gravel cleaner ("riffle sifter"). Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region; 1968. 8 p. Progress report 1967.

Summers, V. C.; Neubauer, E. K. Closing report for the coastal stream improvement and rehabilitation program. Portland, OR: Fish Commission of Oregon; 1965. 46 p.

Sweet, M. Fish habitat improvement information for the Alaska Region. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region; 1975. 13 p.

Winegar, H. Fencing. Report from fish habitat improvement workshop; 1978 September 26-27; Ochoco Ranger Station, Prineville, OR. Portland, OR: Oregon Department of Fish and Wildlife; 1978. 17 p. (p. 9).

DIRECTORY FOR PERSONAL COMMUNICATIONS

Anderson, J. W. (1978)
USDI Bureau of Land Management
333 South Fourth
Coos Bay, OR 97420

Bender, R.; Mullarkey, W. (1978)
Oregon Department of Fish and Wildlife
300 Fifth Street, Bay Park
Coos Bay, OR 97420

Claire, E. (1978)
Oregon Department of Fish and Wildlife
P.O. Box 19
John Day, OR 97845

Cowan, L. (1981)
Washington State Department of Fisheries
115 General Administration Building
Olympia, WA 98504

Evans, W. A. (1978)
USDA Forest Service
630 Sansome Street
San Francisco, CA 94111

Everest, F. H. (1981)
USDA Forest Service
Forestry Sciences Laboratory
3200 Jefferson Way
Corvallis, OR 97331

Hammer, R. (1978)
USDI Bureau of Land Management
Eugene District Office
1225 Pearl Street
Eugene, OR 97401

Heller, D. (1978, 1981)
USDA Forest Service
Mt. Hood National Forest
19559 Division
Portland, OR 97030

Narver, D. W. (1978)
British Columbia Ministry of the Environment
Fish and Wildlife Branch
400-1019 Wharf Street
Victoria, BC V8W 2Z1

Nelson, D. C. (1978)
Alaska Department of Fish and Game
P.O. Box 3150
Soldotna, AK 99669

Oliver, F. (1978)
USDI Bureau of Land Management
Roseburg, OR 97470

Slaney, P. A. (1981)
British Columbia Ministry of the Environment.
Fish and Wildlife Branch
Vancouver, BC V6T 1W5

White, R. J. (1981)
Department of Biology
Montana State University
Bozeman, MT 59715

Wilson, D. A. (1978)
Washington State Department of Fisheries
115 General Administration Building
Olympia, WA 98507

Winegar, H. (1978)
Oregon Department of Fish and Wildlife
Paulina Star Route, Box 5
Prineville, OR 97754