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REVIEW OF EFFECTS OF ENVIRONMENTAL DEGRADATION ON THE FRESHWATER STAGES OF ANADROMOUS FISH

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SUMMARY

Early research efforts begun in the 1950s and continued to the present to address the problems of environmental degradation on anadromous fish were centered mainly on fish behavioural work designed to provide solutions to fish passage problems. Information leading to solutions to passage problems for both adult and juvenile salmonids caused by dams and impoundments in the Columbia River was the highest priority of this research. Research on various fisheries enhancement measures was also begun in the late 1960s to increase production of Columbia River salmon.

The main conclusions, remedial actions recommended, and future research needs that were derived from this research are summarized.

1. INTRODUCTION

This report traces the Northwest and Alaska Fisheries Center's (NWAFC) research on environmental aspects from 1931 to the present. Most of this research focused on describing the effects of various environmental perturbations which existed or were predicted to occur. Some of these studies led to establishment of criteria for water quality standards for fish; others led to the establishment of programs to provide solutions to problems such as those caused by construction of dams. Water pollution including heated effluents from nuclear-powered generating plants are not considered here.

2. EARLY RESEARCH EFFORTS (1931-1950)

From 1931 to 1950, very little effort was expended on environmental studies because the projected level of development, with the exception of dam construction in the Pacific Northwest, was not perceived to be of sufficient magnitude to cause serious environmental problems to the fishery resources. Most of the research effort was therefore centered on studies related to the management of various fisheries. As early as 1933, however, studies were begun to deal with passage problems resulting from the construction of Bonneville, Rock Island, and Grand Coulee Dams on the Columbia River. These studies included thorough surveys of tributary streams to determine the distribution of salmonid populations in relation to the installation of irrigation diversion screens, an evaluation of the relocation of the anadromous fish runs cut off by Grand Coulee Dam, and a review of available knowledge on fish facilities for passing salmon at dams (Stansby, 1979).

The tributary surveys clearly showed the proper location for placement of irrigation diversion screens and eventually resulted in a major program of installation and evaluation of these screens throughout the Columbia River drainage. This program continues today.

The relocation of the anadromous fish runs cut off by Grand Coulee Dam began in 1939. It consisted of trapping adult salmon (Oncorhynchus spp.) and steelhead (Salmo gairdneri) and transporting them to holding areas where they matured; the eggs could then be taken and transferred to satellite hatcheries at Icicle Creek (near Leavenworth), Entiat, and Winthrop, Washington. Fish were reared to smolting size and released into the Wenatchee, Entiat, and Methow River drainages; several years' evaluation of this program indicated conclusive success (Fish and Hanavon, 1948; Fulton and Pearson, 1981).

In later years, however, continued dam construction seriously reduced these and other fish runs in the upper Columbia River, and it became clear that adequate knowledge was not available to design efficient fish passage facilities at dams. Fish behaviour studies were therefore initiated in 1950 to begin gathering the information needed to design both adult and juvenile fish passage facilities. Thus, the NWAFC's first major research effort relating to environmental problems was centered on fish behaviour work designed to find solutions to fish passage problems caused by dams.

3. FISH PASSAGE RESEARCH (1950-1981)

By 1950, the large-scale development of the Columbia River Basin for hydroelectric power was under way. Three huge dams affecting anadromous fish were already in operation (Rock Island, Bonneville, and Grand Coulee),

and fifteen more major dams, which would seriously threaten the survival of salmon and steelhead runs, were being proposed (Fig. 1).

For the next three decades, scientists of the Coastal Zone and Estuarine Studies (CZES) Division (formerly Fish Passage Research Program) of the NWAFC and its predecessor agencies were engaged in large-scale research efforts to obtain information related to the behaviour, abilities, and physiology of the migrant fish. The dams produced sudden, enormous changes in the environment of anadromous fish: huge lakes replaced swift flowing rivers; spawning grounds were inundated; water temperature regimes were modified; predator, competitor, and disease relations were upset; and food supplies were affected. The necessity for providing safe passage over the physical obstructions of dams was an obvious reality. Of equal importance was the need to protect the fish when the changes made by dams in the basic environment were too severe. Because there were to be many dams, the cumulative effect of small losses, injuries, or delays at each became a serious threat.

3.1 Adult fish passage at dams

Although fishways had been in use for many years, the large-scale fishway construction necessary on the Columbia River, and the variety of new situations that had to be faced, required more information on fish behaviour and abilities than was available. Some of the questions that needed to be answered were surprisingly simple, such as: At what rate do fish ascend fishways? What is the maximum water velocity through which fish can swim? How does light affect the rate of ascent in fishways? Other questions had a direct bearing on the cost of fishways, such as: How

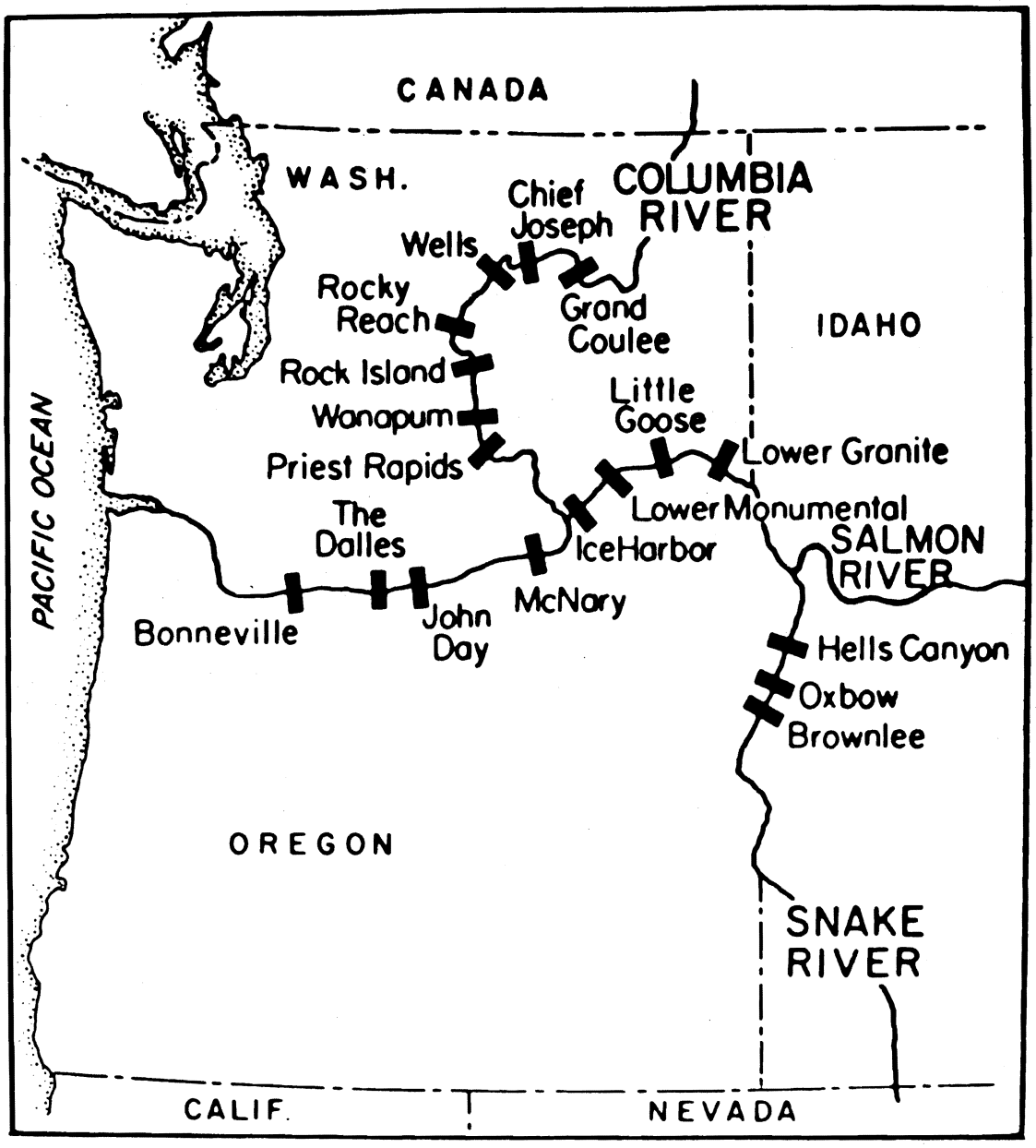

Figure 1.--Location of main stem dams in the Columbia River Basin.

large a fishway is needed for a given number of fish? How steep can a fishway be without causing fish to tire or fail to ascend? How long can a fishway be without fatiguing fish? To gain answers to these and similar questions, a special laboratory for fishery-engineering research was constructed at Bonneville Dam (Collins and Elling, 1960). Here it was possible to measure the reactions of anadromous fish under controlled experimental conditions while the fish were actually migrating. Fish were diverted from one of the major fishways into the laboratory where their responses to full-scale fishway situations were observed and recorded. Fish then swam out of the laboratory to continue their migration upstream.

Experiments conducted at the laboratory provided data on the spatial requirements of salmon in fishways (Elling and Raymond, 1959), on rates of movement of fish ascending fishways, and on the effects on fish performance of fishway slope (Collins et al., 1961) and fishway length (Collins et al., 1962). Scientists measuring both performance and physiological indices such as blood lactate and inorganic phosphate could find no evidence of fatigue from ascending fishways when proper hydraulic conditions were obtained (Conner et al., 1964). It was concluded that the ascent of a properly designed fishway was only a moderate exercise for fish, possibly similar to swimming at a "cruising" speed that can be maintained over long periods of time.

Tests to measure swimming abilities indicated that the critical velocity of water was between 2.4 and 4 meters per second (m/s) (Weaver, 1962). Velocities above this range proved to be an obstacle to a significant number of fish, although some individual fish had a much

greater ability. The maximum observed swimming speed was 8.1 m/s by a steelhead trout.

Examination of fish preferences for light conditions revealed marked differences in species (Long, 1959). Steelhead, given a choice of light and dark channels, selected a dark channel. Chinook salmon (*Oncorhynchus tshawytscha*) appeared indifferent under the same conditions and moved randomly into both light and dark channels. Steelhead moved more quickly through fishways that were darkened yet, in passing through pipes and open channels, showed an increase in passage speed when light was added (Slatick, 1970). Presented with a choice of channels with a high velocity (4 m/s) and a low velocity (0.9 m/s) both salmon and steelhead showed a strong preference for the high velocity.

Full-scale models of complete fishway designs (Fig. 2) were tested in the laboratory before being put into use at a dam. Even after being constructed at a dam, new fishway designs were carefully evaluated in actual operation (Weaver *et al.*, 1972).

The search for information on the behaviour of adult fish was also extended into river situations. Individual fish were tracked by means of sonic and radio tags to determine their patterns of movement when approaching dams, under a variety of flow conditions, so as to improve the design and placement of fishway entrances (Monan *et al.*, 1975). Tracking studies of fish movements after leaving fishway exits showed the importance of their proper location because of the possibility of the fish being swept back downstream over the spillway of the dam (Monan and Liscom, 1975). Studies conducted to evaluate fishway entrances and collection systems at John Day Dam (Johnson *et al.*, 1982) showed the importance of developing

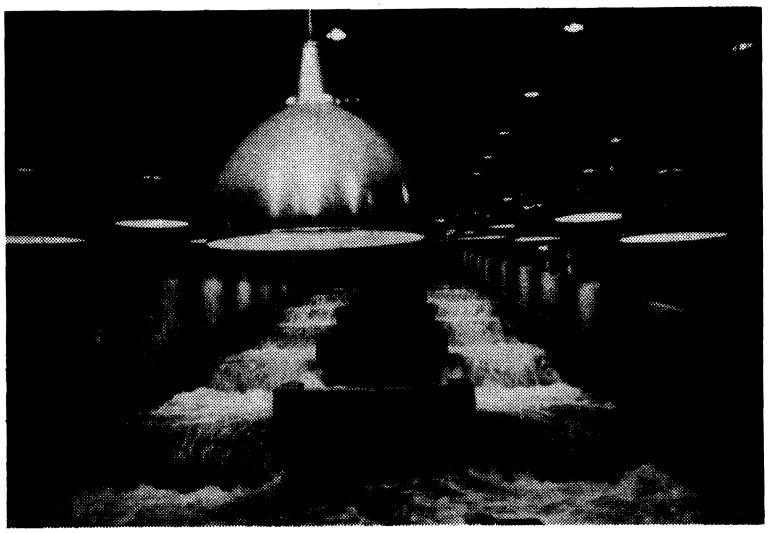

Figure 2.--Ice Harbor design fishway in operation in the Fisheries-Engineering Laboratory.

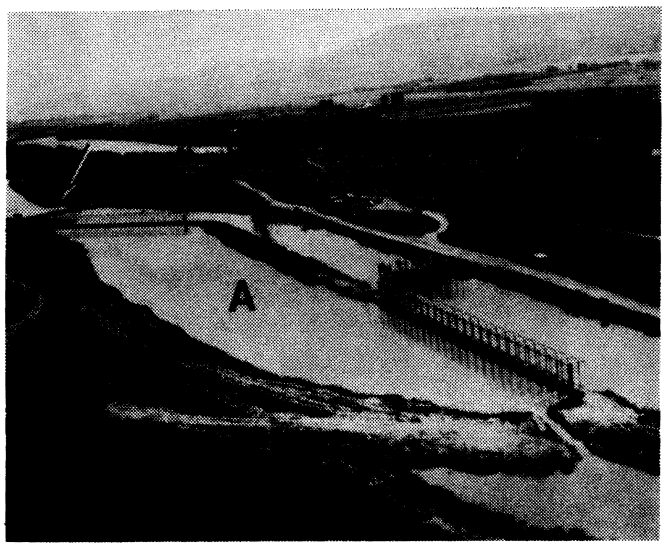

Figure 3.--Physical facilities of experimental fish-guiding site at Prosser, Washington. Waterflow is from right to left. Experimental canal (A) had v-type electrode array, an array trap, and a water-velocity control structure to divert excess flow through a water-bypass channel which was screened at both ends to prevent entry of fish. Arrow points to rotary drum screens used to evaluate fish-guiding efficiency of electrical field created by electrode array.

operating criteria (discharge volumes, velocities, and locations) for adult fishway collections systems. When proper operating criteria were maintained, fish passage was significantly improved. These studies and others have led to the establishment of operating criteria for most fishways in the Columbia River.

3.2 Juvenile passage at dams

Young salmon migrants on their way to the sea in the Columbia River may have to pass over as many as nine major dams. Losses of juveniles that passed downstream over spillways were found to be generally very small. For young fish that passed through the turbines, however, the hazards were great, from 9 to 30% being lost at each dam from direct and indirect factors (Bell *et al.*, 1967; Long *et al.*, 1968).

3.2.1 Fish guiding

A major research effort was undertaken by NWAFC scientists to find a way to divert young migrants away from turbine intakes. Laboratory and field studies included the use of electricity, lights, louvers, water jets, air jets, travelling screens, and sound.

Investigations into the use of electricity included studies of electrical parameters harmful to fish (Collins 1952), most effective in creating electrotaxis (Collins *et al.*, 1975) and eliciting sensory avoidance responses. Success in laboratory experiments led to large-scale field tests of the use of pulsed direct current to guide downstream migrants (Fig. 3) (Pugh *et al.*, 1970). Limitations to the practical use of electrical guiding for use in diverting fish from turbines became apparent. Major field applications required guiding of migrants of several species

over a broad range of sizes. Voltages needed to affect the small fish were lethal to large fish and, therefore, a sequence of electrical fields was required necessitating elaborate systems of electrodes (Collins et al., 1975). The guiding effectiveness of electricity for all juveniles decreased rapidly as the water velocity increased, thus limiting its potential application to situations where flow could be controlled to less than 0.311 m/s.

Experiments to guide downstream migrants in large-scale fixed and floating installations revealed that louvers were practical only where water flows could be carefully controlled and floating debris was not a problem (Bates and Pesonen, 1960). Electrical fields tested in conjunction with louvers proved to be no more effective than louvers alone (Pugh et al., 1967).

The capacity of jets of water and air to guide young migrants was examined. Although water jets were effective in diverting fish at appropriate approach velocities, the angle of array and jet pressure, the extensive maintenance of equipment, and the high volumes of water required made this technique impractical. A screen of bubbles created by air jets diverted young migrants effectively during daylight, but poorly during darkness (when most fish migrate), even when the bubble screen was illuminated. The poor results in darkness precluded the use of this device as a functional method for collecting fish.

Sound, as a medium for guiding fish, was also explored in the laboratory and under field conditions. Broad-spectrum noisemakers did not divert fish successfully, but specific high intensity frequencies produced orientative responses. A maximum avoidance response was obtained with low

frequencies of 35 to 170 Hz, but problems associated with its practical application precluded its use in large-scale installations at dams (Vanderwalker, 1967).

Arrays of fixed and moving lights were also examined for their potential in guiding young fish. They were found to be relatively ineffective during bright daylight and also during periods of high turbidity, which are frequent at the time of major juvenile migrations in the Columbia and Snake Rivers.

Rotary screens had been used successfully on a number of installations on the tributaries of the Columbia and Snake Rivers to prevent young migrants from entering irrigation-water diversions. The technical problems involved and the cost of such fixed mechanical devices for screening entire turbine intakes on a main stream dam made this approach impractical. A continuously travelling screen, suspended at an angle to the stream flow to divert young fish, was tested at the Stanfield Irrigation Canal near Echo, Oregon (Fig. 4) (Bates, 1970). Although successful in diverting fish in an 8.5-meter wide flume at velocities up to 1.8 m/s, it presented significant engineering and cost problems when extrapolated to a full-size installation at a major dam.

3.2.2 Turbines

At the same time that studies were undertaken to find a practical way to divert downstream migrants away from turbine intakes, another large-scale research effort was directed toward evaluating and reducing losses of young fish that were passing through the Kaplan turbines used on

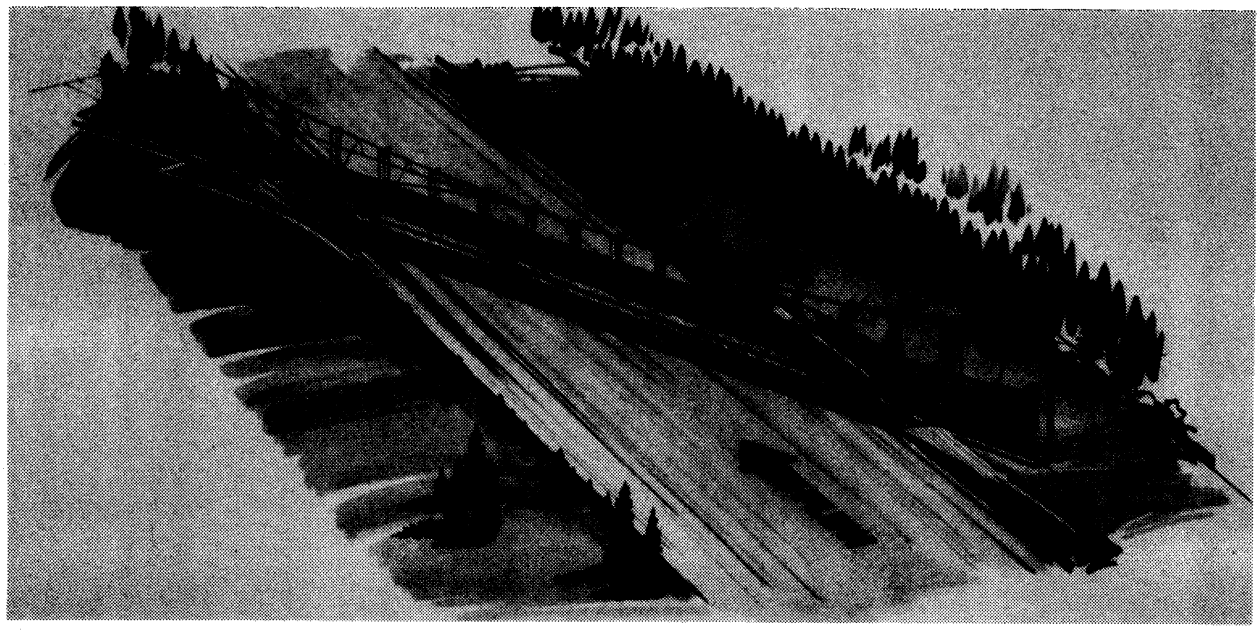

Figure 4.--Sectional view of Model V screen installed and tested during 1967 in the Stanfield Irrigation Canal, a diversion of the Umatilla River near Echo, Oregon.

the Columbia River. A giant recovery net that strained the entire discharge of a turbine was developed for use at Bonneville Dam. Distribution of fingerlings in the turbine intake was measured, and through the use of specially designed release capsules and the recovery net, the relation of distribution to injury was studied (Long and Marquette, 1967). The nature and extent of the injuries to juvenile migrants passing through turbines were detailed and related to various modes of turbine operation. Several techniques to reduce mortality, including entrained air, were tried, but none sufficiently reduced turbine mortalities.

Because fish were concentrated near the ceiling of the turbine intake, a system for diverting juveniles out of the turbine intake through the use of a specially designed travelling screen was feasible (Fig. 5) (Smith and Farr, 1975; Matthews et al., 1977). A diversion system was developed that took advantage of existing gatewells (used for storing gates for unwatering turbines) to collect the fish for subsequent passage around the dam. Once the fish had bypassed the dam, they were returned to the river to continue their migration or were transported downriver by barges or trucks. Research designed to improve this type of diversion and bypass system is currently in progress. Additional research is also under way to devise other methods of bypassing fish. These include: (1) use of scanning sonar to detect the abundance of fish at dams so that operations of the dam can be modified (such as turning off turbines and spilling water) to pass juvenile fish and (2) development of simpler diversion devices such as stationary screens and forebay skimmers for diversion of fish from the turbine intakes (Krcma et al., 1980).

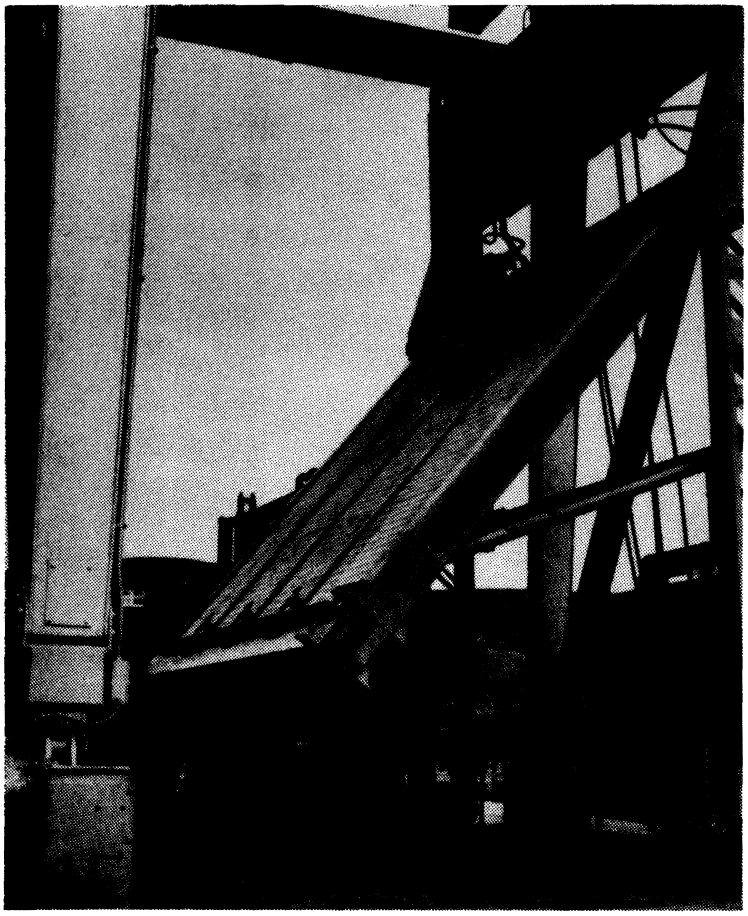

Figure 5.--Travelling screen developed by NMFS for collection of juvenile salmon from turbine intakes.

3.3. Passage through impoundments

One basic question that had to be answered was whether the impoundments behind the dams were in themselves barriers to the migration of fish. The ability of adult salmon and steelhead to move through the impounded river was assessed by the analysis of differences in counts at Rock Island Dam over a 27-year period from 1933 to 1960. It was found that the counts of adult chinook, sockeye (*Oncorhynchus nerka*), and coho salmon (*Oncorhynchus kisutch*) and steelhead at Rock Island Dam did not change significantly in 27 years, in spite of the creation of four impoundments and dams downstream (Zimmer and Davidson, 1962).

Assessment of the ability of adult chinook salmon to pass through a large impoundment was made at the 92-kilometer long Brownlee Reservoir (Trefethen and Sutherland, 1968). Fish, with sonic tags attached, released in the reservoir near the dam passed through the impoundment, reached the spawning grounds, and spawned successfully. Other studies done in reservoirs formed by lower head dams (30.5 m or less) in the Columbia River also indicated that passage of adults through these impoundments was not a serious problem.

Juvenile migrants were not as fortunate in migrating through the large reservoirs behind high dams such as the Brownlee Dam where the young fish found conditions too severe. A high degree of thermal stratification develops in the reservoir with surface temperatures reaching levels lethal to young salmon while the cooler subsurface water becomes deficient in oxygen (Raleigh and Ebel, 1968). The impoundment, for all practical purposes, was an impassable barrier for juvenile salmon and steelhead.

Research on the effects of the impoundments behind "river run" dams (all about 30.5 m high) on the Columbia River showed that the average impoundment delayed young migrants about 3 days (Raymond, 1968). The favorable seasonal freshets and floods that had rapidly carried young fish to the sea were being eliminated. In the impoundments, the water (and the fish) moved more slowly. Studies showed that fish from the upper river were delayed almost a month in reaching the estuary (Ebel et al., 1979). and extended the exposure of the young fish to hazards such as disease and predation.

Temperature regimes in the river, because of the greater surface area and volume of the impoundments, shifted and were increased during the late summer and autumn when high water temperatures can become critical, particularly to adult spawning salmonids. The habitat of many of the salmon's competitors and predators was improved. Successful passage of juvenile salmonids depended upon (1) the length and volume of the impoundment, (2) the relative volume of flow through the impoundment at the time of migration, and (3) both the physical and biological environment in the impoundment.

A recent analysis, relating the size of adult populations returning to the Snake River to the passage conditions they encountered as juveniles, showed that adult returns were well correlated with the survival rates of corresponding juvenile smolt populations that had produced the adults (Raymond, 1979). For example, during two extremely low flow years (1973 and 1977) survival of juvenile migrants was estimated at <5%; this was due to adverse conditions in the impoundments and the fact that all juvenile migrants had to pass through the turbines of seven or eight dams on their

way to the sea. The corresponding adult populations returning from these years were at record low values. During years of high flow (1971 and 1972), success of juvenile passage was substantially higher and adult returns were correspondingly higher.

In the late sixties, however, studies revealed that substantial losses to juvenile migrant populations were occurring even during years of high flow. These studies also revealed that supersaturation of atmospheric gasses in the Columbia and Snake Rivers was widespread with levels reaching 143% of air saturation occurring during high flow periods (Ebel, 1969). Gas bubble disease caused by these high levels was prevalent among the juvenile and adult salmonid populations migrating at that time (Beiningen and Ebel, 1970; Ebel, 1971). Further investigation showed that large volumes of water passing over the spillways of most of the dams completed at that time entrained air and plunged it to substantial depths causing widespread supersaturation. The long series of reservoirs formed by the dams prevented equilibration of the atmospheric gas, resulting in exposure of juvenile and adult migrants to high levels of supersaturation over hundreds of kilometers of their migration route. Because of the seriousness of the situation, a large-scale, multi-agency effort was launched to solve the problem, with NWAFC researchers providing a majority of the research information. The problem was solved by installation of spillway deflectors at key dams which prevented plunging and entrainment of air by the water being spilled (Fig. 6). Other studies conducted during this period led to the establishment of water quality criteria for dissolved atmospheric gas. Concentrations of atmospheric gas in excess of 110% air saturation and any temperature increases above 17-20°C were considered detrimental to fish populations in the Columbia River.

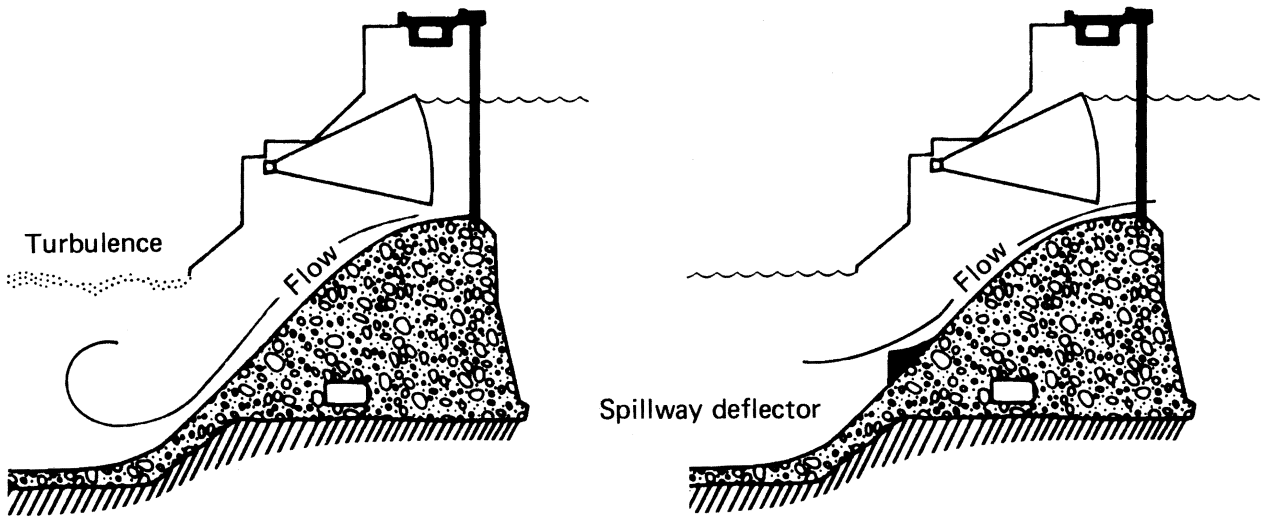

Figure 6.--Diagramatic sketch of typical spillway deflector installed at key dams in the Columbia River.

Concurrently (1968), research was begun at Ice Harbor Dam to determine the feasibility of collecting smolts at dams and transporting them downstream as a method of reducing downstream losses (Ebel et al., 1972). The results of this early work were encouraging, and research continued at Little Goose Dam when completed in 1971 (Ebel, 1979) and at Lower Granite Dam in 1975 (Park et al., 1980). The main objective of this research was to determine whether adult returns could be increased both to the fishery and to the parent stream or hatchery by collecting and transporting juveniles. It proved to be extremely successful for steelhead, and was sufficiently successful for chinook salmon to encourage the U.S. Army Corps of Engineers (CofE) to begin a major collection and transport operation from Little Goose, Lower Granite, and McNary Dams (Smith et al., 1981). This effort continues, along with research which is now centered on studies designed to improve the system for chinook salmon.

Because of the success of the work with naturally migrating smolts, research was initiated in 1978 to determine the homing imprint requirements that would allow transportation of various species of salmonids directly from hatcheries without impairing the fish's homing abilities. The primary objectives are to determine: (1) whether a single imprint or a series of stimuli (sequential imprinting) for various stocks was needed; (2) a triggering mechanism to activate the homing imprint; and (3) the relationship between the physiological condition of the fish and their ability to imprint, e.g., by measuring gill Na^+-K^+ ATPase activity. The ability to activate the imprint mechanisms at the proper time should assure a suitable homing cue that, coupled with transportation, should result in high smolt survival and ensure adequate return to the homing site or hatchery.

Preliminary adult return data from experiments conducted in 1978 and 1979 show that transporting the fish under various treatment conditions resulted in improved survival, but homing to the parent hatchery was diminished (Slatick et al., 1981). There was, however, one notable exception. Steelhead trucked from Dworshak Hatchery, held in the Clearwater River, and then subsequently barged to a release location downstream of Bonneville Dam, returned at a higher rate at all locations (the fishery below Bonneville, the sport fishery in the Clearwater River, and Dworshak Hatchery) than controls released at the hatchery. These data suggest that if the proper treatment can be isolated, it is possible to transport directly from a hatchery to downstream locations and still maintain suitable homing to the parent hatchery. Additional research into this area is obviously needed and continues at this time.

4. FISHERIES ENHANCEMENT (1969-1981)

The Fisheries Enhancement Task of the NWAFC was begun in 1968 to conduct research in advanced fish culture technology and to increase the production of Columbia River salmon. In 1969, this emphasis was broadened to include many aspects of marine aquaculture; and the program was located at the Manchester Marine Experimental Station near Manchester, Washington.

Programmed releases of tagged coho and chinook salmon, cultured in floating cages at Manchester, demonstrated that the tactic of delaying the release could alter the normal migrations. Delayed release coho salmon from the pilot farm studies remained in Puget Sound and contributed heavily to the local sport fishery. In addition, as the fish approached maturity, they returned to the net-pen release site (Manchester) and not to the

freshwater hatchery site where they originated. This was one of the first demonstrations of "imprinting" salmon in seawater. Another cooperative project involved culturing, imprinting, and releasing coho salmon from a diked tidal lagoon. This study successfully demonstrated that the coho salmon could migrate out to sea following normal routes but would return exclusively to the lagoon release site. This presents the possibility of establishing terminal fishing areas, where all returning adults could be harvested (Novotny, 1975; 1980).

Cooperative delayed-release studies were established with the Washington Department of Game and sport fishermen's clubs to determine if the delayed release programs could be applied to sea-run cutthroat trout (*Salmo clarki*). It was found that, when cultured in net-pens for one summer and released in Hood Canal, they contributed to the Hood Canal sport fishery at a rate of 20 to 1 compared with normal hatchery releases.

As a result of these studies, pen-culture delayed-release programs are now routinely used by native Indian projects and the Washington Departments of Fisheries and Game in both seawater and freshwater lake systems.

4.1 Captive broodstock studies

There is a pressing need to preserve certain races of chinook salmon that represent threatened stocks (such as those of Snake River and White River). Task scientists have had limited success in culturing fall and spring chinook salmon to maturity and are continuing with this effort at the present time. Culturing the fish to maturity may be the only solution to preserving these races (Joyner and Mahnken, 1975).

Task scientists were successful in culturing sea-run cutthroat and rainbow trout to maturity with a high degree of egg viability (80 to 90%). Hybrid rainbow steelhead trout crosses were grown to maturity as 2-year-old spawners weighing from 2 to 5 kg. Some females were held for three consecutive spawnings (5-year-olds) from the seawater net-pens. The sea-run cutthroat trout broodstock program has been so successful that the Washington Department of Game has been able to meet from captive broodstocks all of its egg requirements for their Shelton Hatchery.

The excellent success with the broodstock program led Task scientists to conduct experimental culture programs with the Atlantic salmon (*Salmo salar*). The first broodstocks proved to be quite resistant to stresses and seawater diseases; hearty males and females, with a high degree of egg viability (60 to 95%), matured as 4-year-old adults. The resulting progeny were normal, healthy fish.

The successful Atlantic salmon broodstock studies by the NWAFC's scientists at Manchester, Washington, led to a cooperative Atlantic salmon restoration project between the National Marine Fisheries Service, Northwest and Northeast Regions. Limited quantities of eyed eggs from Maine were shipped to the NWAFC's Manchester and Seattle facilities. Task scientists are now culturing the progeny from these selected strains to maturity in net-pens at Manchester.

From the small numbers of eggs supplied by the Northeast Atlantic Salmon Commission each year, NWAFC scientists will eventually be producing 3 million eyed Atlantic salmon eggs to northeast salmon hatcheries to benefit this important restoration program.

4.2 Smoltification

Because the state and federal hatcheries on the Snake and Columbia Rivers are required to produce many millions of salmon and steelhead to augment the wild populations that have declined steadily with the progressive construction of dams, it has become increasingly important to maximize the survival of the fish released from the hatchery systems. Thorough studies have been conducted at over 30 hatcheries on coho and chinook salmon and steelhead to determine: (1) the relationships of quantitative changes in the gill enzyme, Na^+-K^+ adenosine tryphosphatase (ATPase) to other smoltification indices and seawater adaptation (Zaugg, 1970; Zaugg and McLain, 1972; Adams et al., 1975; Clarke et al., 1978; Prentice et al., 1979; Dickhoff et al., 1982); (2) the relationships of thyroid hormones to smoltification and seawater adaptation (Prentice et al., 1979; Folmar and Dickhoff, 1980; Dickhoff et al., 1982); (3) changes in plasma electrolyte levels during the smolting process (Zaugg and McLain, 1970; Prentice et al., 1979; Folmar and Dickhoff, 1980; and Dickhoff et al., 1982); and (4) the relationship of fish health in the normal hatchery populations to smoltification indices and survival.

Preliminary examination of some of the available data from juveniles moving into the estuary indicates that migration rates of coho salmon are correlated to peak Na^+-K^+ ATPase enzyme activity levels in the gills, and the survival of test fish transferred to seawater at Manchester is positively correlated to increasing activity of the thyroid hormone thyroxine. The data collected from the many hatcheries sampled indicated that peak enzyme and hormone levels do not occur at the same time, and that each hatchery should be treated as a separate entity to maximize survival after release.

Simultaneously, the collection of fish health information provided significant data regarding hatchery fish populations. Although most hatchery stocks proved to be in excellent condition, some were found to be in trouble. In one case, chemical bath treatments for therapeutic purposes just prior to release did not alter the normal gill Na^+-K^+ ATPase profile, but apparently substantially reduced comparative seawater survival after the fish were transferred to net-pens at Manchester. Similarly, several other stocks of salmon had normal gill Na^+-K^+ ATPase enzyme profiles but suffered from severe anemia, latent bacterial kidney disease infections, or both; thus survival in the sea is expected to be poor (Novotny and Harrell, 1979). Poor returns of adults from one release group that normally would have been expected to be high correlates with heavy latent bacterial kidney disease infections in the juveniles.

Task scientists have been conducting experiments to determine the best possible techniques for altering and controlling smoltification to coincide with the most favorable oceanic conditions at the time of release.

5. SUMMARY AND CONCLUSIONS

Early research efforts begun in the 1950s and continued to the present to address the problems of environmental degradation on anadromous fish were centered mainly on fish behavioural work designed to provide solutions to fish passage problems for both adult and juvenile salmonids caused by dams and impoundments in the Columbia River. Research on various fisheries enhancement measures was also begun in the late 1960s to increase production of Columbia River salmon.

The main conclusion, remedial actions recommended, and future research needs that were derived from this research are summarized.

5.1 Adult fish passage at dams

1. Velocities in adult fish passage facilities should fall within the range of 2.4 to 4.0 m/s for optimum passage of salmonids. Presented with a choice of channels with high velocity (4 m/s) and low velocity (0.9 m/s), both salmon and steelhead showed a strong preference for high velocity.

2. Darkened fishways improve steelhead passage; chinook salmon were indifferent to light in fishways.

3. Design and placement of fishway entrances and exits is critical to the success of adult passage facilities.

4. Operating criteria for fishways should be established and maintained for optimum fish passage efficiency.

5.2 Juvenile passage at dams

Fish guiding

1. Use of electrical guidance systems to divert fish from turbines or divert them into bypass flumes or traps in rivers was effective under controlled conditions, but was impractical for operational field applications.

2. Louvers were practical for field application in areas where flow could be carefully controlled, but were impractical for most field applications.

3. Use of water and air jets, sound, and lights to guide juvenile migrants were effective only under limited and controlled environmental conditions. Large-scale use at dams or in rivers was impractical.

4. Travelling screens, suspended at an angle to the stream flow, were effective in flumes or irrigation canals for guiding juvenile migrants, but costs and engineering problems preclude their use at dams or large streams.

5. Travelling screens placed vertically in turbine intakes were effective in diverting juvenile migrants from turbine intakes at dams where areas in the dam such as gatewells were available for diversion of the fish. Criteria for successful application of vertical travelling screens at dams are being developed.

5.3. Passage through impoundments

1. Adult passage of anadromous salmonids through both large and small reservoirs was not a serious problem in reservoirs studied on the Columbia River, except during periods of high water temperature.

2. Juvenile migrants were adversely affected by the impoundments on the Columbia River, which caused substantial delays in migration. These delays, coupled with changed environmental conditions in the river, caused substantial mortality to juvenile migrants which was as high as 95% in the Columbia River during low flow periods.

3. Studies of the effect of water temperatures and supersaturation of atmospheric gas on salmonids led to the establishment of water temperature and atmospheric gas standards for the Columbia River. Any increase in temperature above 17-20°C or increase in atmospheric gas above 110% of the air-saturation value was considered detrimental to fish in the Columbia River.

5.4. Fisheries enhancement

1. Programmed releases of tagged coho and chinook salmon, cultured

in floating cages in Puget Sound, showed that delayed releases resulted in changed migrational behaviour and increased harvest in Puget Sound.

2. Imprinting of coho salmon in salt water was demonstrated and is now used as a management tool for establishing terminal fisheries of known stock.

3. Culturing sea-run cutthroat, rainbow trout, and Atlantic salmon to maturity in salt water, with a high degree of egg viability, was demonstrated. The technique is now used to establish broodstock for endangered and threatened stocks.

4. Studies on smoltification of coho salmon in hatcheries demonstrated a definite relationship between levels of Na^+-K^+ ATPase activity in the gills and thyroxin levels and degree of smoltification. They also showed that the level of smoltification varied among hatcheries and that each hatchery must be treated as a separate entity if smoltification indices are to be used to maximize survival after release.

6. FUTURE EMPHASIS

On the basis of future needs for information relative to environmental factors affecting the fishery resources of the Columbia River and the Pacific Northwest, the NWAFC believes its research emphasis should be focused on the following areas.

6.1 Fish passage

Fish passage problems of both adult and juvenile anadromous fish still exist and will undoubtedly be further exacerbated by future developments of all types in the Pacific Northwest.

Adult passage facilities still need improvement to eliminate delays and losses; for example, improvement of environmental conditions in the river at the entrance to fishway facilities. Information is needed to determine what the optimum conditions are at specific sites.

Juvenile passage facilities are operational for some types of dams, but improvements need to be made. Most dams in the Columbia River do not have juvenile passage facilities, and new technologies will have to be developed to provide effective juvenile passage facilities at all dams.

Collection and transportation systems now in use are effective for steelhead and fall chinook salmon, but considerable improvement is needed to achieve optimal effectiveness for other species such as spring chinook salmon. Additional research is needed to isolate areas in the collection and transportation system where improvements can be made.

6.2. Fishery enhancement

Fishery enhancement has become an important research area primarily because the attempt to restore the declining fishery resources with hatchery production has not achieved the intended objectives. On the contrary, the fishery resources continue to decline in terms of contribution to the catch, in spite of increased hatchery production. Thus, research focused on methods to increase quality and survival of both wild and hatchery salmonid stocks becomes a viable option.

Recent research results indicated that continued research with the goal of increasing quality and survival of smolts released from hatcheries can reverse the downward trend with minimal increase in costs. Research on smoltification, disease, nutrition, and genetics appears to have the

greatest potential for improving the fishery. The key to evaluation of certain enhancement strategies is knowledge of early ocean behaviour and survival.

Little is known of the fate of juvenile salmonids during the first 6 months of their ocean residence. Knowledge of nearshore ocean factors affecting early ocean life of various salmonid stocks is critical to solving the mysteries of differential survival of stocks. Thus, research centered on the early, ocean life history of salmonids should also be emphasized. The ultimate goal would be to understand the nearshore ocean ecosystem which salmonids occupy in their first year of life.

The two areas of research relating to environmental effects described above are among those which the NWAFC should emphasize in the future. Research designed to provide captured broodstock for threatened or endangered salmonid species should also continue to be emphasized if restoration projects now under way are to be successful.

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