Effects of Environmental Degradation on the Freshwater Stage of Anadromous Fish

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INTRODUCTION

This chapter traces the Northwest and Alaska Fisheries Center's (NWAFC) research on environmental aspects from 1931 to the present. Most of this research effort focused on providing information to describe 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; other studies led to establishment of programs to provide solutions to environmental insults such as the fish passage problems caused by construction of dams.

EARLY RESEARCH EFFORTS (1931-50)

From 1931 to 1950, very little effort was expended on environmental studies because the projected level of development with 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 of the laboratory was therefore centered on studies related to management of the various fisheries. As early as 1933, however, studies were begun to deal with the fish passage problems resulting from construction of Bonneville, Rock Island, and Grand Coulee Dams on the Columbia River. These studies included thorough surveys of tributary streams to determine distribution of salmonid populations in relation to 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 and steelhead and transporting them to holding areas where they matured, and the eggs could be taken and transferred to satellite hatcheries at Icicle Creek (near Leavenworth), Entiat, and Winthrop, Washington. Fish were reared to

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smolting size at these sites 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 behavior 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 behavior work designed to find solutions to fish passage problems caused by dams.

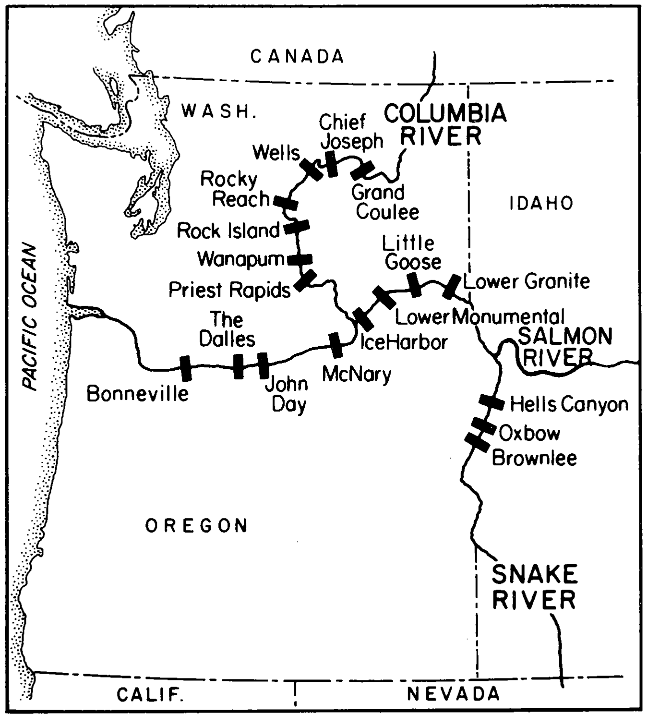


Figure 1
Location of main stem dams in the Columbia River Basin.

FISH PASSAGE RESEARCH (1950-81)

By 1950, the large scale development of the Columbia River Basin for hydroelectric power was underway. Three huge dams affecting anadromous fish were already in operation (Rock Island, Bonneville, and Grand Coulee), and 15 more major dams, which would seriously threaten the survival of salmon and steelhead runs, were being proposed (Figure 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 behavior, 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 dam became a serious threat.

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 behavior 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 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 (Figures 2 and 3) 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 of fishway slope (Collins et al. 1961) and fishway length (Collins et al. 1962) on fish performance. 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 occurred at flows between 8 and 13 feet per second (fps) (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 26.7 fps 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 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 (13 fps) and a low velocity (3 fps), both salmon and steelhead showed a strong preference for the high velocity.

Full-scale models of complete fishway designs (Figure 4) were tested n 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

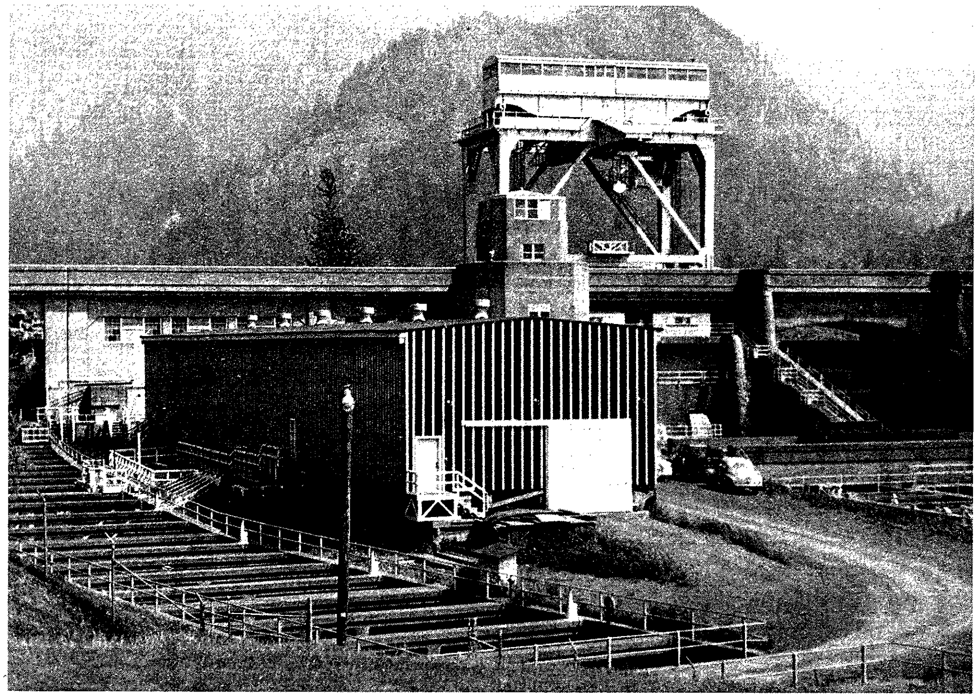


Figure 2
Fisheries-Engineering Laboratory adjoining Washington-shore fishway at Bonneville dam.

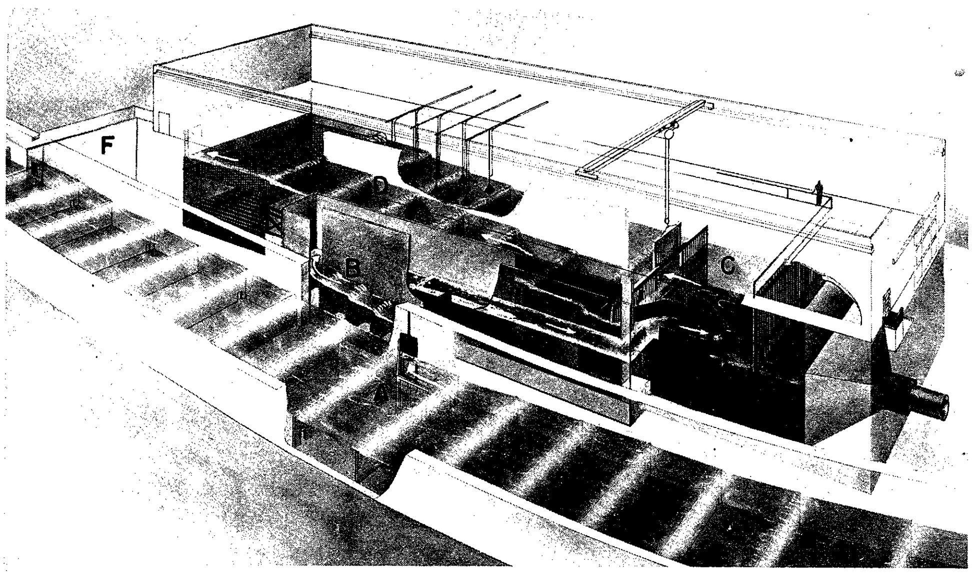


Figure 3
Sketch of Fisheries-Engineering Research Laboratory showing its relationship to the Washington-shore fishway. Fish are diverted from the main fishway by a picketed lead (A) and ascend the entrance fishway (B) to a collection pool (C) in the laboratory. After release, they pass through an experimental area (D) to the flow introduction pool (E) and then out the exit fishway (F) where they return to the main fishway.

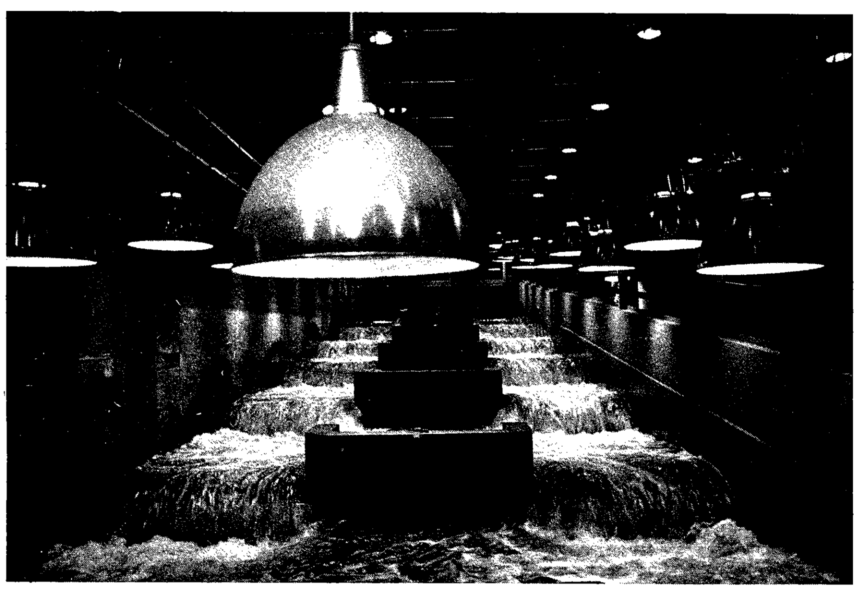


Figure 4
Ice Harbor design fishway in operation in the Fisheries-Engineering Laboratory.

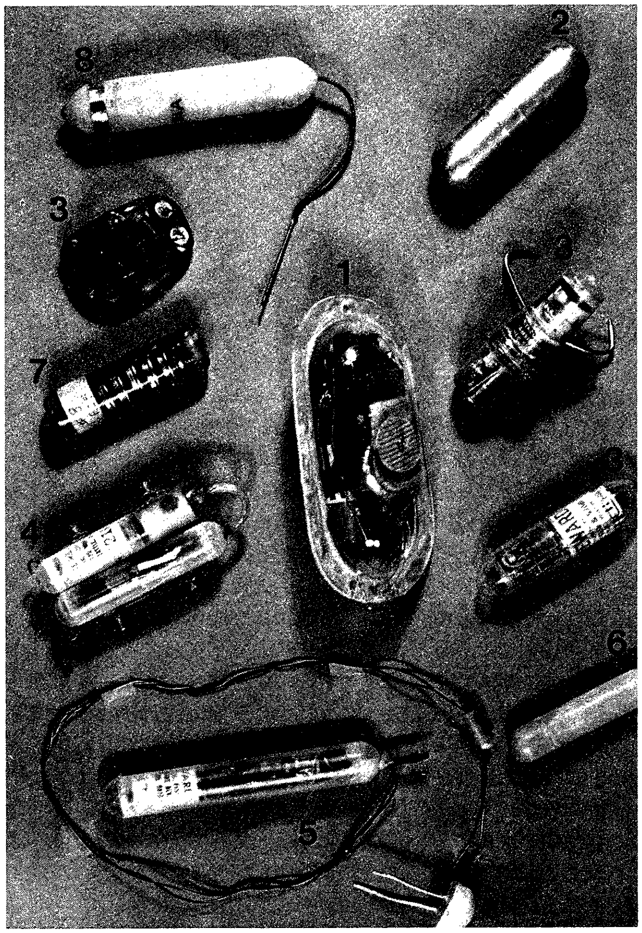


Figure 5
Electronic tags: (1) first sonic tag, (2, 3) early model external sonic tags, (4) twin back-pack sonic tag, (5) sonic tag (crystal fastened on fish's snout, (6) temperature sensitive sonic tag, (7) current model internal sonic tag, and (8) radio tag.

Figure 6
Manned radio tracking station at Lower Monumental Dam.

The search for information on the behavior of adult fish was also extended into river situations. Individual fish were tracked by means of sonic and radio tags (Figures 5 and 6) to determine their patterns of movement approaching dams, under a variety of flow conditions, for improving the design and placement of fishway entrances (Monan et al. 1975). Tracking studies of fish movements after leaving fishway exits showed the importance of the proper location of fishway exits because of the possibility of the fish being swept back downstream over the spillway of the dam (Monan and Liscom 1975).

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% of the fish passing through the turbines were lost at each dam from direct and indirect factors (Bell et al. 1967; Long et al. 1968).

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, traveling 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 (Figure 7) (Pugh et al. 1970). Limitations to the practical use of electrical guidance in diverting fish from turbines became apparent. Major field applications required guiding 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). 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 1 fps.

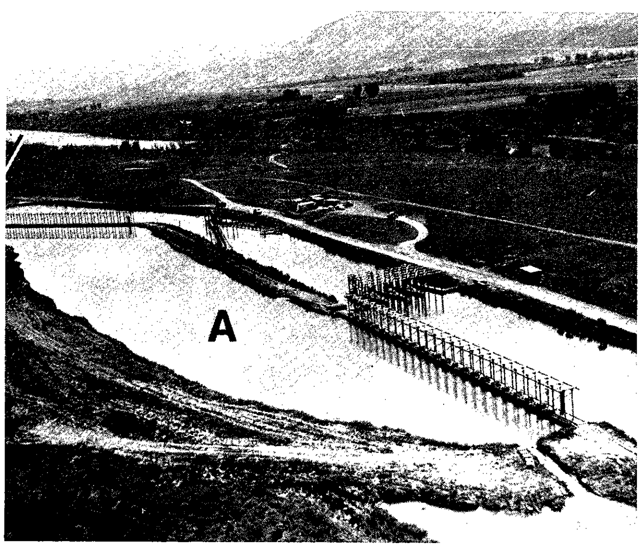


Figure 7
Physical facilities of experimental fish-guiding site at Prosser, Washington. Waterflow is from right to left. Experimental canal (A) had v-type electrode array, an array trap, and a water-velocity control structure to divert excess flow through a water-bypass channel which was screened at both 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.

Experiments to guide downstream migrants with louvers in large-scale mixed 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 lighted. 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 the low frequencies of 35 to 170 Hz but problems associated with 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

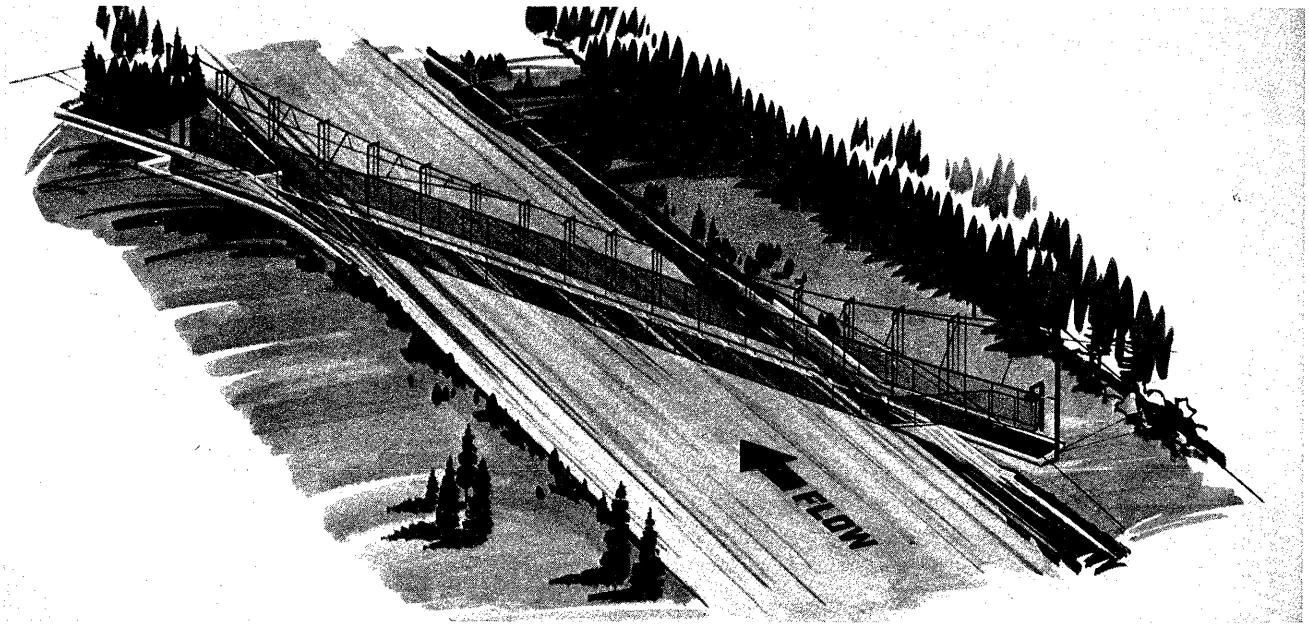


Figure 8
Sectional view of model v screen installed and tested during 1967 in the Stanfield Irrigation Canal, a diversion of the Umatilla River near Echo, Oregon.

the 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 stem dam made this approach impractical. A continuously traveling screen suspended at an angle to the stream flow to divert young fish was tested at the Stanfield Irrigation Canal near Echo, Oregon, (Figure 8) (Bates 1970). Although successful in diverting fish in a 28-ft wide flume in velocities up to 6 fps, it presented significant engineering and cost problems when extrapolated to a full size installation at a major dam.

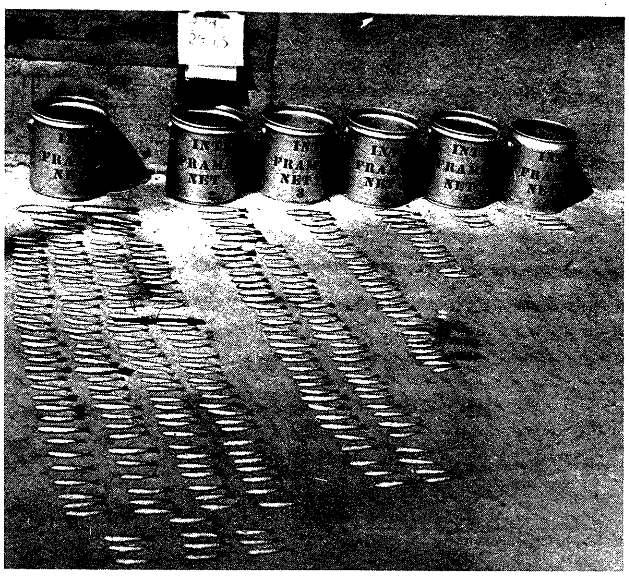
Turbines.--At the same time that studies were undertaken to find a practical way to divert downstream migrants away from turbine intakes, another large-scale research effort was directed toward evaluating and reducing losses of young fish that were passing through the Kaplan turbines used on the Columbia 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 (Figure 9), 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 was 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.

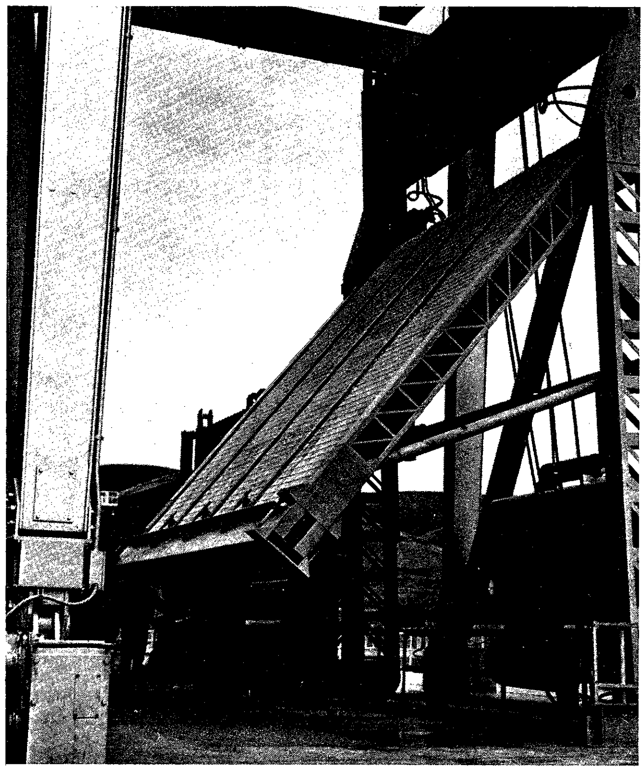
Because fish were concentrated near the ceiling of the turbine intake, a system for diverting juveniles out of the turbine intake through the use of a specially designed traveling screen was feasible (Figure 10) (Smith and Farr 1975; Matthews et al. 1977). A diversion system was developed that took advantage 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

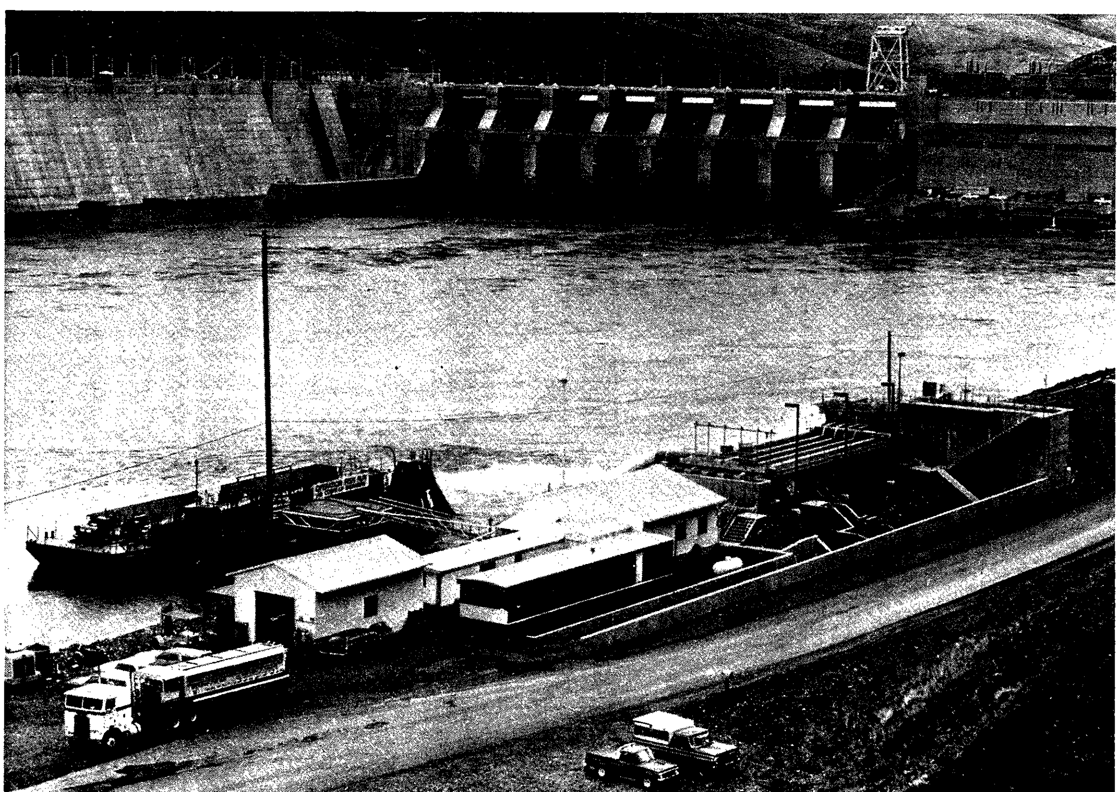
Figure 9 (top left)
Actual catch of juvenile salmonid migrants in fyke nets placed in turbine intakes at Bonneville Dam.

Figure 10 (top right)
Traveling screen developed by NMFS for collection of juvenile salmon from turbine intakes.

Figure 11 (bottom)
At dams juvenile fish can be loaded into trucks or barges for transport to release sites below Bonneville Dam.







continue their migration or were transported downriver by barges or trucks (Figure 11). Research designed to improve this type of diversion and bypass system is currently in progress. Additional research is also underway to devise other methods for bypassing fish. These include 1) use of scanning sonar to detect 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).

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, and coho salmon 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 57-mile 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 carried out in reservoirs formed by lower head dams (100 ft 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. Research studies made in the Brownlee Dam impoundment showed that adult fish were able to migrate through the long reservoir successfully, but 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 100 ft high) on the Columbia River showed that the average impoundment delayed young migrants about 3 days (Raymond 1968). The freshets and floods that had rapidly carried young fish to the sea were being controlled. Thus, a favorable seasonal occurrence under which juvenile salmonids had evolved had been 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). This delay in migration through the river 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 increased during the late summer and early fall 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. Passage success of juvenile salmonids related to 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 return percentages were well correlated with 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%. The low survival 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 during these years were at record lows. During high flow years (1971 and 1973), juvenile passage success 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 high flow years. These studies also revealed that supersaturation of atmospheric gases in the Columbia and Snake Rivers was widespread with levels reaching 143% during high flow periods (Ebel 1969). Gas bubble disease (Figure 12) 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 and caused the widespread supersaturation. The long series of reservoirs formed by the dams prevented equilibration of the atmospheric gas, resulting in the 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 (Johnsen and Dawley 1974). The problem was solved by installing spillway deflectors at key dams which prevented plunging and entrainment of air by the water being spilled (Figure 13).

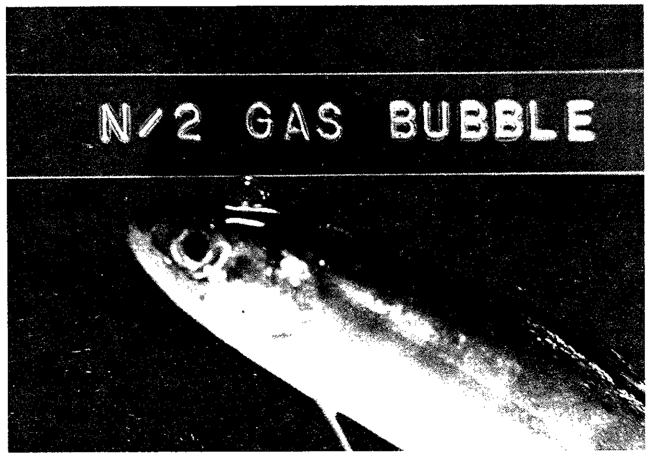


Figure 12
Juvenile salmon with gas bubble disease from the Columbia River.

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,

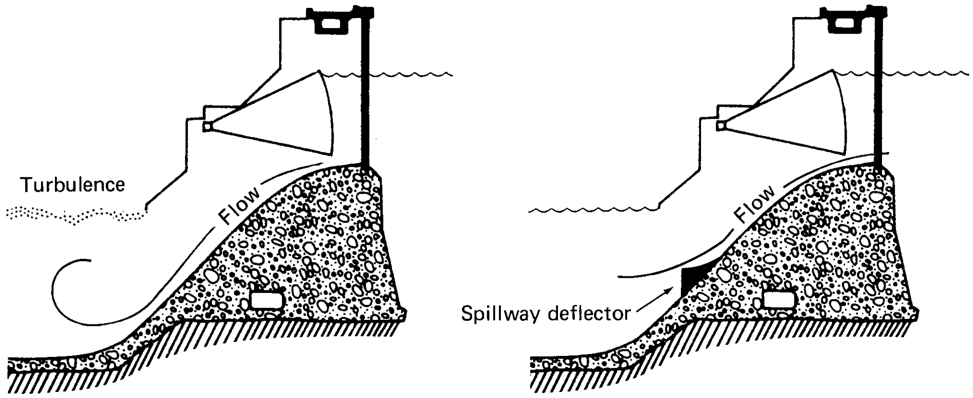


Figure 13
Diagramatic sketch of typical spillway deflector installed at key dams in the Columbia River.

and research continued at Little Goose Dam when it was 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 of the homing research are as follows: 1) determine whether homing requires a single imprint or a series of stimuli (sequential imprinting) for various stocks of salmonids; 2) determine a triggering mechanism to activate the homing imprint in salmonids; and 3) determine the relationship between the physiological condition of fish and their ability to imprint, e.g., by measuring gill Na^{+}-K^{+} ATPase activity, etc. 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 from 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.

Effect of Temperature Changes

The passage of the Federal Water Quality Act of 1965 required the establishment of water quality standards for protection of aquatic life throughout the United States. In the process of establishing standards during 1958-68, state and federal water pollution control agencies recognized water temperature as an important factor affecting aquatic life. In attempting to define temperature requirements in the standards, however, pollution control authorities found that information was insufficient on the precise limits needed to protect various aquatic ecosystems.

The Columbia River Thermal Effects Study was initiated in 1968 in response to the specific problem of inconsistent temperature standards adopted for the Columbia River by Oregon and Washington (Environmental Protection Agency et al. 1971). To resolve these inconsistencies, improved knowledge on temperature requirements of the Columbia's Pacific salmon and improved techniques for evaluation and prediction of temperature in the Columbia system were needed.

About the time these standards were established, public and private electric power interests in the Northwest announced forecasts of vastly increased power demands. The hydroelectric power potential of the Northwest was nearly exhausted, and thermal power sources were planned to meet future needs. This presented further potential for modification of the thermal regime of the Columbia River system. Initially, power producers assumed they could use Columbia River system waters for once-through cooling at thermal power plants. The prospect of numerous discharges of large quantities of heated effluents to inland waters made it imperative to obtain better information as quickly as possible to establish temperature standards that could be defended with adequate scientific data.

Center scientists participated in this multi-agency study and contributed a substantial portion of the information obtained. Research by Center scientists included studies on adult salmon behavior in relation to river temperatures (Monan et al. 1975; Stuehrenberg et al. 1978), thermal tolerance of juvenile salmonid and nonsalmonid fish (Snyder et al. 1970), thermal tolerance of salmonids in relation to nitrogen supersaturation (Ebel et al. 1971), thermal shock and survival of juvenile salmonids (Snyder 1970), effects of temperature acclimation on resistance to thermal challenge (McConnell and Blahm 1979), thermal tolerance of zooplankton (Craddock 1970), timing and movement of juvenile salmon (Raymond 1969), and temperature prediction (Water Resources Engineers 1969).

Studies on adult migrational behavior showed that fish ceased migrating into the Snake River from the Columbia River when the temperature of the Snake River exceeded the Columbia River by about 5°C and that generally upstream migration slowed or ceased at temperatures exceeding 21.1°C.

Thermal tolerance of juvenile chinook, chum, coho, and sockeye salmon and steelhead was tested at the Prescott Field Station located on the lower

Columbia River. Columbia River water, with ambient water quality changes, was used to determine whether temperature tolerances determined in the existing water quality of the Columbia River differed from previously published data obtained in other laboratories.

Generally, the tests showed that thermal resistance was reduced by 3° to 5°C from previously published laboratory findings. The occurrence of supersaturation of atmospheric gas in the water, at the time most of the tests were performed, was determined to be the most important factor reducing temperature tolerance. This was confirmed in the laboratory in a controlled test.

Thermal tolerance tests conducted on nonsalmonids included eulachon, yellow perch, threespine stickleback, and white sturgeon. Eulachon were less tolerant than salmonids, whereas yellow perch, threespine stickleback, and sturgeon were more tolerant. There were no previously published data for comparison; LD 50s ranged from 22°C for eulachon to 34°C for yellow perch.

Tests of thermal shock were also conducted on juvenile salmon and trout. These tests were performed to simulate passage of fish through thermal effluent produced by a nuclear power plant. Test temperatures ranged from 26° to 30°C, a range known to represent temperatures that could be produced by the currently designed power plants. Generally, the tests showed that 50% mortality usually occurred within 2 hours of exposure. This was believed to be much longer than natural migrants would be exposed in a thermal plume, unless the reactor was located in the lower river where flow reversals occur and the fish would be held in the plume for an extended duration.

At the laboratory in Seattle, yearling sockeye and coho salmon and steelhead were tested to determine the effects of previous temperature acclimation on their resistance to high temperatures. The fish were acclimated to 5°, 10°, 15°, 20°, and 23°C. They were tested at 28°, 30°, and 32°C.

At all test temperatures the trend, as acclimation temperature increased, was toward increased resistance to loss of equilibrium and to death. Resistance was highly positive at 28°C, much less at 30°C, and barely evident at 32°C, suggesting that 28°C is perhaps a critical upper limit for acclimation to significantly influence resistance to heat.

Studies on timing, distribution, and movement of juvenile salmon in relation to river temperatures were conducted throughout the Columbia and Snake Rivers to predict the possible effects of temperature increases at various locations and seasons of the year. Although the studies showed that peak migrations of salmon and steelhead occurred in May and June when effects of temperature increases would be minimal because of high river flow, substantial numbers of fish were present in the river from March to September. Notable was the major migration of fall and summer chinook salmon through the mid-Columbia (the Hanford area) in July and August when temperatures were often as high as 21.1°C. These studies also showed that a significant number of the fish were shore oriented, which also had a bearing on the effect that thermal plumes from nuclear plants might have on juvenile migrants.

Lethal temperature for the zooplankton <u>Daphnia</u> sp. and <u>Bosmina</u> sp., the most abundant cladocerans in the lower Columbia River, was found to be around

27°C; thus, standards set for salmonids would also protect these important cladocerans known to be a selected food source for many of the fish in the river.

A temperature prediction model was formulated for the Columbia River and proved to be quite accurate for average temperatures with a maximum error of 0.67°C. Center scientists provided much of the data for this model which was eventually formulated by Water Resources Engineers for the Federal Water Quality Administration (now EPA). The model showed that from April through November 1967, the existing Hanford reactor complex raised the simulated water temperature an average of 1.11°C at the confluence of the Snake River, which on initial observation did not appear to be a serious problem. However, fishery scientists from the Center showed that during periods of low flow and high atmospheric temperature, the potential increase was substantially greater than 1.11°C. In addition, it was pointed out that fish live in the river 24 hours a day, 365 days a year and are subjected to whatever temperature that prevails at any time. They are not fortunate enough to be subjected to only computed average temperatures.

In summation, as a result of this multi-agency effort, the conflict of standards for the Columbia River was resolved and optimum temperatures for production of fish resources in the Columbia River were recommended for migration routes, spawning areas, and rearing areas. The upper allowable temperature for any species of juvenile salmonid should be a minimum of 3°C below the ultimate, upper lethal temperature; 20°C was considered to be adverse for salmonids and 17°C was considered to be the upper end of the optimum temperature range for juvenile salmonids. Between 17° and 20°C, any increase in temperature was considered to be detrimental to juvenile salmonids.

ENVIRONMENTAL RESEARCH

Shortly after the passage of the Water Quality Act of 1965, other environmental laws (e.g., National Environmental Policy Act, 1970; Marine Resources Protection and Sanctuary Act, 1972; and the Clean Water Act, 1977) were passed. At about the same time, the Bureau of Commercial Fisheries was transferred from the Department of Interior to the newly established National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce and renamed the National Marine Fisheries Service. These events resulted in broader responsibilities in environmental areas for the NMFS Fishery Centers and the NMFS Regional Offices. As a result, additional research into various areas which were previouusly not included in the overall mission of the Bureau of Commercial Fisheries was inititated.

Offices of Habitat Investigation, Marine Pollution, and Environmental Research laboratories were established in NOAA, and increased investigative responsibilities were assigned to the Centers. These investigations included baseline habitat studies, studies to determine the effect of various pollutants, studies to evaluate proposed developments involving dredging in estuaries, and studies to evaluate natural disasters such as hurricanes and the eruption of Mount St. Helens.

NWAFC scientists have concentrated on several programs designed to evaluate the effects that major federal and nonfederal activities would have on resources of the Northwest. The following is a brief synopsis of some of the studies which have provided information to help protect and manage (enhance) the Columbia River aquatic resources.

Fire Retardants

Increased use of chemical fire retardants to combat forest fires in the Columbia River drainage caused concern by fishery agencies over the possible impact of these retardants on fish life, particularly juvenile salmonids. Center scientists determined the toxicity of these retarants to fish by use of flow-through bioassays. The results provided information which was used by the U.S. Forest Service, the Bureau of Land Management, and state agencies to establish more environmentally sound application practices (Blahm 1978).

Dredging

Maintenance of the Columbia River ship channel by the CofE requires dredging nearly 5 million yd^3 of material each year from the river below Bonneville Dam. Several studies have been conducted by Center personnel to determine the impact of this dredging on the fishery resources of the Columbia River (Blahm et al. 1979a). Several methods of dredging were assessed, e.g., flow-lane disposal (Blahm and McConnell 1979) and agitation dredging (Blahm et al. 1979b) for shallow channels. Studies indicated minimal impact if proper operating procedures were followed. The CofE now use the recommendations developed from these studies when dredging.

Creation of subtidal habitat from dredged material was also investigated (McConnell et al. 1978). The studies indicated that biological productivity, while not greatly increased in the test area, was not decreased. Emergent plants and upland grasses grew well, and suitable water-oriented bird habitat was created.

Offshore ocean disposal of dredged material was also investigated and provided the information for an environmental impact statement for this procedure (Durkin and Lipovsky 1977). The study indicated some temporary adverse effects to aquatic biota, but recovery was quite rapid in the disposal sites selected. Continued use of these sites, however, will require additional assessment.

Mining

Preliminary studies of black sand mining in the ocean near the Columbia River have indicated that very little impact will occur on the fishery resources. Because obstructions could inhibit the Dungeness crab fisheries at certain times of the year, the state of Washington has required a 2-year sampling program to be initiated as mining occurs.

Eruption of Mount St. Helens

The eruption of Mount St. Helens in May 1980 resulted in the deposition of millions of tons of ash, mud, and debris into the Toutle, Cowlitz, and Columbia Rivers. Scientists of NMFS were in a position to help assess the effects of the eruption because field studies were underway at the time. Data were obtained on changes in water quality, fish behavior and survival, and impacts of the clean-up procedures.

Water quality data indicated that temperature and turbidity in the Toutle and Cowlitz Rivers were lethal for fish from 1 to 2 weeks immediately after the eruption. Bioassays and field sampling in the Columbia River and its estuary indicated that turbidity was increased from a normal 5 to 1,680 Jackson turbidity units (JTU). Direct mortality of most aquatic organisms in the Columbia River and its estuary was not apparent; however, some benthic organisms were covered with silt. Behavior patterns of fish and other aquatic organisms were altered for a short period. For example, demersal organisms normally found near the bottom were captured near the surface, and frequency distribution patterns of juvenile salmon and steelhead entering the estuary were substantially changed.

Continued water quality sampling has indicated a steady decline in turbidity. Dredging and other clean-up activities conducted by the CofE was governed mainly by imminent threats of flooding; however, some aquatic degradation was minimized by altering clean-up procedures based on recommendations from the NMFS which were developed from the water quality monitoring. Scientists of NMFS will continue assessing the effect of the eruption to the extent possible.

Columbia River Estuary Data Development Program

Increased emphasis from all quarters for more development in the Columbia River estuary prompted the Pacific Northwest River Basins Commission to begin a 5-year, multi-agency estuarine study in 1979. The study was designed to provide information on various estuarine habitats for controlling agencies which make decisions on proposed developments. Adequate information on the impacts of these developments would allow decisions to be made which would minimize the adverse impact on aquatic resources.

The role of Center scientists in this study is to identify key fish species utilizing the estuary and determine their food habits and geographic and temporal distribution. The study is about 75% complete but was terminated in September 1981 because of budget cuts.

Oil Spill Response

Center personnel are also part of an oil spill response team set up to respond to oil spills in the Columbia River. The mission of Center personnel is to provide biological information to assess the impact of spills. In June 1978, an oil spill did occur and Center scientists responded with timely information on the biological impact. The impact was minimal, and clean-up operations conducted by the U.S. Coast Guard were efficient.

FISHERIES ENHANCEMENT (1969-81)

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 (Figure 14) near Manchester, Washington.

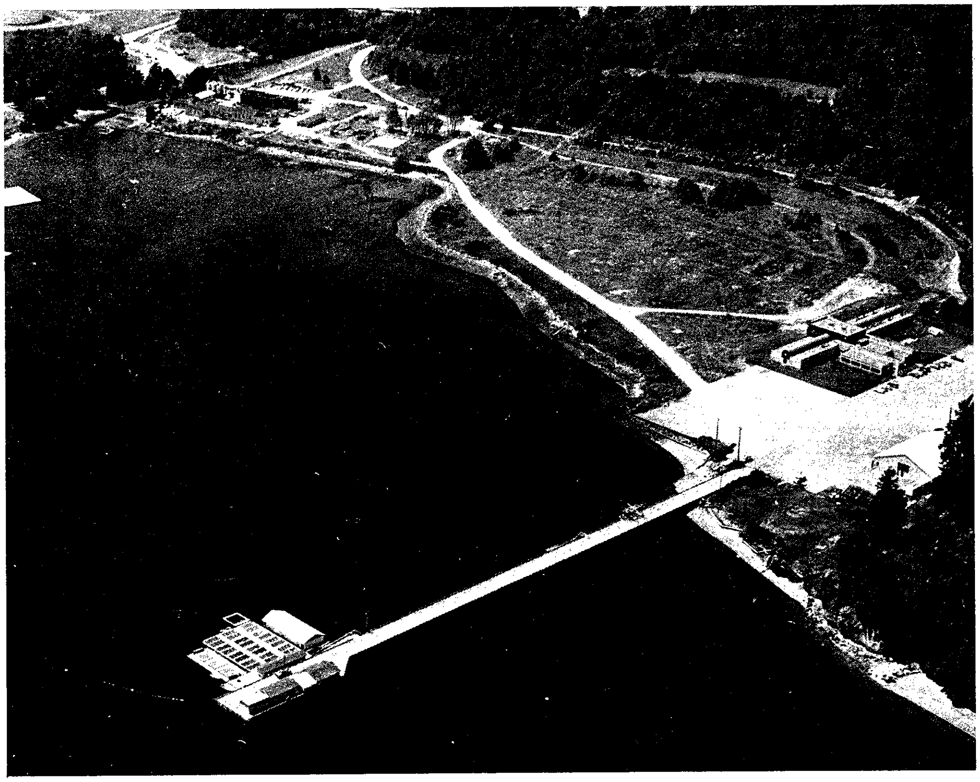


Figure 14
Manchester Marine Experimental Station on Clam Bay, near Manchester, Washington.

Net-Pen culture

During the period 1969-71, the major research emphasis was on culturing Pacific salmon in floating cages (net-pens) in seawater. The initial studies in seawater adaptation, nutritional requirements, diseases, and general husbandry of coho and chinook salmon in seawater cage-culture systems provided encouraging and promising data (Harrell 1973; Novotny 1972). The results indicated that chinook and coho salmnon could be reared from an entry size of 5 to 20 g to a size of 200 to 500 g in 8 to 10 months in seawater with reasonable efficiency and survival (Mahnken 1970). This provided the impetus for two exciting projects:

1. The development of a complete, large-scale pilot farm to demonstrate that coho and chinook salmon could be grown from the fertilized egg to a marketable size of 250 to 500 g in 18 months. The product would be a pan-sized salmon that would provide a meal for one or two persons from a single fish and would not compete with the wild-caught adult salmon trade.

2. The development of cooperative research with the Washington Department of Fisheries to determine if regional salmon sports fisheries could be enhanced by releasing salmon from the floating net-pens after the fish had been cultured there for extended periods.

Both of these projects were successful. The demonstration pilot farm was jointly funded by NOAA and private industry, and over 65 tons of pan-sized coho and chinook salmon were sold to test markets during the 2-year life span of the pilot farm. There are now two commercial salmon-culture farms operating in Puget Sound that produce over 500 tons of pan-sized salmon each year and at least one farm in British Columbia (Novotny ,1975; Mahnken 1975; Mahnken and Waknitz 1979).

Programmed releases of tagged coho and chinook salmon, cultured in floating cages at Manchester, demonstrated that this 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 possiblity 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. We found that sea-run cutthroat trout cultured in net-pens for one summer and released in Hood Canal contributed to the Hood Canal sport fishery at a rate of 20 to 1 when compared to 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 Fisheries and Game departments in both seawater and freshwater lake systems.

Task scientists monitored the environment during the pilot farm studies and after the installation of the first commercial farm. They determined the effects of intensive net-pen culture operations on benthic fauna and the natural environmental factors that would limit cage culture operations.

In conjunction with the salmon research, Task scientists studied the possibilities of culturing "companion crops" (molluscs, crustaceans, and marine plants) in net-pens in association with salmon (Hunter 1975; Prentice 1975). Task scientists and graduate students successfully cultured the commercially valuable spot prawn, Pandalus platyceros, from the fertilized egg through maturity (full cycle) and demonstrated that the prawns could live and grow in the same pens with the salmon and go through a successful mating at maturity (Rensel and Prentice 1977, 1979, 1980).

Captive Broodstock Studies

Healthy, fast-growing coho and chinook salmon and cutthroat trout held back from test-marketing or release were raised in separate net-pens for potential experimental broodstocks. With coho salmon, growth was accelerated, and large numbers of mature 2-year old fish of both sexes weighing from 1.5 to 4.5 kg with varying degrees of egg viability in the females were produced. The results of these efforts were later expanded by the commercial farms for the production of their own accelerated 2-year old broodstocks. Task scientists have had limited success in culturing fall and spring chinook salmon to maturity and are continuing with this effort. There is a pressing need to preserve certain races of chinook salmon that represent threatened stocks (such as Snake River fall and White River spring chinook salmon). 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 all of its egg requirements for their Shelton Hatchery from captive broodstocks.

The excellent success with the broodstock program led Task scientists to conduct experimental culture programs with the Atlantic salmon. 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 Atlantic salmon resources of the northeastern United States have been in jeopardy for many years due to overfishing of the adult stocks by foreign fleets on the high seas, regional fisheries, and degradation of the freshwater habitat. Although the high-seas fishing has been banned in recent years, and many of the poor freshwater habitats have been restored, there are not enough adult brood fish to supply all of the eggs that are needed by the new Atlantic salmon hatcheries on the northeastern coast of the United States (Mahnken and Joyner 1973). The successful Atlantic salmon broodstock studies by the Center scientists at Manchester, Washington, led to a cooperative Atlantic salmon restoration project between the NMFS Northeast and Northwest Regions. Limited quantities of eyed eggs from Maine were shipped to the Center's Manchester and Seattle facilities. Task scientists are now culturing the progeny from these selected strains to maturity in net-pens at Manchester.

The favorable sea temperatures and sheltered waters of Puget Sound present an ideal environment for culturing Atlantic salmon to maturity. From the small numbers of eggs supplied by the Northeast Atlantic Salmon Commission each year, Center scientists will be able to produce enough captive brood fish to return over 3,000,000 eyed Atlantic salmon eggs to northeast salmon hatcheries in this important restoration program.

Disease Research

One of the major problems that confronted Task scientists from the very beginning of the marine salmon culture programs has been diseases caused by infectious bacteria. Some of these diseases are the result of pathogenic bacteria normally found in the marine environment (namely those that cause vibriosis); others originate with the fish in their freshwater environment and are carried in a latent stage (Harrell and Schiewe 1974; Harrell et al. 1976b; Novotny 1978). Task scientists have developed rapid diagnostic procedures that allow most fishery workers to identify approximately 80% of the vibriosis problems within 1 or 2 days (Harrell et al. 1975; Novotny et al. 1975).

The major problems associated with the intensive culture of salmon in the marine environment are caused by vibriosis, which prevails under certain stress conditions. Task scientists identified a number of serotypes of *Vibrio anguillarum* (Harrell and Schiewe 1974; Harrel et al. 1976), the pathogenic bacteria that cause vibriosis, and they developed the first multiple vaccines used to prevent this highly infectious fish disease (Harrell et al. 1976a; Harrell 1978; Novotny et al. 1978). Task scientists demonstrated the practicality and usefulness of vibrio vaccines and assisted commercial salmon growers and state and federal agencies with practical applications of vibrio vaccines. They also were instrumental in assisting in and advising on the development of the first private industries established for the commercial production of fish vaccines. There are now at least three firms in the United States and two in Canada producing fish vaccines.

Task disease specialists identified problems in the culture of broodstocks due to latent freshwater diseases, such as furunculosis and bacterial kidney disease, and to infections of major organ tissues by sporozoan parasites and marine viruses (Ellis et al. 1978; Novotny 1978).

Nutritional Studies

Task scientists cooperate with other Center scientists in the field of salmon nutrition. There is a pressing need in aquaculture to develop as many alternate and economical sources of protein supplements for fish feeds as can be found. The major source of protein for most trout and salmon diets comes from high-quality fish meals. Herring and anchovy meals are becoming more costly and more difficult to obtain each year; however, any substitutions for the herring meal portions of salmon diets must be of sufficient quality and contain the proper amino acid balance to promote the growth and development of normal organ tissues.

Tests have been conducted on meals prepared from dogfish (sharks), single-cell protein (primarily yeasts), and various types of waste products produced in fish processing operations. In general, the research has demonstrated that between 25 and 50% of the herring meal portions of salmon diets can be replaced with these more economical sources of protein without affecting growth or survival (Spinelli and Mahnken 1976; Mahnken et al. 1980)

Ultraviolet Light

Task scientists have been able to use the successes in culturing the marine pandalid prawns to conduct a series of experiments demonstrating the significance of ultra-violet (UV) light in our environment. Atmospheric scientists are concerned about the depletion of ozone in the earth's upper atmosphere as a result of the excessive use of fluorocarbons by industrialized societies. The ozone layer prevents excessive amounts of UV light from reaching the earth's surface. Controlled laboratory experiments were conducted at the Manchester Marine Experimental Station, using the cultured larvae of the pandalid prawns as sensitive, biological test organisms. In nature, these larvae are found at the surface of the sea during a portion of the early larval stages. Consequently, increases in UV radiation might affect the normal development of these animals. After a series of tests under regulated UV light in the laboratory, it was found that increases in the amount of UV light could seriously reduce survival in the critical larval stages. Many organisms that represent important sources of food for salmon in the ocean are frequently found near the surface at some time in their lives (Damkaer et al. 1980).

Research with UV light has demonstrated

that certain frequencies of light are more destructive than others. Tests conducted on the effects of varying frequencies of light on salmon eggs indicated that this was also true for fish. The results of the experimentation with salmon eggs may lead to the possibilities of culturing in the presence of only certain frequencies of light which would not harm the eggs but which might reduce diseases.

Genetic Studies

Since 1977, more of the scientific expertise within the Task has been devoted to solving problems related to management and enhancement of the dwindling stocks of chinook and coho salmon and steelhead of the Columbia River system. For example, Task geneticists have been researching the identification of racial stocks of fish by using naturally occurring biochemical markers. Small samples of organ tissue are collected for processing and for the electrophoretic separation of the various biochemical markers. Scientists can use these markers to separate unique stocks of fish during the commercial fishing season on the lower Columbia River. This provides fishery managers with the ability to assess the proportions of critically important stocks entering the fishery each period and to regulate accordingly. It is possible that the same techniques may be used in the future to identify stocks of salmon in the international, commercial salmon fishing zones between the United States and Canada (Utter et al. 1976a; Utter et al. 1976b).

Smoltification

Task scientists have also been conducting extensive field research on the physiological mechanisms that control the "smolting" process in juvenile salmon and the relationship of these mechanisms to survival in seawater. Anadromous salmon and trout go through progressive, hormone-related physiological and morphological changes prior to and during the normal transition that permits them to migrate from a pure, freshwater environment to full seawater with a 3.4% salt concentration (Folmar 1979; Folmar and Dickhoff 1980). 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 triphosphatase (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; Folmar et al. 1980); 2) the relationships of thyroid hormones to smoltification and seawater adaptation (Prentice et al. 1979; Folmar and Dickhoff 1980; Folmar et al. 1980); 3) changes in plasma electrolyte levels during the smolting process (Zaugg and McLaine 1970; Prentice et al. 1979; Folmar and Dickhoff 1980; Folmar et al. 1980); and 4) the relationship of fish health in the normal hatchery populations to smoltification indices and survival.

Scientists and technicians collected thousands of random samples from the many populations of hatchery salmon and steelhead before and after the normal spring smolting periods. The hatcheries were visited at intervals of 1 to 2 weeks. Gills and blood serum were analyzed for Na^+-K^+ ATPase enzyme, thyroid hormones, and electrolyte levels. Blood samples for basic hematology and tissue samples for histopathological examination were collected in large numbers to provide a sound statistical base for normal populations. Morphological data on individual fish were collected, and live samples were transported as far as 600 miles to the seawater rearing pens at Manchester to determine relative seawater survival. Continuous records of growth, survival, visual morphology, and causes of death were maintained during the 4 to 12 months of seawater culture.

Almost all of the groups and/or stocks studied were representative of tagged populations. Data on the returning adults from these hatchery releases are now being assembled and analyzed. 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 populations 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.

Similar studies were conducted during the same time periods on stocks of hatchery fish that were involved in extensive imprinting and "homing" experiments in Washington, Oregon, and Idaho. The objectives of the disease portion of the homing studies were primarily to determine if the fish's capabilities of imprinting to release sites were in any way compromised.

Task scientists have been conducting experiments to determine the best possible techniques for altering and controlling smoltification. In the future, as more information becomes available regarding the most favorable time periods for passage into the ocean, fish hatchery managers may be able to alter the timing of release, through controlled smoltification, to coincide with the most favorable oceanic conditions.

GENERAL EXPERTISE AND RECOGNITION

The expertise provided by the CZES Division's scientists has been recognized both nationally and internationally (Joyner et al. 1974). Scientists have been called upon to assist in planning fish-passage facilities, aquaculture development projects, and biotelemetry projects. They have been requested to provide environmental assessment and impact information. They have also established training programs for Northwest Indians (Novotny 1969) and have provided detailed information for federal participation in the management of salmon resources in the Pacific Northwest under the legal jurisdiction of the Judge Boldt decisions (Waknitz et al. 1978). They have also provided training for French and Polish scientists and technicians.

Several of the Division's scientists have been called upon to serve on continuing international cooperative programs, such as the U.S.-Japan Natural Resources Cooperatives (UJNR) and the U.S.-France Scientific Missions (NOAA-CNEXO). Similar cooperatives are being proposed by the Polish government (Harache and Novotny 1976).

This recognition of the expertise of the Division's scientific staff is supported by the excellent program of documentation of research results through the publication of scientific and technical literature for fisheries experts, commercial fish farmers, water management entities, power producing entities, the general public, and other groups. Over 500 scientific and technical publications and processed reports are proof of the excellent work conducted by Division scientists in the past 50 years.

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 CZES Division of the Center believes its research emphasis should be focused on the following areas:

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, 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.

Habitat Investigations

Future developments such as increased port dredging to improve ship entrances, industrial plant construction, offshore mining, increased oil tanker traffic, and siting of future coal storage facilities could potentially cause further degradation of an already altered aquatic environment. Information will be needed on the impacts of these activities to the aquatic habitats supporting existing and future fishery resources.

Additional dredging of various types is planned for several ports in the Northwest to deepen and widen ship channels. For example, plans are underway to deepen and widen the Columbia River ship channel; this requires over 10 million yd^3 of material to be removed and deposited somewhere in the aquatic environment. Detailed knowledge of the biological communities in the dredge area will be critical in recommending measures to minimize detrimental impacts to the fishery. Thus, emphasis on research to characterize habitats and assess impact of various perturbations to the environment should continue.

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 determining an evaluation of certain enhancement strategies is knowledge of early ocean behavior 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 three areas of research relating to environmental effects described above are among those which the Center 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 underway are to be successful.

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