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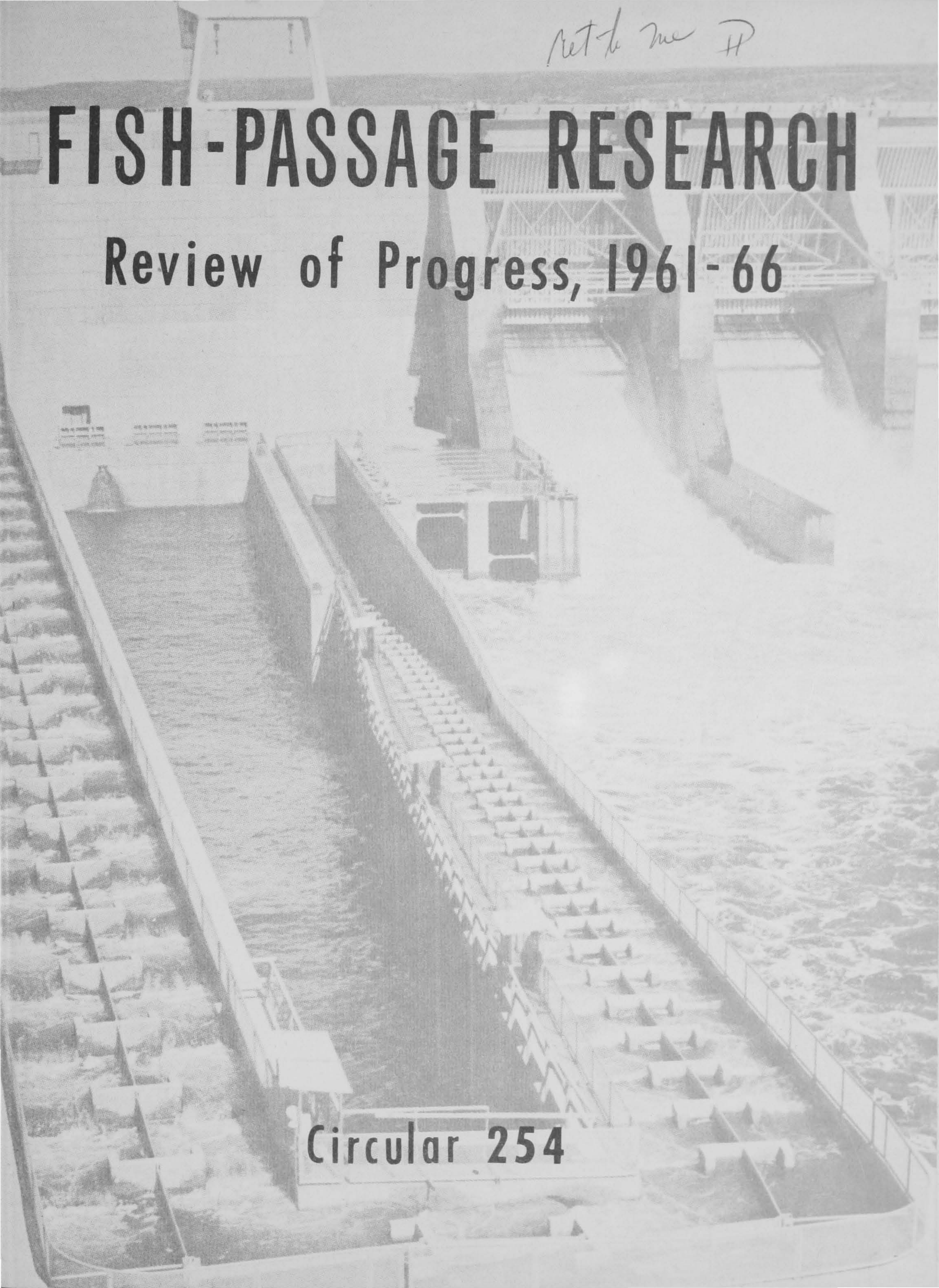
FISH-PASSAGE RESEARCH

Review of Progress, 1961-66



Circular 254

UNITED STATES DEPARTMENT OF THE INTERIOR

U.S. FISH AND WILDLIFE SERVICE

BUREAU OF COMMERCIAL FISHERIES

FISH-PASSAGE RESEARCH
Review of Progress, 1961-66

By

PARKER S. TREFETHEN

Circular 254

Washington, D.C.

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FOREWARD

An investigation of problems of fish passage at high dams proposed for the Middle Snake River began in 1961 at the request of Secretary of the Interior Stewart L. Udall. The Fish-Passage Research Program became involved in the investigation, which was planned and conducted jointly by State and Federal fishery agencies and included work at high and low dams, at rivers and reservoirs, and in laboratories. Much information was obtained on the behavior, abilities, and requirements of migrating fish under situations expected to develop at high dams; the information was used as a basis for decisions on development of water resources.

The Bureau of Commercial Fisheries Fish-Passage Research Program was supervised by Gerald B. Collins, Director, and Carl H. Elling, Assistant Director. Principal research assistants were Parker S. Trefethen and H. William Newman. The research was coordinated by the Columbia Basin Fishery Technical Committee, composed of representatives of fish and game agencies of Idaho, Oregon, and Washington, and of the Bureau of Sport Fisheries and Wildlife and the Bureau of Commercial Fisheries. Annual reviews were presented to this committee and to the directors of the State agencies whose counsel, guidance, and cooperation contributed to the progress of research. A major review of progress at the end of 1964[1] demonstrated the need to sustain the attack on problems of fish passage in the Columbia River system.

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[1] Fish-Passage Research Program. 1964. Fish-Passage Research Program review of progress. U.S. Fish Wildl. Serv., Bur. Com. Fish., Fish-Pass. Res. Prog., Seattle, Wash. Five volumes, various paginations, various authors, limited distribution. [Processed.]

Cover.—North shore fishway, fishway entrance, and part of spillway at Ice Harbor Dam.

CONTENTS

ABSTRACT

Results of accelerated laboratory and field experiments to investigate problems of anadromous fish passage at high dams are summarized. Studies were made on: the passage of adult and juvenile fish through large, medium, and small impoundments; design and operation of adult fish-passage facilities at dams; mortalities of juvenile fish passing through turbines and methods of reducing losses; collection of juvenile fish from rivers, streams, and reservoirs; transportation of juvenile fish; and the effect of the changing environment on passage and survival. Publications by the staff are listed.

FISH-PASSAGE RESEARCH
Review of Progress, 1961-66

PARKER S. TREFETHEN, Fishery Biologist

Bureau of Commercial Fisheries
Fresh Water and Estuarine Research
Seattle, Wash. 98102

INTRODUCTION

Problems of passage and survival of anadromous salmonids (Oncorhynchus spp.) have become increasingly acute since the construction of dams began in the Columbia River system over 3 decades ago. As dams were built and impoundments formed, rapid and dramatic changes took place: The dams became barriers to migration; lakelike reservoirs replaced rivers; temperature regimes and food supplies were modified; competitor-predator and disease relations were changed; flow patterns were altered; and spawning areas were diminished.

Environmental changes that have already taken place are being amplified by the continuing development of the Columbia River and its major tributary, the Snake. In a few years the river flow will be almost entirely controlled by dams (fig. 1), little or no spilling will take place, and most seaward migrants will pass through turbines. Additional masses of water will be heated by the sun and by thermal electric plants. Hydroelectric power plants will operate to peak demand, which will further change water temperature and flow downstream.

Figure 1.—Locations of dams authorized or completed in the Columbia River system. (Adapted from map prepared by Washington State Department of Fisheries.)

Figure 2.—Field stations from which activities on fish passage were conducted by Federal and State agencies. Headquarters were in Seattle, Wash.

From field stations in Washington, Idaho, Oregon, and California (fig. 2), the Fish-Passage Research Program has defined critical problems and devised practical methods to expedite migration between the spawning areas and the sea. The progress of the program, from its inception in 1961 through calendar year 1966, is summarized here under four major problem areas: effect of impoundments on migration of fish; collection and transportation of juvenile migrants; passage of migrant fish at dams; and adaptability of fish to new environments.

HIGHLIGHTS -- 1961 - 66

The passage of juvenile salmonids through an impoundment is related to the length and volume of the reservoir, the volume of flow at time of migration, and the physical and biological environment. Adult salmonids appear able to migrate through the large impoundments that are to be developed in the middle Snake River, but it is unlikely that young salmonids will be successful in their migrations. If natural runs are to be maintained, young migrants must be collected before they enter a reservoir and transported downstream around the dam.

Different methods for collecting fish were compared. Louvers, electrical devices, water jets, and air bubbles are partially successful, but their economical and practical application is limited to areas that have little debris and where water flow can be controlled. A promising new device, a traveling screen placed at a steep angle diagonal to the flow of water, appears to be capable of withstanding heavy loads of debris and high velocities of water in major rivers. Scale models of the device are undergoing mechanical and engineering tests to provide data for installation of a prototype.

An estimated 25 percent of seaward migrants that entered turbine intakes of Columbia River dams were found to accumulate in the gatewells (open slots upstream of turbine for storage of gates--see fig. 3). Methods were devised to collect these fish and bypass them around the dams. Distribution studies within the turbine intake showed that most of the fish were near the ceiling, which suggested the possibility that more fish could be diverted into the gatewells.

The distribution studies in the turbine intakes, coupled with preliminary work on mortality in turbines and studies of models (showing well-ordered flows through the turbines), suggested that young migrants probably pass through turbines along defined routes rather than disperse throughout the water mass. Research equipment and operational methods were extensively developed to define the scope and cause of injury and mortality; possibly losses of fish may be reduced by modifying turbines, by introducing entrained air (fig. 4), or by rescheduling turbine loads.

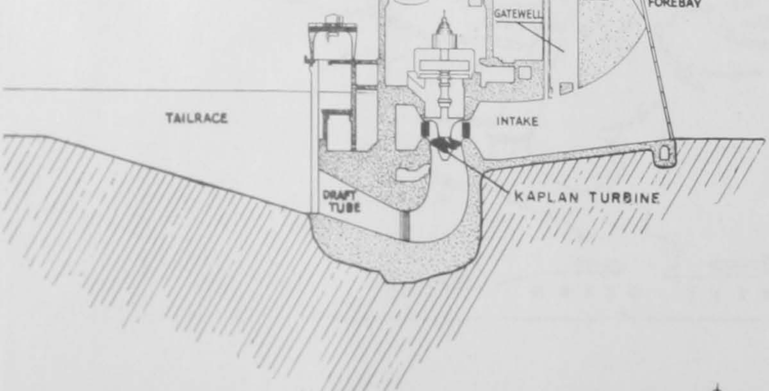


Figure 3.—Young fish migrating downstream in turbine intake enter through the bottom opening and accumulate in gatewells (shown in cross section of a dam) from which they may be collected and safely bypassed around dams. Gatewell shown is 16 feet wide.

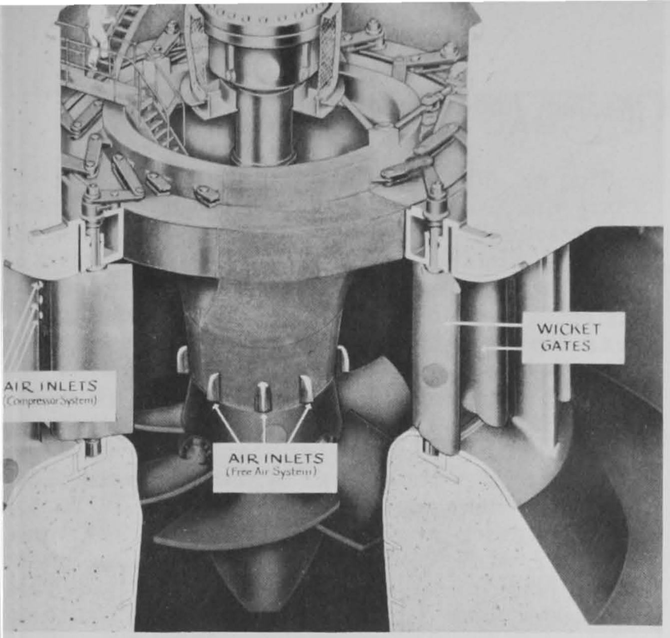


Figure 4.—Air added to water passing through turbines can attenuate cavitation, low pressure, and violent currents, which are suspected of contributing to mortalities of young salmonids.

Other studies revealed that water temperatures in the Columbia Basin were becoming critical in the late summer. Projected hydroelectric and thermal power developments will intensify the problem; the peaking operations of hydroelectric plants will accelerate heating of water during low-flow periods. Some respite may be possible from releases at depths of cold water from upstream storage areas, but statutory control of thermal pollution seems to be most appropriate action.

The ability of adult migrants to pass through pipes of different configurations was demonstrated; studies are continuing on how such factors as light intensity, water velocity, and water temperature affect efficiency of passage. Pipes can be used to provide routes from several collection points below a dam to a common fishway, to extend fishway exits above a dam away from hazardous areas, or to provide passage beneath highways.

The passage and performance of migrating adult salmonids through a fishway with a slope of 1 foot in 10 was as efficient as passage through a conventional fishway slope of 1 in 16. Steeper and less expensive fishways are now being built at new dams in the Columbia and Snake Rivers.

Significant numbers of adult fish fell back over the spillways. Some of them survived, returned over the dams, and were counted again. The frequency of these "fallbacks" at lower river dams, where the numbers of fish are larger and the flows higher than at dams farther upstream, could produce high losses of adult migrants and may account for discrepancies between the numbers of fish counted at succeeding dams.

EFFECT OF IMPOUNDMENTS ON MIGRATION OF FISH

A basic question was whether large impoundments, corollaries of high dams, are impassable barriers to migrating anadromous fish. Assessments were thus made on fish passage through large, medium, and small impoundments from 4 to $57\frac{1}{2}$ miles long with storage capacities from 19,000 to 4,500,000 acre feet (fig.5).

Large Impoundment

Studies of passage by adult chinook salmon through $57\frac{1}{2}$-mile-long Brownlee Reservoir indicated that adult fish released in the reservoir attained spawning grounds as successfully as those fish transported around the impoundment and released in the river above it. Passage through the lakelike environment did not impair the ability of the fish to spawn successfully.

On the other hand, few juvenile fish passed downstream through Brownlee Reservoir during average drawdown and early filling. These were wild and hatchery-reared chinook (O. tshawytscha) salmon. Passage was successful, however, of hatchery-reared chinook, coho (O. kisutch) and sockeye (O. nerka) salmon, when low pool, high inflow from the Snake River, and high discharge at the dam coincided with downstream migration (fig. 6).

Environmental conditions became critical during the summer (fig. 7). Surface water temperatures reached 81° F.; dissolved oxygen where temperatures were less than 70° F. were 0 to 4 p.p.m. (parts per million). Despite these rather stringent physical conditions for survival and an abundance of predators and competitors, some fish held over and left the reservoir after nearly 1 year of residence.

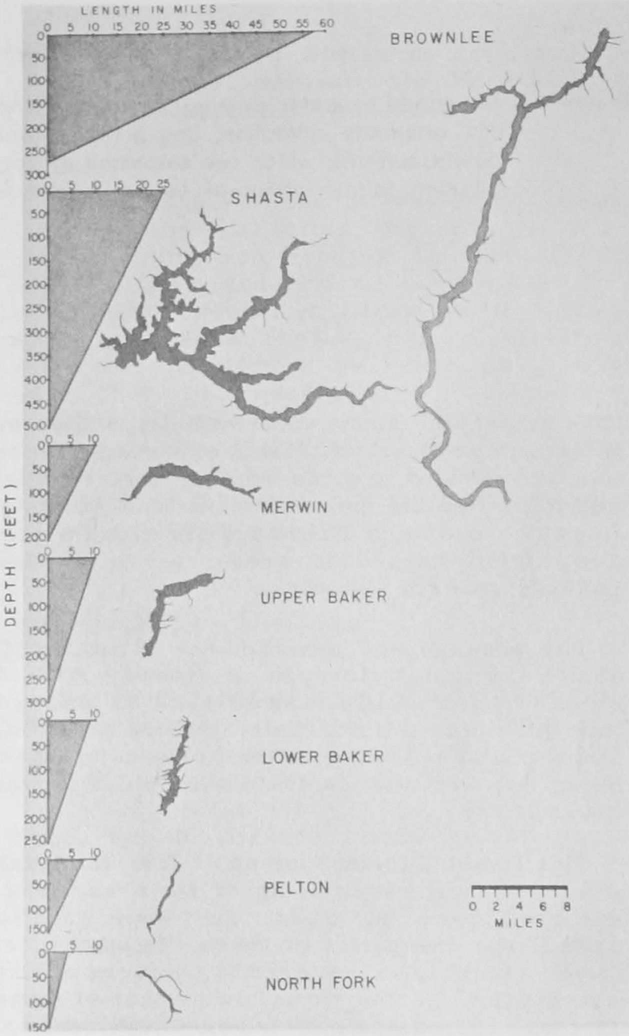


Figure 5.—Size and configuration of impoundments where fish passage was studied.

A sharply defined area at the head of the reservoir, where cold river water plunged beneath warmer reservoir water, appeared to delay seaward migrants. Although subsurface density currents were observed, migrant fish confined their movement primarily to the surface layer.

Medium Impoundment

Studies by the California Department of Fish and Game indicated that chinook salmon fry released in the 25-mile-long Sacramento arm of Shasta Reservoir moved to within 4 miles of the dam in 16 days before disappearing from sample catches. No fish were observed near the dam even though water was spilled during this migratory period. Remains of salmon fry found in stomachs of rainbow trout (Salmo gairdneri), brown trout (S. trutta), and bluegill (Lepomis machrochirus) indicated that predators took a toll of the migrants. The mortality was not total, however; 3- to 5-pound salmon were caught by sport fishermen the year after release. This remarkable growth was attributed to excellent forage provided by threadfin shad (Dorosoma petenense) that are present in huge numbers.

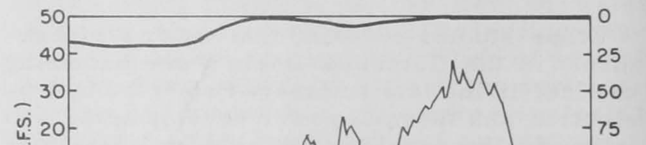


Figure 6.—Escapement of young chinook salmon from a large impoundment — Brownlee Reservoir. Similar patterns occurred for hatchery-reared coho and sockeye salmon.

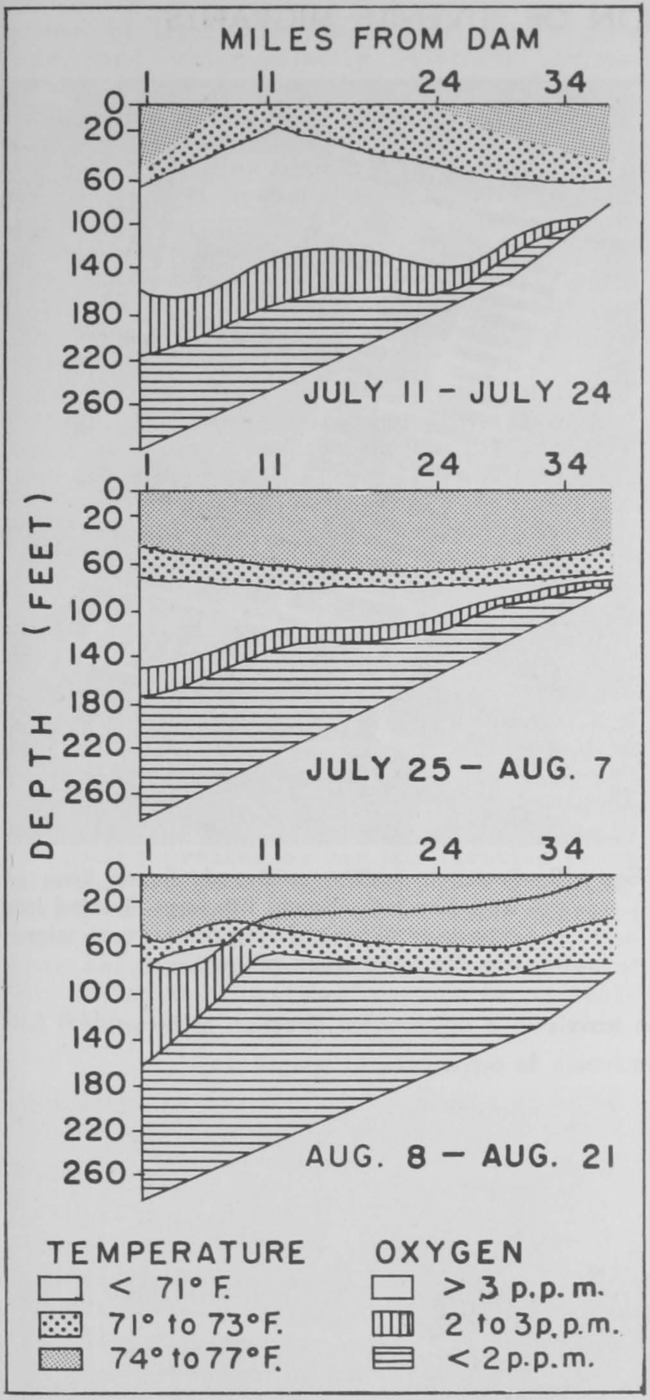


Figure 7.—Changes in environment decrease the area (unshaded) that is suitable for survival of young fish. Temperature increases at the surface, and oxygen concentration decreases at depths.

Small Impoundments

Lake Merwin.--To study the escapement of coho salmon from this 10-mile-long reservoir the Washington Department of Fisheries used an experimental surface collector immediately upstream of Ariel Dam. The efficiency of collection, which ranged from 10 to 65 percent, was not a true measure of escapement because it appeared that the deep turbine intakes disrupted surface currents and presumably carried fish below the mouth of the collector. Survival of young salmon in the reservoir was low. Predation by rainbow trout (Salmo gairdneri) and squawfish (Ptychocheilus oregonensis) appeared to be a major factor reducing survival.

Upper and lower Baker Lakes.-- The Washington Department of Fisheries reported successful passage of coho and sockeye salmon through these reservoirs (9.8 and 9.0 miles long). Turbine intakes here were near the surface. Escapement from both reservoirs through surface collectors provided a basis for estimating passage through lower Baker Lake. Estimates based on sample counts indicated that all of the coho salmon and 95 percent of the sockeye salmon that left upper Baker Lake also passed through the lower lake.

Pelton and North Fork Reservoirs.--The Fish Commission of Oregon judged the passage and survival of adult migrants to be satisfactory at North Fork (4.0 miles long) but unsatisfactory at Pelton (7.5 miles long). The problems at Pelton Reservoir were compounded by construction of a dam at the upstream end of the impoundment; poor survival, which seemed to be related to predation and other factors, suggest a marginal environment for salmonids. A comparison of environment in the two reservoirs indicated that North Fork was less alkaline, had the lower maximum dissolved oxygen, warmed more slowly in the spring, and had the greater ratio of water displacement.

COLLECTION AND TRANSPORTATION OF JUVENILE MIGRANTS

Because we realized that some of the impoundments would be impassable to anadromous fish, we directed some of our studies toward developing methods of economical collection and toward assessing the effect of transportation on migration, survival, and the ability of fish to return as adults. We experimented with the collection methods in a major facility at Troy, Oreg. (fig. 8), and in smaller flumes and laboratories in Oregon and Washington.

Collection from Rivers

A technique under development for collecting seaward migrants involves an endless traveling screen suspended diagonally across a river moving downstream at about the speed of the water (fig. 9). The device will be capable of withstanding high flow and debris loads of a major river in flood. Tests in a 40-foot-wide flume in velocities up to 5 f.p.s. (feet per second) successfully diverted fish into a bypass; experiments are in progress to define the necessary mechanical and engineering features of the design for installation of a prototype.

Experiments to guide and collect downstream migrants in large-scale, fixed and floating installations revealed that louvers are most practical where water flow can be controlled and debris is not a serious problem. Under controlled conditions, the significance was

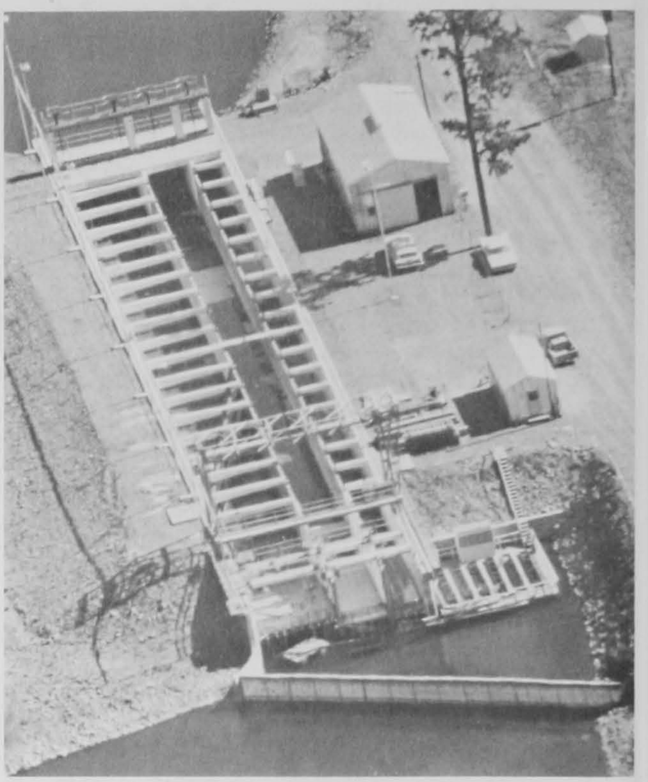
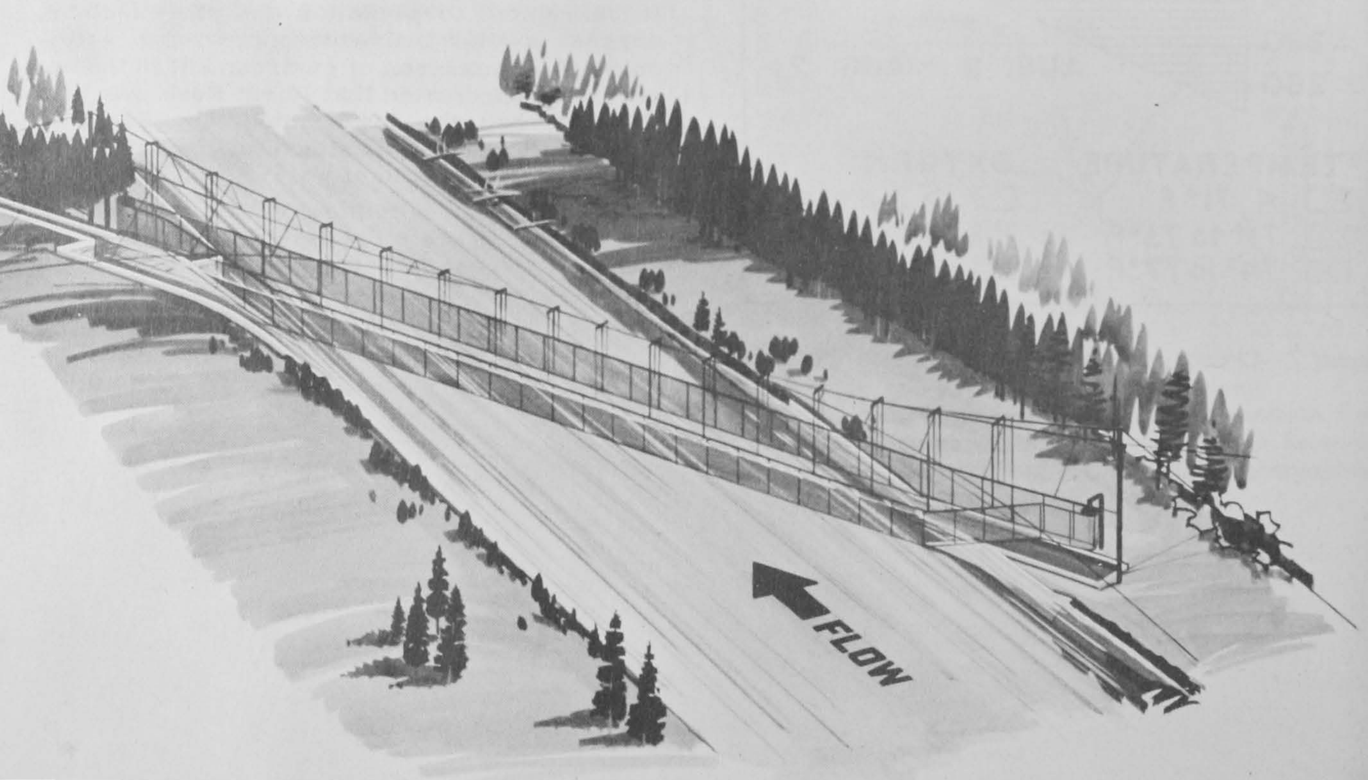


Figure 8.—Research facility on Grande Ronde River at Troy, Oregon. Young fish were diverted into experimental area during downstream migration for observation of behavior.

Figure 9.—Artist's concept of a traveling screen. The screen travels in a downstream direction to divert young downstream migrants into a bypass.



shown of light and visual relations, bypass size, and water-velocity relations. Downstream migrants were guided most efficiently in daylight; black louvers usually were more efficient than white louvers both night and day in water velocities from 1.5 to 3.5. f.p.s. The efficiency of a bypass was increased when it was widened from 6 to 24 inches. Water velocity in and approaching a bypass was found to influence collection efficiency. Preliminary data suggested that efficiencies improved as bypass velocities were increased over approach velocities (fig. 10).

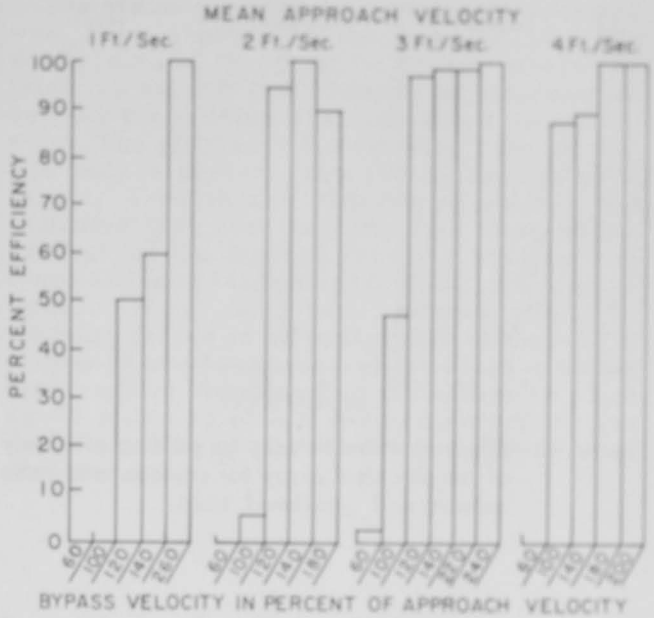


Figure 10.—Bypass efficiency in relation to bypass and approach velocities (preliminary data).

In guiding young migrants within an electrical field on a prototype scale (fig. 11), we found that pulsed direct current was most effective where water velocities were less than 0.5 f.p.s. (fig. 12). An electrical field applied to louvers of different spacings proved to be no more effective than louvers alone (table 1).

Jets of water and air were used in a flume at Carson, Wash., to guide migrants into collection areas. Although water jets (fig. 13) 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.

Figure 11.—Prototype of electrical field installation to guide juvenile salmonids.

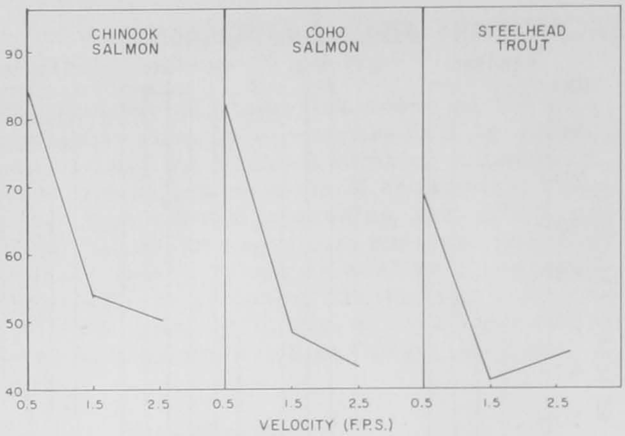


Figure 12.—Effect of water velocity on guiding efficiency of an electrical array for chinook and coho salmon and steelhead trout.

Table 1.--Comparison of guiding efficiencies of louvers with electrical power on and off

Louver spacing	Electrical power condition	Tests	Average efficiency
Inches		Number	Percent
4.75	On	3	82.7
	Off	3	84.4
10.00	On	3	79.1
	Off	3	69.8
16.00	On	4	50.9
	Off	4	56.3

Figure 13.—Jets of water deflecting seaward migrants.

Sound, as a medium for guiding fish, was explored in the laboratory and under field conditions. Broad-spectrum noisemakers did not divert fish successfully, but specific frequencies of high intensity produced orientative responses. A maximum avoidance response was obtained with the low frequencies of 35 to 170 c.p.s. (cycles per second). Conceivably, sound could be applied under certain conditions, either by itself or with other devices, to deflect migrants.

Collection from Reservoirs

A potentially effective method for collecting fish at dams is based on their natural behavior in the turbine intakes. An estimated 25 percent of the fish that entered an intake swam upwards toward the ceiling, passed through a 4-foot opening, and accumulated in the intake gatewells. These fish eventually sound and pass downstream through the turbine.

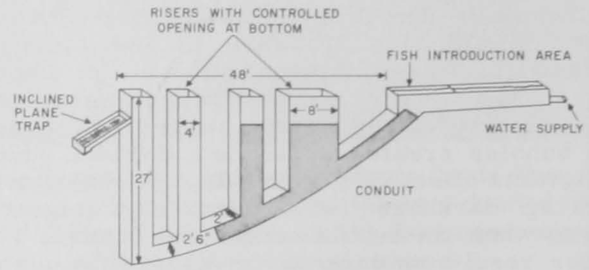


Figure 14.—Simulated turbine intake used to examine factors that influence entrance of young fish into gatewells.

Because high concentrations of fish are necessary for a collection method to be effective, experiments were directed toward determining factors that influenced this natural behavior. In a simulated turbine intake in our fishery-engineering research facility at Bonneville Dam (fig. 14), light placed near the opening in the ceiling increased the number of fish in the gatewells; baffles located on the intake ceiling did not significantly alter their behavior. At the Biological Laboratory, Seattle, coho and sockeye salmon actively swam upward in a pressure chamber when pressure was increased enough to equal a depth increase of less than 2 feet (fig. 15). This information suggests that natural behavior can be reinforced to increase the number of fish in gatewells and that further efforts to redistribute fish in turbine intakes will be profitable.

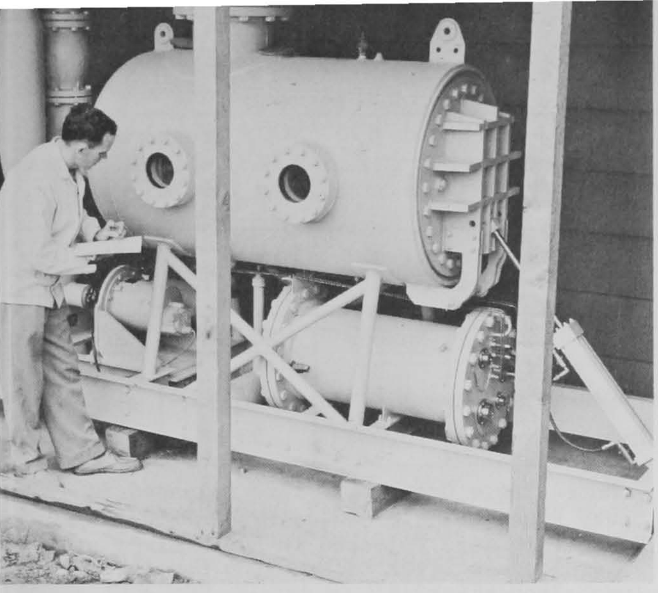
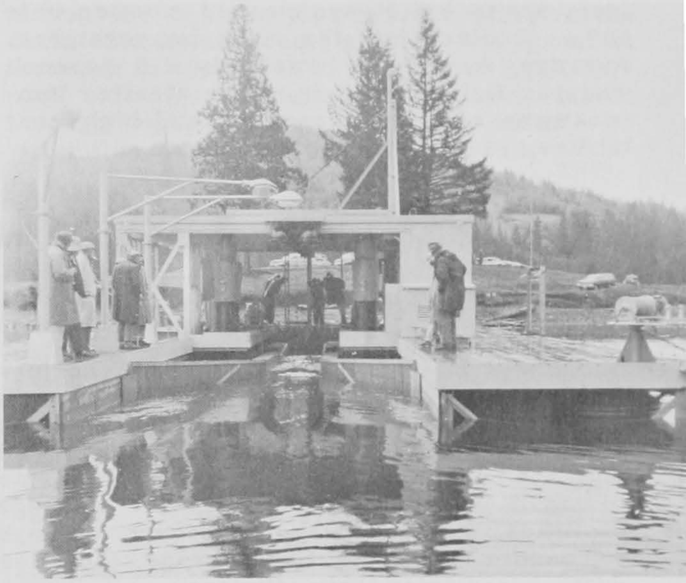


Figure 15.—Hydraulic chamber for studying response of fish to pressure changes.

The efficiency of the experimental collector was also studied at the head of Mayfield Reservoir in the Cowlitz River, where we tried to exploit the tendency of migrants to be near the surface when entering an impoundment. The efficiency for yearling coho salmon was only 4 percent; few underyearlings were caught, even though distribution studies had indicated that over half the fish were within 12 feet of the surface. Similar studies with traps and long lead nets at the head of Brownlee Reservoir produced poor catches (fig. 17). The difficulties in collecting fish at the head of a storage impoundment--where stage of filling may require movement of collectors as much as 20 miles to obtain desired velocities and depth--may be greater than those in rivers or streams.

Figure 16.—Experimental artificial floating outlet used in collection experiments at Ariel Dam.



Another collection device--a floating artificial surface outlet--was highly successful at Baker Lake, Wash.; but similar devices at other sites were relatively unsuccessful. In Lake Merwin at Ariel Dam the device collected only 10 percent of the juvenile migrants during the first year (fig. 16). After limnological studies of Baker and Merwin Lakes (showing dissimilar water flow and stratification), the opening of the collector at Lake Merwin was modified to capture migrants to depths of 28 feet in water conditions approaching those at Baker Lake. Although the efficiency rose to 65 percent, other problems, such as flow patterns and fish distribution near the dam, suggested that other methods of collection would be more feasible.

Figure 17.—System of long leads and fingerling trap to measure the effectiveness of collecting downstream migrants near the head of Brownlee Reservoir.

Transportation

Native downstream migrants from spawning of spring-run chinook salmon were collected in the fall from Eagle Creek, a tributary of Brownlee Reservoir, and transported to the Snake River below the Brownlee-Oxbow dam complex. The survival of these wild fish was compared with that of hatchery-reared fingerlings from the same stock that were hatched and released in the spring from a hatchery in Rapid River, a tributary of the Salmon River which enters the Snake River downstream from Oxbow Dam. A better recovery of marked wild fish than of hatchery fish (table 2) was made from gatewells of Ice Harbor Dam. Although the difference in recovery may have been due to difference in survival, a delay in movement of hatchery fish was indicated by the recovery of some hatchery fish 1 year later.

We also examined the feasibility of handling and transporting fish that were collected during periods of high water temperatures. Seaward migrants were removed from water ranging from 59° to 64° F. and marked in water 4° to 10° F. cooler than the river temperatures. Average mortality was only 1.5 percent, whereas fish marked in water at river temperatures suffered immediate and high mortalities.

Table 2.--Marked native (Eagle Creek) and hatchery-reared (Rapid River) chinook salmon recovered at Ice Harbor Dam 1964-65

Rearing area	Released	Recaptured	Estimated survival[1]
	Number	Number	Percent
Eagle Creek...	4,129	32	19.3
Rapid River...	50,000	33	1.6

Note--Eagle Creek fish were released in Snake River below Brownlee-Oxbow Dams; Rapid River fish were released in Rapid River and entered Snake River below Oxbow Dam through the Salmon River.

[1] Based on average efficiency (4 percent) of gatewells to collect downstream migrants at Ice Harbor Dam.

PASSAGE OF MIGRANT FISH AT DAMS

Adult Fish Passage

Research by the Bureau, in the Fisheries-Engineering Research Laboratory of the U.S. Army Corps of Engineers at Bonneville Dam on the Columbia River, were primarily concerned with the behavior, abilities, and requirements of adult salmon migrants in fish-passage facilities. We emphasized the search for ways to reduce costs of fish-passage facilities without impairing their efficiency.

Diffusion water velocity.--Tests with floor and wall diffusers demonstrated that the introduction of diffusion water at any velocity tended to increase passage times. It appears, however, that velocity standards for floor and wall diffusers, which are necessary for prescribed flows in lower ends of fishways, could be increased 100 percent without causing appreciable delays. The addition of entrained air had no effect on fish passage.

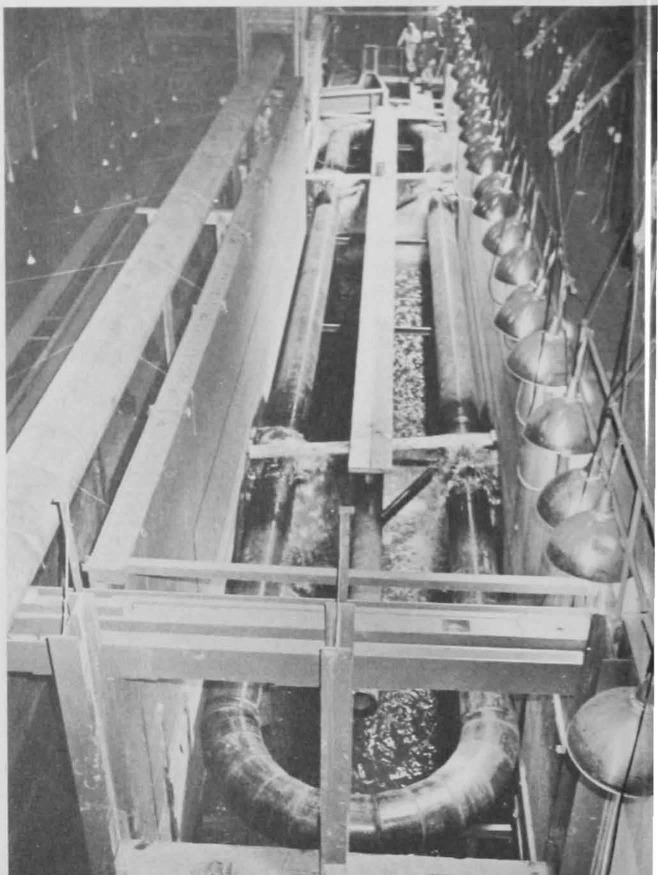


Figure 18.—Oval-shaped endless pipe used in fish-passage experiments. Water flow, depth, and light intensity were varied.

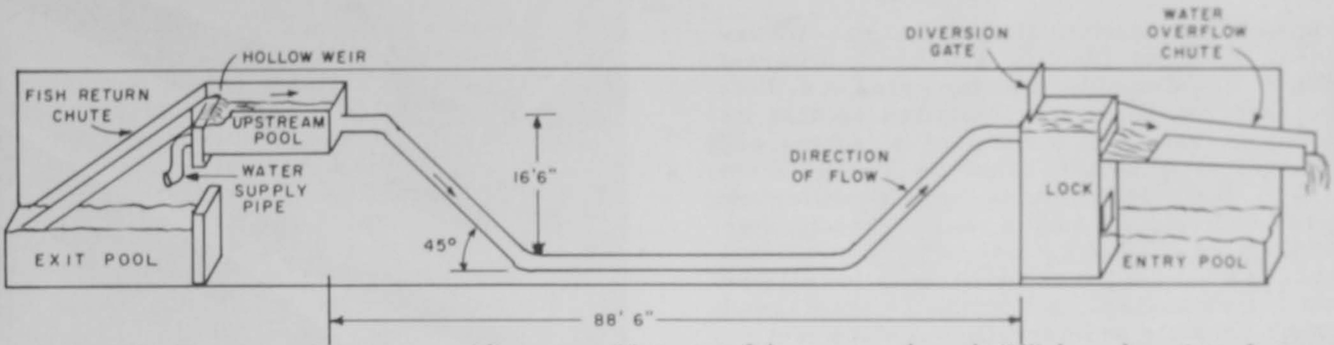


Figure 19.—Experimental apparatus (diagrammatic) to test fish passage through "U"-shaped section of pipe.

Passage through pipes.--The entry of fish into 1-, 2-, and 3-foot-diameter pipes was explored. The carrying capacity of the 2-foot pipe and the effect of water velocity, light, and depth of flow on passage in 1-, 2-, and 3-foot pipes were studied. A transition zone from holding area to pipe--provided by a 10-foot-long truncated cone tapered from a diameter of 3 feet to fit the pipe--did not improve entry of fish into the 2-foot pipe but did improve the efficiency of entry into the 1-foot pipe. Capacity of a 2-foot pipe, 90 feet long, was 12 fish per minute for a 60-minute period and 15 fish per minute for a peak 20-minute period.

Within the 2- and 3-foot diameter pipes, the water velocities of 1 to 4 f.p.s. did not affect passage of chinook or sockeye salmon or of steelhead trout (Salmo gairdneri); within the 1-foot pipe, the water velocities at the lower f.p.s. moved sockeye salmon and steelhead trout slower, but the water velocity of 1 f.p.s. was not suitable for chinook salmon. Lighted pipes speeded the passage of all species tested except summer-run chinook salmon, which moved through the pipe more quickly in the dark. Steelhead trout showed the greatest increase in speed due to addition of light. Chinook salmon and steelhead trout moved faster through pipes that were partially filled with water than through pipes that were full.

After these studies, experiments were run on the passage of fish through an oval endless pipe system (fig. 18) and through a "U"-shaped section of pipe (fig. 19). In the endless pipe, fish swam futher under lighted conditions, but rates of movement for 1 mile were about the same for light and dark pipes. Chinook salmon swam faster at a water velocity of 3.5 f.p.s. than at 2.0 f.p.s. Sockeye salmon passed through the 2-foot-diameter "U"-shaped pipe (103 feet long) with no apparent difficulty in water velocities of 1 to 4 f.p.s. The passage of other species of salmon through this pipe is being studied.

Response to orifices.--Chinook and coho salmon and steelhead trout were offered a choice of entering vertical or horizontal orifices (fig. 20) located at depths of 3 and 9 feet (to center line of orifice) below the surface. The vertical orifice generally was more suitable than the horizontal orifice, and the shallow orifice was more suitable than the deep orifice for salmon and trout.

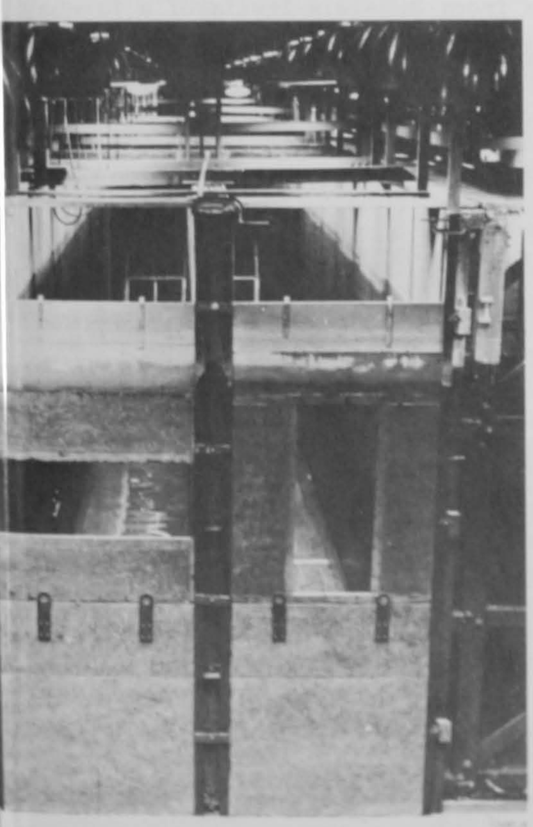


Figure 20.—Equipment used for comparing responses of adult salmon to vertical and horizontal orifices in a weir.

Submerged counting station design.--We explored ways to identify and count different species of salmonids in turbid water. A 4-foot-square light panel was installed so that its distance from the window of a submerged observation chamber could be varied from 1 to 4 feet. Fish counts and identification were accurate in turbid water (Secchi disc readings of 2.0 and 2.8 feet) when the interval between the light panel and observation window was 2 feet or less, but identification was not always possible at intervals of 3 and 4 feet.

Separation of fish.--Mechanical methods for separating fish were studied. Tests were run to separate (1) races of chinook salmon, (2) species of salmonids, and (3) salmonids from nonsalmonids.

A mechanical apparatus that required a fish to ascend a weir onto a slide--from which it was diverted into a proper channel--proved to be practical (fig.21). Success depends on the experience and competence of the operator.

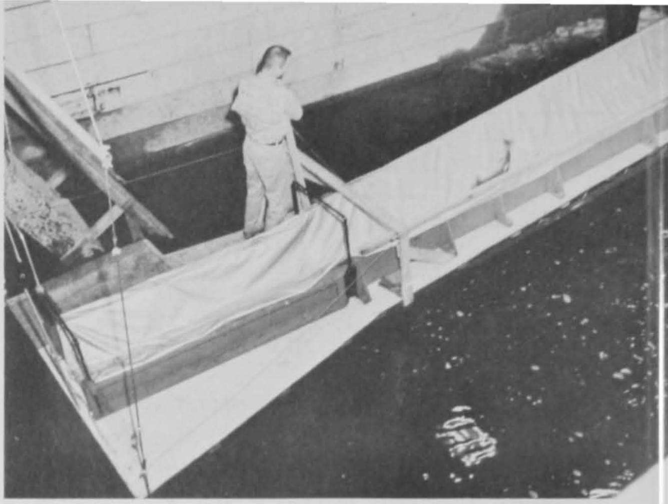


Figure 21.—Experimental fish separator, made from polyethylene, suspended on frame. Operator identifies adult fish in chute and diverts it to desired area.

Response to temperature.--Adult fish, offered a choice of channels with temperatures 3°, 7°, and 15° F. above river temperature, showed a preference for ambient river temperature; however, many fish entered the channels containing warmer water, even when ambient temperature was 65° F. When river temperature increased to 68° F., no fish entered the channel in which water was 15° F. above the river water, and only a few entered the channel with water 7° F. warmer than the river. Further studies are to be made on response of fish to warmer and cooler temperatures, in view of the temperature differentials that may be created in the future by water drawn for collection and passage facilities from different levels of a forebay.

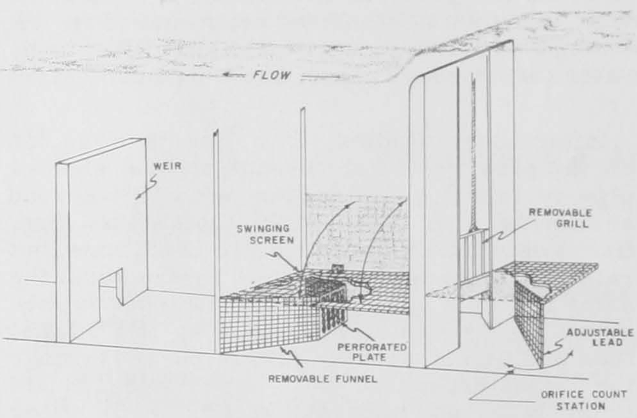


Figure 22.—Apparatus (diagrammatic) for tests in separating salmon from other fish in fishway pool. Adult salmon were forced to swim over the weir, whereas smaller fish passed through the orifice and perforated plate.

Fish within a fishway pool were separated by means of perforated plate screens and gratings located upstream from an orifice (fig. 22). Perforated plates (with $2\frac{1}{2}$-inch-diameter holes) diverted about 61 percent of the suckers (Catostomus spp.) into a trap; it seems probable that, with refinement, other species of fish could be separated by this method and removed from fishways if necessary.

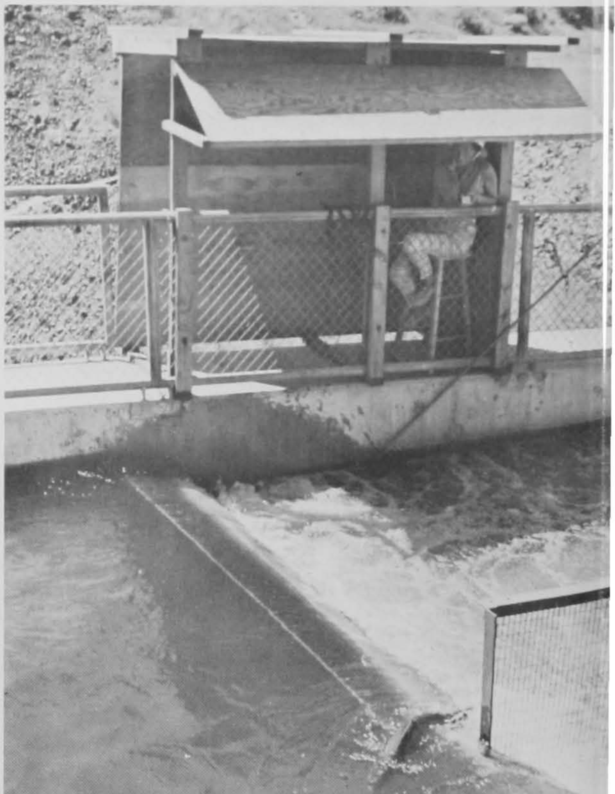


Figure 23.—Observer counting a chinook salmon as it crosses the last weir in 1-in-16 foot slope fishway at Ice Harbor Dam.

Fishway slope.--Experiments on the effect of fishway slope on passage were extended to a prototype fishway. In the laboratory, BCF personnel had determined that, with proper hydraulic conditions, slopes steeper than the conventional (1 foot in 16) were suitable for passing upstream migrants. Slopes of 1 in 10 and 1 in 16 in fishways at Ice Harbor Dam (fig. 23) showed little difference in performance (proportions of adult salmonids negotiating the fishways, rate of passage, and fallback). An example of passage in the two fishways is given in figure 24.

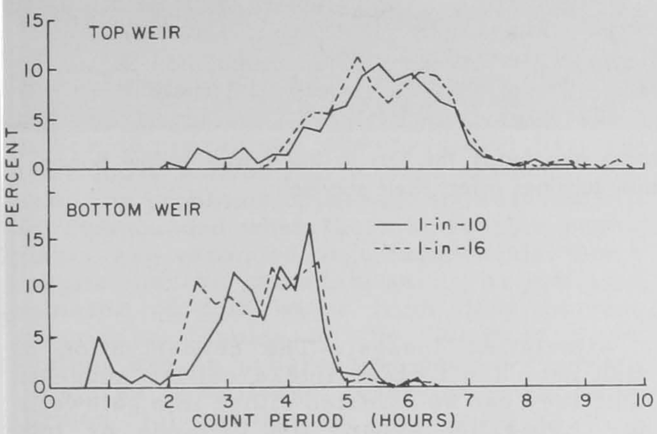


Figure 24.—Percentage of spring chinook salmon crossing bottom and top weirs (of test sections) of 1-in-10 foot and 1-in-16 foot slope fishways at Ice Harbor Dam.

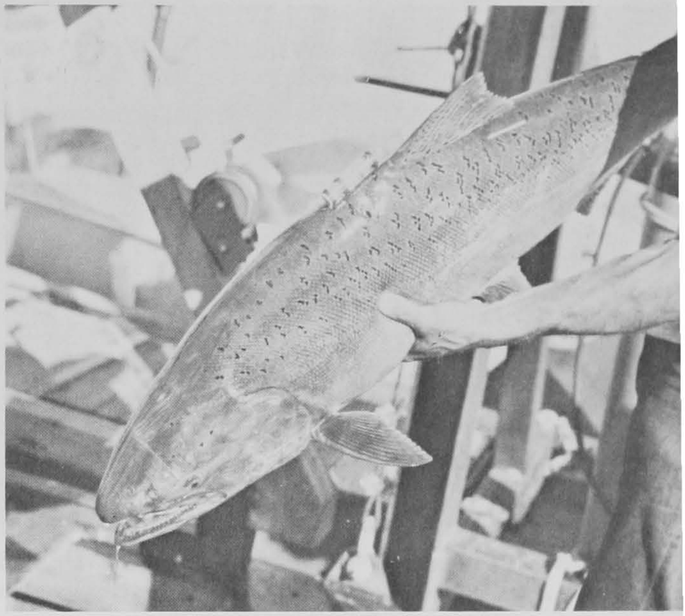


Figure 25.—Sonic tag on fish emits signals that can be identified by boat-mounted or shore-based receiving equipment.

The sonic tag was improved to increase its life to 15 weeks, and a new attachment technique was devised to reduce tag loss. The tag is now inserted into stomachs of adult salmon; only the transducer is exposed.

Fallback of Adult Chinook Salmon

Of the 30 fish bearing sonic tags (fig. 25), which were tracked above Ice Harbor Dam, 3 were swept back through the spillgates (fig. 26). Further studies indicated the extent of fallback from the north and south ladders--150 and 1,100 feet, respectively, from the nearest spillway. During low flows of 50,000 to 100,000 c.f.s., fallback frequencies recorded by fixed acoustic monitors at each spillgate were 18.5 percent at the north ladder and 3.5 percent at the south ladder. At higher flows, few fish ascended the north ladder and no observations of fallback were possible; fallbacks at the south ladder increased to 15.5 percent. Presumably a similar or greater increase would have occurred at the north ladder if fish had been available. Fallbacks were estimated at 2,350 of the 12,279 fish counted over Ice Harbor Dam during the spring run. About 50 percent of the recorded fallbacks were counted over the dam a second time, suggesting that this recounting may be a source of discrepancies in fish counts at succeeding dams.

Figure 26.—Movements of three fish bearing sonic tags that fell back over the spillway at Ice Harbor Dam.

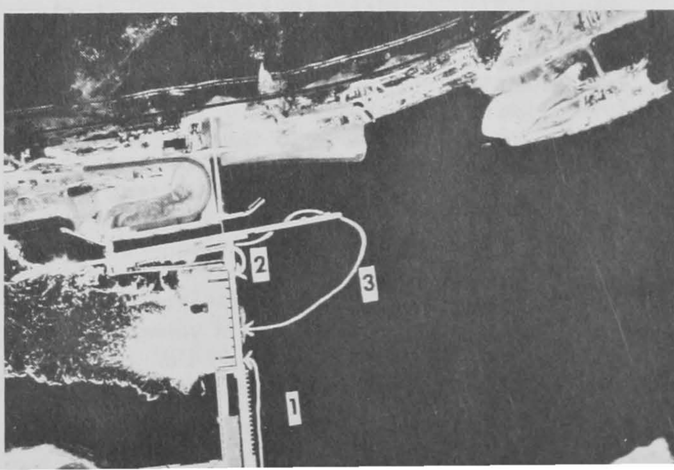


Figure 27.—Giant net strains the entire discharge of a turbine and leads the fish to the barge below Bonneville Dam. Captured fish are observed to see how turbines affect their survival.

Juvenile Fish Passage

Methods were investigated to evaluate and reduce losses of young fish at turbines. The experiments were related to foreseeable changes in behavior of the fish as water runoff is more controlled by regulated releases from upriver storage reservoirs and as increasing demands for power require that more turbines be operated at overload rating.

Turbine studies.--We developed a giant recovery net (fig. 27) to strain fish from the entire discharge (14,000 c.f.s.) of a turbine; holding facilities to retain fingerlings collected by the net; apparatus for releasing fish in turbine intakes at specific locations; acoustic and electronic equipment for detecting and recording noises associated with cavitation within the turbine; and a device for examining distribution of migrants in a turbine intake. Observations at The Dalles and McNary Dams showed that 70 percent of the downstream migrants that entered turbine intakes were within 15 feet of the ceiling (fig. 28). Studies on fish mortality in relation to depth of entry into the turbine intake suggested that fish pass through the turbine along defined routes rather than disperse throughout the water mass. Preliminary tests indicated that high turbine loads increase mortality significantly; these tests are being followed by experiments to define the lethal agents.

Alleviating losses.--The concentration of fish near the turbine-intake ceiling suggests that they can be diverted either into gatewells for bypassing around the turbines or into specific water masses for passage through the least dangerous areas in the turbine. Chinook salmon and steelhead trout were bypassed at Bonneville Dam through a test orifice, bored through a wall between a gatewell and the adjoining ice and trash sluiceway, which passed water from the forebay to the tailrace. Experiments at Ice Harbor Dam with an 18-inch orifice, tapered and attached to an 8-inch siphon tube which passed fish to an adjacent sluiceway, indicated that best efficiences were obtained when the orifice was in a corner of the gatewell at a 5-foot depth. Further investigations are needed to increase the number of fish that can be collected and bypassed.

Figure 28.—Frequency distribution of young migrants in turbine intake of McNary Dam at 7-foot intervals from ceiling (left) to bottom (right).

The change from a river to an impounded environment is of special interest because of its effect on migrating salmonids. Such factors as increasing temperature, saturation of the water with nitrogen, and competition from other species of fish that have increased because of the new environments, can affect profoundly the survival, rates and timing of migration, ability of fish to return to home streams, and incidence of disease.

Temperature

Past trends of water temperature indicate that conditions for salmonids are approaching critical levels in hot weather (fig 29). Still higher temperatures are predicted (fig. 30) after more hydroelectric dams are built. The resulting problems of passage and survival will be compounded when thermal reactor power plants are expanded on a large scale. Some respite may be gained, however, by judicious releases of cold water from deep, upriver reservoirs. Studies on the Columbia River system are in progress to predict (1) temperatures in a large reservoir, soon to be formed, (2) changes in the timing of peak river temperatures, brought about by releases of storage water at Canadian dams now under construction, and (3) benefits on downstream water from releases of water at 50°, 60°, and 70° F. from Grand Coulee Dam.

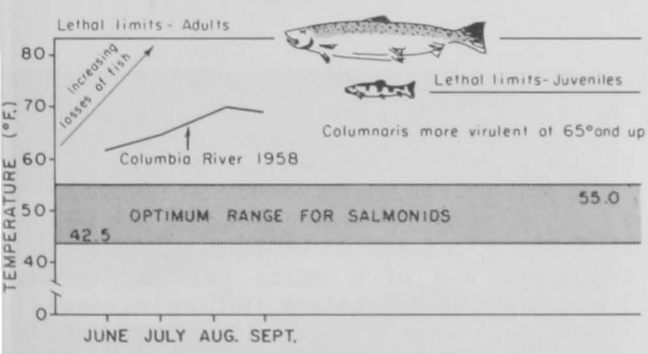


Figure 29.—Water temperatures in Columbia River at Priest Rapids Dam are above optimum for salmon and are increasing.

Research on the effects of water temperature on behavior of adult salmonids suggested that if colder water were introduced into fishways, fish would ascend the pools more slowly. Thus it is not feasible to reduce water temperature to stimulate movement. Lower performance levels were demonstrated by young salmonids in colder water--a significant consideration in relation to guiding devices in which fish must exert effort to reach a bypass.

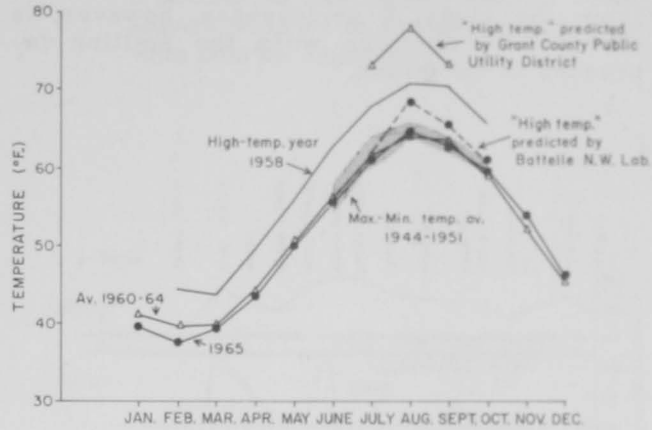


Figure 30.—Water temperatures in Columbia River (between Grand Coulee and Priest Rapids Dams) of past and present years are expected to increase in the future.

Studies were made on holding adult salmon until maturation in an artificial environment created at a terminal point in their migration. Fish were removed from the river where they were exposed to high temperature and disease organisms and held in mechanically refrigerated and recirculated water. The technique was economically feasible. Viability of eggs were not affected by the cool water.

Dissolved Nitrogen

Levels of dissolved nitrogen in the Columbia River were higher than would be expected with the warming of the river in the summer. Nitrogen levels above and below dams indicated that supersaturation is related to the spilling characteristics of dams (fig. 31). For example, concentrations of dissolved nitrogen below Bonneville Dam and most of the other dams increased when water of the forebay was supersaturated but decreased at Priest Rapids Dam. This information suggests that the degree to which nitrogen is added or dissipated from the water mass may be related to the spillway bucket and to the depth of the tailwater below the spillway; at Priest Rapids Dam the design of the bucket is different and the tailwater is lower than at other dams on the river. No increase in nitrogen levels were noted below the turbines of any of the dams, and there was no decrease in nitrogen in the reservoirs that were examined. Some decrease in nitrogen was noted in unimpounded sections of the river, but this was not sufficient to reduce saturation below a potentially dangerous level.

High concentration of dissolved nitrogen may be a problem when migrants are forced to remain near the surface for extended periods in the river system and when fish are artificially propagated in facilities that use water from the river. It seriousness, however, is expected to diminish when the spilling decreases in the future.

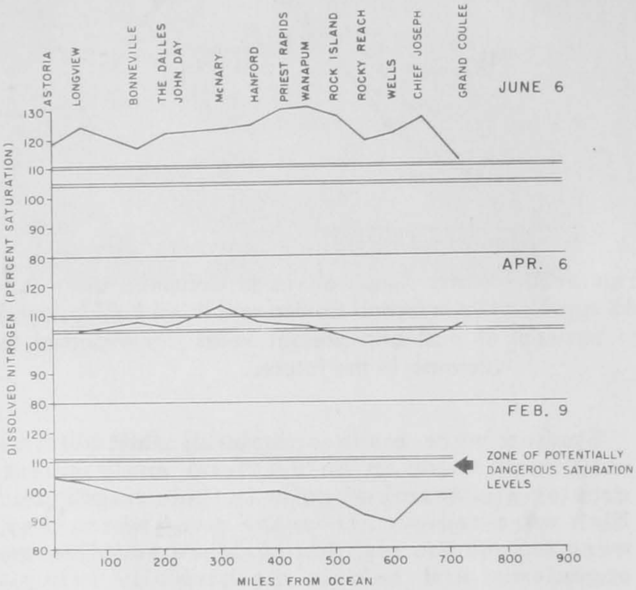


Figure 31.—Extensive spilling in June increased saturation levels of nitrogen below spillways well above the potentially dangerous zone (105-110 percent) at all points in the Columbia River (1966).

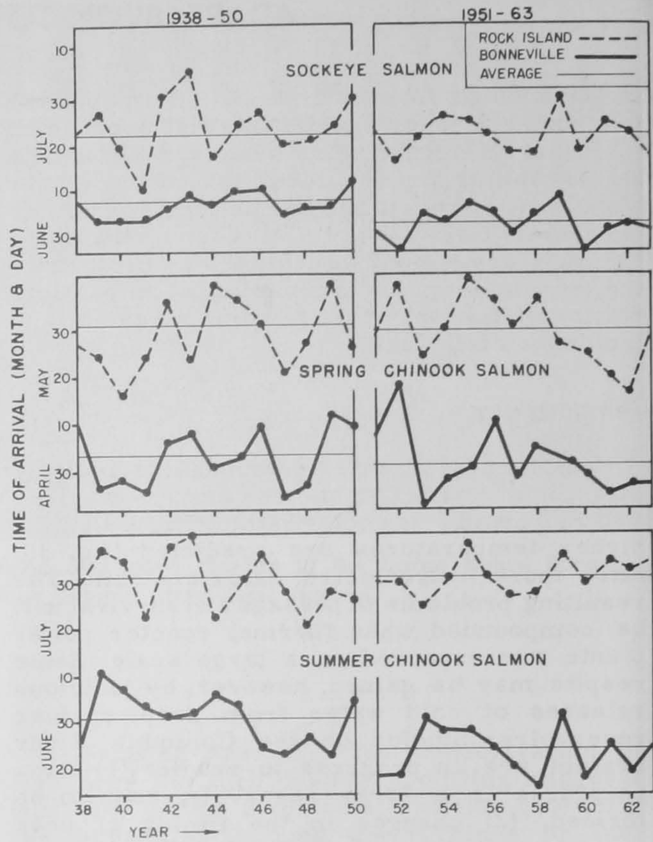


Figure 32.—Arrival of adult salmon at Rock Island Dam did not change significantly in 24 years in spite of dam construction and formation of numerous impoundments after 1951.

Rates and Timing of Migration

In adult sockeye and chinook salmon runs between Bonneville and Rock Island Dams during a 24-year period, the fish reached the upriver dam (Rock Island) at about the same time after the river was almost totally impounded as they did when there were no impoundments between the two dams (fig. 32). Sockeye salmon now require only 2 days more to reach Rock Island Dam than they did previously, when no intermediate barriers existed.

Assessment of juvenile migration was made possible by the successful collection of portions of the migrant population from the turbine intake gatewells (fig. 33). A thermal branding technique (hot or cold) provided a quick method for marking fish (fig. 34) so they could be indentified on recapture at successive dams downstream and at the estuary. Time of migration and population estimates to chinook fingerlings varied between years--1964-66 (fig. 35). Rates of movement appeared to be related to spilling; movement of 14 miles per day in the river and of 6 miles per day through McNary Reservoir before spilling increased to 23 miles in the river and 12 to 14 miles in the reservoir after spilling. In the estuary, young migrants apparently remained in local areas for 2 to 3 weeks before moving seaward. These data will be invaluable for assessing the effect of subsequent dams and environmental changes on seaward migration.

Activity cycles of fish were observed because of their importance in our predicting behavior during passage. Cycles of activity (fig. 36) of juvenile sockeye and coho salmon were similar; maximum activity was between 6:00 p.m. and midnight. Chinook salmon migrants were most active from midmorning to late afternoon.

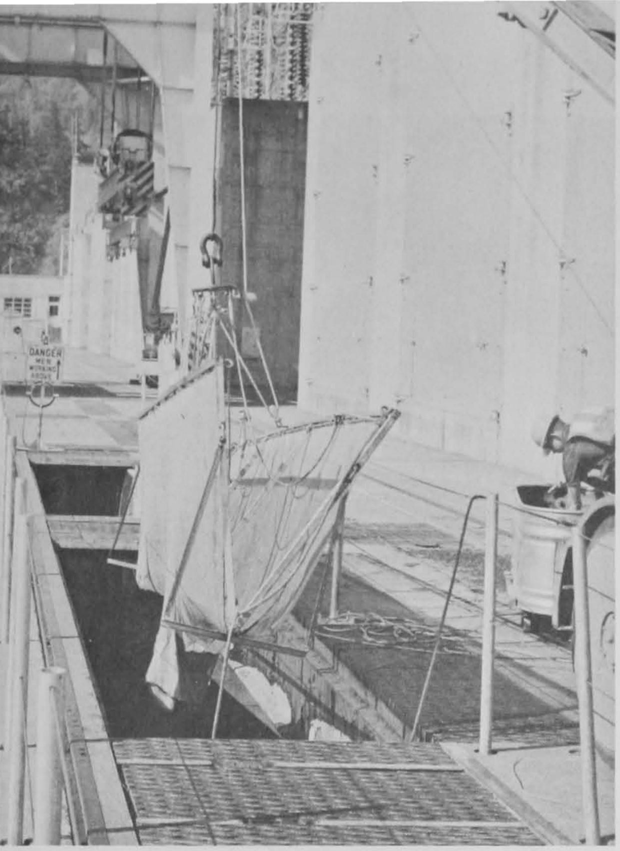


Figure 33.—Device used to remove young salmon from a gatewell for marking and releasing. Subsequent recapture at downstream dams provides data on migration.

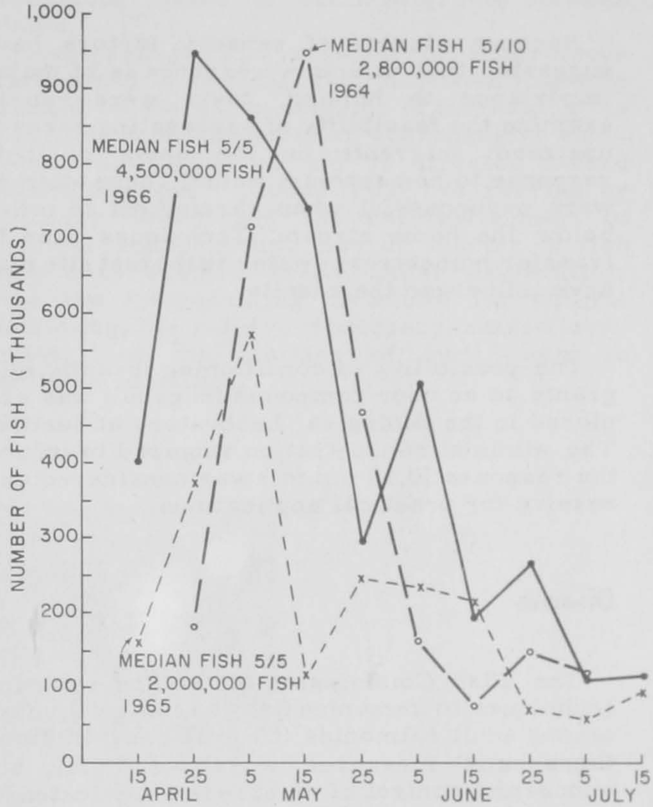


Figure 35.—Time of migration and estimated populations of young chinook salmon fingerlings past Ice Harbor Dam in the Snake River in 1964, 1965, and 1966.

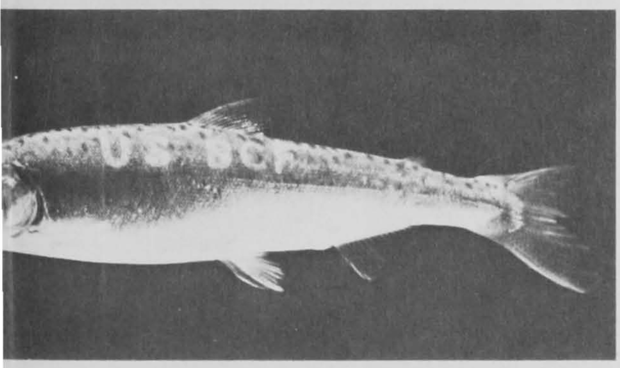


Figure 34.—Fish branded by application of mild heat. Similar marks can be made with extreme cold.

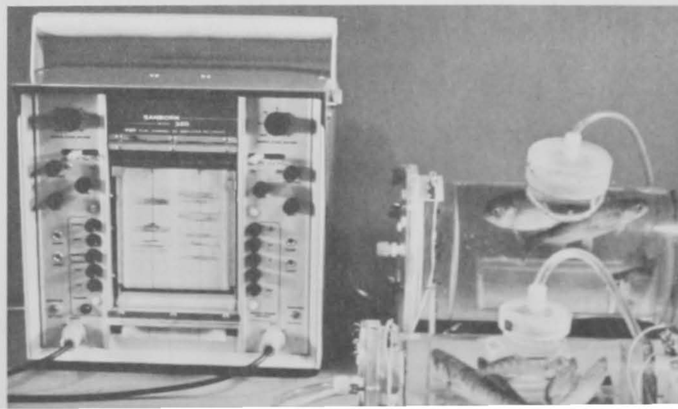


Figure 36.—Periodic activity of juvenile sockeye salmon being measured in laboratory apparatus.

Homing Ability

Adult salmon returning to the Brownlee area demonstrated their ability to select specific streams for spawning. Although no data were available to show that the selected spawning areas were natal streams, spring-run chinook salmon entered and spawned in tributaries to the reservoir that historically carried spring-run fish, whereas the fall chinook salmon passed through the reservoir, continued about 75 miles up the Snake River, and spawned in their traditional areas.

Because studies of sensory factors have suggested that olfactory response is of major importance to homing, tests were run to examine the feasibility of segregating races of upstream migrants on the basis of their response to homestream water. These attemps were unsuccessful when carried out 25 miles below the home stream. Techniques used to transfer homestream water to the test site may have influenced the results.

The possibility of conditioning juvenile migrants to an odor compound (eugenol) was explored in the Biological Laboratory at Seattle. The minimal concentration required to induce the response (0.18 p.p.m.) was considered excessive for practical applications.

Disease

The Fish Commission of Oregon explored techniques to immunize fish and control disease among adult salmonids (figs. 37 and 38). Some therapeutic measures were beneficial, but successful control of disease is complicated by many factors, including water temperature before and after fish arrive at holding facilities An internal parasite, Ceratomyxa sp., is regarded as a serious problem of survival in the Middle Snake River. We cannot hope to control this parasite until we understand its life history and can interrupt its transmission between hosts.

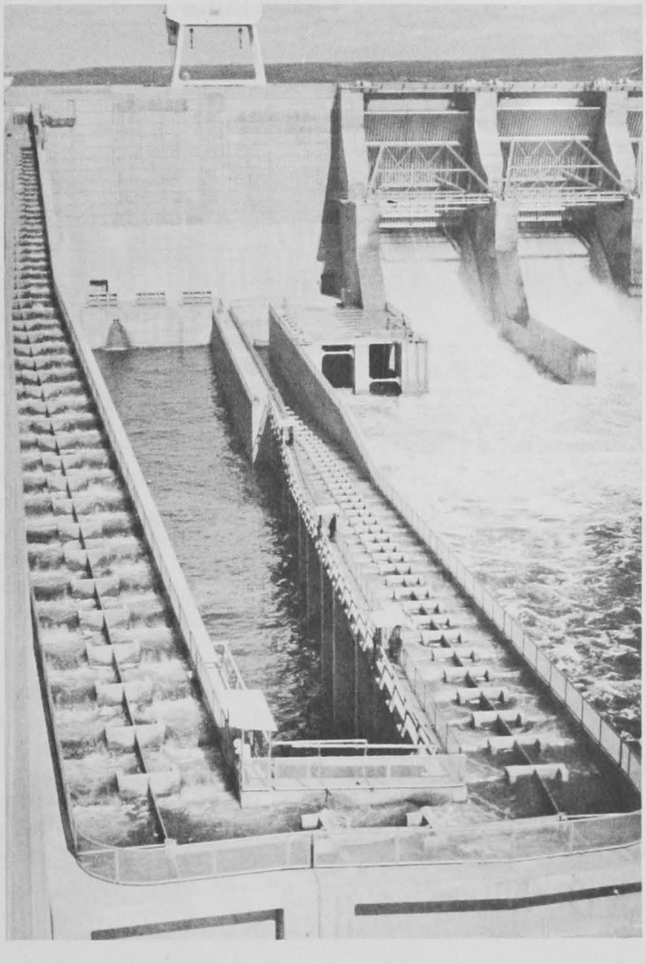
Figure 37.—Topical application of malachite green in experiments to control fungus, disease, and parasites.

OUTLOOK

Our research has confirmed that downstream migrants will face increasingly serious problems on their journey to the sea; the Program is now concentrating on the passage and survival of juvenile salmonids. Studies are continuing to devise methods to alleviate losses at turbines. Losses of fish are certain to increase as river flows become more completely controlled, spilling becomes almost nil, and most young migrants must move downstream through the turbines. We are attempting to assess the effect of the changing environment on migration and survival of fish and to predict deteriorations in the environment so that corrective action can be recommended. Preventive measures for high mortalities from such detrimental factors as temperature and pollution are under study. Collection methods are also being examined--plans are being completed for a prototype device to prevent young salmon from entering areas with an unsuitable environment.

Adult salmonids appear able to pass over dams and reach spawning areas, but not without severe losses when conditions are adverse. Research is being extended on improving passage facilities for these adults, attracting fish to fishway entrances, and directing them away from dangerous areas. Sonic tags are being used to examine the unaccountable losses of adult migrants between dams.

As passage and survival of anadromous fish continue to improve, emphasis logically should be placed on methods of increasing the production of salmon in an everchanging environment. Studies should be directed toward examining the productivity of rearing or nursery areas and the reestablishment of natural runs through use of species of fish native to specific areas. Other possibilities are the transplanting of adults for natural spawning, the release of hatchery-reared juveniles, and the planting of eyed eggs in suitable locations.



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June H. Watson	do	Editorial Assistant

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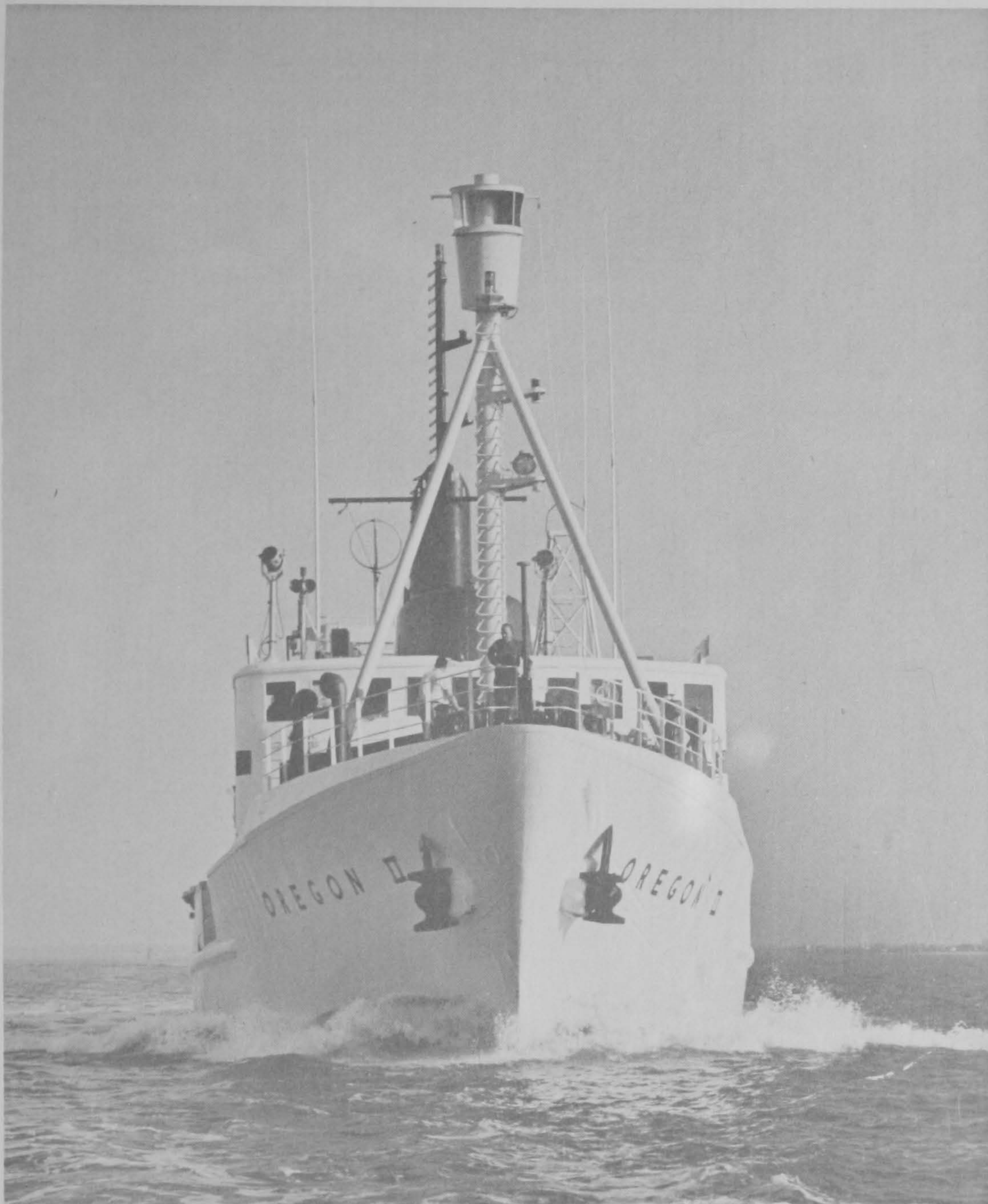

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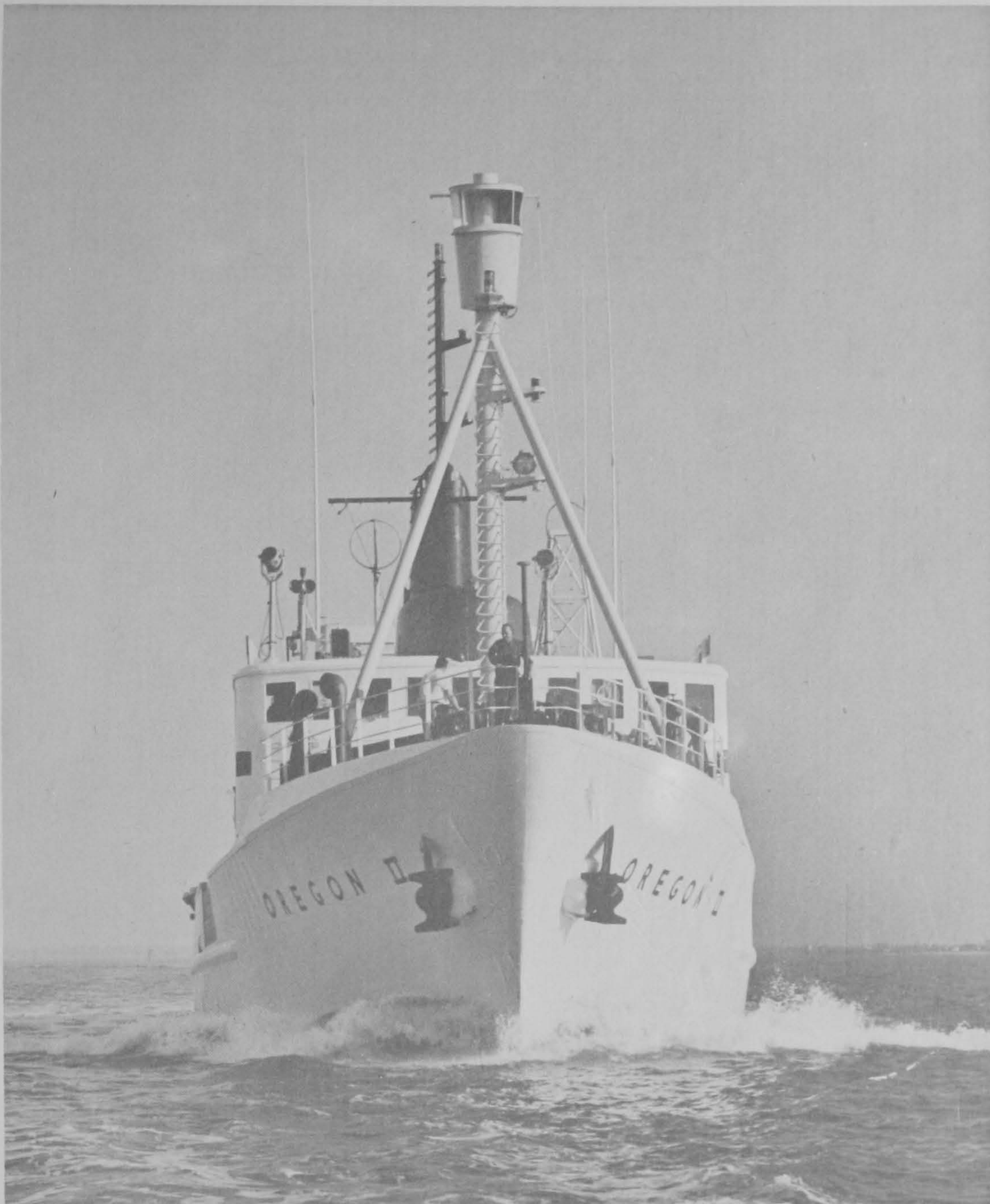

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